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InSIEME

Infrastructure Security in Electricity Markets

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Infrastructure Security in Electricity Markets

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Institute for the Protection and Security of the Citizen (IPSC)
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Action *Security of Critical Networked Infrastructures*

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1 Introduction

InSIEME (*Infrastructure Security In Electricity Markets*) is a GIS-based application that aims at supporting system analysis of complex, highly interconnected systems (i) by determining the reaction of such systems to abnormal initial events that affect their operability state and (ii) by providing visual spatial data representation of the system state.

InSIEME is an application that targets business decision makers, policy makers, other stakeholders, professionals.

The application is mainly designed for the evaluation of critical infrastructure systems, which usually are characterized by a large number of components from different, and not necessarily evident related, subsystems. The system under discussion in ***InSIEME*** is the Italian 360 kV Electricity Grid.

InSIEME is developed as a ***CRISA*** (*Critical Infrastructures Security Assessment Assistant*) project, which confers increased capabilities of analysis of complex system architectures, as well as of the functionality, capabilities and interconnectivity of constituent parts, based on various types of data characterizing the system. In addition, two models - of *error dispersion* and *influence flow* were developed and implemented, in order to enhance the capabilities of the project in assisting decision making processes.

A major goal for ***InSIEME*** was to prove the viability of a new approach in the applied systems analysis, which consists in *building a system and perform simulations starting from the GIS representation of the system under discussion*. In other words, the GIS is not primarily used for visualizing the system, but as a *source* for system definition. This is in fact a different approach to the *Application – GIS* relationship. In most cases the system is first analytically defined, and then the GIS is used to *visualize* the defined system (*analytical – GIS* approach). Instead, ***InSIEME*** takes the other way around, which means that the analytical representation of the system is built based on *an already existing GIS representation* (*GIS – analytical* approach).

In line with these, in ***InSIEME*** the system analysis would typically consist of two major phases:

1. ***Define the System*** starting from the GIS representation.
2. ***Analyze the System*** using the *error dispersion* and *influence flow* models.

A collection of toolsets for both phases of system analysis was provided.

The proposed models are designed to represent complex, interconnected systems by the interdependencies of the constituent components, as well as to simulate the cascade effects phenomenon that occurs in this type of architectures.

Several remarks are in order, from the outset: first, the focus *is not* on the *cause* of the error, but on the *effect*, considered here as '*the lack of capability of service providing*'. The *cause* that leads to the incapability of service providing is not taken into account. The models try to simulate how component operability *influences* the operability of the related component(s) and how this effect is spreading itself (diffuses) within the system.

Throughout this paper the *incapability of service providing* will also be referred to as *error* or *effect*.

Second, the models do not simulate the effect propagation based on physical, operational or any other types of additional models. ***InSIEME***'s are generic models that have to be customized for each type of application.

The system is analyzed and characterized from this *incapability of service providing* point of view. ***InSIEME*** provides information regarding (i) the overall functionality of the system, and (ii) the operability of the components, given a number of components that operate at a lower than optimal level. This can be seen as a two-level analysis, one at the system component level, and the second at the infrastructure level.

The models address two approaches for the system analysis: the first one - *the Static Model*, provides visual and analytical representations of the system state given an initial distribution of components operating at different levels of capability. The second, *the Dynamic Model*, allows the dynamic analysis of the system state when the distribution of error-characterized components as well as their operability levels vary in time. Moreover, the *Dynamic Model* allows the visualization and tracing of the error diffusion on a *step-by-step* basis.

Chapter 2 of this paper presents the rationale behind the ***InSIEME*** simulation part. The formalism for the analytical representation of the system and the general description of the proposed models – *The Error Dispersion Model* and *The Influence Flow Model* – are presented in **Chapter 3**. **Chapter 4** covers aspects related to ***InSIEME*** application, focusing on the user-interface and the typical workflows. In **Chapter 5** two relevant examples of system analysis are given, for both the *Static* and *Dynamic* type of simulations. Finally, **Chapter 6** offers several concluding remarks regarding the work and presents some possible improvements and further developments.

2 Rationale

Both simulation models (static and dynamic) start from the same assumptions, namely:

- The System is made of *components*.
- The components are classified in *classes*, based on either type, functionality, or characteristics.
- The components interact with each other (the operability of one component influences the operability of one or several of the other components).
- *Weights of influence* are established between the classes and are considered to be *a priori* known. The weights characterize the level at which a component from one class affects a component from another (*how much an operational incapability of a component from one class influences the capability of a connected component belonging to another class*, or *what percent of the incapability of service-providing of one component goes to the component(s) related to it*).
- The errors are introduced in the system through *Error Injection Points (EIP)*.
- The errors diffuse within the system on *Influence Levels*, via *Error Injection Routes (EIR).*

In the sequel, a more detailed look at the models is offered.

The system state of 'health' is given by its components' capability of providing *the service*. A system is considered *fully functional* when all the constituent components present no deficiency in providing the service they are designed for.

A component's failure in providing the service (initial event) leads to a failure (decrease of capability) of the components related to it. The newly influenced components affect the components related to them, and so on. The error propagation is *one-directional*. The process continues until all the components are affected or the error is damped out. The error at the component's level leads to a perturbation in the overall system functionality.

The model introduces the *Error Injection Points* as a *source of disfunctionality* of the system. An *EIP* is a *virtual system component*, and can be attached to any system component (the component is declared as *EIP*). The level of operability of the *system component* is controlled through the *EIP*. A system can present one or more *EIP*s.

The error is spreading throughout the system starting from the *EIP*, on *Influence Levels (IL)*, following *Influence Paths (IP)* also referred to as *Error Injection Routes (EIR)*. The *Influence Levels* are characteristic to every *EIP* and are generated radially, having the *EIP* as origin. Mainly, the process can be synthesized as follows: the *EIP* component first influences the components directly related to it (first level of influence), then, each of the components of the first level influences the ones directly connected to them (second level), and so on. The process ends when no components are found to be influenced, or the system boundaries are reached. For fully interconnected systems, the process ends when all the components are reached.

The following important assumption is worth emphasizing when generating the influence levels: *a component may influence the interconnected components* ***only one time****, and the influenced components* ***do not*** *influence the influencing component.* This means that the influence process *is not* bidirectional. For example, if the system component B is influenced by the system component A, A will not be influenced by, or influence *again* B.

InSIEME Influence Propagation Law*: a component may influence the interconnected components* ***only one time****, and the influenced components* ***can not*** *influence the influencing component.*

In this process, the influencing component (the source) is referred to as *parent*, while the affected components are referred to as *children ("kids")*.

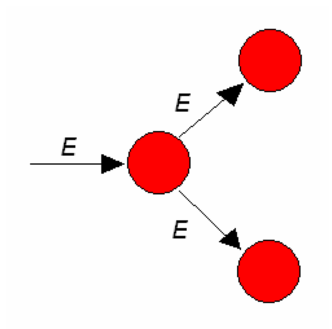
In the *parent-kid* approach, the condition above can be read as 'a component becomes *parent* only one time, and it is not influenced by its *kids*'.

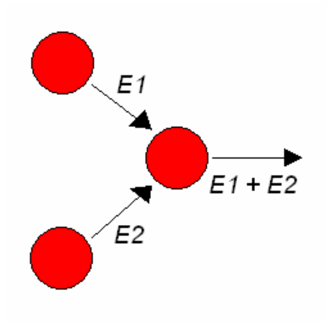
Every *EIP* contributes with the generated error at the components' level to the total error of the system components. The contributions are *cumulative*.

The following assumptions are made regarding the propagation of error in *crossroad* situations (Fig. 3.1)

Note that in the crossroad cases above, the weights of influence between components are not taken into account. This approach can lead to an *amplification of the error* effect in the *junction* case Fig 3.1(b).

Two quantities are introduced: (i) the *Incapability Index*, specific to the system component, to characterize the capability of service providing of the components and, (ii) the *Infrastructure Failure Index* to characterize the overall system health state, based on the constituent components *Incapability Indexes.*

<table>
<tr><th>Case</th><th>Behavior Description</th></tr>
<tr><td>
</td><td>One component influences more than one component (split)

In this case one considers that the influencing component conveys the same error to all the related components.</td></tr>
<tr><td>
</td><td>More than one component influence a single component (junction)

In this case one considers that the influenced component is affected by all the influencing components. The error of the influenced component is computed as the sum of all contributions from the influencing components.</td></tr>
</table>

Figure 3.1(a) Split, (b) Junction

The next chapter gives a description of the *error dispersion* and *influence flow* models implemented in ***InSIEME***.

3 The Models – Formalism

In this chapter a detailed description of the *error dispersion* and *influence* models is given. The models are presented in a formalized form, together with the algorithms involved.

The assumptions are the ones in **Chapter 2** of this paper. Let us recall a few major points, and make several considerations regarding the models'.

The first, and probably the most important aspect to be kept in mind is that the models' focus is on *effects* seen as *concepts*. The simulation's target value is the generic *capability of service providing*, and we talk about *the influence propagation* based on more or less subjective considerations, and not on real physical or engineering laws. The physical *cause* of the error is not considered – what matters is how a component incapability *affects* the related components' *capability*.

The models are inspired mainly by two major conceptual frameworks: the *perceptron model* for neural networks, and the *fuzzy cognitive maps*. According to the first, the system can be seen as an interconnected network of *neurons* (components). Unlike the perceptron model, our 'neuron' can have more outputs (axons). The system is fully functional when all the neurons are on the *zero* excitation level. The failure of service providing of a component corresponds to an increase in the excitation level of the correspondent neuron. The entire network is affected by this, through the propagation of the signal from the source neuron to the connected ones. The level of excitation of the last affected neurons is given by the activation function. The last activated neurons affect in turn the neurons related to them, and so on. The process continues until all the neurons are reached, or the excitation signal is damped. The network excitation level is determined by the neurons levels, this corresponding to the *system operability* state.

3.1. System Definition

Consider a system S defined as a *non-weighted*, *non-oriented* graph

$$S = G(V, E)\,, \qquad (3.1.1)$$

with *V* the set of *S's* nodes, and *E* the set of edges. The following hold:

$$E = \{(v_i, v_j) \mid v_i \in V, v_j \in V, i \neq j\} \quad (3.1.2)$$
$$E \subseteq [V^2] \quad (3.1.3)$$

The elements of *V* correspond to the system components, and *E* reflects *the connectivity* between the components. We will refer to *S* as the *system's graph*.

The system's graph is *non-oriented*, because it is assumed that two components can affect each other regardless the *direction* of influence. In other words, the *influence flow* is bi-directional.

Example

Let us consider the system *S* in Fig. 3.2. The system will be used throughout this chapter to illustrate the concepts, for a better understanding of the models.

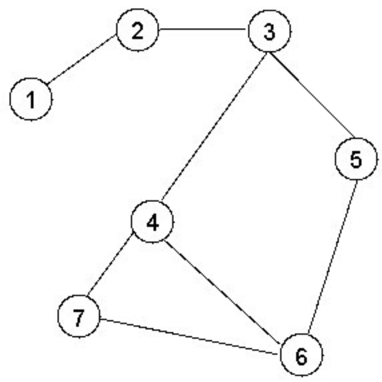


Figure 3.2 System representation

The system has 7 components. The interconnections between the components are the edges of the graph. Analytically, the system is defined as:

S=G(V,G)
$$V = \{1,2,3,4,5,6,7\} \quad (3.1.4)$$
$$E = \{(1,2),(2,3),(3,4),(3,5),(4,6),(4,7),(5,6),(7,6)\}$$

3.2. The Classification of System Components

As indicated before, the components are grouped in classes with regard to their functionality, design, or any other classification criteria. We will denote the classes as C_i , $i = \overline{1..n}$, and *n* – the number of classes.

In the context, $C(v_i) = j$ means that component $v_i \in V(S)$ belongs to class *j*.

Example (continued)

Consider that the components of system *S* are grouped in two categories, *CIRCLE* and *SQUARE*. Components {2,4,5} are *SQUARE*-type and components {1,3,6,7} are *CIRCLE*-type.

C_1 = *CIRCLE*
C_2 = *SSQUARE*

The system graph is modified to illustrate the components classification (Fig. 3.3).

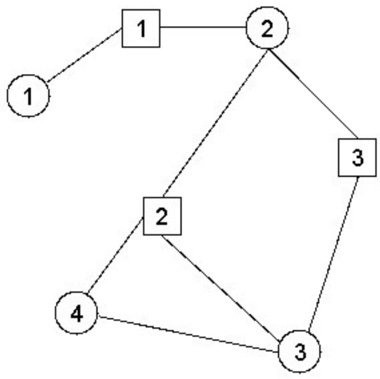


Figure 3.3 (a) The System graph

The components are renumbered in consideration of their class.

3.3. The Influence Intensity

It is assumed that *the intensity of influence* of two components depends on the parent classes. This is the expression of the idea that different *types* of components would differently affect each other from the *functionality* point of view. Moreover, depending on *where* the influence is coming from (*incoming direction* of influence) the levels of interaction between objects of two classes can be different.

The analytical expression of this is the *influence weights matrix*, with the *influencing* components as lines, and the *influenced* components as columns. This is a square matrix, with the number of lines equal with the number of system classes.

Let w_{CiCj} (with C_i the influential class, and C_j the influenced class) be the influence weights. The following hold:

i) $0 \leq w_{C_iC_j} \leq 1$, where

ii) w_{CiCj} = 0, meaning that components from class C_i do not affect whatsoever the components in C_j.

iii) w_{CiCj} = 1, meaning that components from class C_i totally affect the components in C_j.

Influenced Class (columns); Influential Class (rows)

$$\begin{bmatrix} w_{C_1C_1} & w_{C_1C_2} & w_{C_1C_3} \\ w_{C_2C_1} & w_{C_2C_2} & w_{C_2C_3} \\ w_{C_3C_1} & w_{C_3C_2} & w_{C_3C_3} \end{bmatrix}$$

Usually, the Influence Weights Matrix (IWM) is not symmetrical, and the diagonal elements are 1 (components from the same class are totally interconnected).

Some remarks would help in a better understanding of the concept. The influence here reflects *how* the functional incapability of one component affects the capability of the component(s) directly related to it, by passing on part (or all) of the failure. This could be seen as the *propagation* of the failure.

On the other hand, w_{ij} (i) *cannot be negative*, because when taking the effect as a *concept*, one cannot conceive that diminishing the capability in one component would result in an increase in the capability of other component and, (ii) *cannot be higher than 1* because, in this approach, the propagated error cannot be higher than the initial one.

Example (continued)

For the considered case *IWM* is a two-by-two squared matrix, and assuming that the components *fully influence* each other regardless the parent classes one has

$$IWF = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

3.4. Quantification and Classification of Error

The system is analyzed on two levels: first, on the *components level*, and second on the *overall system functionality*. The first provides information regarding the *health* status of each of the system components, and the analytical expression is the *Incapability Index*. The second is based on the operability status of all the system components, and provides information regarding (i) the *level of dispersion* of the error within the system, and (ii) *the severity* of the error (how much an error affects the overall operability of the system). The severity of the error is expressed by the *Infrastructure Failure Index* and the *Weighted Infrastructure Failure Index* quantities.

Definition of Incapability Index

We introduce the *Incapability Index* (*II*) as a measure of a system component's capability of service providing. In fact, *II* is the one-complement of the component functionality (capability of service providing). *II* of a component v_i is defined as

$$II(v_i) = \begin{cases} 0, \text{if the component fully provides the service} \\ 1, \text{if the component is in a total 'denial of service' state} \end{cases}$$

(3.4.1)

$$0 \le II(v_i) \le 1$$

For instance, a value of *II(v$_i$)* = 0.2 means that component v_i only provides 80% of the service.

The rationale behind taking *II* within the [0,1] interval is that, as indicated before, this model focuses on *effect* and *the effects propagation – influence flow*, seen as *failure of service providing*, as opposed to the *cause-effect* process simulation.

Based on the value of its *II*, a system component is said to be in either one out of three operability states: *Fully Functional, Partially Disabled,* or *Out of Order.* The classification is made according to two *threshold limits*, as follows:

$$v_i \text{ is } \begin{cases} \text{Fully Functional, if } 0 < II(v_i) <= ITL \\ \text{Partially Disabled, if } ITL < II(v_i) <= STL \\ \text{Out of Order, if } STL < II(v_i) < 1 \end{cases} \qquad (3.4.2)$$

where

$v_i \in V(S)$ - system component *i*
II - Incapability Index
ITL - Inferior Threshold Limit
STL - Superior Threshold Limit

A pertinent question may arise: why explicitly include in the classification the *Fully Functional* level? The answer relates to what '*Fully Functional'* means, namely that even if the error level is negligible for the respective component, the component is, however, touched by the error. This is also reflected in (3.4.2) by the strict order relationship defining the *Fully Functional* state.

Given the system $S = G(V, E)$ we define:

$\|S\|_{FF}$ the number of elements of *V* that are *Fully Functional*;
$\|S\|_{PD}$ the number of elements of *V* that are *Partially Disabled*;
$\|S\|_{OO}$ the number of elements of *V* that are *Out of Order*;

The following stands true:

- $\|S\|_{FF} + \|S\|_{PD} + \|S\|_{OO} \le |S|$, with $|S|$ the system's graph *order*;

- the number $\left(\|S\|_{FF}+\|S\|_{PD}+\|S\|_{OO}\right)$ represents *how many system components are influenced*, while
- $|S|-\left(\|S\|_{FF}+\|S\|_{PD}+\|S\|_{OO}\right)$ returns the number of components *unaffected* by the error.

If $II(v_i) > 0$, we will say that v_i *is reached* by the error.

Definition of Infrastructure Failure Index and Weighted Infrastructure Failure Index

The *Infrastructure Failure Index (IFI)* and the *Weighted Infrastructure Failure Index (WIFI)*, are defined as alternative, and equally useful, measures of the failure at the *system level*. *IFI* is computed as the total number of system components that are *at least* reached by the error, divided by the total number of system components, as follows:

$$IFI(S)=\frac{\|S\|_{FF}+\|S\|_{PD}+\|S\|_{OO}}{|S|}\ , \tag{3.4.3}$$

where

$\|S\|_{FF}$, $\|S\|_{FF}$, $\|S\|_{FF}$ and $|S|$ are defined in the previous paragraph.

The *Weighted Infrastructure Failure Index* is computed using the *importance weights* that characterize each of the functional conditions of the components, by the equation:

$$WIFI(S)=\frac{1}{|S|}\left(w_{FF}*\|S\|_{FF}+w_{PD}*\|S\|_{PD}+w_{OO}*\|S\|_{OO}\right)\ , \tag{3.4.4}$$

where

w_{FF} - importance weight for *Fully Functional*;
w_{PD} - importance weight for *Partially Disabled*;
w_{OO} - importance weight for *Out of Order*;

Equations (3.4.3) and (3.4.4) are different from the point of view of their meaning. While *IFI* represents the level of *dispersion* of the error within the system (how many components are affected by the error), *WIFI* is a *measure of severity* of the error at the system level (how much damage the error did to the system).

From the formulae for *IFI* and *WIFI* it follows that:

i) $0 \le IFI(S) \le 1$;
ii) $IFI(S) \ge WIFI(S)$; (3.4.5)
iii) $IFI(S) = WIFI(S)$, for $w_{FF} = w_{PD} = w_{OO} = 1$

We introduce *Infrastructure Failure*, denoted *IF* as a means of the system overall operability state. *IF* classification is made with regard to three acceptability intervals: *Acceptable, Partially Acceptable* or *Unacceptable*. Accordingly, the value of *IFI* or *WIFI* are as follows:

$$IF = \begin{cases} \text{Acceptable, if } 0 < IFI(WIFI) <= ITL \\ \text{Partially Disabled, if } ITL < IFI(WIFI) <= STL \\ \text{Out of Order, if } STL < IFI(WIFI) < 1 \end{cases}, \quad (3.4.6)$$

where

IFI - Infrastructure Failure Index;
WIFI - Weighted Infrastructure Failure Index;
ITL - Inferior Threshold Limit;
STL - Superior Threshold Limit.

Some remarks are in order:

The threshold limits (ITL and STL) in (3.4.6) *are considered system-defined quantities*. This means that the components are not differently classified with regard to the class they belong to.

ITL and STL are adjustable to reflect the *risk perception*. This approach is also reflected in *Weighted Infrastructure Index* computation. The *importance weights* reflect how different operability states of the system components are perceived by the analyst. This depends on many factors, such as the analyzed system, geo-political environment, development level of the area considered, safety culture, etc.

3.5 Error Generation and Influence Flows

First, let us recall some basic assumptions regarding the error generation and dispersion. An error is considered a component's loss of the capability of service providing. This is reflected by a value of component's *II* higher than 0. As mentioned, the error is generated at an *Error Injection Point*.

Loosing part of functionality, the affected component influences (or not) the components it interacts with. The influence is quantified by a loss of capability of the respective components (increase of *II*), and is modulated by the *influencing–influenced* interaction characteristics, given by the influence weights. The newly influenced components continue to *spread* the error out to the connected components. The process continues until the system boundaries are reached (all the components are influenced) or the error is damped.

It is said that components affected in one influence propagation step - as presented above - belong to the same *influence level*. The whole process describes the *influence flow*. One can see that the influence flow is characteristic to the error injection point.

The influence flow is considered a non-recursive process. Moreover, the error is spreading from one influence level to the next *simultaneously* and *omni-directionally*. As a consequence, a component *can only be influenced once* by the error coming from the influencing component(s).

Every *EIP* injects its contribution of error which, at the components level, is summed up. The operability of a system characterized by a distribution of *EIP*'s is affected by the operability of its components.

Discussion: One can also look at the influence flow assumptions approach from a *wave propagation* perspective. The process of error generation, propagation and accumulation at the component's level from this viewpoint is presented in Fig.3.4. One has here a system with 27 components. The interconnections between the components are not displayed, since they are no relevant in this case. The number of system classes is also not important. The components are distributed accordingly to their relationship with the error sources and interconnectivities between them.

Three of the components are defined as *Error Injection Points* (*EIP 1*, *EIP 2*, *EIP 3*). The *influence levels* are represented as circles (donuts), centered on the respective *EIPs*.

For each *EIP*, the components on level *i* are directly affected by the component(s) from level (*i* -1) and affect the components from level (*i* +1). If a component falls inside the intersection between the *influence areas* of two or more *EIPs*, the total effect at the component level is *the sum of all contributions* from the respective *EIPs*.

The system state can be described as:

EIP	***Influence Levels***	**Affected Components per Influence Level**	
EIP 1	*4*	L_{11}	1
		L_{12}	4
		L_{13}	1
		L_{14}	2
EIP 2	*4*	L_{21}	1
		L_{22}	1
		L_{23}	2
		L_{24}	3
EIP 3	*3*	L_{31}	2
		L_{32}	4
		L_{33}	1

where L_{ij} is the *EIP i* 's influence level *j*.

There are three components affected both by *EIP 1* and *EIP 2.* The *Incapability Index* for these components is computed as:

$$II_{SC1} = II_{SC1}(L_{12}) + II_{SC1}(L_{21})$$
$$II_{SC2} = II_{SC2}(L_{12}) + II_{SC2}(L_{21})$$
$$II_{SC3} = II_{SC3}(L_{14}) + II_{SC3}(L_{23})$$

where

$II_{SC}(L_{ij})$ - the *Incapability Index* generated by *EIP i* at level *j.*

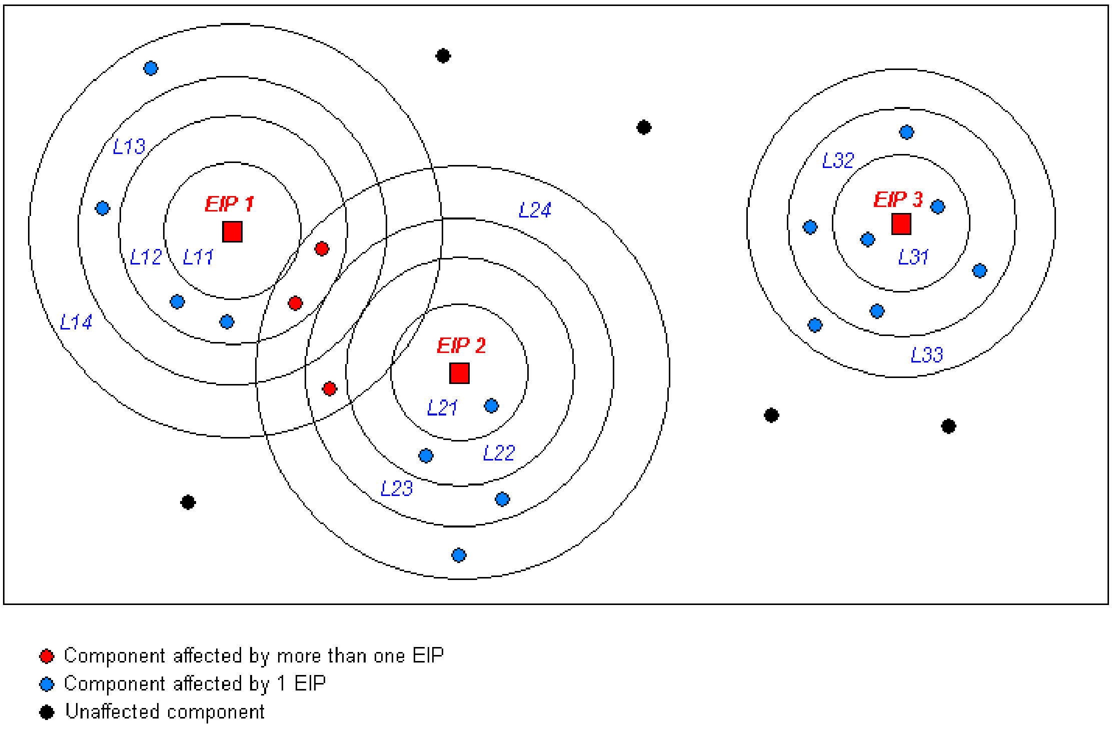


Figure 3.4 (a) Wave-type error propagation

Summarizing, the influence *flows* through the system starting from an *EIP* following *routes* defined based on the *connectivity* between the components. We introduce $I \stackrel{\Delta}{=} G(V', E')$ referred to as *error injection graph (EIG)* or *influence flow graph*, the graph characterizing the error flow process. *I* is a *weighted* and *oriented* sub-graph of the system graph *S*.

$$I \stackrel{\Delta}{=} G(V', E') \qquad (3.5.1)$$

with

$$V' \subseteq V,$$
$$E' = \{(v_i^{'}, v_j^{'}, w) \mid v_i^{'} \in V', v_j^{'} \in V', i \neq j, w = IWM(C(v_i^{'}), (v_j^{'}))\}$$

The weight moderating the interaction between the classes of the influencing and influenced components is attached to each edge of the *EIG*. *v'ᵢ* is the influencing component, and *v'ⱼ* is the influenced component.

The flow *direction* is given by the sequence $v'_l - v'_j$.

In other words, the triple $(v_i^{'}, v_j^{'}, w)$ defining an edge should read as:

'Component v'_i with $Il(v'_i)$ influences the component v'_j, this being reflected in a change in the incapability index of the last one, function of w.'

or

'A percent w of the error of v'_i 'goes' to v'_j.'

The *Error Injection Graph* is built based on the system graph through an iterative process that can be summarized in a *parent – kid* approach as:

Starting from the EIP component as kid, declare the kids determined in the last step as parents and get the new parents' kids until no kids are found.

We denote *L* as the influence level and say that $L(v_i) = a$ means that component v_i is on level *a* of influence.

The *error injection graph generation* algorithm is presented in the sequel.

	Algorithm 3.1			
S0	Initialize components $V' = \{v_o\}$, $IL(v_0) = 0$ $E' = \varnothing$ $cStep = 0$			
S1	While *StopCondition* = FALSE repeat steps 2 to 8			
	S2	For each node $v_i \in V'$ with $IL(v_i) = cStep$		
		S3	Get $N_S(v_i)$, the set of all neighbors of v_i from *S*	
		S4	For each $v_j \in N_S(v_i)$, $j = \overline{1, d(v_i)}$ repeat steps 5 to 6	
			S5	if $\{v_j, v_i\} \in E'$ jump to **STEP 7**
			S6	Update the EIG and set v_j

				$V' = V' \cup \{v_j\}$ $w = IWM\left(C(v_i), C(v_j)\right)$ $E' = E' \cup \{v_i, v_j, w\}$ $IL(v_j) = cStep + 1$
	S7	`cStep = cStep + 1`		
	S8	`Verify StopCondition` $StopCondition = \begin{cases} TRUE, \text{ if } X = \varnothing \\ FALSE, \text{ if } X <> \varnothing \end{cases}$, where $X = \{x_i \in V' \mid IL(x_i) = cStep\}$		

Discussion: The set *V'* of the error injection graph is initialized with one element, which is the *error origin*, the *EIP*. Step **S5** ensures that the model influence propagation condition is fulfilled.

Important information for characterizing system's *comparative vulnerability* to errors occurring at different components can be extracted from the error injection graph. Thus, one finds:

- *The number of influence levels required for the error generated by an EIP to* ***maximize its effect*** *on the system (maximum cover over the system)*, is given by

$$\max_i \left(IL\left(v_i'\right)\right), \quad i = \overline{1..d(V')} \tag{3.5.2}$$

- *Which is (are) the level(s) in which the highest number of components are simultaneously affected, and which are the influential and influenced components*:

A relevant information can also be extracted from the error injection graph: *the influence paths* corresponding to the error flow from an error injection point to a component.

Example (continued)

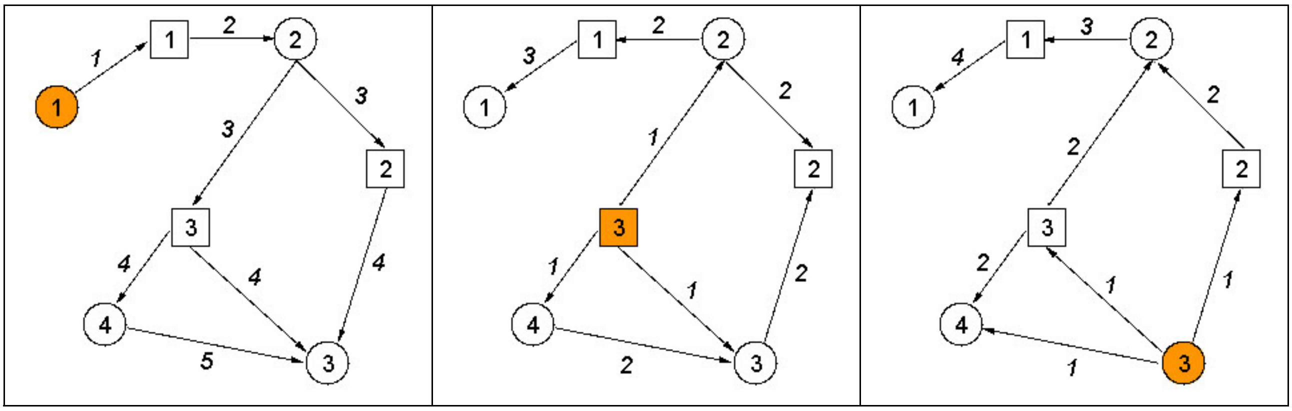
Let us consider three error injection points for the system *S*, namely C_1, S_3 and C_3. The *error injection graphs* are obtained by applying *Algorithm 1* for each of the considered *EIP*s. We denote $I_{C1}(V'_{C1}, E'_{C1})$, $I_{S3}(V'_{S3}, E'_{S3})$, $I_{C3}(V'_{C3}, E'_{C3})$ the injection graphs associated to C_1, S_3 and C_3, respectively.

The definition of I_{C1}, I_{S3}, I_{C3} is presented in Table 3.1 :

EIP	EIG	Structure	Maximum Influence Levels
C_1	I_{C1}	$V'_{C1}=\{C_1,S_1,C_2,S_3,S_2,C_4,C_3\}$ $E'=\{(1,C_1,S_1,1),(2,S_1,C_2,1),(3,C_2,S_3,1),(3,C_2,S_2,1),$ $(4,S_3,C_4,1),(4,S_3,C_3,1),(4,S_2,C_3,1),(5,C_4,C_3,1)\}$	5
S_3	I_{S1}	$V'_{S3}=\{S_3,C_4,C_3,C_2,S_2,S_1,C_1\}$ $E'=\{(1,S_3,C_4,1),(1,S_3,C_3,1),(1,S_3,C_2,1),(2,C_4,C_3,1),$ $(2,C_3,S_2,1),(2,C_2,S_1,1),(2,C_2,S_2,1),(3,S_1,C_1,1)\}$	3
C_3	I_{C3}	$V'_{C3}=\{C_3,S_3,C_4,S_2,C_2,S_1,C_1\}$ $E'=\{(1,C_3,S_4,1),(1,C_3,C_4,1),(1,C_3,S_2,1),(2,S_3,C_4,1),$ $(2,S_3,C_2,1),(2,S_2,C_2,1),(3,C_2,S_1,1),(4,S_1,C_1,1)\}$	4

Table 3.1

The *EIP*s, with the associated error injection graphs are presented in Fig. 3.5 (a), (b), (c). The error injection points are depicted in red and the influence flow is represented by the directed edges of the graphs. The numbers associated to the graph edges are *the influence levels*.



(a) (b) (c)

Figure 3.5 Error injection points and associated graphs

One can see that, from the overall system error coverage viewpoint, the same system can be differently influenced by a perturbation depending on the initial affected component localization. More precisely, the number of influence steps required by the error to affect all the system components depends on the system connectivity. In our case, we can say that component *S3* is the most critical in the process of error propagation.

3.6 The Influence Paths

Another useful information can be extracted from the error injection graphs: *which are the paths followed by the error generated by an EIP to reach a component*?

As indicated, the influence of an error injection point *flows* through the system by propagating from the source (the *EIP*) in all directions, following the interconnections between the system's components.

We define the *Error Injection Path* or *Route* as the sequence of components influenced (touched by) an error generated by an *EIP* to reach a component from the *EIP* graph. Based on system's interconnections, there can be *more than one route* connecting the error injection point (the source) to a component (the destination). We will refer to all the routes connecting an *EIP* to a component as to *Error Injection Routes (Paths)*.

We denote:

$P(x_s,x_d)$ – the error injection *paths* connecting x_s (the source) to x_d (the *destination*). (3.6.1)
$P_k(x_s,x_d)$ – the error injection path *k* connecting x_s to x_d.

The following hold:

$I_S(x_s)$ – error injection point defined in system *S.* (3.6.2)

$$x_d \in I_S(x_s)$$
$$P(x_s,x_d) \subseteq I_S(x_s)$$
$$P(x_s,x_d) = \bigcup_k P_k(x_s,x_d)$$

The above expresses that $P(x_i,x_j)$ is a sub-graph of the error injection graph and each $P_k(x_i,x_j)$ is a *path-type* sub-graph of *P*.

From this, the sequence of determining the error injection routes appears natural: first, *P* is generated from the error injection graph; next, each route P_k is extracted from *P*.

We define:

$$P(x_s,x_d) \stackrel{\Delta}{=} \{p_i\} \qquad (3.6.3)$$

with

$$p_i = \{c, x_i, l\} \qquad (3.6.4)$$

where

c – counts the influence levels;
$x_i \in V(I_s(x_s))$;
l – the position in P of p_i 's influencing component.

The l component will be used in the procedure to extract the individual routes from the paths graph.

We also consider that for a path component p_i like (3.6.4) one has:

$$C(p_i) = c \\ X(p_i) = x_i \\ L(p_i) = l \tag{3.6.5}$$

Once the error injection paths graph is built, the next phase is to *separate* each influence route $P_k(v_s,v_d)$.

We define:

$$P_k(x_s, x_d) \stackrel{\Delta}{=} \{p_i^k\} \tag{3.6.6}$$

with

$$p_i = \{x_i\} \tag{3.6.7}$$

where

$$x_i \in V(I_s(x_s)).$$

The number of distinct routes is given by the number of occurrences when the source component (v_s) is encountered in $P(v_s,v_d)$. The process is iterative and can be summarized as follows:

Starting from v_s, go to next route component in $P(v_s,v_d)$ until v_d is reached.

The next route component is given by the *position in the routes set* of the *parent* component – $L(v_i)$, where v_i is the current component.

The Algorithm

A. *Construction of error injection paths graph P*

Several preliminary remarks are in order:

1) From the error injection graph structure, as well as from the general influence rule adopted for this model, one can see that *a component can be reached in different influence steps* within the error injection graph.
2) The algorithm used for construction of the error injection paths graph is bottom-up type, which means that the graph is built starting from destination and ending to the start point (the error injection point).

	Algorithm 3.2			
S0	Initialize $p_0 = \{0, vd, -1\}$ $P = \{p_0\}$ $c = 0$			
S1	While *StopCondition* = FALSE repeat steps 2 to 5			
	S2	c=c+1		
	S3	For each node $p_i \in P$ with $C(p_i) = c-1$		
		S4	Get X from $E_{I_S(x_s)}(X, p_i)$, the set of all neighbors of p_i from the error injection graph $I_S(x_s)$	
		S5	For each $x_j \in X$, $j = \overline{1, d(p_i)}$ repeat **S6**	
			S6	$P = P \cup \{c, x_j, L(p_i)\}$
S7	Verify *StopCondition* $StopCondition = \begin{cases} TRUE, \text{ if } X = \varnothing \\ FALSE, \text{ if } X <> \varnothing \end{cases}$			

B. *Extraction of individual routes Pk*

We introduce an additional set S_L defined as:

$$S_L = \{L(p_i) \mid p_i \in \{P(v_s, v_d) \cap \{x_s\}\}\} \qquad (3.6.8)$$

Equation (3.6.8) express that S_L's elements are *the position* in $P(v_s,v_d)$ where v_s is encountered. $|S_L|$ gives the number of distinct routes connecting v_s to v_d. S_L will be used as starting point in the iterative process of isolating the distinctive paths from $P(v_s,v_d)$.

	Algorithm 3.3		
S0	Initialize Get S_L from $P(v_s,v_d)$; $k=0$		
S1	For each $cPos \in S_L$ repeat steps **S2** to **S6**		
	S2	$k=k+1$	
	S2	Initialize route $P_k = \varnothing$	
	S3	While *StopCondition* = FALSE repeat steps **S4** to **S6**	
		S4	$P_k = P_k \cup \{P(cPos)\}$
		S5	$cPos = L(P(cPos))$
	S6	Verify *StopCondition* $StopCondition = \begin{cases} TRUE, \text{ if } c\text{Pos} = \text{-1} \\ FALSE, \text{ if } c\text{Pos} \neq \text{-1} \end{cases}$	

Example (continued)

Let us consider the error injection point EIP_{C1} as in the previous section. We want to determine all the paths the error generated by EIP_{C1} follows to reach C_3. Accordingly, we will have $x_s = C_1$, $x_d = C_3$.

Applying *Algorithm 3.3*, one gets:

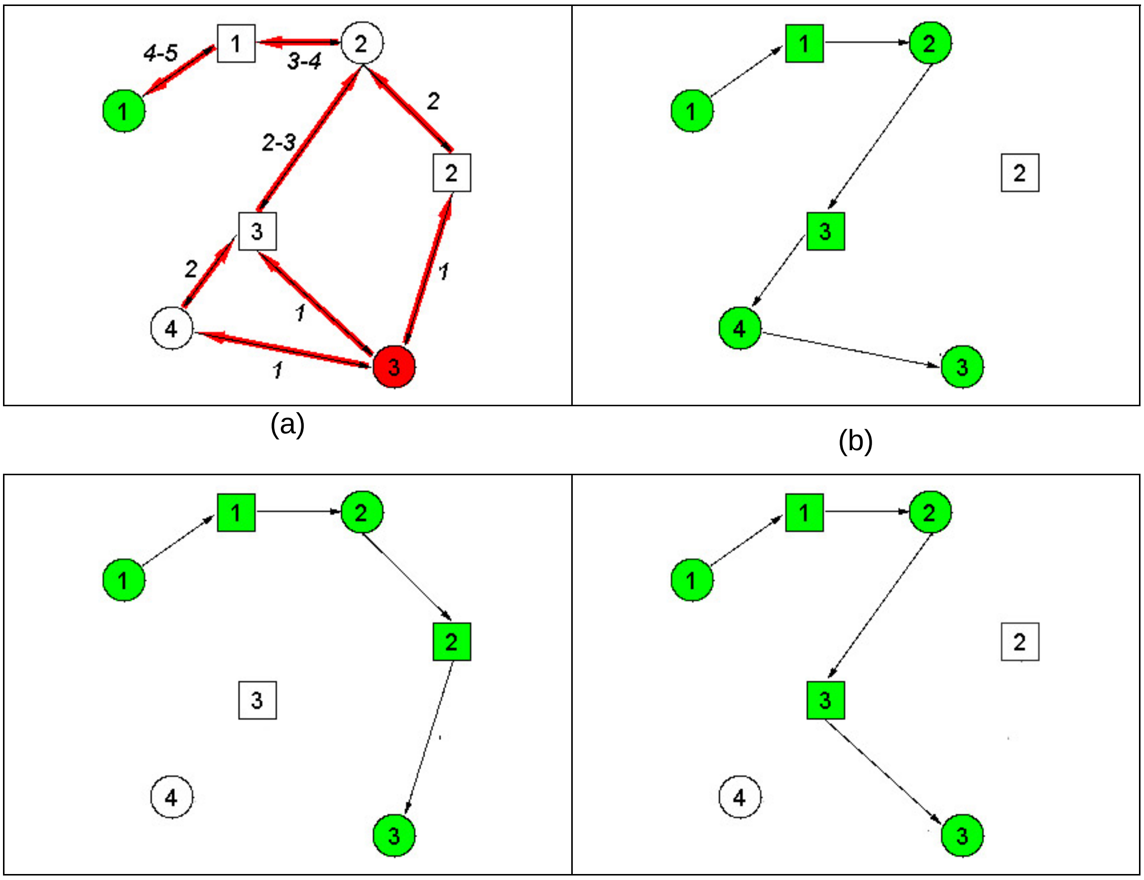
$$P(C_1,C_3) = \begin{Bmatrix} \{0,C_3,-1\},\{1,S_3,0\},\{1,S_2,0\},\{1,C_4,0\},\{2,C_2,1\},\{2,C_2,2\},\{2,S_3,3\}, \\ \{3,S_1,4\},\{3,S_1,5\},\{3,C_2,6\},\{4,C_1,7\},\{4,C_1,8\},\{4,S_1,9\},\{5,C_1,12\} \end{Bmatrix}$$

Analyzing $P_1(C_1,C_3)$ one can see that the error injection point (C_1) is reached three times. This means that there are three distinct routes from C_1 to C_3. On the other hand, once a split-point is encountered by the error, the error flow is tracked-down for each of the branches, regardless of any eventual junction encountered next.

Applying Algorithm 3.3 the following routes are extracted from $P(C_1,C_3)$:

$$P_1(C_1,C_3) = \{C_1,S_1,C_2,S_3,C_4,C_3\}$$
$$P_2(C_1,C_3) = \{C_1,S_1,C_2,S_2,C_3\}$$
$$P_3(C_1,C_3) = \{C_1,S_1,C_2,S_3,C_3\}$$

Figure 3.6 represents the error injection paths graph (a) and the error routes (b), (c), (d) for the considered example. The direction of the arches in case (a) reflects *the generation* direction. The numbers attached to each arc shows *the generation steps*.



(a) (b)

(c) (d)

Figure 3.6
(a) The influence paths graph $P(C_1,C_3)$; (b) Error route 1 $P_1(C_1,C_3)$;
(c) Error route 2 $P_2(C_1,C_3)$; (d) Error route 3 $P_3(C_1,C_3)$

3.7 The Error Dispersion and the Influence Flow Simulation

The two proposed simulation models aim at supporting the evaluation of system's complexity-induced vulnerability.

A static approach for simulating the *influence-induced error propagation* is taken for the *Error Dispersion* model, while in the *Influence Flow* model a dynamic approach is adopted.

Both models share the same assumptions on the error propagation (influence flow) presented in this chapter. To recall, it is assumed that the error starts from *one component* which becomes an error injection point. The error of the initial component *influences* the connected components which, in turn, become error sources for the next connected components. The error follows the error injection routes hold by the influence flow graph.

The simulation is comprised of two distinct phases:

1. Determine the propagation of error within each error injection graph.
2. Update the system components' *II* based on the contributions from each of the *EIPs* – if any.

We will refer to the first phase as *updating the error injection graph*, and to the second as *updating the system components status*.

The *induced incapability index of the destination node* is added to each edge of the error injection graph. The edges set will be now:

$$E' = \{(v_i', v_j', w, II_{ji}) \mid v_i' \in V', v_j' \in V', i \neq j, w = IWM(C(v_i'), (v_j'))\}, \qquad (3.7.1)$$

with II_{ji} the incapability index of v_j *induced* by v_i.

The induced incapability index is computed with the formula:

$$II_{ji} = II_i * w_{ij} \qquad (3.7.2)$$

3.7.1 The Error Dispersion Model – The Static Simulation

The Error Dispersion model's main goal is to express the *operability pattern* of the system, given a distribution of error injection points. In other words, the error dispersion model simulates how a distribution of error injection points affects the operability of the system's components.

The initial terms for the model are:

$S = G(V, E)$ the system;

$I_S(v_i)$, with $v_i \in V(S), i = \overline{1..n}$, a number of *n* error injection points of *S*.

We denote $II(I_s(v_i))$ the *incapability index* (the error) injected in the system by the error injection point v_i.

Updating the Error Injection Graphs - The Algorithm

Given: $I_S(v_S) = G(V', E')$ an error injection point of system *S*.

	Algorithm 3.4	
S1	For each $e_k = \{v_i, v_j, w_k, II_{ji}\} \in E(I_s(v))$ with $k = \overline{1,..,\lvert E(I_S)\rvert}$	
	S2	$II(v_i) = \sum II(X, vi)$
	S3	$II(e_i) = II(v_i) * w_k$

The algorithm can be summarized as follows: compute the propagation of error on each edge of the influence flow graph *starting from the source*. The error of the influencing component is obtained from the edges *pointing* to that component.

Since (i) a component can be reached several times on different paths of the same error injection graph and (ii) the error propagation is considered for each edge, the sum of all the incoming errors for the influencing component should be performed *before* computing the error passed to the influenced component (step **S2**).

The edge set of the influence flow graph is scanned from the error source (top-down) towards the graph bounding. The order edges are added to *E(I)* (Alg. 3.4) ensures that for an edge (v_i, v_j) *there is at least one edge* (v_k, v_i) previously encountered, which means that the incapability index of v_i is already computed.

From the influence direction point of view, we can say that the error propagation is computed *from the influencing component towards the influenced one*. In other words, the computation is performed from the influencing component perspective.

Updating the System's Components Status – The Algorithm

The updating of the system's components status consists in computing the incapability index of all the system components, based on the error induced by each of the error injection points.

The influence composition rule is simply additive. The computation is made first within the error injection path, and then the result is transferred to the component. Even though this leads to an increased complexity of the algorithm, this approach proves useful from the computational time viewpoint in the case of large systems containing one or more subsystems.

The algorithm is presented in the sequel.

	Algorithm 3.5
S0	Clear the system nodes

	$II(v_i)=0$, $v_i \in V(S)$, $i=\overline{1,..,\vert S\vert}$			
	S1	For each error injection graph $I_S^{\,l}$ repeat steps **S2** to **S6**		
		S2	For each $e_k=\{v_i,v_j,w_k,II_{ji}\}\in E(I_s^{\,i})$ with $k=\overline{1,..,\vert E(I_S^{\,i})\vert}$	
			S3	if v_j marked go to step **S2**; else
			S4	$II=\sum II(X,v_j)$
			S5	Update the value of the *II* of system component corresponding to v_j $II(v_m)=II(v_m)+II$, where $v_m\in V(S)$, $v_m \cong v_j$
			S6	Mark v_j

The Error Dispersion Simulation

The algorithm for the error dispersion simulation is:

	Algorithm 3.6
S0	Initialize System state: - Define the error injection points; - Set the error intensity (*II*) for each of the error injection points.
S1	Compute the error dispersion along each error injection graph - execute Algorithm x for each error injection point.
S2	Update the system components - execute Algorithm xx.

Example (continued)

Consider the system *S*, and the error injection point C_1. For an incapability index $II(C_1)=0.2$, the following results are obtained for (i) the error injection graph edges and (ii) the component's operability state:

$$E(I_S(C_1))=\{(1,C_1,S_1,1,0.2),(2,S_1,C_2,1,0.2),(3,C_2,S_3,1,0.2),(3,C_2,S_2,1,0.2),$$
$$(4,S_3,C_4,1,0.2),(4,S_3,C_3,1,0.2),(4,S_2,C_3,1,0.2),(5,C_4,C_3,1,0.2)\}$$

	Component	Incapability Index
V(S)	*C1*	0.2
	S1	0.2
	C2	0.2
	S2	0.2
	S3	0.2
	C3	0.6
	C4	0.2

The amplification effect occurring in junction-encountering cases is visible in this example. Component's C_3 incapability index is 0.6, even though the error injected by C_1 is 0.2. The reason is that C_3 accumulate the influence *from three sources*, respectively S_2, S_3 *and* C_4.

3.7.2 The Influence Flow Model – The Dynamic Simulation

The influence flow model allows tracking the error propagation on a step-by-step basis (one influence level at a time). In other words, the model allows the *visualization of the error flow* throughout the system.

We define the *time step*, or *simulation step*, the time the errors go from one influence level to the next one. The dynamic simulation is quantified in time steps. One can say that in the dynamic simulation each computational step *handles only the propagation of error during one time unit*.

Moreover, the error injection points' failure intensities, *are not stationary* during the simulation (the *II* of the *EIP* is function of time), thus giving a high flexibility in simulating complex scenarios. The number of the system's error injection points can also vary in time. For instance, the simulation can start with five error injection points, then after several simulation steps some more *EIPs* may be added to the system while two of the initial ones may be removed. During all these, the values for the *EIPs* may vary in time.

As mentioned, an error injection point's incapability index is a function of time. To represent this, we introduce the *Trend*, denoted *T*, which characterizes the *EIP* evolution in time. We will have:

$$II(I(v_i))^t = II(I(v_i))^{t-1} + T_{I(v_i)}{}^t \qquad (3.7.2.1)$$

where

- $II(I(v_i))^t$ is the incapability index of error injection point v_i at simulation time t;
- $II(I(v_i))^{t-1}$ is the incapability index of error injection point v_i at simulation time $t-1$; and

- $T_{I(v_i)}{}^t$ is the trend of the error injection point at time *t*.

If we denote S^t the system state at moment *t*, one can say that

$$S^t\left(S^{t-1}, I^t(v_i)\right) \quad (3.7.2.2)$$

which means that the system state at moment *t* depends of the system state at moment *t-1* and the error injection points at moment *t*.

Generally, the dynamic model is used to *evaluate the system response and behavior with respect to different evolution, distribution and intensities of the errors*.

Updating the Error Injection Graphs - The Algorithm

The dynamic behavior is given *by the direction of updating the error injection graphs*. Unlike with the static model, here the update procedure is *bottom-up*. The error propagation is computed *from the influenced component* perspective. In other words, the influenced component is *the main actor* and it gets all the error contributions from its influencing components.

Consider the influence flow graph at moment *t*, and the position of the current updated component (v_i) denoted by *p*. The following remark is of utmost importance in understanding this algorithm: *all the components* ***above*** *the current one are characterized by the incapability index at moment* (*t-1*). Following this, the incapability index of the current component at moment *t* is computed with regard to the values of the incapability indices of its influencing components at (*t-1*). Moreover, due to the fact that an influencing component can be reached on different influence levels, *only the influencing components from the influence level prior to the current one are taken into account*.

The algorithm for updating an error influence flow graph is described in the sequel.

Given: $I_S(v_S) = G(V',E')$ an error injection point of system *S*, and *T* the error variation trend.

	Algorithm 3.7	
S1	For each $e_k = \{l_k, v_i, v_j, w_k, II_{ji}\} \in E(I_s(v))$ with $k = \lvert E(I_S) \rvert..1$ repeat steps **S2** and **S3**	
	S2	Compute the error contribution of the influencing components at moment (*t-1*)

		$II^{(t-1)}(v_i) = \sum II^{(t-1)}(X, vi)$ where $X = \{x_l \in \{x_l, v_i\} \mid IL(\{x_l, v_i\}) < l_k\}$
	S3	Compute the error of the influenced component at moment (*t*) $II^{(t)}(e_i) = II^t(v_j) = II^{(t-1)}(v_i) * w_k$
S4	Update the error injection point's incapability index $II^{(t)}(v_s) = II^{(t-1)}(v_s) + T$	

Updating the System Components Status – The Algorithm

The algorithm for updating the system's components is similar to Algorithm 3.5 presented in Section 3.7.1.

The Influence Flow Simulation

The algorithm for one influence flow simulation step is:

	Algorithm 3.8
S0	Initialize System state: - Modify the error injection points (optional); - Modify the error intensity trends (*T*) for each of the error injection points (optional).
S1	Compute the error dispersion at moment *t* along each error injection graph with regard to the error dispersion at moment (*t-1*) - execute Algorithm x for each error injection point.
S2	Update the system components - execute Algorithm xx.

Example (continued)

Consider the system *S*, and the error injection point C_1.

The incapability index of C_1 will have the following time evolution, according to the trend $T(C_1)$:

$T(C_1)$	Duration (simulation steps)	$II(C_1)$ evolution
0.3	2	0 – 0.6
-0.6	1	0.6 – 0

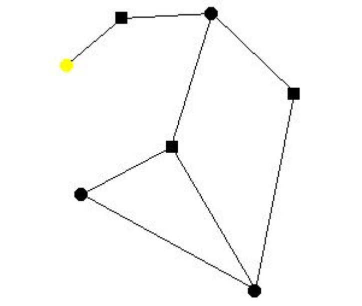
This simulates a ramp-shaped error for two time steps, followed by an immediate recovery of the error source component. The simulation will continue until the effects of the initial failure vanish from the system.

The following results are obtained:

Results after simulation step 1

$$E^{(1)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0), (2, S_1, C_2, 1, 0), (3, C_2, S_3, 1, 0), (3, C_2, S_2, 1, 0),$$
$$(4, S_3, C_4, 1, 0), (4, S_3, C_3, 1, 0), (4, S_2, C_3, 1, 0), (5, C_4, C_3, 1, 0)\}$$

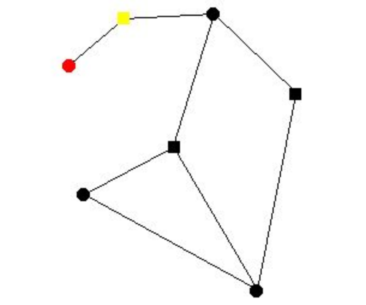
	Component	Incapability Index
V(S^(0))	*C1*	0.3
	S1	0.0
	C2	0.0
	S2	0.0
	S3	0.0
	C3	0.0
	C4	0.0



Results after simulation step 2

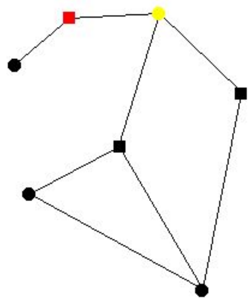
$$E^{(2)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0.3), (2, S_1, C_2, 1, 0), (3, C_2, S_3, 1, 0), (3, C_2, S_2, 1, 0),$$
$$(4, S_3, C_4, 1, 0), (4, S_3, C_3, 1, 0), (4, S_2, C_3, 1, 0), (5, C_4, C_3, 1, 0)\}$$

	Component	Incapability Index
V(S^(2))	*C1*	0.6
	S1	0.3
	C2	0.0
	S2	0.0
	S3	0.0
	C3	0.0
	C4	0.0



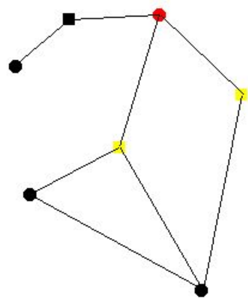
Results after simulation step 3

$$E^{(3)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0.6), (2, S_1, C_2, 1, 0.3), (3, C_2, S_3, 1, 0), (3, C_2, S_2, 1, 0), (4, S_3, C_4, 1, 0), (4, S_3, C_3, 1, 0), (4, S_2, C_3, 1, 0), (5, C_4, C_3, 1, 0)\}$$

	Component	Incapability Index	
V(S$^{(3)}$)	*C1*	0.0	
	S1	0.6	
	C2	0.3	
	S2	0.0	
	S3	0.0	
	C3	0.0	
	C4	0.0	

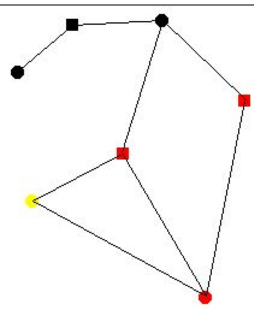
Results after simulation step 4

$$E^{(4)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0), (2, S_1, C_2, 1, 0.6), (3, C_2, S_3, 1, 0.3), (3, C_2, S_2, 1, 0.3), (4, S_3, C_4, 1, 0), (4, S_3, C_3, 1, 0), (4, S_2, C_3, 1, 0), (5, C_4, C_3, 1, 0)\}$$

	Component	Incapability Index	
V(S$^{(4)}$)	*C1*	0.0	
	S1	0.0	
	C2	0.6	
	S2	0.3	
	S3	0.3	
	C3	0.0	
	C4	0.0	

Results after simulation step 5

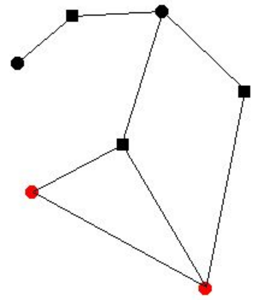
$$E^{(5)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0), (2, S_1, C_2, 1, 0), (3, C_2, S_3, 1, 0.6), (3, C_2, S_2, 1, 0.6), (4, S_3, C_4, 1, 0.3), (4, S_3, C_3, 1, 0.3), (4, S_2, C_3, 1, 0.3), (5, C_4, C_3, 1, 0)\}$$

	Component	Incapability Index	
V(S$^{(5)}$)	*C1*	0.0	
	S1	0.0	
	C2	0.0	
	S2	0.6	
	S3	0.6	
	C3	0.6	
	C4	0.3	

Results after simulation step 6

$$E^{(6)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0), (2, S_1, C_2, 1, 0), (3, C_2, S_3, 1, 0.6), (3, C_2, S_2, 1, 0),$$
$$(4, S_3, C_4, 1, 0), (4, S_3, C_3, 1, 0.6), (4, S_2, C_3, 1, 0.6), (5, C_4, C_3, 1, 0.3)\}$$

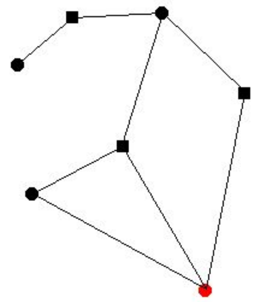
	Component	Incapability Index
V(S$^{(6)}$)	*C1*	0.0
	S1	0.0
	C2	0.0
	S2	0.0
	S3	0.0
	C3	1.0
	C4	0.6



Results after simulation step 7

$$E^{(7)}(I_S(C_1)) = \{(1, C_1, S_1, 1, 0), (2, S_1, C_2, 1, 0), (3, C_2, S_3, 1, 0.6), (3, C_2, S_2, 1, 0),$$
$$(4, S_3, C_4, 1, 0.6), (4, S_3, C_3, 1, 0), (4, S_2, C_3, 1, 0), (5, C_4, C_3, 1, 0.6)\}$$

	Component	Incapability Index
V(S$^{(7)}$)	*C1*	0.0
	S1	0.0
	C2	0.0
	S2	0.0
	S3	0.0
	C3	0.6
	C4	0.0



After simulation step 8, all the components are back in line, as fully operational and unaffected by error.

In the pictures above, the *black* components are the ones unaffected by error, the *yellow* ones have an incapability index lower than 0.5 and the *red* ones have an incapability index higher than 0.5.

Another interesting result obtained by using the dynamic model is also reflected in this example. It concerns what can be termed as a *wave* effect in error propagation. One can see, when analyzing the results in a step-by-step manner, that even though the error generating component is back to the fully functional state (it does no longer injects any error through the system), the already generated failure continues to propagate itself, following the initial pattern of the error generated by the *EIP*.

4 *InSIEME* – The Application

4.1 System Requirements

InSIEME is developed on ESRI's *ArcView*® 3.3 *GIS* platform, as a ***CRISA*** project. The application was also tested on previous versions of *ArcView* with partially successful results. The current version is design to work only under Microsoft® *Windows*™ operating systems.

The infrastructure system considered is the Italian 360 KW power grid. The focus is on electricity generation and transportation networks.

4.2 Application Framework

This section presents the ***InSIEME*** framework, focusing on the typical *workflow*, and presenting elements of *user-interface* and *utilization guidelines*. Details regarding the implementation of the models in ***Chapter 3*** are also given.

A certain level of proficiency with *ArcView* is a prerequisite.

A correspondence between ***InSIEME*** systems and *ArcView* native objects should be established. A list of the ***InSIEME*** system structural components and their correspondent *ArcView* objects is given in the sequel.

	InSIEME System	***ArcView GIS***
1	Primary data source	The Project
2	Component	Theme Feature
3	Component type (class)	Theme *Only themes characterized by 'Feature Data Source Type'*

InSIEME provides a collection of tools for (i) *System definition (construction)* and (ii) *System analysis*. All the tools can be accessed from the *System Analyst Gateway*.

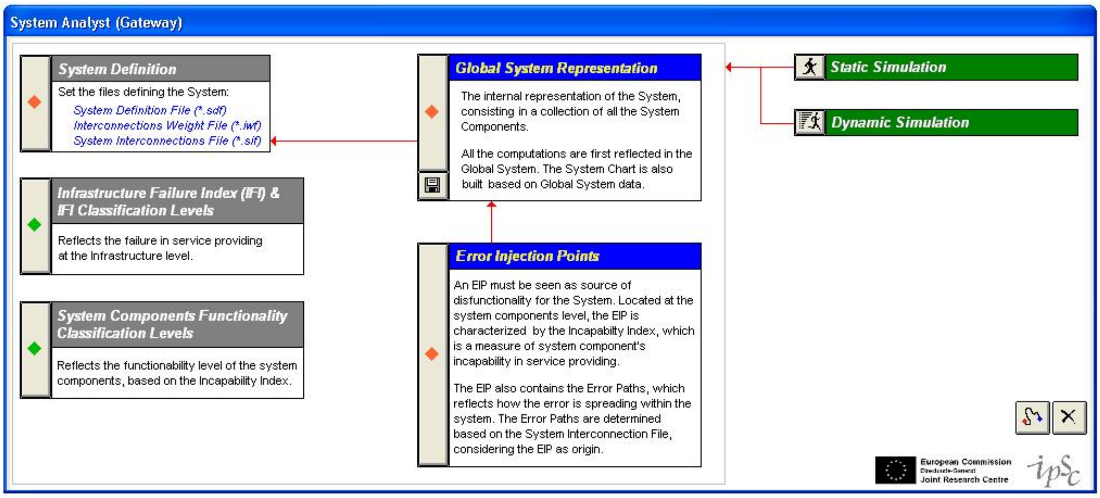


Figure 4.1. The System Analyst Gateway

From *The Gateway* the following can be started:

- *System Definition* – for the management of the system structural definition.
- *Global System Representation* – for generating the *global representation* of the current system (details - later on in this chapter).
- *Infrastructure Failure Index & Infrastructure Classification Levels* and *System Components Functionality Classification Levels* – for the management of the risk levels.
- *Error Injection Points* – for the management of the system's error injection points.
- *Static Simulation* – for initiating an *error dispersion* simulation session.
- *Dynamic Simulation* – for initiating an *influence flow* simulation session.

4.2.1 Building a System

As indicated, an ***InSIEME*** system is built *starting from the GIS representation* of the infrastructure. The GIS representation is a collection of ArcView *themes*. Each theme is an ***InSIEME*** *component-type class*. The theme's *features* are the system components.

Building a system involves several steps presented here from both perspectives, ***InSIEME*** and *ArcView* respectively:

1. ***(InSIEME)*** Define the system components' *classes*.
   (ArcView) Select *the themes* relevant to the infrastructure system.

2. ***(InSIEME)*** Establish the *influence intensity weights* of the defined classes.
   (ArcView) None.

3. ***(InSIEME)*** Define the system *by the interconnections* between components.
   (ArcView) Select *the features (pairwise)* based on the interconnections.

InSIEME holds the system definition information in three files, corresponding to each of the steps above.

The System Definition File (.sdf)* – contains the system classes. The *name* of the class will be referred to as the *key*. The *ArcView* theme corresponding to the class is represented by *the theme data source* (the *shape (shp)* file).

The advantage of this representation is that the system classes are correctly defined *irrespective* of the *ArcView* theme *names*. In other words, one can change the name of the *themes* in the *view*, but this action should not be reflected in the system definition.

The Interconnections Weight File (.iwf)* – holds the weights characterizing the influence level between the classes.

The System Interconnections File (.sif)* – holds the pairs of interconnected components. The *sif* file is in fact the one *defining* the system, since the ***InSIEME*** system is basically characterized by *the interconnection pattern* between the components.

The following is worth noticing: *an **InSIEME** system component is referenced by **its parent class** and **the index** of the corresponding ArcView feature*

The advantage of modularizing the system definition is that this approach confers a greater flexibility of the systems construction processes. For instance, for the same data sources (shape files) one can define several sub-systems with regard to the interconnection between the components, or the number of relevant components. In this case, the *sdf* and *iwf* files would be the same, only the *sif* files having to be built for each of the subsystems.

Building a system - How to…

1. From *The Analyst Gateway* launch *System Definition Manager* (Fig. 4.2).

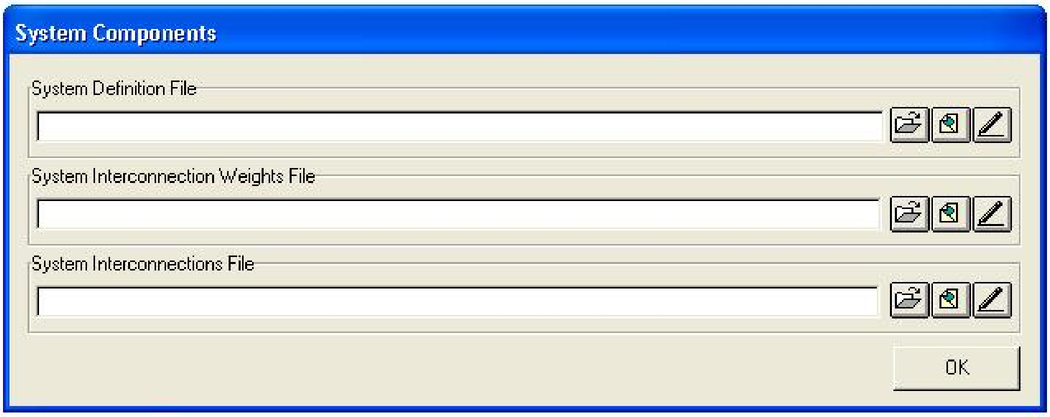


Figure 4.2. The System Definition Manager dialog

2. Create the *System Definition File*

2.1 Click *New* button in *System Definition File* tab. The *System Definition File Manager* will pop-up (Fig. 4.3).

2.2 Click *Add New Class* button.

2.2.1. Select the desired *shape* file (usually located in '*Shapes*' sub-folder of ***InSIEME*** folder).

2.2.2. Provide *the key (name)* for the new class.

2.3 When done, click *Save* button to save the *sdf* file.

3. Create the *Interconnections Weights File*

3.1 Click *New* button in *System Interconnections Weights File* tab and provide a name for the *iwf* file.

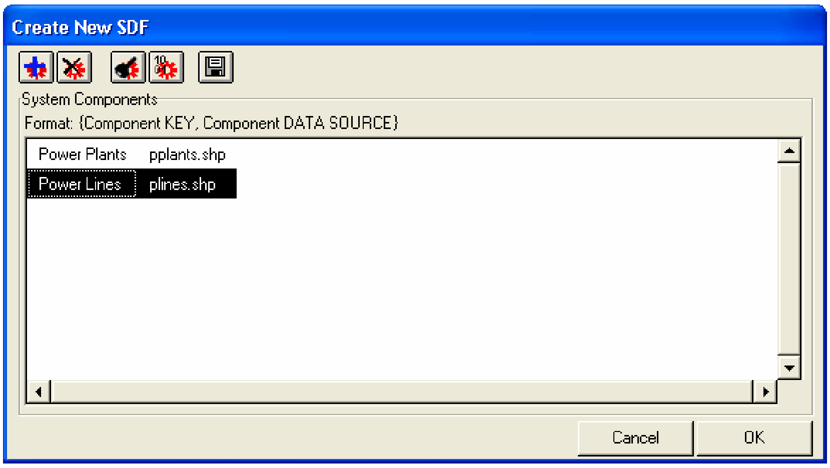


Figure 4.3. New System Definition File dialog

Note: Since the interconnections weights file is built based on the system definition file, ***ONE CANNOT CREATE*** a new *iwf* ***BEFORE*** selecting / creating the system's definition file.

3.2 Click *Edit* button to change the default values for the interconnection influence levels. This is done from the *Edit IW* window (Fig. 4.4)

3.3 When done, click *Save* button to save the *iwf* file.

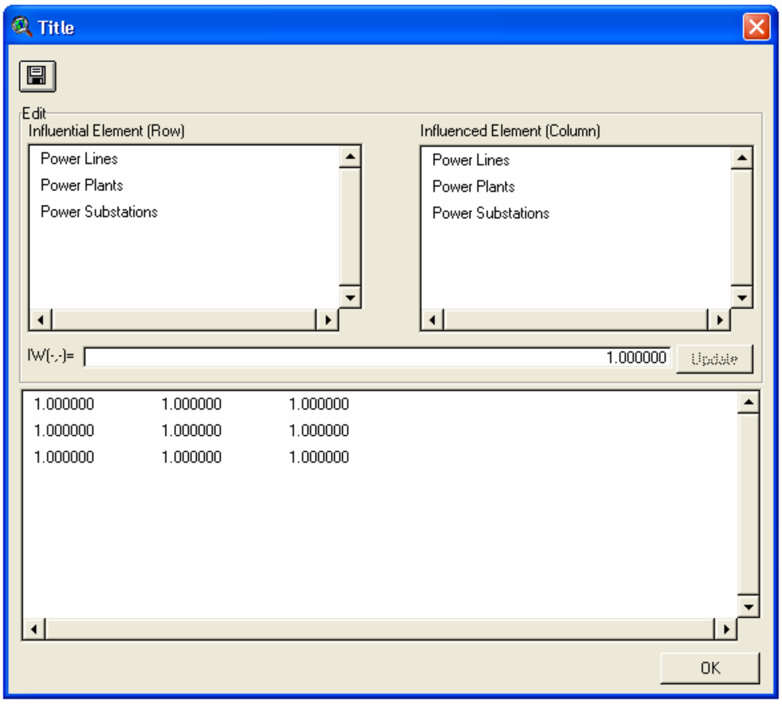


Figure 4.4. Edit IW dialog

4. Create the *System Interconnections File*

4.1 Click *New* button in *System Interconnections File* tab and provide a name for the *sif* file.

4.2 Click *Edit* button to start the *Edit SIF* window (Fig. 4.5)

4.3 With the system view active, start building the pairs corresponding to the interconnected components. The components are selected from the system's graphical representation using the *selection tools* .

4.4 When done, click *Save* button to save the *sif* file.

Note: The *selection tools* are used to provide data *directly from the graphical representation of the system*. For convenience, the selection tools pictogram is usually the same throughout the application.

In strongly connected systems building the system interconnection file may prove to be a tricky job, due to the large number of interacting pairs. ***InSIEME*** provides two features to help the developer to trace the defined interconnections: the first is to highlight the components in the system view on a pair-by-pair basis. This is performed by checking the *Highlight interconnection in system view* box in *the Edit SIF* window. The effect is that, when a pair of components is selected in the

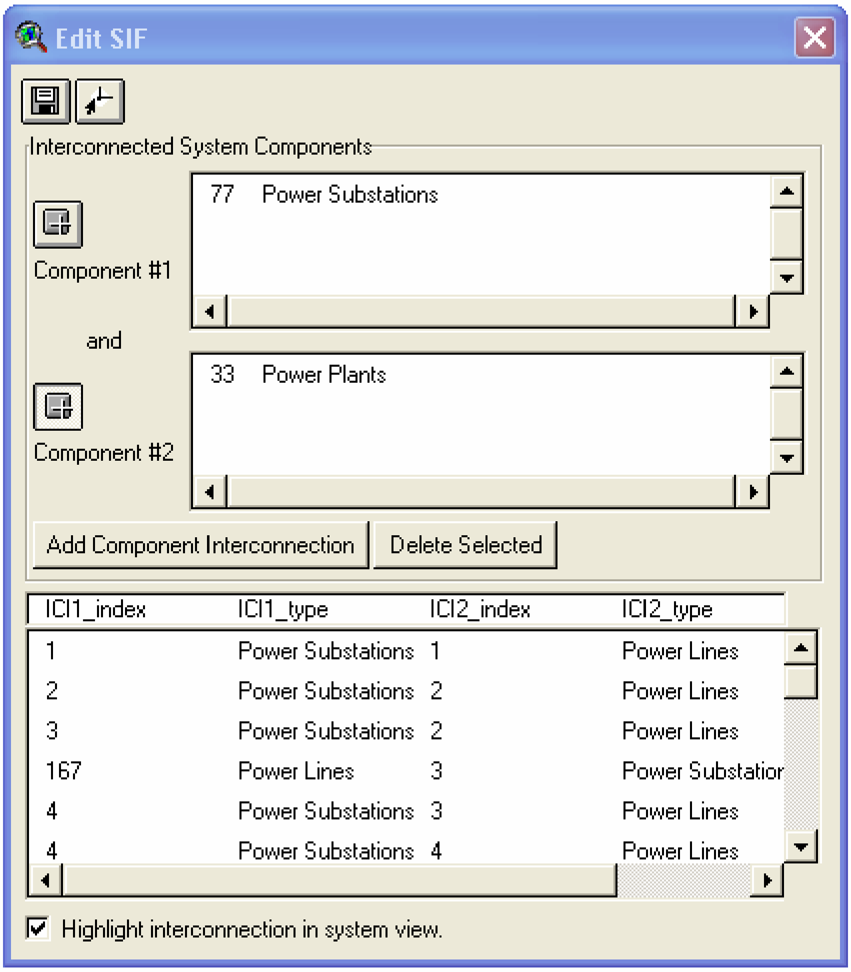


Figure 4.5. Edit System Interconnections File dialog

interconnections list, the corresponding components are highlighted in the system view. The second is to highlight *all the defined interconnections* in the system view. Do this by clicking the *Highlight interconnections* button .

4.2.2 Working Session

A typical working session in ***InSIEME*** goes by three steps:

1) *Define the system*
2) *Define the error injection points* (the initial error distribution within the system)
3) *Analyze the system* (run simulation and get the results)

InSIEME provides the tools for each of the tasks above.

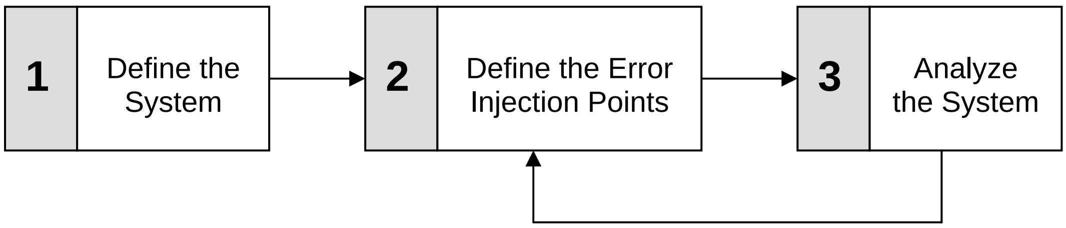


Figure 4.6. ***InSIEME*** workflow

Define the system

Defining the system implies (i) to select the system definition files describing the system to be analyzed, and (ii) to generate the *Global System Representation* for the current system.

The definition files are selected from the *System Definition Manager*, by choosing *Open* for each type of files.

The *Global System Representation (GSR)* holds the system components and corresponds to the *vertex set V* of the system graph. The global system representation is built based on the data from the system interconnection file. In other words, the system definition process is backward: first, the system graph edges are defined (the interconnections); next, the nodes (system components) are extracted from the set of edges. This approach has been adopted in order to avoid resource overloading (e.g. add more components than necessary), as well as possible errors due to nodes–edges incompatibilities (e.g. edges that refer to nodes that do not exist).

The Global System Representation is automatically built by ***InSIEME*** from the current system's *interconnections file*. However, due to the considerable amount of time required by this procedure in the case of large systems, ***InSIEME*** provides the option of saving a GSR on disk. Three options are available when dealing with the GSR:

- *Generate new Global System Representation* – the GSR is built based on the current *sif* file. This is the recommended option since the GSR is sure to be built error-proof from the edge-nodes compatibility viewpoint.
- *Select an already generated GSR* – this should be used when a GSR was already generated and saved on disk.
- *Use the current GRS.*

Note: Attention should be exercised when selecting the system definition files. If there are incompatibilities between files (e.g. different class keys, *sif* files referencing components that do not exist in the ArcView themes, etc.) the simulation session will crash.

Define the system – How to…

Select the system definition files – from the *System Definition Manager* accessed from *System Analyst Gateway*.

Generate / Select GSR

1. Start *Global System Representation* from the *System Definition Manager*.

2. Create / select the GSR from the possible options (Fig. 4.7).

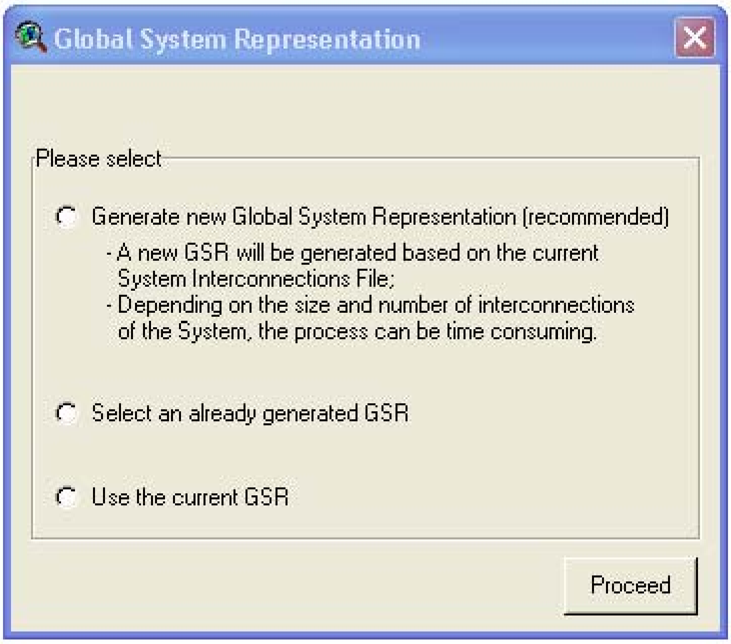


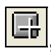
Figure 4.7. The Global System Representation selection dialog

Define the error injection points

Defining the error injection points implies to set the initial spatial distribution of *EIP*s within the system. As indicated, the simulation procedures deal with the system state, given a distribution of components that are not operating at the design level.

The system's *EIP*s can be managed either from a distinct management tool (Fig. 4.8), or directly from within the simulation control window. Once an *EIP* is built, it can be saved on disk as **.EIP* file.

The EIP Manager – How to…

Create new EIP - From the *EIP* Manager, activate the *selection tool* , then click the target system component in the system view.

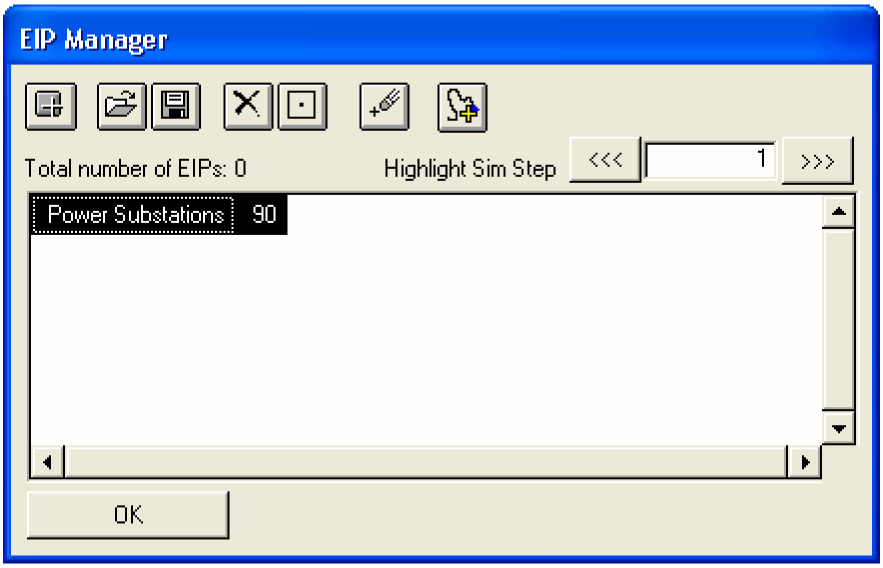


Figure 4.8. The Error Injection Points Manager dialog

Save EIP – Select the *EIP* from *EIP*s list, then click *Save* button and provide a name for the *EIP* file. The default folder where the *EIP* files are hold is *<**InSIEME**>\Systems\EIPs\.*

Add an EIP from file – Click *Open* button and select the file corresponding to the *EIP*.

Delete an EIP from list – Select the target *EIP* in list, then click *Delete EIP* button .

Select and Center – Select the target *EIP* in list, then click *Select and Center* button .

Reset the EIP – The reset procedure ensures that the *EIP* characteristic values (*Trend, Incapability Index*) are set to zero. Select the target *EIP* in list, then click *Reset EIP* button .

Get Route – Select the target *EIP* in list corresponding to the start point of the route, then click *Select Destination* button and click the destination component in the system view. The GetRoute dialog will start in *EIP from list* mode (see Section X).

Adjust Threshold Limits

This pre-simulation phase is optional. As indicated, the severity of the impact caused by the incapability index of the system's components is set by choosing the threshold limits to define the operability states of a component (components level) and the threshold limits to characterize the system's overall operability state (system level).

The operability states for a component are set using the *System Component Functionality Classification Levels* feature, accessed from the *System Analyst Gateway*.

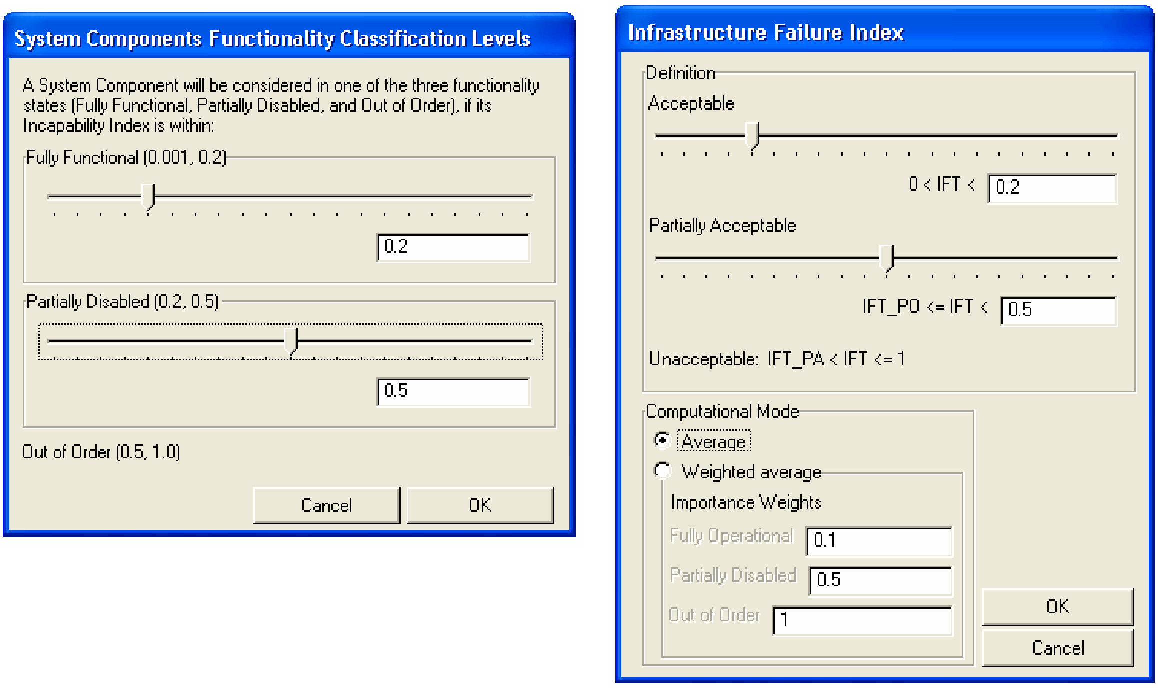


Figure 4.9. The System Threshold Limits Manager dialogs

When *OK* is selected, the user is prompted about reflecting the changes in the system view. If *Yes*, ***InSIEME*** automatically updates the legend of the themes in the system view to reflect the new settings for the threshold limits.

To set the threshold limits for the *Infrastructure Failure Index* and *Weighted Infrastructure Failure Index* one should start the *IFI Classification Levels* module from the *System Analyst Gateway*. The *importance weights* can also be modified from the same dialog box.

The Static Simulation – Error Dispersion Model

When all the phases above are completed, the system is properly defined for the effective analysis. To start an analysis based on the *Error Dispersion Model* one should select *Static Simulation* in the *System Analyst Gateway*.

The simulation is controlled through the *Static Simulation* window (Fig. 4.10). The Static Simulation control window is split into four areas, as follows:

- *Error Injection Points Management* (1) providing the same tools as the *Error Injection Points Manager*.
- *Results Visualization and Statistics* (2)
- *EIPs Control* (3).
- *Simulation Control* (4).

An analysis procedure implies (i) to set the *Incapability Indexes* for each of the system's *EIP;* (ii) to run the simulation; and (iii) to analyze the results.

Simulation Procedure – How to…

Set the EIPs' error level

1. Select the error injection point in *EIP* list.
2. Click *Change* button.
3. Provide the incapability index in *Trend* textbox.
4. Press ***Enter***.

Notes:

1. The current error injection point *is not* updated until *Enter* key is pressed after providing the trend.
2. If only one *EIP* in *EIP* list, *double-click* in *EIP* list to refresh the information in *Simulation Window*.

Run simulation – click *Run* button . When the computational phase is done, the results are reflected in the system view.

To reset the system, one should use the *Reset* button .

For details regarding the result analysis please refer to Section '*The Analysis*', to follow.

The Dynamic Simulation – Error Flow Model

To start an analysis based on the *Error Flow Model* one should select *Dynamic Simulation* in *System Analyst Gateway*.

The simulation is controlled through the *Dynamic Simulation* window (Fig. 4.11). The Dynamic Simulation control window is split into six areas, as follows:

- *Error Injection Points Management* (1) providing the same tools as the *Error Injection Points Manager*.
- *Results Visualization and Statistics* (2)
- *EIPs Control* (3).

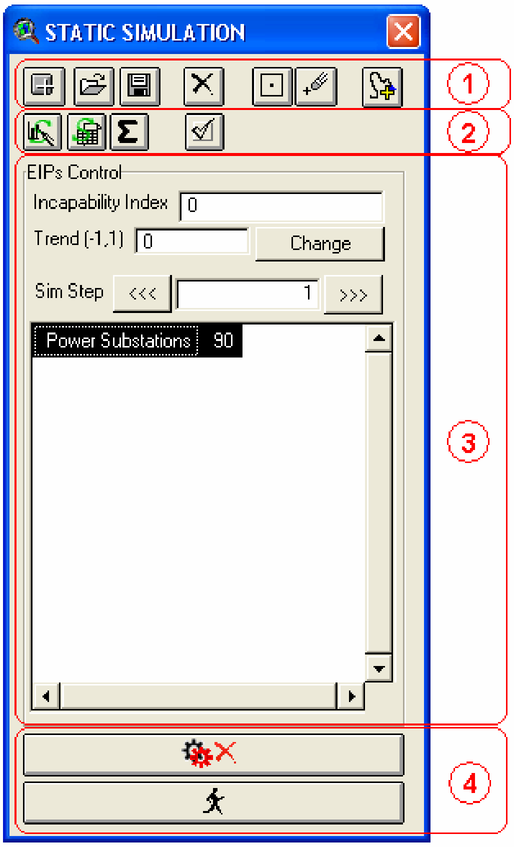


Figure 4.10. The Static Simulation run dialog

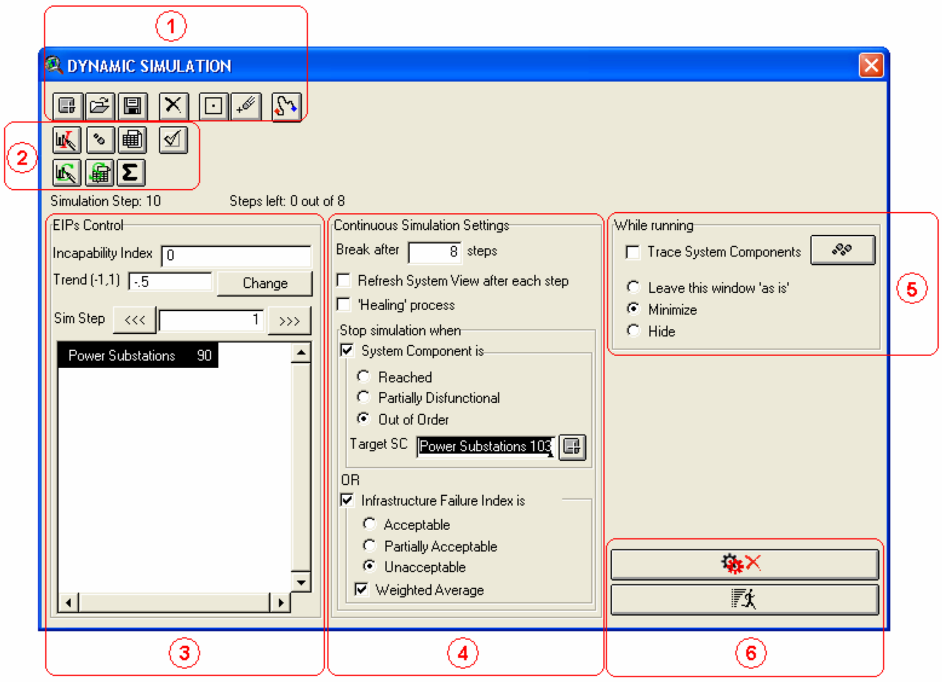


Figure 4.11. The Dynamic Simulation run dialog

- *Continuous Simulation Settings and Simulation Stop Conditions* (4).
- *Simulation Window Behavior* (5).
- *Simulation Control* (6).

The dynamic simulation module provides a variety of options that are useful in analyzing the system behavior to error-induced stress.

Stop Conditions – The simulation stops when either of the stop conditions are reached. The conditions refer to components operability state, or the system failure state. A typical example of using the stop conditions is to determine if a given dynamic of error leads to an incapability index higher than the *Partially Disfunctional* state of a target component, or to an *Unacceptable* state of the system failure.

'Healing process' should be selected when the system is already in a dysfunctional state (e.g. WIFI is *Unacceptable*) and one wants to determine which is the system dynamic and how many simulation steps are required for placing the system in an *Acceptable* state.

An analysis procedure implies:

(i) Set the *Incapability Index Trends* for each of the system's *EIP.*
(ii) Set the number of continuous simulation steps.
(iii) Set simulation stop conditions.
(iv) Run simulation.
(v) Analyze results.

The analysis

InSIEME provides a number of tools that are helpful in analyzing the system. This section covers several evaluation techniques and the tools to be used in the process.

Visualize the error propagation from an EIP, on a simulation step-by-step basis

This feature allows the visualization of the connections between system components that are traveled by the error in the specified simulation step. The current step also indicates the current influence level.

This feature is useful, for instance, in determining the order in which the components are reached by the error, or the influence level corresponding to the highest number of components that are simultaneously affected by the error.

The feature is available from any application module that handles the system's *EIP*s. The user should select the target *EIP* in the *EIP* list, then navigate from one simulation step (influence level) to another using the arrow buttons next to the Simulation Step textbox. The result is the highlight of the current interconnections in the system view.

Extracting the error injection routes

The error injection routes hold the sequence of components reached by the error on the way from an *EIP* to a target component. As indicated in Chapter 3, the origin of the route is an *EIP*.

The starting point can be selected (i) as one of the system *EIP*s or (ii) as any of the system components. In the last case, a temporary *EIP* will be generated for the component selected as starting point. The temporary *EIP will not* be added in the system *EIP* list.

To extract the error routes one should access the *Get Paths* feature, either (i) by selecting *Get Error Paths* button from the *System Analyst Gateway*, or (ii) by selecting the destination component in the system view using the *Get Error Paths* selection tool from any application that handles the system *EIP*s.

Once the routes are extracted, the following features are available:

- *Show All* – highlights the components *from all the routes* in the system view.
- *Show Selected* – highlights *only* the components *of the selected route* in the system view.
- *Real Data* – provides a text report containing the selected route components. The components are listed using the *real data* (e.g. Name) extracted from the corresponding themes data sources. The real data are extracted from the *label field* of each of the themes. Each record is formatted as: { *parent class*, *real data*, *incapability index* }.

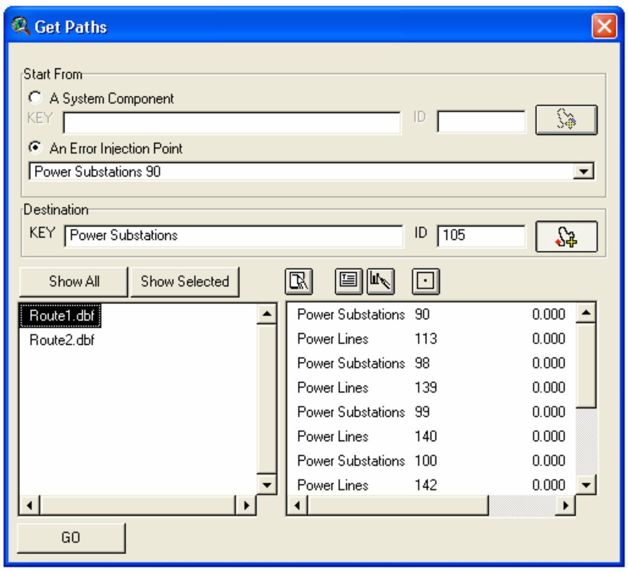


Figure 4.12. The get Paths dialog

- *Details* of the selected route – provides a statistic along the route, given as a text report with the following structure:

Route Statistics
ERROR INJECTION PATH: *name* Number of influenced System Components Influenced System Components by type: Component Type: *the parent class* - Encountered: *number of components* - Percent of total encountered Route Length: Most affected component(s) along the route Value of incapability Index *of the most affected component* From *parent class*, system component *real data* Overall Incapability Index (averaged): *computed as the sum of the incapability indexes of the components along the route divided by their number.*

- *Chart* the Incapability Index along the selected route.

Note: If the starting point of the route *is not* a system *EIP*, any information regarding the error along the route is irrelevant, since the incapability indices of the components of the temporary *EIP* are set to 0. In other words, if the analysis is focused on the error values (e.g. evaluating the error on a route after a simulation procedure) the option of selecting the *EIP* from the system *EIP*s should be used.

The System Components Chart

The System Components Chart displays the incapability indices of all the system components. It reflects the impact of the initial failures on the system operability.

The System Table

The System Table holds the system state given by the component error level. The components are given by *real data*.

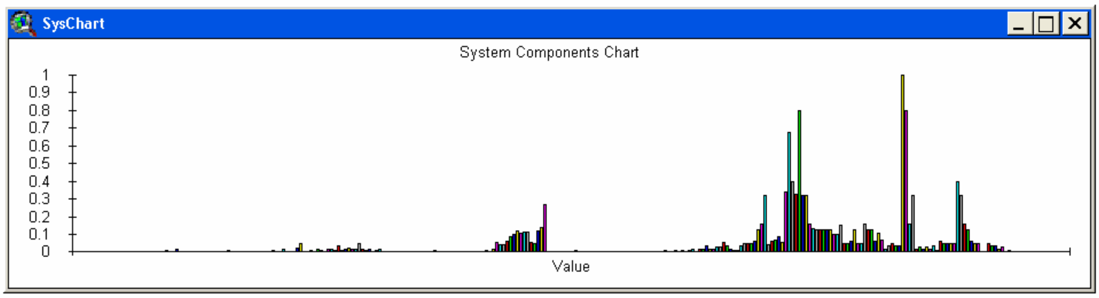


Figure 4.13. Example of System Components Chart

Tracing System Behavior in Time

This is only available in *Dynamic Simulation*. The system behavior is expressed by the variation of the *Infrastructure Failure Index* and *Weighted Infrastructure Failure Index* on each simulation step, and given as a chart. By analyzing the chart, one can obtain information regarding:

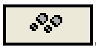
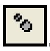
- the most critical simulation steps - from the number of components simultaneously affected by the error viewpoint, given by the ramp of the IFI graph, or
- the most critical simulation steps - from the severity of the impact the error has on the system, given by the ramp of the WIFI graph.

Trace Components

Only available in *Dynamic Simulation* mode. By using this feature, the analysis is driven towards the system components level.

For each of the system components that are selected to be *traced*, ***InSIEME*** keeps the record of the incapability index at each simulation step. The result is the dynamic of error affecting the component. A chart, as well as a table in *real data* format with all the traced components is provided (Fig. 4.14*b*).

The procedure of tracing components requires several steps:

1) Build the traced components list.
    a. In *Dynamic Simulation* window, click *Edit Traced System Components List* button . The *Trace System Components* dialog will pop up.
    b. Using the selection tool from the *Trace System Components* add the target components by selecting them from the system view.
2) Run simulation
3) Visualize results…
    a. …as chart – in *Dynamic Simulation* window, click *Display Traced Element Chart* button . Select the elements you want to display from the list that will pop up, then click *OK*.

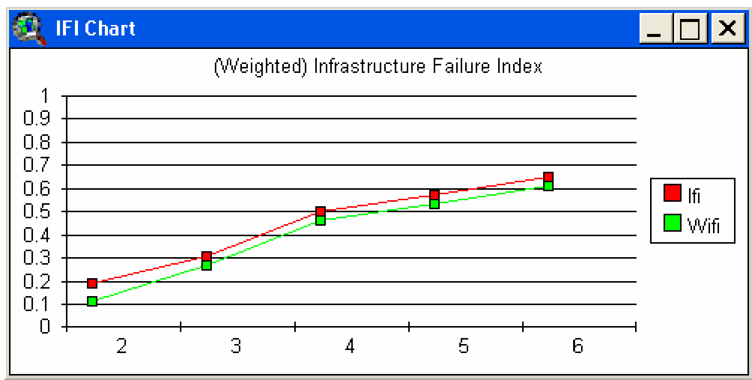
b. …as table – in *Dynamic Simulation* window, click *Display Traced Element Table* button .

Simulation Results Statistics

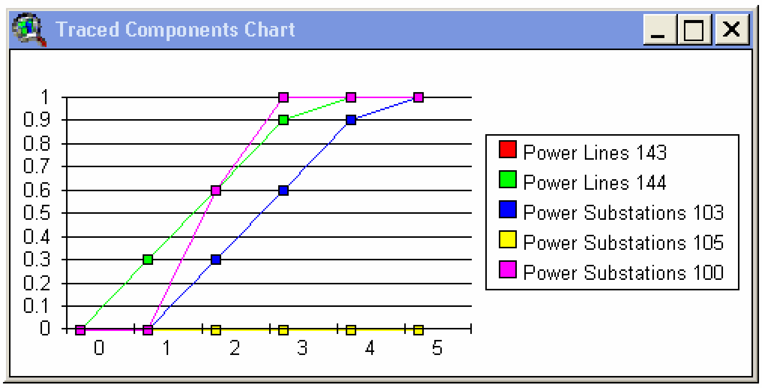
These are determined with regard to the current state of the system. The following information is available:

- *The Infrastructure Failure Level* based on *IFI* and *WIFI.*
- *The number of reached system components.*
- *The number and percent of total system components reached by error, BY TYPE (CLASS).*
- *The number system components that are reached, BY OPERABILITY LEVEL.*
- *The overall incapability index of the system.*

- *The most affected system components*, and
- For each of the system *EIPs*, *the number and the list of the affected components*.



(a)



(b)

Figure 4.14. Example of charts
(a) *IFI / WIFI* Chart; (b) Traced components chart

Such features, together with the CRISA-specific and native ArcView analytical tools, would make ***InSIEME*** a potentially effective tool in assessing the vulnerability of the complex systems via error propagation mechanisms.

5 *InSIEME* Showcase

This chapter gives two examples of effective use of ***InSIEME*** by providing two workflows, the first for the Static Simulation and the second for the Dynamic Simulation. The analysis does not cover all the possible methods of assessment; however, it is considered representative in giving an idea about the capability of ***InSIEME***.

5.1 Pre-Assessment Phase

As indicated in the previous chapter, the first step in using ***InSIEME*** is to *define the system*. The ***InSIEME*** system is defined by the files *crisa.sdf*, *crisa.iwf* and *crisa.sif*.

Once these files are selected as system definition files, the system is properly defined and one can proceed with the simulation and assessment phase.

5.2 Static Simulation

5.2.1 The Scenario

We will consider the following scenario to be assessed:

EVENT 1: due to unknown causes, a failure occurs in the power substation RAVENA CANALA, leading to a drop in its operability state (capability of service providing) by 50%. This is equivalent with an increase of the incapability index by 0.5.

EVENT 2: following EVENT 1, a failure of the power plant BRINDISI SUD is also observed. The power plant operability drops by 75%, which is equivalent with a value of 0.75 of its incapability index.

Queries

1. *How many influence steps* are required for the error to reach all the system components starting from each of the error sources?

2. What is the *system operability state* after each of the EVENTS?

Which are the routes from each error source to power plant Torrevaldaliga?

5.2.2 The Workflow

For our example we will take the default values for the threshold limits and the influence weights matrix. The influence weights matrix is:

	PL	*PSS*	*PP*
Power Lines (PL)	1.0	0.6	0.4
Power Substations (PS)	0.85	1.0	0.3
Power Plants (PP)	0.9	0.85	1.0

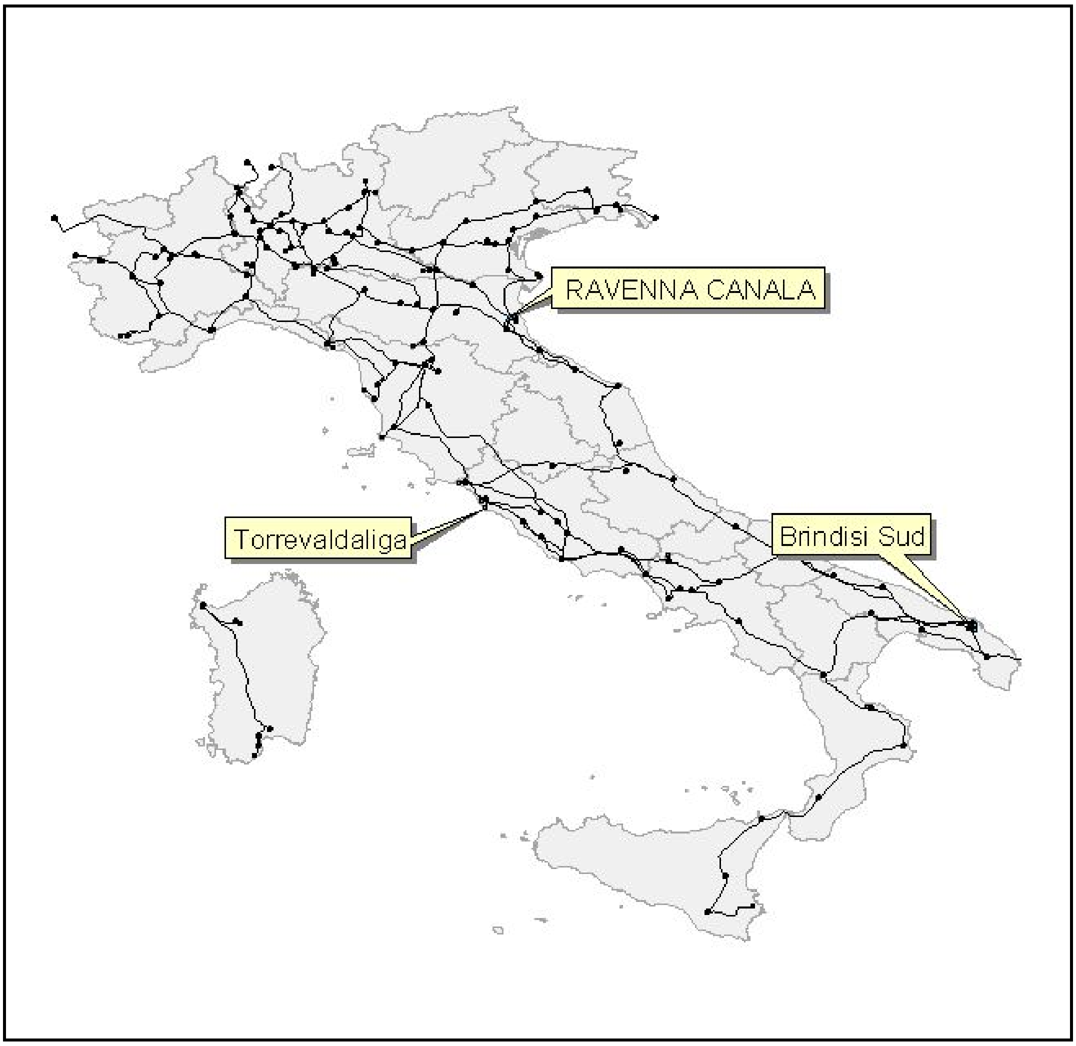


Figure 5.1

From the scenario it results that two system error injection points has to be defined, located at the power substation RAVENA CANALA and power station BRINDISI SUD, respectively (Fig. 5.1). In Fig. 5.1 the power plant Torrevaldaliga, which is subject to the analysis requested in Task 3, is also indicated.

A workflow that would answer the given queries is proposed in the sequel.

Solving Task 1

One possible way to determine the *number of influence levels* that are required for the error to reach all the system components starting from each of the error sources is to use ***InSIEME***'s *Highlight Influence Level Components in System View*. *Highlight next level* should be selected until the level counter stops incrementing.

Solving Task 2

A. Run *Static Simulation* with the following settings, to represent EVENT 1:

Settings for Static Simulation run corresponding to EVENT 1	
EIP	***Incapability Index***
RAVENA CANALA BRINDISI SUD	*0.5* *0*

B. Get the results of the simulation from previous step:

- *Graphical Results*
    - *System Components Chart*;
    - *System State GIS Representation* – from the system view.
- *Analytical and Statistical Results*
    - *System Chart*
    - *Simulation Report*

C. With the system in current state, run *Static Simulation* with the following settings:

Settings for Static Simulation run corresponding to EVENT 2	
EIP	***Incapability Index***
RAVENA CANALA BRINDISI SUD	*0.5* *0.75*

D. Repeat Step C.

Solving Task 3

Task 3 is achieved using *Get Routes* feature provided by ***InSIEME***. To get relevant information regarding the error dispersion *along* the determined routes, *Get Routes* should be accessed from the *Static Simulation Window*, using the *destination selection tool* to select the power plant Torrevaldaliga from the system view.

5.2.3 The Results

Results for Task 1

Results for Task 1 – which is the number of influence levels required by the error to reach all the system components.	
Starting from	***Influence levels***
RAVENA CANALA	*37*
BRINDISI SUD	*57*

Results for Task 2

Results of the simulation of EVENT 1

The *GIS representation* is the one from the system view. It is represented in Fig. 5.3.

The incapability indexes of all the system components can be graphically visualized using the *System Components Chart* feature (Fig. 5.4).

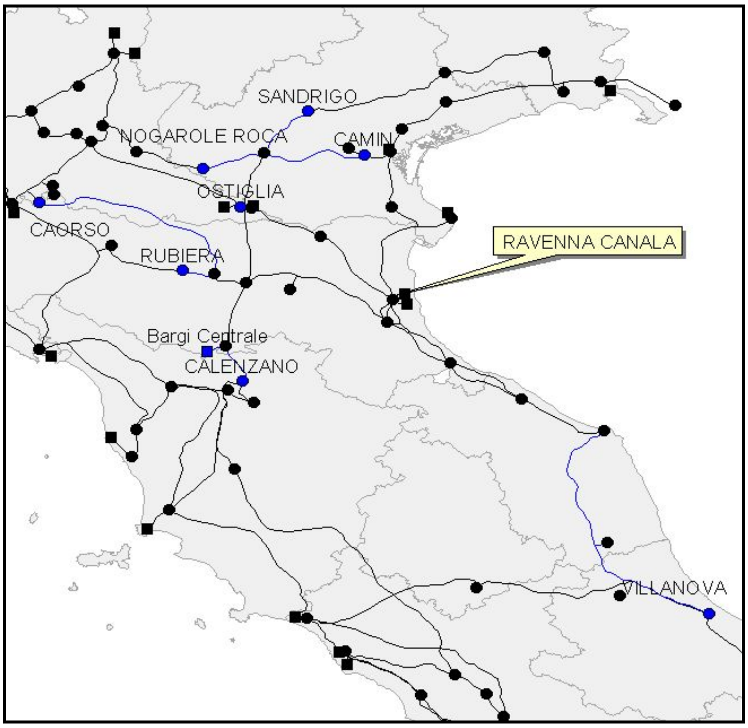


Figure 5.2 The components reached on the eight influence level by the error injected by RAVENA CANALA.

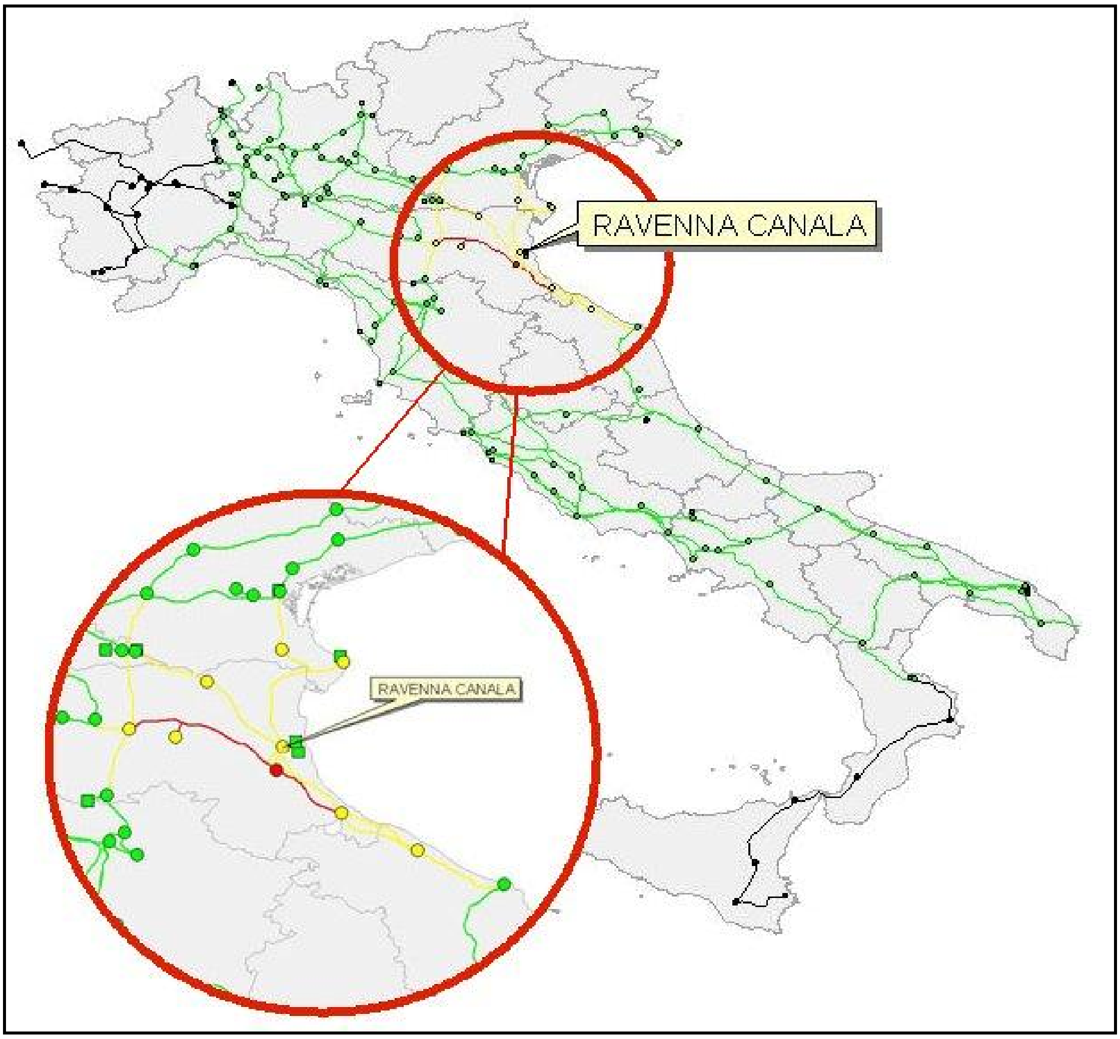


Fig. 5.3 The system state after the simulation corresponding to EVENT 1. Zoom to the area characterized by *partially disabled* system components.

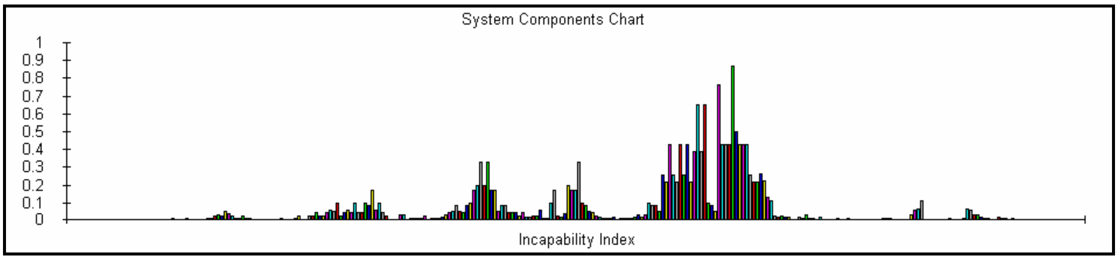


Fig. 5.4 The *system components chart* after the simulation corresponding to EVENT 1.

The *system components table* is given is the sequel. Note that the following is only an excerpt containing:

- the components that are reached by the error, and
- *only* the Power Plants and Power Substations components.

The extended version of this table is given in the Appendix.

Table 5.1 ***System Components Table after EVENT 1 – Excerpt***

Key	Name	Incapability Index	Classification
Power Substations	FORLI ORAZIANA	0.765	Out of Order
Power Substations	RAVENNA CANALA	0.500	Out of Order
Power Substations	COLUNGA	0.390	Partially Disabled
Power Substations	MARTIGNONE	0.390	Partially Disabled
Power Substations	FANO E.T.	0.260	Partially Disabled
Power Substations	ADRIA SUD	0.255	Partially Disabled
Power Substations	FERRARA FOCOMORTO	0.255	Partially Disabled
Power Substations	PORTO TOLLE	0.255	Partially Disabled
Power Substations	S. MARINO IN XX	0.255	Partially Disabled
Power Substations	BARGI STAZIONE	0.199	Fully Functional
Power Substations	DUGALE	0.199	Fully Functional
Power Substations	S. DAMASO	0.199	Fully Functional
Power Plants	Enipower Ravenna	0.170	Fully Functional
Power Plants	Porto Corsini	0.170	Fully Functional
Power Substations	CANDIA	0.133	Fully Functional
Power Substations	CALENZANO	0.101	Fully Functional
Power Substations	CAMIN	0.101	Fully Functional
Power Substations	CAORSO	0.101	Fully Functional
Power Substations	NOGAROLE ROCA	0.101	Fully Functional
Power Substations	RUBIERA	0.101	Fully Functional
Power Substations	SANDRIGO	0.101	Fully Functional
Power Plants	Porto Tolle	0.087	Fully Functional
Power Plants	Sermide	0.087	Fully Functional
Power Plants	Bargi Centrale	0.068	Fully Functional
Power Substations	ROSARA	0.068	Fully Functional
Power Substations	VILLANOVA	0.068	Fully Functional
Power Substations	NA#8	0.059	Fully Functional
Power Substations	CREMONA	0.058	Fully Functional
Power Substations	PIACENZA	0.058	Fully Functional
Power Substations	CORDIGNANO	0.052	Fully Functional
Power Substations	LONATO	0.052	Fully Functional
Power Substations	PARMA VIGHEFFIO	0.052	Fully Functional
Power Substations	POGGIO A CAIANO	0.052	Fully Functional
Power Substations	RFX CNR	0.052	Fully Functional
Power Substations	TAVARNUZZE	0.052	Fully Functional
Power Substations	SERMIDE	0.047	Fully Functional
Power Substations	LARINO	0.035	Fully Functional
Power Substations	VILLAVALLE	0.035	Fully Functional
Power Plants	Dolo	0.034	Fully Functional
Power Substations	GORLAGO	0.032	Fully Functional
Power Substations	NAVE	0.032	Fully Functional
Power Substations	NA#3	0.030	Fully Functional
Power Substations	LA CASELLA	0.029	Fully Functional
Power Substations	LA SPEZIA	0.029	Fully Functional
Power Substations	NA#10	0.029	Fully Functional
Power Substations	NA#9	0.029	Fully Functional
Power Substations	TAVAZZANO	0.029	Fully Functional
Power Substations	MARGINONE	0.026	Fully Functional
Power Substations	PIAN DELLA SPERANZA	0.026	Fully Functional
Power Substations	SUVERETO	0.026	Fully Functional
Power Substations	UDINE OVEST	0.026	Fully Functional
Power Substations	OSTIGLIA	0.024	Fully Functional
Power Plants	Piacenza	0.020	Fully Functional
Power Substations	DOLO	0.019	Fully Functional
Power Substations	VENEZIA NORD	0.019	Fully Functional

Power Substations	**ANDRIA**	0.018	Fully Functional
Power Substations	**FOGGIA**	0.018	Fully Functional
Power Substations	**MONTALTO**	0.018	Fully Functional
Power Substations	**S. FIORANO**	0.016	Fully Functional
Power Plants	**Montalto C.le**	0.015	Fully Functional
Power Substations	**BULCIAGO**	0.015	Fully Functional
Power Substations	**NA#2**	0.015	Fully Functional
Power Substations	**NA#4**	0.015	Fully Functional
Power Substations	**NA#5**	0.015	Fully Functional
Power Substations	**VIGNOLE B.**	0.015	Fully Functional
Power Substations	**ROMA SUD**	0.014	Fully Functional
Power Substations	**ACCIAIOLO**	0.013	Fully Functional
Power Substations	**PLANAIS**	0.013	Fully Functional
Power Substations	**ROMA NORD**	0.013	Fully Functional
Power Substations	**FLERO**	0.012	Fully Functional
Power Substations	**REDIPUGLIA**	0.012	Fully Functional
Power Substations	**ROMA EST**	0.012	Fully Functional
Power Plants	**La Casella**	0.010	Fully Functional
Power Plants	**La Spezia**	0.010	Fully Functional
Power Plants	**Tavazzano**	0.010	Fully Functional
Power Substations	**PRESENZANO**	0.010	Fully Functional
Power Substations	**ROMA OVEST**	0.010	Fully Functional
Power Substations	**SALGAREDA**	0.010	Fully Functional
Power Plants	**Piombino Termica**	0.009	Fully Functional
Power Substations	**AURELIA**	0.009	Fully Functional
Power Substations	**BARI O.**	0.009	Fully Functional
Power Substations	**BENEVENTO 2**	0.009	Fully Functional
Power Substations	**BRINDISI**	0.009	Fully Functional
Power Substations	**VALMONTONE**	0.009	Fully Functional
Power Plants	**Ostiglia**	0.008	Fully Functional
Power Substations	**NA#1**	0.008	Fully Functional
Power Substations	**PIAN CAMUNO**	0.008	Fully Functional
Power Substations	**PIEVE A**	0.008	Fully Functional
Power Substations	**SOAZZA**	0.008	Fully Functional
Power Substations	**VADO L.**	0.008	Fully Functional
Power Substations	**ROSEN**	0.007	Fully Functional
Power Plants	**Edolo**	0.006	Fully Functional
Power Plants	**San Fiorano**	0.006	Fully Functional
Power Substations	**DIVACA**	0.006	Fully Functional
Power Substations	**NA#12**	0.006	Fully Functional
Power Substations	**LATINA NUCLEARE**	0.005	Fully Functional
Power Substations	**MATERA**	0.005	Fully Functional
Power Substations	**NA#7**	0.005	Fully Functional
Power Substations	**S. SOFIA**	0.005	Fully Functional
Power Plants	**Monfalcone**	0.004	Fully Functional
Power Plants	**Presenzano**	0.004	Fully Functional
Power Substations	**GARIGLIANO S.NE**	0.004	Fully Functional
Power Substations	**MUSIGNANO**	0.004	Fully Functional
Power Plants	**Ferrera E.**	0.003	Fully Functional
Power Plants	**Roncovalgrande**	0.003	Fully Functional
Power Plants	**Torrevaldaliga**	0.003	Fully Functional
Power Plants	**Torrevaldaliga Nord**	0.003	Fully Functional
Power Plants	**Vado L.**	0.003	Fully Functional
Power Substations	**LAINO**	0.003	Fully Functional
Power Substations	**NA#11**	0.003	Fully Functional
Power Substations	**PATRIA**	0.003	Fully Functional
Power Plants	**Rosen**	0.002	Fully Functional
Power Substations	**BAGIO**	0.002	Fully Functional
Power Substations	**CEPRANO**	0.002	Fully Functional
Power Substations	**MONTECORVINO**	0.002	Fully Functional
Power Substations	**S. MARIA CAPUA V.**	0.002	Fully Functional
Power Substations	**TARANTO NORD**	0.002	Fully Functional
Power Plants	**Rossano**	0.001	Fully Functional
Power Substations	**GALATINA**	0.001	Fully Functional

Power Substations	**NA#6**	0.001	Fully Functional
Power Substations	**ROSSANO**	0.001	Fully Functional
Power Substations	**S.NE BRINDISI SUD**	0.001	Fully Functional

The Simulation Report after EVENT 1 reads:

Box 1: *System Report after EVENT 1*

THE SYSTEM

DEFINITION

Component Types: 3
 > Power Lines
 > Power Plants
 > Power Substations

Infrastructure Failure is considered:
 > 'Acceptable', if 0 < (W)IFI < 0.2
 > 'Partially Acceptable', if 0.2 <= (W)IFI < 0.5
 > 'Unacceptable', if 0.5 <= (W)IFI <= 1
where:
 - (W)IFI - the (Weighted) Infrastructure Failure Index.

The weights for computing WIFI:
 > Fully Functional: 0.1
 > Partially Disabled: 0.5
 > Out of Order: 1

A System Component (SC) is
 > 'Fully Functional', if 0 < II < 0.2
 > 'Partially Disabled', if 0.2 <= II < 0.5
 > 'Out of Order', if 0.5 <= II <= 1
where:
 - II - the Incapability Index of the component.

STATUS

THE INFRASTRUCTURE

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
 Infrastructure Failure Index (weighted)=0.121652

Infrastructure Failure LEVEL: "UNACCEPTABLE", based on
 Infrastructure Failure Index=0.803419

THE SYSTEM COMPONENTS

Number of System Components reached: 314

Reached Components by Type:
 Power Lines - 160, representing 46%
 Power Plants - 24, representing 7%
 Power Substations - 98, representing 28%

Reached Components by Functionality Level:
 From "Power Lines"
  > 3 components 'Out of Order'
  > 18 components 'Partially Disabled'
  > 139 components 'Fully Functional'
 From "Power Plants"
  > 0 components 'Out of Order'
  > 0 components 'Partially Disabled'
  > 24 components 'Fully Functional'
 From "Power Substations"

```
  > 2 components 'Out of Order'
  > 7 components 'Partially Disabled'
  > 89 components 'Fully Functional'

Overall Incapability Index of the system: 0.0569202

Most Affected System Component(s): 1, with the Incapability Index: 0.867
  > Power Lines #98: "Single"

THE ERROR INJECTION POINTS

Number of System Components affected by EIP #1: 314
  >> Power Substations #73 - "RAVENNA CANALA": 0.5
  >> Power Lines #92 - "Single": 0.425
  >> Power Lines #89 - "Double": 0.425

 .
 .
 .

  >> Power Lines #31 - "Single": 0.003
  >> Power Lines #30 - "Single": 0.003
  >> Power Substations #125 - "ROSSANO": 0.001

Number of System Components affected by EIP #2: none
```

Results of the simulation of EVENT 2

The *GIS representation* is the one from the system view. It is rendered in Fig. 5.5.

The incapability indexes of all the system components can be graphically visualized using *System Components Chart* feature (Fig. 5.5).

The *system components table* (in excerpt version) is given Table 5.2.

Table 5.2 *System Components Table after EVENT 2 – Excerpt*

Key	Name	Incapability Index	Classification
Power Substations	**FORLI ORAZIANA**	0.766	Out of Order
Power Plants	**Brindisi Sud**	0.750	Out of Order
Power Substations	**RAVENNA CANALA**	0.501	Out of Order
Power Substations	**S.NE BRINDISI SUD**	0.406	Partially Disabled
Power Substations	**MARTIGNONE**	0.391	Partially Disabled
Power Substations	**COLUNGA**	0.391	Partially Disabled
Power Substations	**FANO E.T.**	0.262	Partially Disabled
Power Substations	**S. MARINO IN XX**	0.257	Partially Disabled
Power Substations	**ADRIA SUD**	0.256	Partially Disabled
Power Substations	**PORTO TOLLE**	0.256	Partially Disabled
Power Substations	**FERRARA FOCOMORTO**	0.256	Partially Disabled
Power Substations	**TARANTO NORD**	0.208	Partially Disabled
Power Substations	**GALATINA**	0.207	Partially Disabled
Power Substations	**S. DAMASO**	0.200	Partially Disabled
Power Substations	**BARGI STAZIONE**	0.200	Partially Disabled
Power Substations	**DUGALE**	0.200	Partially Disabled
Power Plants	**Enipower Ravenna**	0.170	Fully Functional
Power Plants	**Porto Corsini**	0.170	Fully Functional
Power Substations	**CANDIA**	0.137	Fully Functional
Power Substations	**MATERA**	0.110	Fully Functional
Power Substations	**CALENZANO**	0.102	Fully Functional
Power Substations	**CAORSO**	0.101	Fully Functional
Power Substations	**RUBIERA**	0.101	Fully Functional

continue on page 62

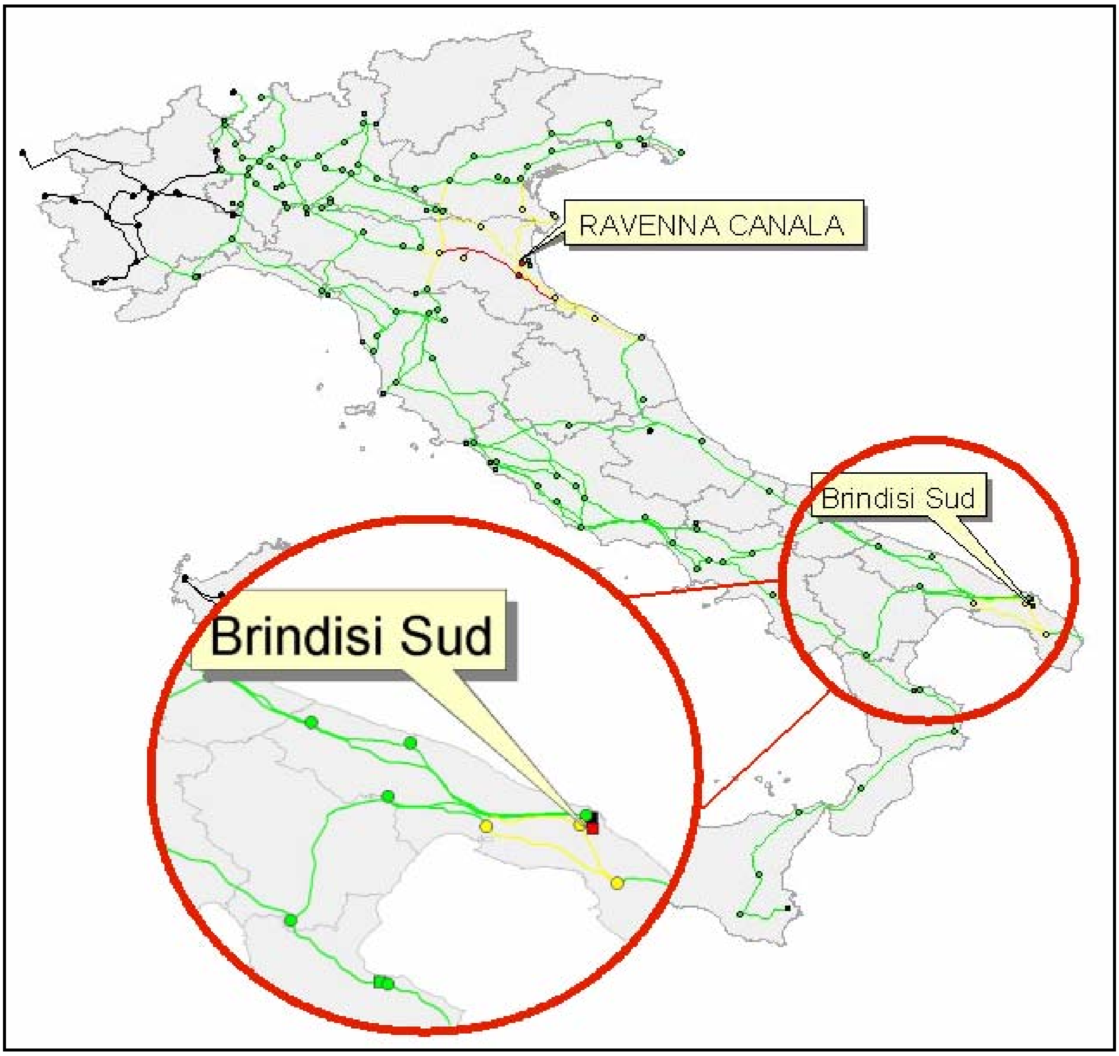


Figure 5.5 The system state after the simulation corresponding to EVENT 2. Zoom to the area characterized by *partially disabled* system components *by BRINDISI SUD*.

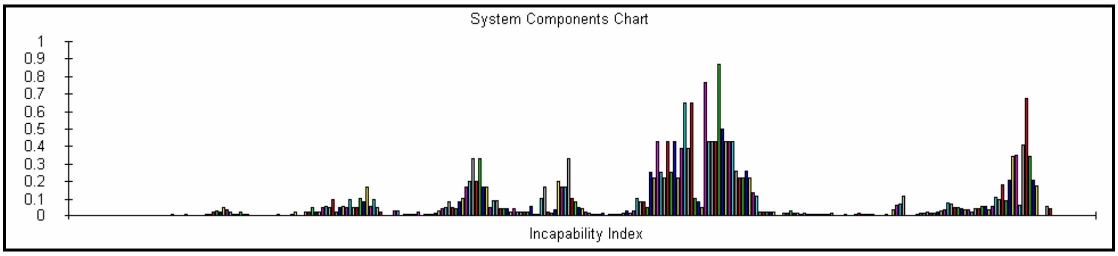


Figure 5.6 The *system components chart* after the simulation corresponding to EVENT 2.

… continued from page60			
Power Substations	**NOGAROLE ROCA**	0.101	Fully Functional
Power Substations	**SANDRIGO**	0.101	Fully Functional
Power Substations	**CAMIN**	0.101	Fully Functional
Power Plants	**Porto Tolle**	0.087	Fully Functional
Power Plants	**Sermide**	0.087	Fully Functional
Power Substations	**VILLANOVA**	0.075	Fully Functional
Power Substations	**ROSARA**	0.072	Fully Functional
Power Plants	**Bargi Centrale**	0.068	Fully Functional
Power Substations	**BRINDISI**	0.062	Fully Functional
Power Substations	**NA#8**	0.059	Fully Functional
Power Substations	**PIACENZA**	0.058	Fully Functional
Power Substations	**CREMONA**	0.058	Fully Functional
Power Substations	**LAINO**	0.056	Fully Functional
Power Substations	**POGGIO A CAIANO**	0.054	Fully Functional
Power Substations	**TAVARNUZZE**	0.053	Fully Functional
Power Substations	**LONATO**	0.052	Fully Functional
Power Substations	**PARMA VIGHEFFIO**	0.052	Fully Functional
Power Substations	**CORDIGNANO**	0.052	Fully Functional
Power Substations	**RFX CNR**	0.052	Fully Functional
Power Substations	**LARINO**	0.049	Fully Functional
Power Substations	**SERMIDE**	0.047	Fully Functional
Power Substations	**FOGGIA**	0.046	Fully Functional
Power Substations	**ANDRIA**	0.045	Fully Functional
Power Substations	**VILLAVALLE**	0.039	Fully Functional
Power Substations	**BARI O.**	0.036	Fully Functional
Power Plants	**Dolo**	0.034	Fully Functional
Power Substations	**GORLAGO**	0.032	Fully Functional
Power Substations	**NAVE**	0.032	Fully Functional
Power Substations	**NA#3**	0.030	Fully Functional
Power Substations	**BENEVENTO 2**	0.030	Fully Functional
Power Substations	**TAVAZZANO**	0.029	Fully Functional
Power Substations	**LA CASELLA**	0.029	Fully Functional
Power Substations	**NA#9**	0.029	Fully Functional
Power Substations	**NA#10**	0.029	Fully Functional
Power Substations	**LA SPEZIA**	0.029	Fully Functional
Power Substations	**MONTECORVINO**	0.029	Fully Functional
Power Substations	**MARGINONE**	0.027	Fully Functional
Power Substations	**PIAN DELLA SPERANZA**	0.027	Fully Functional
Power Substations	**SUVERETO**	0.027	Fully Functional
Power Substations	**UDINE OVEST**	0.026	Fully Functional
Power Substations	**OSTIGLIA**	0.024	Fully Functional
Power Substations	**MONTALTO**	0.022	Fully Functional
Power Substations	**PRESENZANO**	0.021	Fully Functional
Power Plants	**Piacenza**	0.020	Fully Functional
Power Plants	**Rossano**	0.019	Fully Functional
Power Substations	**VENEZIA NORD**	0.019	Fully Functional
Power Substations	**DOLO**	0.019	Fully Functional
Power Substations	**S. SOFIA**	0.019	Fully Functional
Power Substations	**ROMA SUD**	0.018	Fully Functional
Power Plants	**Montalto C.le**	0.016	Fully Functional
Power Substations	**S. FIORANO**	0.016	Fully Functional
Power Substations	**NA#2**	0.015	Fully Functional
Power Substations	**BULCIAGO**	0.015	Fully Functional
Power Substations	**NA#4**	0.015	Fully Functional
Power Substations	**NA#5**	0.015	Fully Functional
Power Substations	**VIGNOLE B.**	0.015	Fully Functional
Power Substations	**ACCIAIOLO**	0.014	Fully Functional
Power Substations	**ROMA OVEST**	0.014	Fully Functional
Power Substations	**VALMONTONE**	0.014	Fully Functional
Power Substations	**ROMA EST**	0.014	Fully Functional
Power Substations	**ROMA NORD**	0.014	Fully Functional
Power Substations	**PLANAIS**	0.013	Fully Functional
Power Substations	**FLERO**	0.012	Fully Functional

Power Substations	**REDIPUGLIA**	0.012	Fully Functional
Power Substations	**AURELIA**	0.011	Fully Functional
Power Substations	**ROSSANO**	0.011	Fully Functional
Power Plants	**Tavazzano**	0.010	Fully Functional
Power Plants	**La Spezia**	0.010	Fully Functional
Power Plants	**La Casella**	0.010	Fully Functional
Power Substations	**SALGAREDA**	0.010	Fully Functional
Power Plants	**Piombino Termica**	0.009	Fully Functional
Power Substations	**LATINA NUCLEARE**	0.009	Fully Functional
Power Substations	**S. MARIA CAPUA V.**	0.009	Fully Functional
Power Plants	**Ostiglia**	0.008	Fully Functional
Power Plants	**Presenzano**	0.008	Fully Functional
Power Substations	**VADO L.**	0.008	Fully Functional
Power Substations	**SOAZZA**	0.008	Fully Functional
Power Substations	**NA#1**	0.008	Fully Functional
Power Substations	**PIEVE A**	0.008	Fully Functional
Power Substations	**PIAN CAMUNO**	0.008	Fully Functional
Power Substations	**GARIGLIANO S.NE**	0.008	Fully Functional
Power Substations	**ROSEN**	0.007	Fully Functional
Power Substations	**PATRIA**	0.007	Fully Functional
Power Plants	**Edolo**	0.006	Fully Functional
Power Plants	**San Fiorano**	0.006	Fully Functional
Power Substations	**NA#12**	0.006	Fully Functional
Power Substations	**DIVACA**	0.006	Fully Functional
Power Substations	**NA#7**	0.005	Fully Functional
Power Substations	**SCANDALE**	0.005	Fully Functional
Power Plants	**Monfalcone**	0.004	Fully Functional
Power Plants	**Torrevaldaliga Nord**	0.004	Fully Functional
Power Plants	**Torrevaldaliga**	0.004	Fully Functional
Power Substations	**CEPRANO**	0.004	Fully Functional
Power Substations	**MUSIGNANO**	0.004	Fully Functional
Power Plants	**Vado L.**	0.003	Fully Functional
Power Plants	**Ferrera E.**	0.003	Fully Functional
Power Plants	**Roncovalgrande**	0.003	Fully Functional
Power Substations	**NA#11**	0.003	Fully Functional
Power Plants	**Rosen**	0.002	Fully Functional
Power Substations	**BAGIO**	0.002	Fully Functional
Power Substations	**RIZZICONI**	0.002	Fully Functional
Power Substations	**NA#6**	0.001	Fully Functional
Power Substations	**SORGENTE**	0.001	Fully Functional
Power Substations	**PATERNO**	0.001	Fully Functional
Power Substations	**CHIARAMONTE GULFI**	0.001	Fully Functional

The Simulation Report after EVENT 2 is:

Box 2: *Simulation Report for EVENT 2*

THE SYSTEM

DEFINITION

Component Types: 3
 > Power Lines
 > Power Plants
 > Power Substations

Infrastructure Failure is considered:
 > 'Acceptable', if 0 < (W)IFI < 0.2
 > 'Partially Acceptable', if 0.2 <= (W)IFI < 0.5
 > 'Unacceptable', if 0.5 <= (W)IFI <= 1
where:
 - (W)IFI - the (Weighted) Infrastructure Failure Index.

```
The weights for computing WIFI:
  > Fully Functional: 0.1
  > Partially Disabled: 0.5
  > Out of Order: 1

A System Component (SC) is
  > 'Fully Functional', if 0 < II < 0.2
  > 'Partially Disabled', if 0.2 <= II < 0.5
  > 'Out of Order', if 0.5 <= II <= 1
where:
  - II - the Incapability Index of the component.


STATUS

THE INFRASTRUCTURE

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
  Infrastructure Failure Index (weighted)=0.140456

Infrastructure Failure LEVEL: "UNACCEPTABLE", based on
  Infrastructure Failure Index=0.837607

THE SYSTEM COMPONENTS

Number of System Components reached: 326

Reached Components by Type:
  Power Lines - 166, representing 47%
  Power Plants - 25, representing 7%
  Power Substations - 103, representing 29%

Reached Components by Functionality Level:
  From "Power Lines"
    > 4 components 'Out of Order'
    > 21 components 'Partially Disabled'
    > 141 components 'Fully Functional'
  From "Power Plants"
    > 1 components 'Out of Order'
    > 0 components 'Partially Disabled'
    > 24 components 'Fully Functional'
  From "Power Substations"
    > 2 components 'Out of Order'
    > 13 components 'Partially Disabled'
    > 88 components 'Fully Functional'

Overall Incapability Index of the system: 0.0709373

Most Affected System Component(s): 1, with the Incapability Index: 0.869
   > Power Lines #98: "Single"

THE ERROR INJECTION POINTS

Number of System Components affected by EIP #1: 314
   >> Power Substations #73 - "RAVENNA CANALA": 0.5
   >> Power Lines #92 - "Single": 0.425
   >> Power Lines #89 - "Double": 0.425

  …

   >> Power Lines #31 - "Single": 0.003
   >> Power Lines #30 - "Single": 0.003
   >> Power Substations #125 - "ROSSANO": 0.001

Number of System Components affected by EIP #2: 176
   >> Power Plants #23 - "Brindisi Sud": 0.75
   >> Power Lines #149 - "Single": 0.675
```

```
>> Power Substations #107 - "S.NE BRINDISI SUD": 0.405
…

>> Power Lines #74 - "Single": 0.001
>> Power Lines #61 - "Single": 0.001
>> Power Lines #63 - "Single": 0.001
```

Results for Task 3

The error injection routes from power substation RAVENNA CANALA to power plant Torrevaldaliga.

Total number of routes detected: 2. The routes are rendered in Figure 5.7.

The following is a description of each determined route, compiled from the *Real Data* and *Details* features provided by ***InSIEME*** in *Get Routes* dialog.

Route 1	
Real Data	> "Power Substations", "RAVENNA CANALA", with II="0.425" > "Power Lines", "Single", with II="0.255" > "Power Substations", "S. MARINO IN XX", with II="0.217" > "Power Lines", "Single", with II="0.13" > "Power Substations", "FANO E.T.", with II="0.221" > "Power Lines", "Single", with II="0.133" > "Power Substations", "CANDIA", with II="0.113" > "Power Lines", "Single", with II="0.068" > "Power Substations", "VILLANOVA", with II="0.058" > "Power Lines", "Single", with II="0.035" > "Power Substations", "VILLAVALLE", with II="0.03" > "Power Lines", "Single", with II="0.018" > "Power Substations", "MONTALTO", with II="0.015" > "Power Lines", "Double", with II="0.009" > "Power Substations", "AURELIA", with II="0.008" > "Power Lines", "Single", with II="0.003" > "Power Plants", "Torrevaldaliga", with II="0.003"
Details and Statistics	Number of System Componenets influenced: 17 Influenced System Components by type: Component Type: Power Lines - Encountered: 8 - Percent of total encountered: 47 Component Type: Power Plants - Encountered: 1 - Percent of total encountered: 6 Component Type: Power Substations - Encountered: 8 - Percent of total encountered: 47 Route Length:543.399 (UNITS_LINEAR_KILOMETERS) Most affected components along the route: 1 Value of incapability Index: 0.425 From "Power Substations", system component "RAVENNA CANALA" Overall Incapability Index (averaged): 0.102412

Route 2	
Real Data	> "Power Substations", "RAVENNA CANALA", with II="0.425" > "Power Lines", "Single", with II="0.255" > "Power Substations", "S. MARINO IN XX", with II="0.217" > "Power Lines", "Single", with II="0.13" > "Power Substations", "FANO E.T.", with II="0.221" > "Power Lines", "Single", with II="0.133" > "Power Substations", "CANDIA", with II="0.113" > "Power Lines", "Single", with II="0.068" > "Power Substations", "VILLANOVA", with II="0.058" > "Power Lines", "Single", with II="0.035" > "Power Substations", "VILLAVALLE", with II="0.03" > "Power Lines", "Single", with II="0.018" > "Power Substations", "MONTALTO", with II="0.015" > "Power Lines", "Double", with II="0.009" > "Power Substations", "AURELIA", with II="0.008" > "Power Lines", "Single", with II="0.003" > "Power Plants", "Torrevaldaliga", with II="0.003"
Details and Statistics	Number of System Componenets influenced: 17 Influenced System Components by type: Component Type: Power Lines - Encountered: 8 - Percent of total encountered: 47 Component Type: Power Plants - Encountered: 1 - Percent of total encountered: 6 Component Type: Power Substations - Encountered: 8 - Percent of total encountered: 47 Route Length:536.819 (UNITS_LINEAR_KILOMETERS) Most affected components along the route: 1 Value of incapability Index: 0.425 From "Power Substations", system component "RAVENNA CANALA" Overall Incapability Index (averaged): 0.102412

The *incapability index along the route charts* of the determined routes are *the same*. The reason is that, for the ***InSIEME*** system and in the considered case, the sequence of components is the same for both routes. Differences between routes are represented here by *different power lines* that connect *components from the same class*. This implies the same computations sequence for the incapability indices.

Figure 5.8 renders the *incapability index along the route 2*. Note the peak that indicates the convergence of two or more channels of error propagation at the power substation FOGGIA.

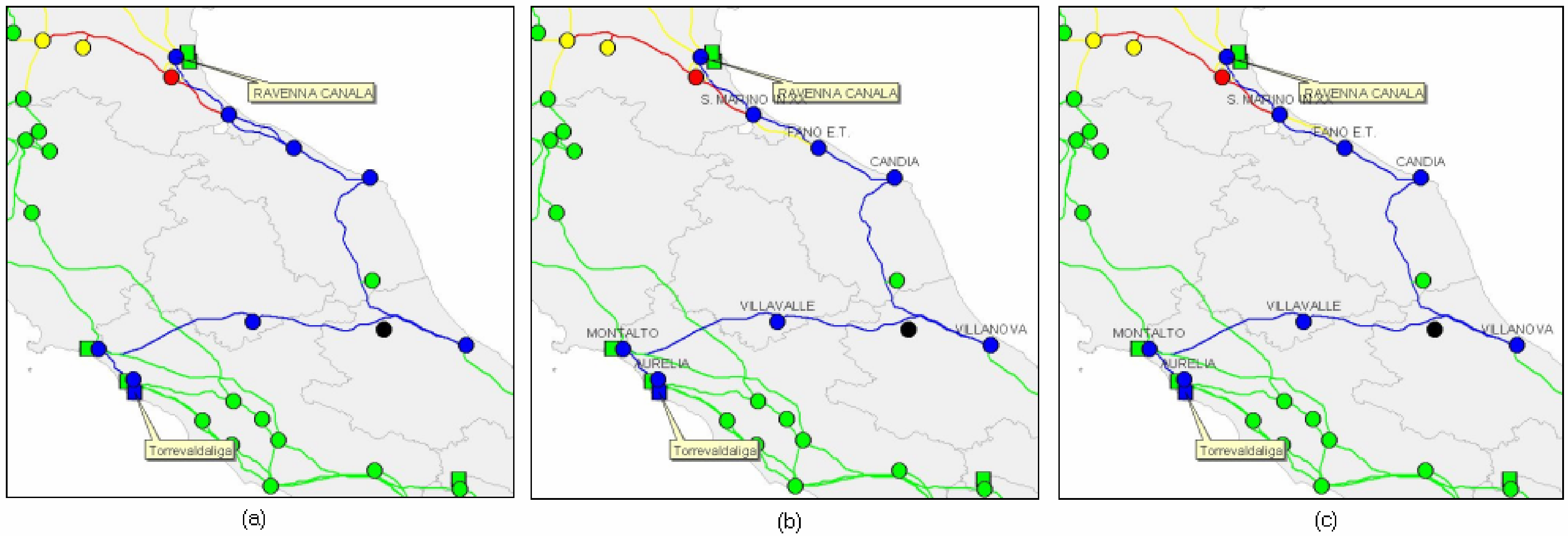


Figure 5.7 The error injection routes from **RAVENNA CANALA** to ***Torrevaldaliga***
(a) All routes; (b) Route 1; (c) Route 2

The error injection routes from power plant BRINDISI SUD to power plant Torrevaldaliga.

Total number of routes detected: 5. Depending on the scale of the GIS representations, the differences between two routes are not always evident. This situation is encountered in our case for Route 4 and Route 5. Figure 5.9 shows the difference between the two routes by zooming-in to the respective area; note how the difference is indistinguishable in Figure 5.10 (e) (f).

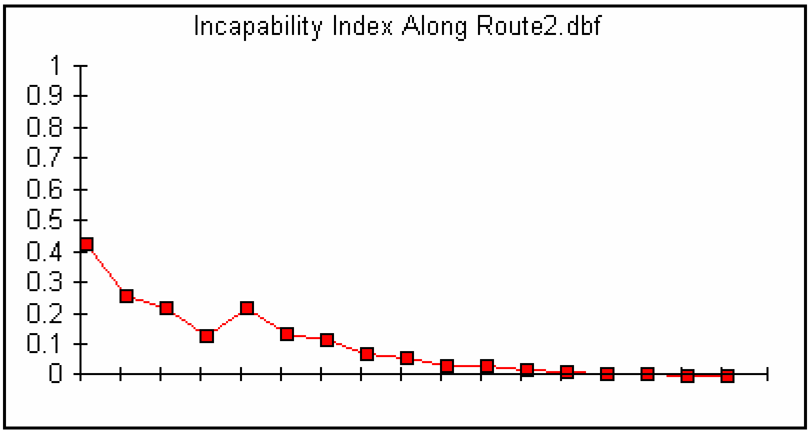


Figure 5.8 Incapability index along Route 2 from RAVENNA CANALA to Torrevaldaliga

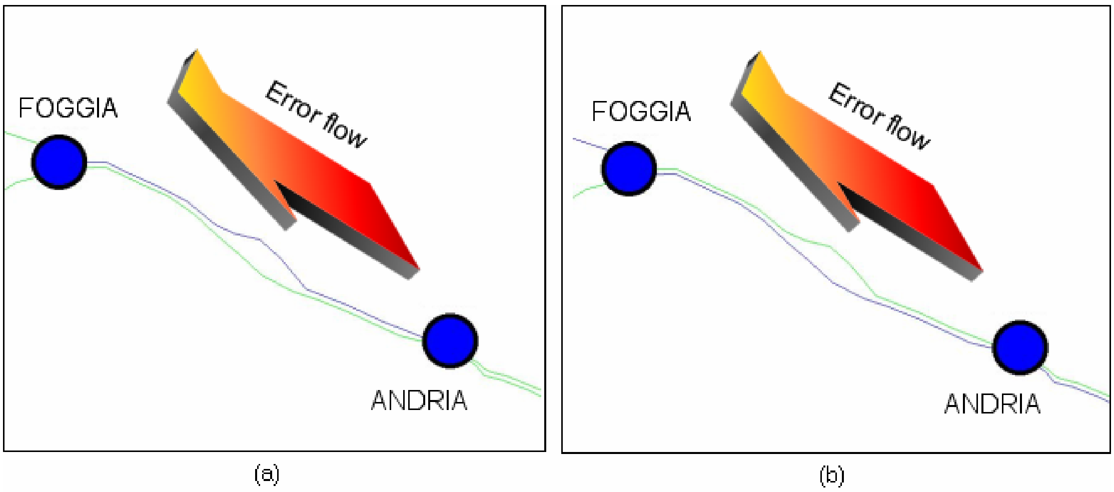


Figure 5.9 Zoom-in to the difference area of Route 4 and Route 5 from BRINDISI SUD to Torrevaldaliga

The following is a description of each determined route, compiled from the *Real Data* and *Details* features provided by ***InSIEME*** in *Get Routes* dialog.

Route 1	
Real Data	> "Power Plants", "Brindisi Sud", with II="0.675" > "Power Lines", "Single", with II="0.405" > "Power Substations", "S.NE BRINDISI SUD", with II="0.344" > "Power Lines", "Single", with II="0.206" > "Power Substations", "TARANTO NORD", with II="0.175" > "Power Lines", "Single", with II="0.105" > "Power Substations", "MATERA", with II="0.089" > "Power Lines", "Single", with II="0.053" > "Power Substations", "LAINO", with II="0.045" > "Power Lines", "Single", with II="0.027" > "Power Substations", "MONTECORVINO", with II="0.023" > "Power Lines", "Single", with II="0.014" > "Power Substations", "S. SOFIA", with II="0.012" > "Power Lines", "Single", with II="0.007" > "Power Substations", "BENEVENTO 2", with II="0.018" > "Power Lines", "Single", with II="0.011" > "Power Substations", "PRESENZANO", with II="0.009" > "Power Lines", "Single", with II="0.005" > "Power Substations", "VALMONTONE", with II="0.004" > "Power Lines", "Double", with II="0.002" > "Power Substations", "MONTALTO", with II="0.003" > "Power Lines", "Double", with II="0.002" > "Power Substations", "AURELIA", with II="0.002" > "Power Lines", "Single", with II="0.001" > "Power Plants", "Torrevaldaliga", with II="0.001"
Details and Statistics	Number of System Componenets influenced: 25 Influenced System Components by type: Component Type: Power Lines - Encountered: 12 - Percent of total encountered: 48 Component Type: Power Plants - Encountered: 2 - Percent of total encountered: 8 Component Type: Power Substations - Encountered: 11 - Percent of total encountered: 44 Route Length:585.355 (UNITS_LINEAR_MILES) Most affected components along the route: 1 Value of incapability Index: 0.675 From "Power Plants", system component "Brindisi Sud" Overall Incapability Index (averaged): 0.08952
Route 2	
Real Data	> "Power Plants", "Brindisi Sud", with II="0.675" > "Power Lines", "Single", with II="0.405" > "Power Substations", "S.NE BRINDISI SUD", with II="0.344" > "Power Lines", "Single", with II="0.206" > "Power Substations", "TARANTO NORD", with II="0.175" > "Power Lines", "Single", with II="0.105" > "Power Substations", "MATERA", with II="0.089" > "Power Lines", "Single", with II="0.053" > "Power Substations", "BRINDISI", with II="0.045" > "Power Lines", "Single", with II="0.027 > "Power Substations", "ANDRIA", with II="0.023"

… continues on page 71

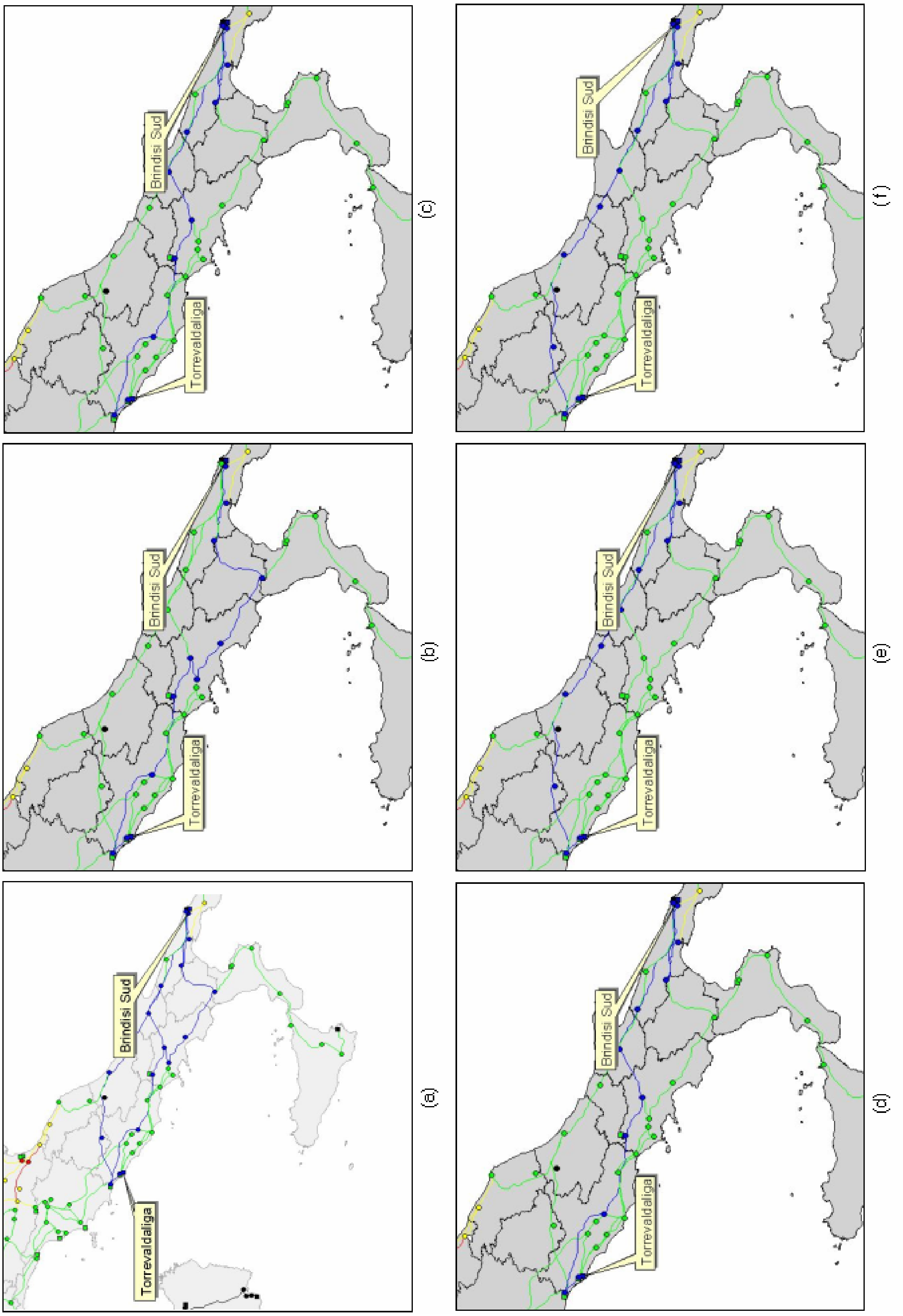


Figure 5.10 The error injection routes from **BRINDISI SUD** to ***Torrevaldaliga***
(a) All routes; (b) Route 1; (c) Route 2; (c) Route 3; (c) Route 4; (c) Route 5

… continued from page69

Real Data	> "Power Lines", "Single", with II="0.014" > "Power Substations", "FOGGIA", with II="0.024" > "Power Lines", "Single", with II="0.014" > "Power Substations", "BENEVENTO 2", with II="0.018" > "Power Lines", "Single", with II="0.011" > "Power Substations", "PRESENZANO", with II="0.009" > "Power Lines", "Single", with II="0.005" > "Power Substations", "VALMONTONE", with II="0.004" > "Power Lines", "Double", with II="0.002" > "Power Substations", "MONTALTO", with II="0.003" > "Power Lines", "Double", with II="0.002" > "Power Substations", "AURELIA", with II="0.002" > "Power Lines", "Single", with II="0.001" > "Power Plants", "Torrevaldaliga", with II="0.001"
Details and Statistics	Number of System Componenets influenced: 25 Influenced System Components by type: Component Type: Power Lines - Encountered: 12 - Percent of total encountered: 48 Component Type: Power Plants - Encountered: 2 - Percent of total encountered: 8 Component Type: Power Substations - Encountered: 11 - Percent of total encountered: 44 Route Length:521.752 (UNITS_LINEAR_MILES) Most affected components along the route: 1 Value of incapability Index: 0.675 From "Power Plants", system component "Brindisi Sud" Overall Incapability Index (averaged): 0.09028
Route 3	
Real Data	> "Power Plants", "Brindisi Sud", with II="0.675" > "Power Lines", "Single", with II="0.405" > "Power Substations", "S.NE BRINDISI SUD", with II="0.344" > "Power Lines", "Single", with II="0.206" > "Power Substations", "TARANTO NORD", with II="0.175" > "Power Lines", "Single", with II="0.105" > "Power Substations", "MATERA", with II="0.089" > "Power Lines", "Single", with II="0.053" > "Power Substations", "BRINDISI", with II="0.045" > "Power Lines", "Single", with II="0.027" > "Power Substations", "ANDRIA", with II="0.023" > "Power Lines", "Single", with II="0.014" > "Power Substations", "FOGGIA", with II="0.024" > "Power Lines", "Single", with II="0.014" > "Power Substations", "BENEVENTO 2", with II="0.018" > "Power Lines", "Single", with II="0.011" > "Power Substations", "PRESENZANO", with II="0.009" > "Power Lines", "Single", with II="0.005" > "Power Substations", "VALMONTONE", with II="0.004" > "Power Lines", "Double", with II="0.002" > "Power Substations", "MONTALTO", with II="0.003" > "Power Lines", "Double", with II="0.002" > "Power Substations", "AURELIA", with II="0.002" > "Power Lines", "Single", with II="0.001" > "Power Plants", "Torrevaldaliga", with II="0.001"

<table>
<tr><td>Details and Statistics</td><td>Number of System Componenets influenced: 25

Influenced System Components by type:
Component Type: Power Lines
- Encountered: 12
- Percent of total encountered: 48
Component Type: Power Plants
- Encountered: 2
- Percent of total encountered: 8
Component Type: Power Substations
- Encountered: 11
- Percent of total encountered: 44

Route Length:527.083 (UNITS_LINEAR_MILES)

Most affected components along the route: 1
Value of incapability Index: 0.675
From "Power Plants", system component "Brindisi Sud"

Overall Incapability Index (averaged): 0.09028</td></tr>
<tr><td colspan="2">Route 4</td></tr>
<tr><td>Real Data</td><td>> "Power Plants", "Brindisi Sud", with II="0.675"
> "Power Lines", "Single", with II="0.405"
> "Power Substations", "S.NE BRINDISI SUD", with II="0.344"
> "Power Lines", "Single", with II="0.206"
> "Power Substations", "TARANTO NORD", with II="0.175"
> "Power Lines", "Single", with II="0.105"
> "Power Substations", "MATERA", with II="0.089"
> "Power Lines", "Single", with II="0.053"
> "Power Substations", "BRINDISI", with II="0.045"
> "Power Lines", "Single", with II="0.027"
> "Power Substations", "ANDRIA", with II="0.023"
> "Power Lines", "Single", with II="0.014"
> "Power Substations", "FOGGIA", with II="0.024"
> "Power Lines", "Single", with II="0.014"
> "Power Substations", "LARINO", with II="0.012"
> "Power Lines", "Single", with II="0.007"
> "Power Substations", "VILLANOVA", with II="0.006"
> "Power Lines", "Single", with II="0.004"
> "Power Substations", "VILLAVALLE", with II="0.003"
> "Power Lines", "Single", with II="0.002"
> "Power Substations", "MONTALTO", with II="0.003"
> "Power Lines", "Double", with II="0.002"
> "Power Substations", "AURELIA", with II="0.002"
> "Power Lines", "Single", with II="0.001"
> "Power Plants", "Torrevaldaliga", with II="0.001"</td></tr>
<tr><td>Details and Statistics</td><td>Number of System Componenets influenced: 25

Influenced System Components by type:
Component Type: Power Lines
- Encountered: 12
- Percent of total encountered: 48
Component Type: Power Plants
- Encountered: 2
- Percent of total encountered: 8
Component Type: Power Substations
- Encountered: 11
- Percent of total encountered: 44

Route Length:689.587 (UNITS_LINEAR_MILES)

Most affected components along the route: 1</td></tr>
</table>

	Value of incapability Index: 0.675 From "Power Plants", system component "Brindisi Sud" Overall Incapability Index (averaged): 0.08968
Route 5	
Real Data	> "Power Plants", "Brindisi Sud", with II="0.675" > "Power Lines", "Single", with II="0.405" > "Power Substations", "S.NE BRINDISI SUD", with II="0.344" > "Power Lines", "Single", with II="0.206" > "Power Substations", "TARANTO NORD", with II="0.175" > "Power Lines", "Single", with II="0.105" > "Power Substations", "MATERA", with II="0.089" > "Power Lines", "Single", with II="0.053" > "Power Substations", "BRINDISI", with II="0.045" > "Power Lines", "Single", with II="0.027" > "Power Substations", "ANDRIA", with II="0.023" > "Power Lines", "Single", with II="0.014" > "Power Substations", "FOGGIA", with II="0.024" > "Power Lines", "Single", with II="0.014" > "Power Substations", "LARINO", with II="0.012" > "Power Lines", "Single", with II="0.007" > "Power Substations", "VILLANOVA", with II="0.006" > "Power Lines", "Single", with II="0.004" > "Power Substations", "VILLAVALLE", with II="0.003" > "Power Lines", "Single", with II="0.002" > "Power Substations", "MONTALTO", with II="0.003" > "Power Lines", "Double", with II="0.002" > "Power Substations", "AURELIA", with II="0.002" > "Power Lines", "Single", with II="0.001" > "Power Plants", "Torrevaldaliga", with II="0.001"
Details and Statistics	Number of System Componenets influenced: 25 Influenced System Components by type: Component Type: Power Lines - Encountered: 12 - Percent of total encountered: 48 Component Type: Power Plants - Encountered: 2 - Percent of total encountered: 8 Component Type: Power Substations - Encountered: 11 - Percent of total encountered: 44 Route Length:694.918 (UNITS_LINEAR_MILES) Most affected components along the route: 1 Value of incapability Index: 0.675 From "Power Plants", system component "Brindisi Sud" Overall Incapability Index (averaged): 0.08968

Figure 5.11 renders the *incapability indexes* graph along Route 1.

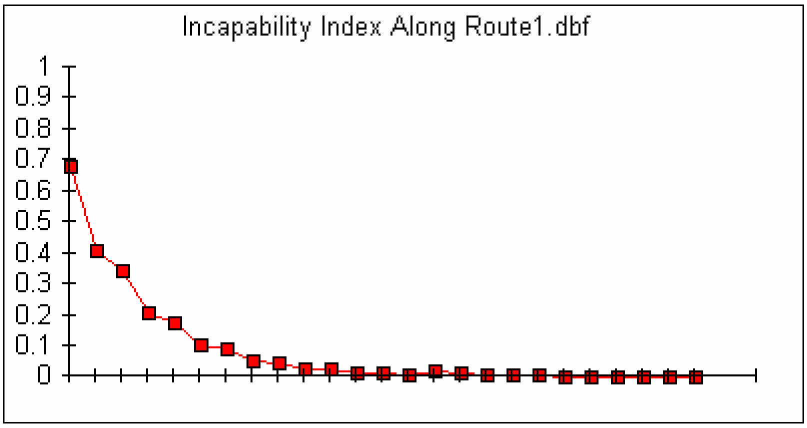


Fig. 5.11 Incapability index along Route 1 from BRINDISI SUD to Torrevaldaliga

5.3 Dynamic Simulation

In this section the results of a dynamic simulation procedure are reported. The presentation is focused on the *system behavior* to error injected *from the same error injection point*. Three error profile inputs are considered, namely a *step* function, a *ramp* function and an *impulse* function.

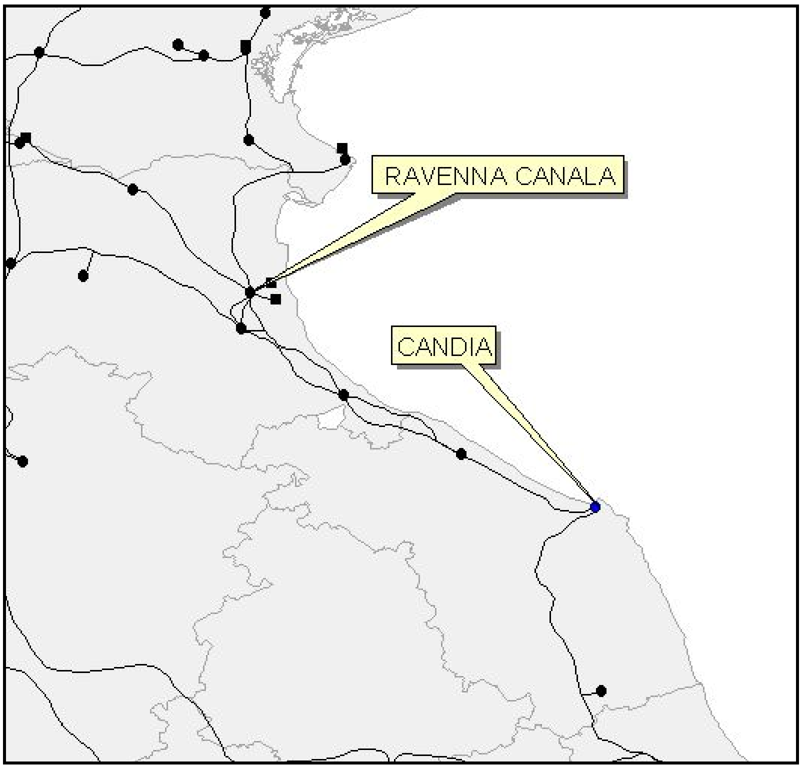


Figure 5.12 System representation for the dynamic simulation examples

The simulation is performed under the following terms:

- *System definition files: crisa.sdf, crisa.iwf, crisa.sif*;
- *System error injection points:* Power Substation RAVENA CANNALA;
- *Stop Condition:* the simulation runs until the Power Substation CANDIA goes into a *Partially Disabled* state; if CANDIA never goes into *partially disabled*, the simulation is also stopped.

The first section details the procedure of simulating and implementing the different shape error signals. The comparative results extracted from the ***InSIEME*** reports generated for each of the simulation sessions are presented in the second section, while the third contains several comparative results regarding the system state during different simulation steps.

5.3.1. Modeling the Error Functions

In the current version ***InSIEME*** does not provide a tool to define an error input profile *prior* to the simulation phase. This is the reason why special attention should be paid to the pre-assessment phase, in order to satisfactorily provide for a proper error variation to be *interactively* implemented during the simulation session.

Figure 5.13 is a description of the error functions that are to be implemented, as well as the corresponding procedure. Details are given in the sequel.

Step Function Case

This case requires no intermediate trend input during simulation. The procedure is:

- Set the error injection point *Trend* to 1;
- Run simulation for any given number of countinuous simulation steps.

Note that in the presented case the step function height is 1, which implies that the error injection point can be left at 1 during the simulation, since the value of the incapability index is limited to 1. If the step height is smaller than 1 the procedure becomes:

- Set the error injection point *Trend* to the value corresponding to the *height* of the step function;
- Run simulation for *one* simulation step.
- Set the error injection point *Trend* to the 0;
- Run simulation for any given number of continuous simulation steps.

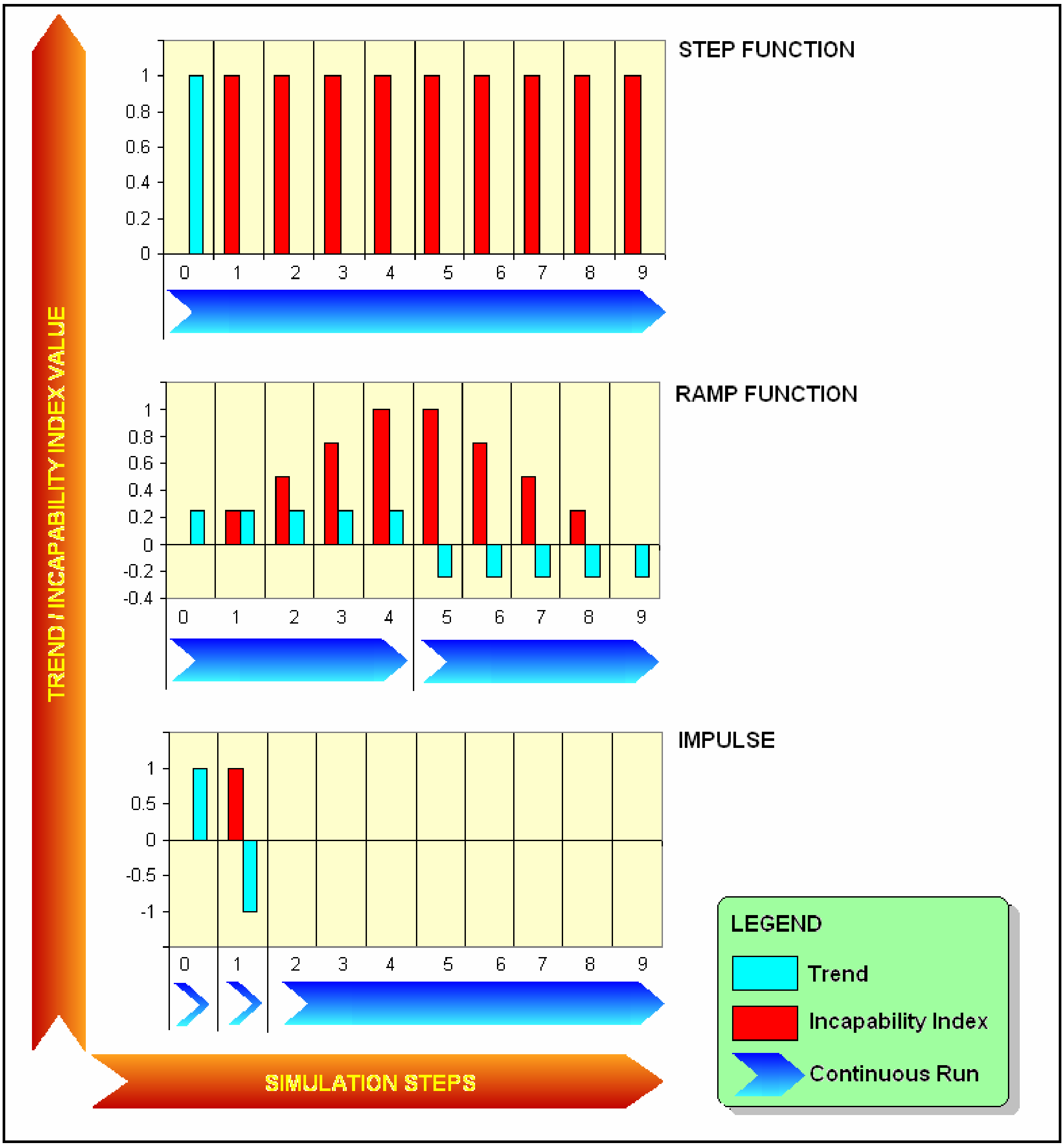


Figure 5.13 Flow chart of the error profiles implementation

Ramp Function Case

This case requires *two* or *three* continuous runs, as follows:

Function ceiling case (three parts)

- Set the error injection point *Trend* to the value corresponding to the *growth* rate of the error;
- Run simulation for a number of continuous simulation steps equal with the integer part of the division between the target error value (maximum error value) and the current *Trend*;
- Set the error injection point *Trend* to 0 if a *ceiling* is requested;
- Run simulation for a number of continuous simulation steps corresponding to the desired *width* of the function ceiling;
- Set the error injection point *Trend* to a negative value corresponding to the *decay* rate of the error;
- Run simulation for any given number of continuous simulation steps.

No function ceiling case (two parts)

- Set the error injection point *Trend* to the value corresponding to the *growth* rate of the error;
- Run simulation for a number of continuous simulation steps equal with the integer part of the division between the target error value (maximum error value) and the current *Trend*;
- Set the error injection point *Trend* to a negative value corresponding to the *decay* rate of the error;
- Run simulation for any given number of continuous simulation steps.

Impulse Function Case

This case requires *three* continuous runs. The procedure is:

- Set the error injection point *Trend* to 1 (or the target value for the impulse height);
- Run simulation for *one* simulation step;
- Set the error injection point *Trend* to (-2);
- Run simulation for *one* simulation step;
- Set the error injection point *Trend* to 0;
- Run simulation for any given number of continuous simulation steps.

The problem of implementing the error functions complicates itself with the scenario's complexity. For instance, the existence of several system error injection points, or different growth / decay rates of the error functions requires a higher attention in designing the error evolution-continuous run charts.

However, a well designed pre-simulation phase allows the implementation of complex scenarios, and the comparative assessment of a large variety of cases.

5.3.2 Results of the Dynamic Simulation

This section introduces several results of the simulations for the scenarios corresponding to the initial settings in Section 5.3 and the three error profiles considered in Section 5.3.1. The results are given in a comparative way, in order to emphasize the different reaction of the system in each of the considered cases.

The error propagation is also assessed at the components' level by tracing the system components reaction to the injected error. The system components that are considered are the power substations along the error injection route from RAVENA CANALA to CANDIA. The following correlation table should be used when reading the *Traced Components Charts* in this section.

InSIEME **Component**	**Real Name**
Power Substation 73	RAVENNA CANALA
Power Substation 72	FORLI ORAZIANA
Power Substation 74	S. MARINO IN XX
Power Substation 75	FANO E.T.
Power Substation 76	CANDIA

➡ The *STOP CONDITION* (Power Substation CANDIA to be *Partially Disabled*) is reached in *all the simulation cases*, as follows:

- *Step Error Case* – after **six** simulation steps;
- *Ramp Error Case* – after **ten** simulation steps;
- *Impulse Error Case* – after **six** simulation case.

➡ The system state representation is given in Figure 5.14. Notice the different error diffusion levels corresponding to the different error profiles. This also emerges from analyzing the data in Figure 5.15, which holds the *system components charts*.

➡ The comparative results for each of the simulation sessions are given in Box 3. The data is excerpted from the corresponding ***InSIEME*** simulation reports.

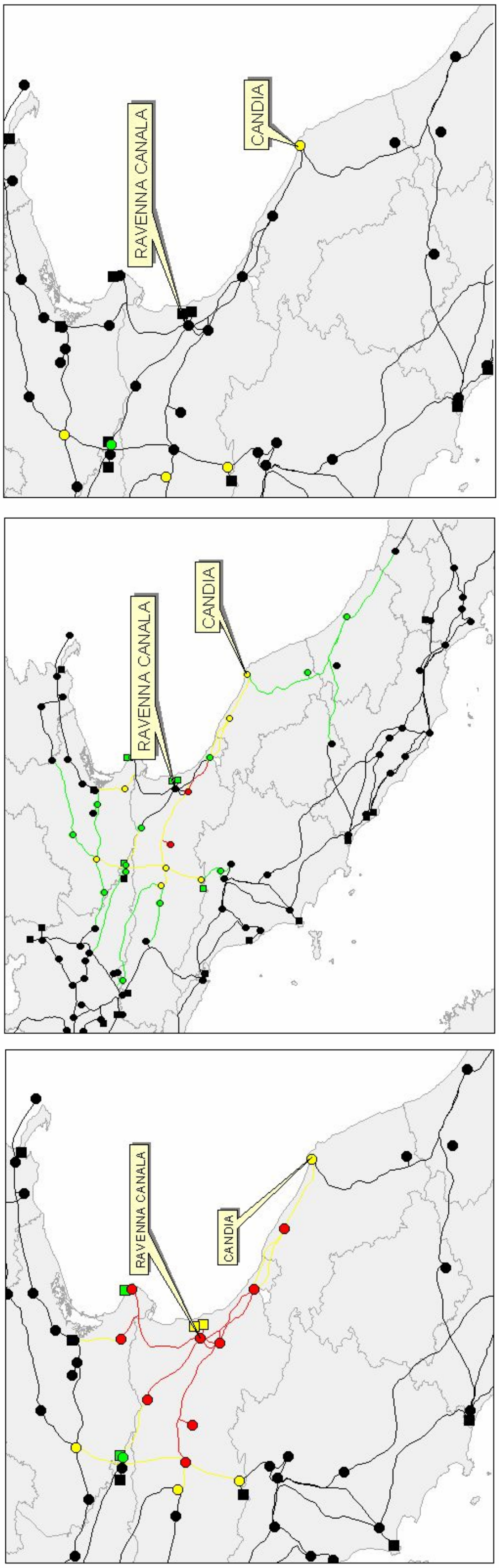
Box 3: *Results*

STEP error function

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index (weighted)=0.0823362

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index=0.11396

continues on page 81



(a) (b) (c)

Figure 5.14 The error impact on the system when the STOP condition is fulfilled, for (a) *step* shape error function ; (b) *ramp* shape error function; (c) *impulse* shape error function

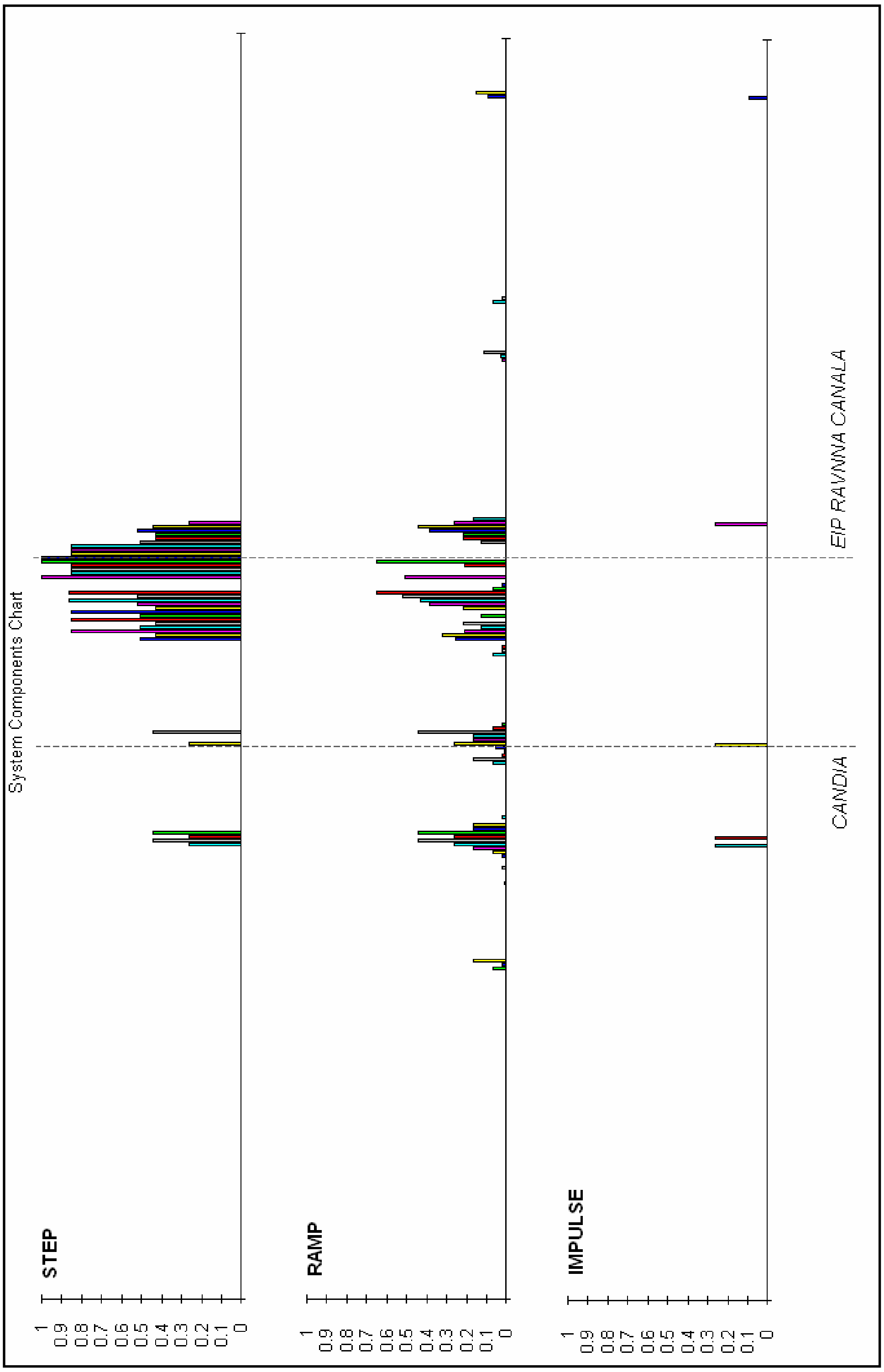


Figure 5.15 The *system components charts* when *STOP* condition is fulfilled.

…continued from page 78

Number of System Components reached: 40

Reached Components by Type:
Power Lines - 22, representing 6%
Power Plants - 4, representing 1%
Power Substations - 14, representing 4%

Reached Components by Functionality Level:
From "Power Lines"
> 12 components 'Out of Order'
> 9 components 'Partially Disabled'
> 1 components 'Fully Functional'
From "Power Plants"
> 0 components 'Out of Order'
> 2 components 'Partially Disabled'
> 2 components 'Fully Functional'
From "Power Substations"
> 9 components 'Out of Order'
> 4 components 'Partially Disabled'
> 1 components 'Fully Functional'

Overall Incapability Index of the system: 0.0634217

Most Affected System Component(s): 3, with the Incapability Index: 1
> Power Substations #72: "FORLI ORAZIANA"
> Power Lines #98: "Single"
> Power Substations #73: "RAVENNA CANALA"

Number of System Components affected by EIP #1: 44

RAMP Error Function

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index (weighted)=0.0501425

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index=0.182336

Number of System Components reached: 64

Reached Components by Type:
Power Lines - 37, representing 11%
Power Plants - 5, representing 1%
Power Substations - 22, representing 6%

Reached Components by Functionality Level:
From "Power Lines"
> 2 components 'Out of Order'
> 12 components 'Partially Disabled'
> 23 components 'Fully Functional'
From "Power Plants"
> 0 components 'Out of Order'
> 0 components 'Partially Disabled'
> 5 components 'Fully Functional'
From "Power Substations"

> 2 components 'Out of Order'
> 7 components 'Partially Disabled'
> 13 components 'Fully Functional'

Overall Incapability Index of the system: 0.0333846

Most Affected System Component(s): 1, with the Incapability Index: 0.651
> Power Lines #98: "Single"

Number of System Components affected by EIP #1: 68

IMPULSE Error Function

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index (weighted)=0.00598291

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
Infrastructure Failure Index=0.014245

Number of System Components reached: 5

Reached Components by Type:
Power Lines - 0, representing 0%
Power Plants - 0, representing 0%
Power Substations - 5, representing 1%

Reached Components by Functionality Level:
From "Power Lines"
> 0 components 'Out of Order'
> 0 components 'Partially Disabled'
> 0 components 'Fully Functional'
From "Power Plants"
> 0 components 'Out of Order'
> 0 components 'Partially Disabled'
> 0 components 'Fully Functional'
From "Power Substations"
> 0 components 'Out of Order'
> 4 components 'Partially Disabled'
> 1 components 'Fully Functional'

Overall Incapability Index of the system: 0.00328775

Most Affected System Component(s): 4, with the Incapability Index: 0.265
> Power Substations #45: "S. DAMASO"
> Power Substations #46: "BARGI STAZIONE"
> Power Substations #53: "DUGALE"
> Power Substations #76: "CANDIA"

Number of System Components affected by EIP #1: 5

The system failure state during the simulations are given in Figure 5.16. This is an expression of the system reaction to the different error profiles.

The influence flow (error propagation) at the traced components level is given in Figure 5.17. Notice how the initial error profiles echo in the case of each of the components.

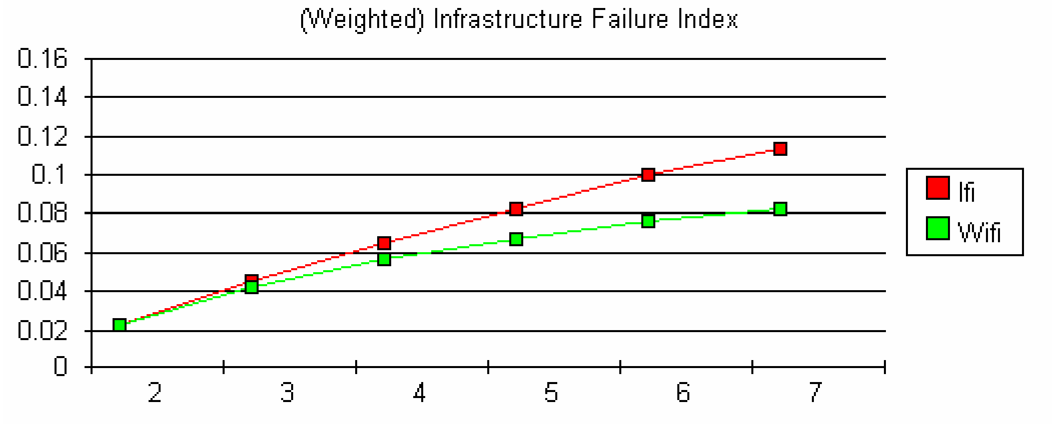
Discussion

This section covers some interesting aspects that emerge from the considered scenarios. First, one can see that the initial task, i.e. to determine if the power substation goes to a *Partially Disabled* state, is achieved for all scenarios. However, the number of simulation steps to get in this state is higher for the *RAMP* case that for the other two. The reason resides in *the intensity level variation* of the injected error: while for the *STEP* and *IMPULSE* cases the error 'jumps' from 0 to 1 in *one* simulation step, in the *RAMP* case it takes *four* simulation steps to reach the maximum value. Due to the fact that the error profile echoes in the subsequent, influenced system components (see Fig. 5.17), the incapability index of the target component (CANDIA) requires more 'time' to ascend to a level higher than the *Partially Disabled* threshold.

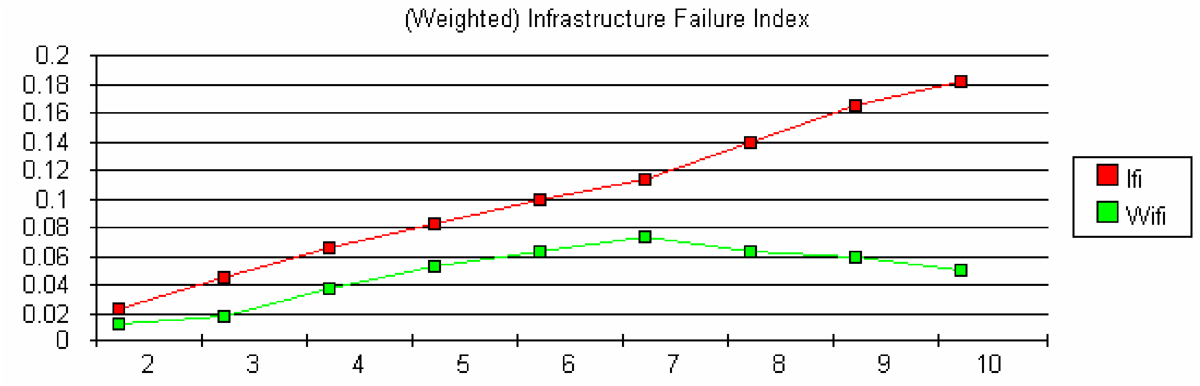
On the other hand, the number of simulation steps in the *STEP* and *IMPULSE* cases is the same, since the *EIP*'s initial incapability index variation and the sequence of influenced components are the same.

The situation when the error continues to spread within the system even though the error injection point is fully recovered, is encountered in *RAMP* and *IMPULSE* cases (see Fig. 5.14, 5.15, 5.17). One can see that at the time the target component goes into a *Partially Disabled* state the *error* is *no longer* injected in the system. This situation is the most evident in the *IMPULSE* case.

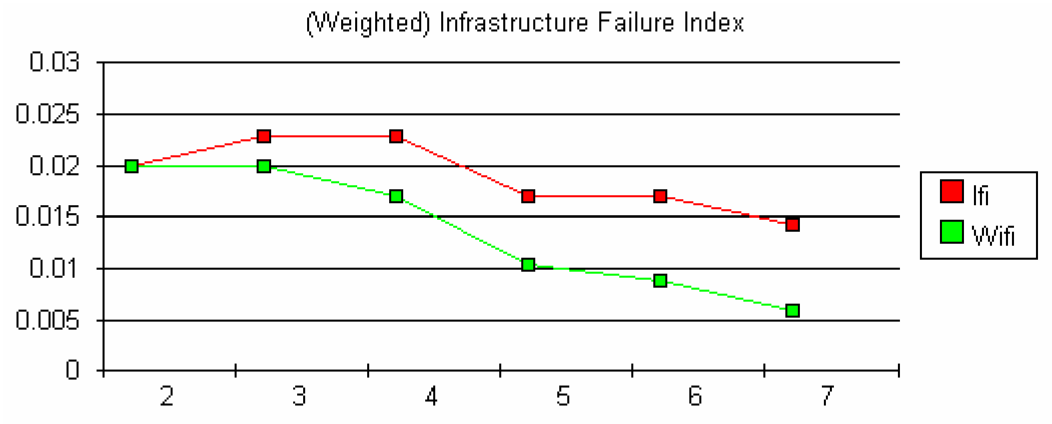
Differences in the system behavior found under diverse error-induced stress situations are also evidenced in these examples. For instance, notice how the error dispersion level (the number of influenced components) is the highest for the *RAMP* case, followed by the ones in *STEP* and *IMPULSE* cases. The reason is again the error profile of the error injection point. The error dispersion is the highest in the *RAMP* case because the target component is reached *before* going to a *Partially Disabled* state. This means that the error cumulates itself at power substation's CANDIA level during several simulation steps; however, after the step when the power plant is *reached* by the error (incapability index higher than zero), CANDIA behaves itself as an influencing component, which leads to a further propagation of error (see Fig. 5.14, 5.15). Remember that the error dispersion is reflected by the *Infrastructure Failure Index* value.



(a)

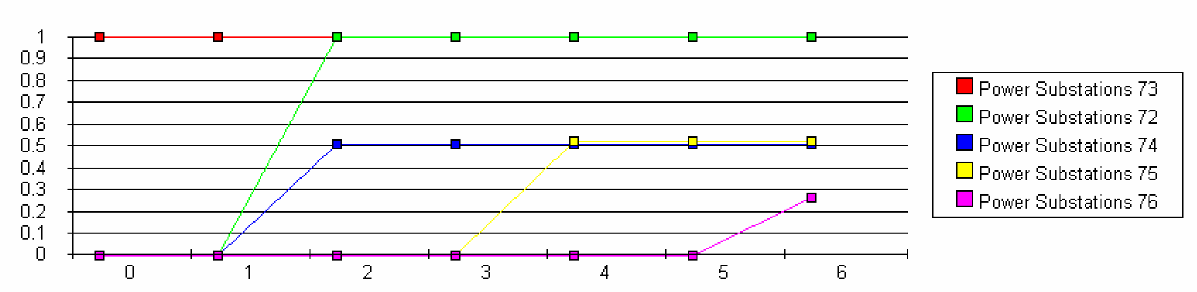


(b)

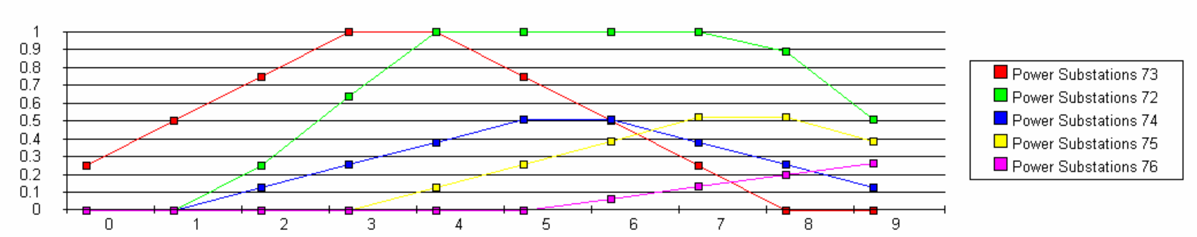


(c)

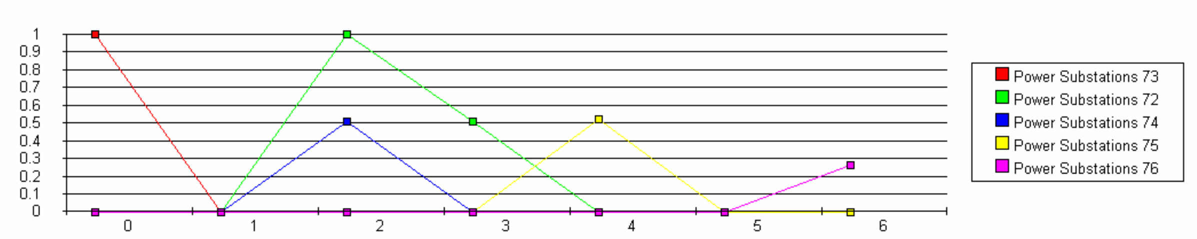
Figure 5.16 System failure state during the simulation sessions.
(a) STEP scenario, (b) RAMP scenario, (c) Impulse scenario



(a)



(b)



(c)

Figure 5.17 Influence flow at the traced components level.
(a) STEP scenario, (b) RAMP scenario, (c) Impulse scenario

Following this, different results can be obtained for the same scenarios, given the *target* of the assessment. For instance, if the goal of the assessment is to categorize the scenarios based on the number of affected components, the results would be *RAMP* scenario, followed by *STEP* and *IMPULSE* scenarios. On the other hand, if the scenarios are categorized based on their *severity* (given by the *Weighted Infrastructure Failure Index*), the results would be *STEP*, *RAMP* and *IMPULSE*. For details, check Figures 5.14 and 5.16 and the *Infrastructure Failure Index* and *Weighted Infrastructure Failure Index* for the scenarios in Box 3.

To conclude a short series of interesting cases, worth noticing is the instance that emerges from Figure 5.16 (b) that renders the system's *IFI and WIFI* values during the *RAMP* scenario. Notice how starting from simulation step 7 *IFI* continues to grow up while *WIFI* presents a going-down trend. The process that leads to this can be summarized as: (i) the error dispersion continues (the number of components that are influenced increases), (ii) the *level* of influence for the newly reached components (the incapability indices) is lower and lower due to components-interaction weights, and (iii) the incapability indices of the already influenced components go down after the error peak has passed. The situation as presented boils down to the following: from (i), the *IFI* value grows up; from (ii) and (iii) the number of components in a *Partially Disabled* state goes down while the one in *Fully Functional* goes up, which leads to a decrease of the *WIFI* value. In other words, the situation corresponds to an increasing number of affected components, and yet to a lesser harm induced into the system.

Section 5.3.3 presents a series of *system snapshots* taken during the simulation sessions, in order to emphasize the differences that occur in each of the scenarios.

5.3.3 System Snapshots During Dynamic Simulation

The current section renders the state of the system in steps 2 and 5 during the simulation sessions considered in this chapter. Maps of the error dispersion, as well as the *system components charts* and data regarding the error impact on the system are given.

Notice the differences in the error propagation shapes, and the relevant values provided.

System State in Step 2

Error injection point: RAVENNA CANALA

	RAVENNA CANALA			SYSTEM	
ERROR PROFILE	***Trend***	***Value***	***Reached Components***	**IFI**	**WIFI**
STEP	1	1	7	0.022792	0.019943
RAMP	0.25	0.5	7	0.022792	0.0128205
IMPULSE	0	0	6	0.017094	0.0105413

Error injection point: RAVENNA CANALA

	RAVENNA CANALA			SYSTEM	
ERROR PROFILE	***Trend***	***Value***	***Reached Components***	**IFI**	**WIFI**
STEP	1	1	29	0.0826211	0.0675214
RAMP	0	1	29	0.0826211	0.0527066
IMPULSE	0	0	6	0.017094	0.0105413

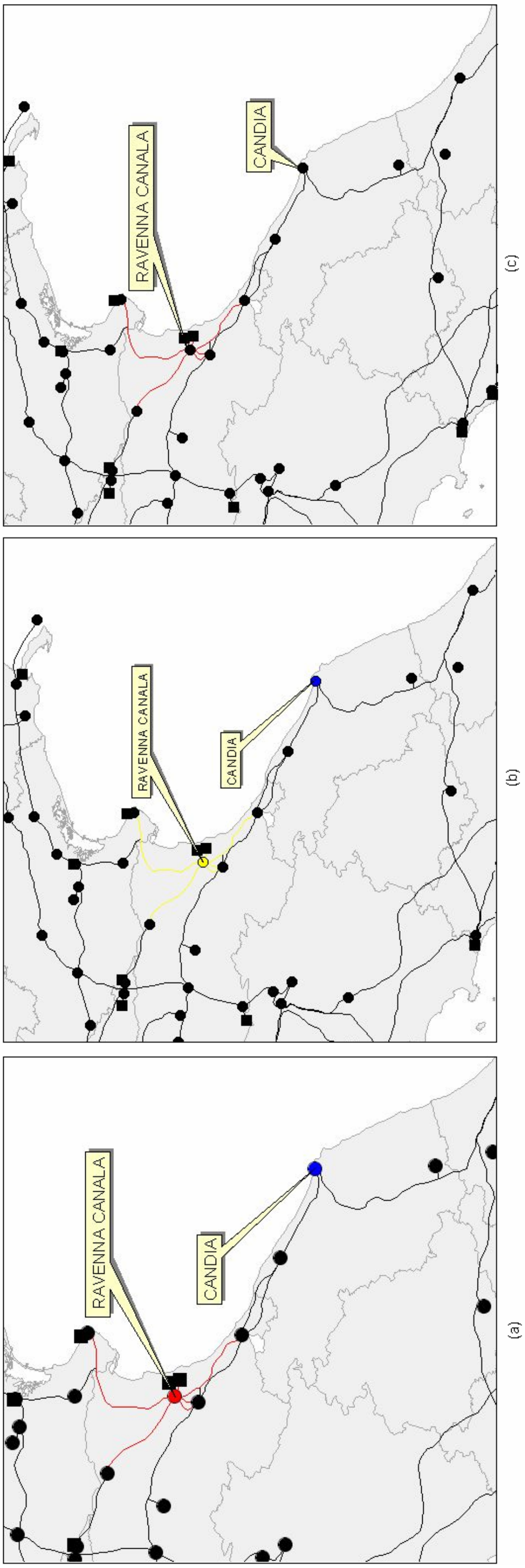


Figure 5.18 The error dispersion in simulation step 2
(a) *step*-shaped error function ; (b) *ramp*-shaped error function; (c) *impulse*-shaped error function

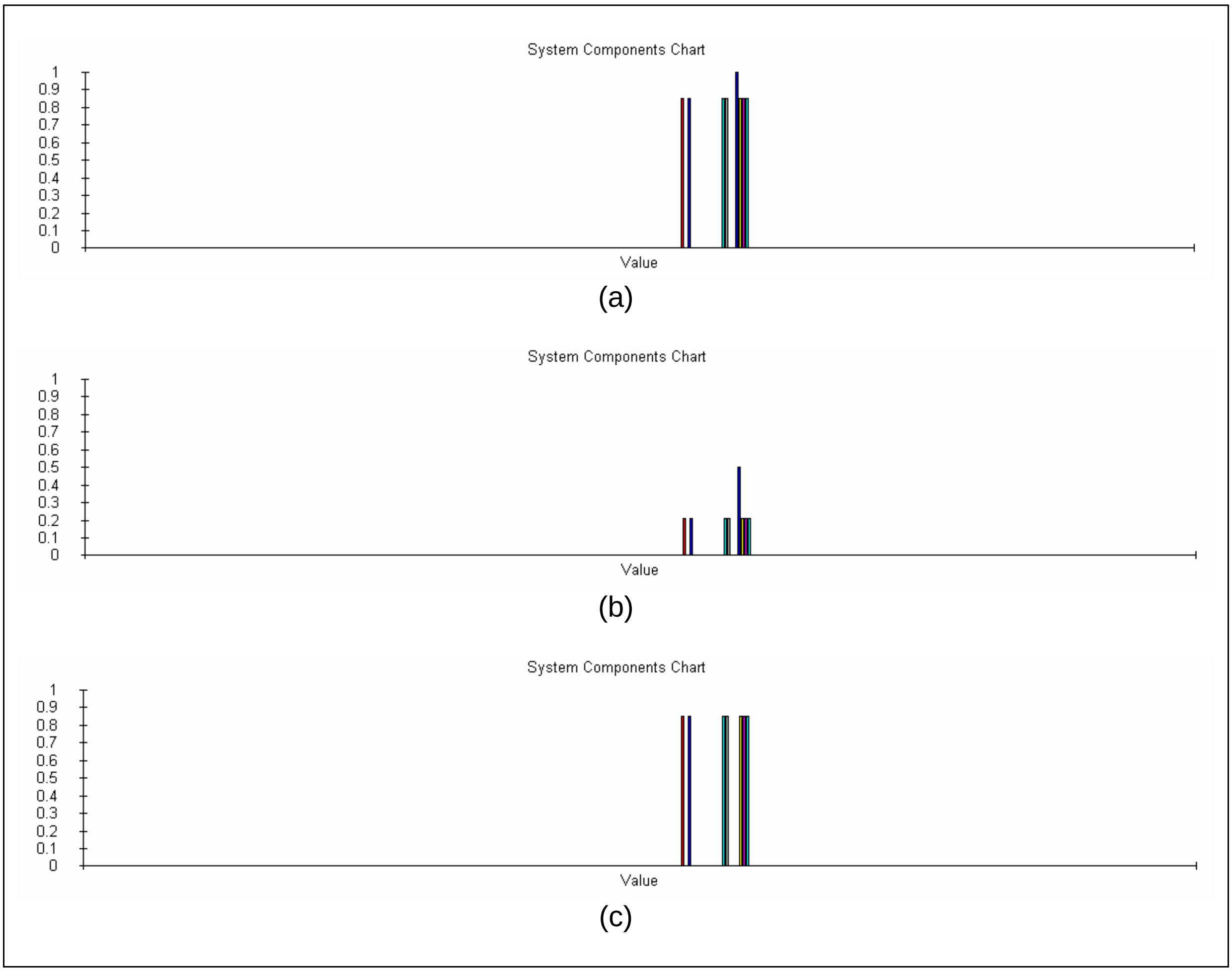


Figure 5.19 System Components Charts in simulation step 2 for
(a) *STEP* case; (a) *RAMP* case; (a) *IMPULSE* case

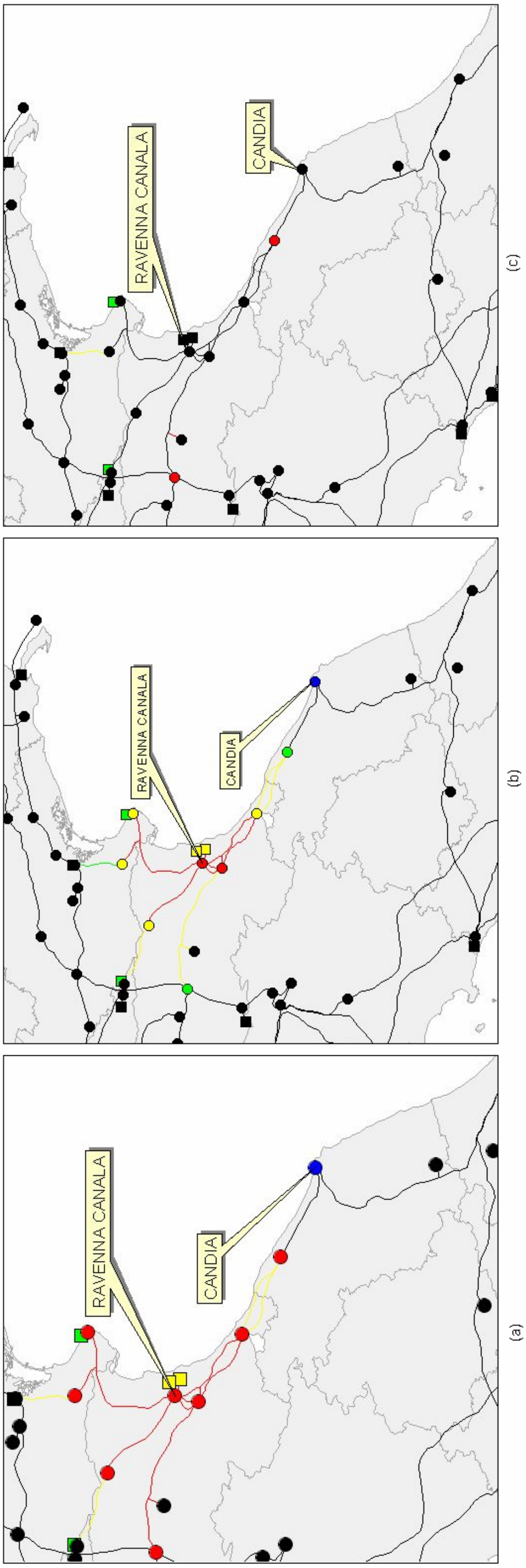


Figure 5.20 The error dispersion in simulation step 5
(a) *step*-shaped error function ; (b) *ramp*-shaped error function; (c) *impulse*-shaped error function

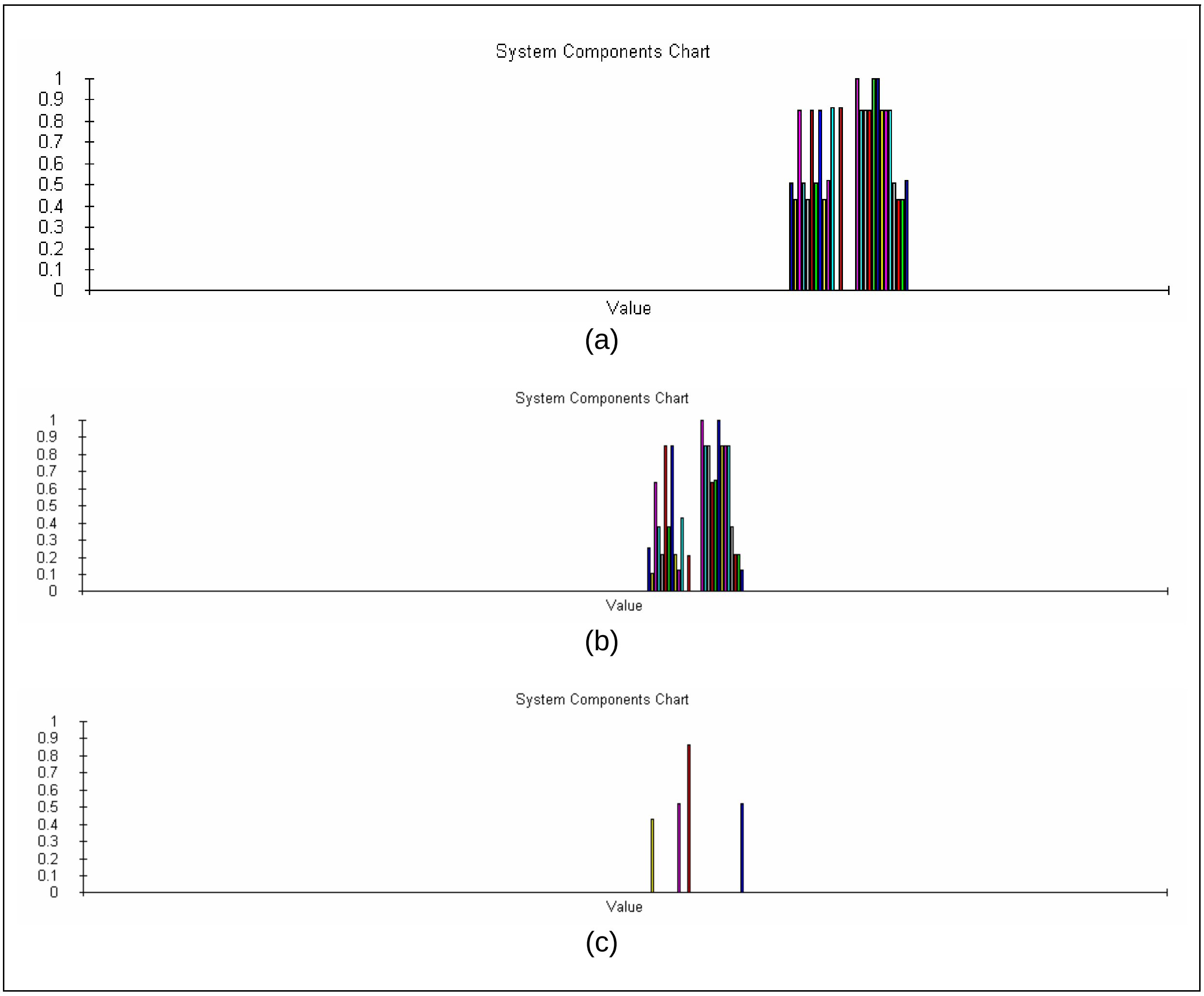


Figure 5.21 System Components Charts in simulation step 2 for
(a) *STEP* case; (a) *RAMP* case; (a) *IMPULSE* case

6 Concluding Remarks and Contemplated Developments

This paper is a review of the ***InSIEME*** concept. The rationale is presented in Chapter 2. The formalism and the analytical explanation of the *error dispersion* and *influence flow* algorithms are given in Chapter 3. The Application is presented in Chapter 4, together with the most common workflows for system vulnerability assessment procedures. Chapter 5 introduces two relevant examples of using ***InSIEME***'s Static and Dynamic Simulation features and the system behavior assessment using these modules.

The examples (scenarios and analysis) given throughout the paper are instrumental in emphasizing aspects related to various types of system behavior under different error injection point distribution and error profiles.

The paper has aimed at highlighting the main features supportive to a meaningful system analysis provided by ***InSIEME*** as well as some basic assessment techniques. Combining these with the CRISA features relating to enhanced multimedia GIS engines, and the native ArcView tools for spatial analysis would make the application a potentially effective tool in assessing the vulnerability of the complex systems via error propagation mechanisms.

InSIEME is a concept proof. All model components may, in principle, be improved. Some possible directions for future development are given in the sequel.

Of first evidence would be to design and implement an algorithm, and the consequent interface allowing a full specification and pre-processing of the time-profile of the injected error, meant to replace the current interactive – and admittedly cumbersome – procedure.

On a different scale, a superior model would imply the possibility of defining the *subsystems* as *collections of system components*. In such an approach, a subsystem is a black-box. The subsystem output is connected to one or more subsystems input lines, or to other *system components*. This allows the definition of *one-to-many* interaction relationships as a *one-to-one* relationship. For instance, let us consider the OIL STOCK MARKET as a system component class containing one component namely SM, the incapability index of which is related to the price of the fuel. SM interacts with *all the thermal-type components* (power plants) of the electricity generating system. In the current model, *one-to-one* interaction relationships should be established for each of the pairs (*SM, thermal power plant*). In the enhanced model, the *Thermal Power Plants* subsystem would be defined as including the thermal power plants of the electricity generating system, and then just a single interaction relationship would be established between SM and the defined sub-system. The immediate advantage of such an approach would be an improvement as far as both the computational time and the time required for the system design phase, while not loosing any capability of differentiating between different component classes.

The definition of the component *Incapability Index* as a *function* of component-type related characteristics would be another *nice-to-have* improvement of the model. The component characteristics are, essentially, structural, operational and functional. The new approach would provide for a better simulation of complex interaction mechanisms, based on a detailed relationship of mutual influence of the components.

To meet one of the current trends in complex system architecture vulnerability assessment, namely the *system of systems* approach, may be another goal to pursue, starting from the ***InSIEME*** concept. However, this would entail significant changes that would affect most of the project, from design to software implementation. Re-engineering the project in a OOP (Object Oriented Programming) manner becomes, in this case, a must. The most natural approach is to adopt ESRI's *Map Objects* for the GIS part. Let it be reminded that *Map Objects* is a collection of GIS representation and analysis tools built around Microsoft's ActiveX technology. The immediate advantage is that the models can be implemented in a high-level programming environment (e.g. *Microsoft Visual C++* or *Microsoft Visual Basic*) with the GIS tools embedded in the project.

Last but not least, a very desirable improvement with ***InSIEME*** - and maybe the most challenging one - would be the radical revamping of the project so as to provide for a full-fledged distributed *team work* approach. The idea is to simultaneously run the application from remote locations by different stakeholders interested in the assessment. Brainstorming sessions, decision making processes or system analysis would become a team work involving people that participates from virtually any location. From the implementation point of view, this entails, *inter alia*, a *client-server* architecture for the project. Placing ***InSIEME*** on INTERNET would also open an avenue towards accessing shared, large and comprehensive databases for data mining and assessment-related information.

Such possibilities, as well as other that may be contemplated would add value to the current work, provided an adequate lead time and resources are secured.

APPENDIX

Full Simulation Report for *EVENT 1*

THE SYSTEM

DEFINITION

Component Types: 3
 > Power Lines
 > Power Plants
 > Power Substations

Infrastructure Failure is considered:
 > 'Acceptable', if 0 < (W)IFI < 0.2
 > 'Partially Acceptable', if 0.2 <= (W)IFI < 0.5
 > 'Unacceptable', if 0.5 <= (W)IFI <= 1
where:
 - (W)IFI - the (Weighted) Infrastructure Failure Index.

The weights for computing WIFI:
 > Fully Functional: 0.1
 > Partially Disabled: 0.5
 > Out of Order: 1

A System Component (SC) is
 > 'Fully Functional', if 0 < II < 0.2
 > 'Partially Disabled', if 0.2 <= II < 0.5
 > 'Out of Order', if 0.5 <= II <= 1
where:
 - II - the Incapability Index of the component.

STATUS

THE INFRASTRUCTURE

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
 Infrastructure Failure Index (weighted)=0.121652

Infrastructure Failure LEVEL: "UNACCEPTABLE", based on
 Infrastructure Failure Index=0.803419

THE SYSTEM COMPONENTS

Number of System Components reached: 314

Reached Components by Type:
 Power Lines - 160, representing 46%
 Power Plants - 24, representing 7%
 Power Substations - 98, representing 28%

Reached Components by Functionality Level:
 From "Power Lines"
  > 3 components 'Out of Order'
  > 18 components 'Partially Disabled'
  > 139 components 'Fully Functional'
 From "Power Plants"
  > 0 components 'Out of Order'
  > 0 components 'Partially Disabled'
  > 24 components 'Fully Functional'
 From "Power Substations"
  > 2 components 'Out of Order'

> 7 components 'Partially Disabled'
> 89 components 'Fully Functional'

Overall Incapability Index of the system: 0.0569202

Most Affected System Component(s): 1, with the Incapability Index: 0.867
> Power Lines #98: "Single"

THE ERROR INJECTION POINTS

Number of System Components affected by EIP #1: 314
>> Power Substations #73 - "RAVENNA CANALA": 0.5
>> Power Lines #92 - "Single": 0.425
>> Power Lines #89 - "Double": 0.425
>> Power Lines #90 - "Single": 0.425
>> Power Lines #91 - "Single": 0.425
>> Power Lines #99 - "Single": 0.425
>> Power Lines #97 - "Single": 0.425
>> Power Lines #96 - "Single": 0.425
>> Power Substations #67 - "FERRARA FOCOMORTO": 0.255
>> Power Lines #88 - "Double": 0.425
>> Power Substations #66 - "PORTO TOLLE": 0.255
>> Power Plants #18 - "Porto Corsini": 0.17
>> Power Plants #17 - "Enipower Ravenna": 0.17
>> Power Substations #74 - "S. MARINO IN XX": 0.255
>> Power Lines #100 - "Single": 0.425
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Lines #93 - "Single": 0.217
>> Power Substations #65 - "ADRIA SUD": 0.255
>> Power Lines #181 - "Single": 0.217
>> Power Lines #98 - "Single": 0.217
>> Power Lines #101 - "Single": 0.217
>> Power Lines #102 - "Single": 0.217
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Lines #95 - "Single": 0.65
>> Power Lines #98 - "Single": 0.65
>> Power Plants #33 - "Sermide": 0.087
>> Power Lines #87 - "Double": 0.217
>> Power Plants #16 - "Porto Tolle": 0.087
>> Power Substations #75 - "FANO E.T.": 0.13
>> Power Substations #75 - "FANO E.T.": 0.13
>> Power Substations #68 - "MARTIGNONE": 0.39
>> Power Lines #191 - "Single": 0.65
>> Power Lines #189 - "Single": 0.078
>> Power Lines #103 - "Single": 0.221
>> Power Lines #86 - "Single": 0.332
>> Power Lines #190 - "Single": 0.332
>> Power Lines #62 - "Single": 0.332
>> Power Substations #69 - "COLUNGA": 0.39
>> Power Substations #123 - "SERMIDE": 0.047
>> Power Substations #76 - "CANDIA": 0.133
>> Power Substations #53 - "DUGALE": 0.199
>> Power Substations #46 - "BARGI STAZIONE": 0.199
>> Power Substations #45 - "S. DAMASO": 0.199
>> Power Lines #94 - "Single": 0.04
>> Power Lines #114 - "Single": 0.113
>> Power Lines #67 - "Single": 0.169
>> Power Lines #76 - "Single": 0.169
>> Power Lines #80 - "Single": 0.169
>> Power Lines #75 - "Single": 0.169
>> Power Lines #74 - "Single": 0.169
>> Power Lines #61 - "Single": 0.169
>> Power Lines #63 - "Single": 0.169
>> Power Substations #52 - "OSTIGLIA": 0.024
>> Power Substations #98 - "VILLANOVA": 0.068
>> Power Lines #182 - "Single": 0.113

>> Power Substations #51 - "NOGAROLE ROCA": 0.101
>> Power Substations #54 - "SANDRIGO": 0.101
>> Power Substations #63 - "CAMIN": 0.101
>> Power Plants #13 - "Bargi Centrale": 0.068
>> Power Substations #70 - "CALENZANO": 0.101
>> Power Substations #44 - "RUBIERA": 0.101
>> Power Substations #32 - "CAORSO": 0.101
>> Power Lines #65 - "Single": 0.02
>> Power Lines #64 - "Single": 0.02
>> Power Lines #113 - "Single": 0.058
>> Power Lines #139 - "Single": 0.058
>> Power Substations #92 - "ROSARA": 0.068
>> Power Lines #66 - "Single": 0.086
>> Power Lines #77 - "Single": 0.086
>> Power Lines #81 - "Single": 0.086
>> Power Lines #82 - "Single": 0.086
>> Power Lines #73 - "Single": 0.086
>> Power Lines #105 - "Single": 0.086
>> Power Lines #60 - "Single": 0.086
>> Power Lines #55 - "Single": 0.086
>> Power Plants #10 - "Ostiglia": 0.008
>> Power Substations #40 - "FLERO": 0.012
>> Power Substations #90 - "VILLAVALLE": 0.035
>> Power Substations #99 - "LARINO": 0.035
>> Power Substations #42 - "LONATO": 0.052
>> Power Substations #55 - "CORDIGNANO": 0.052
>> Power Substations #64 - "RFX CNR": 0.052
>> Power Plants #34 - "Dolo": 0.034
>> Power Substations #71 - "TAVARNUZZE": 0.052
>> Power Substations #47 - "POGGIO A CAIANO": 0.052
>> Power Substations #43 - "PARMA VIGHEFFIO": 0.052
>> Power Lines #54 - "Single": 0.086
>> Power Lines #173 - "Single": 0.01
>> Power Lines #48 - "Single": 0.01
>> Power Lines #54 - "Single": 0.01
>> Power Lines #112 - "Single": 0.03
>> Power Lines #140 - "Single": 0.03
>> Power Lines #49 - "Single": 0.044
>> Power Lines #78 - "Single": 0.044
>> Power Lines #177 - "Double": 0.031
>> Power Lines #194 - "Double": 0.031
>> Power Lines #104 - "Single": 0.044
>> Power Lines #104 - "Single": 0.044
>> Power Lines #109 - "Single": 0.044
>> Power Lines #107 - "Single": 0.044
>> Power Lines #72 - "Single": 0.044
>> Power Lines #59 - "Single": 0.044
>> Power Lines #57 - "Single": 0.096
>> Power Substations #31 - "PIACENZA": 0.058
>> Power Substations #39 - "NA#12": 0.006
>> Power Substations #41 - "NAVE": 0.006
>> Power Substations #80 - "MONTALTO": 0.018
>> Power Substations #100 - "FOGGIA": 0.018
>> Power Substations #41 - "NAVE": 0.026
>> Power Substations #56 - "UDINE OVEST": 0.026
>> Power Substations #61 - "VENEZIA NORD": 0.019
>> Power Substations #62 - "DOLO": 0.019
>> Power Substations #77 - "PIAN DELLA SPERANZA": 0.026
>> Power Substations #78 - "SUVERETO": 0.026
>> Power Substations #48 - "MARGINONE": 0.026
>> Power Substations #33 - "CREMONA": 0.058
>> Power Lines #53 - "Single": 0.049
>> Power Lines #40 - "Single": 0.049
>> Power Lines #58 - "Single": 0.049
>> Power Lines #174 - "Single": 0.049
>> Power Lines #47 - "Single": 0.005
>> Power Lines #45 - "Single": 0.027

>> Power Lines #175 - "Double": 0.015
>> Power Lines #118 - "Double": 0.015
>> Power Lines #115 - "Double": 0.015
>> Power Lines #141 - "Single": 0.015
>> Power Lines #142 - "Single": 0.015
>> Power Lines #135 - "Single": 0.015
>> Power Lines #79 - "Single": 0.022
>> Power Lines #179 - "Single": 0.016
>> Power Lines #110 - "Single": 0.022
>> Power Lines #106 - "Single": 0.022
>> Power Lines #111 - "Double": 0.022
>> Power Lines #108 - "Single": 0.022
>> Power Lines #106 - "Single": 0.022
>> Power Lines #70 - "Double": 0.022
>> Power Lines #71 - "Single": 0.022
>> Power Lines #56 - "Single": 0.049
>> Power Substations #28 - "LA CASELLA": 0.029
>> Power Lines #39 - "Single": 0.049
>> Power Lines #38 - "Single": 0.049
>> Power Lines #37 - "Single": 0.049
>> Power Substations #49 - "LA SPEZIA": 0.029
>> Power Plants #8 - "Piacenza": 0.02
>> Power Substations #35 - "NA#11": 0.003
>> Power Substations #38 - "S. FIORANO": 0.016
>> Power Plants #20 - "Montalto C.le": 0.006
>> Power Substations #85 - "VALMONTONE": 0.009
>> Power Substations #81 - "AURELIA": 0.009
>> Power Substations #102 - "ANDRIA": 0.009
>> Power Substations #102 - "ANDRIA": 0.009
>> Power Substations #97 - "BENEVENTO 2": 0.009
>> Power Substations #59 - "PLANAIS": 0.013
>> Power Substations #60 - "SALGAREDA": 0.01
>> Power Substations #87 - "ROMA NORD": 0.013
>> Power Plants #20 - "Montalto C.le": 0.009
>> Power Plants #19 - "Piombino Termica": 0.009
>> Power Substations #50 - "ACCIAIOLO": 0.013
>> Power Lines #69 - "Single": 0.022
>> Power Substations #34 - "NA#10": 0.029
>> Power Lines #50 - "Single": 0.025
>> Power Substations #30 - "NA#9": 0.029
>> Power Lines #38 - "Single": 0.049
>> Power Substations #29 - "NA#8": 0.059
>> Power Substations #27 - "TAVAZZANO": 0.029
>> Power Lines #192 - "Single": 0.025
>> Power Lines #69 - "Single": 0.025
>> Power Lines #68 - "Single": 0.025
>> Power Lines #46 - "Single": 0.003
>> Power Lines #44 - "Double": 0.014
>> Power Lines #172 - "Double": 0.014
>> Power Lines #43 - "Double": 0.014
>> Power Lines #128 - "Single": 0.008
>> Power Lines #127 - "Single": 0.008
>> Power Lines #120 - "Single": 0.008
>> Power Lines #117 - "Single": 0.008
>> Power Lines #121 - "Single": 0.008
>> Power Lines #116 - "Single": 0.008
>> Power Lines #122 - "Single": 0.008
>> Power Lines #176 - "Single": 0.008
>> Power Lines #143 - "Single": 0.015
>> Power Lines #144 - "Single": 0.015
>> Power Lines #134 - "Single": 0.008
>> Power Lines #137 - "Single": 0.008
>> Power Lines #180 - "Single": 0.011
>> Power Lines #83 - "Single": 0.009
>> Power Lines #119 - "Single": 0.011
>> Power Lines #117 - "Single": 0.011
>> Power Lines #153 - "Single": 0.011

>> Power Lines #69 - "Single": 0.011
>> Power Plants #32 - "La Casella": 0.01
>> Power Lines #34 - "Single": 0.05
>> Power Lines #41 - "Single": 0.05
>> Power Lines #193 - "Single": 0.025
>> Power Lines #36 - "Single": 0.025
>> Power Plants #9 - "La Spezia": 0.01
>> Power Substations #25 - "VIGNOLE B.": 0.015
>> Power Substations #36 - "GORLAGO": 0.002
>> Power Plants #11 - "Edolo": 0.006
>> Power Plants #12 - "San Fiorano": 0.006
>> Power Substations #37 - "PIAN CAMUNO": 0.008
>> Power Substations #96 - "PRESENZANO": 0.005
>> Power Substations #84 - "LATINA NUCLEARE": 0.005
>> Power Substations #86 - "ROMA EST": 0.005
>> Power Substations #82 - "ROMA OVEST": 0.005
>> Power Plants #21 - "Torrevaldaliga Nord": 0.003
>> Power Substations #82 - "ROMA OVEST": 0.005
>> Power Plants #22 - "Torrevaldaliga": 0.003
>> Power Substations #103 - "BARI O.": 0.009
>> Power Substations #106 - "BRINDISI": 0.009
>> Power Substations #96 - "PRESENZANO": 0.005
>> Power Substations #95 - "S. SOFIA": 0.005
>> Power Lines #83 - "Single": 0.011
>> Power Substations #57 - "REDIPUGLIA": 0.012
>> Power Substations #86 - "ROMA EST": 0.007
>> Power Substations #79 - "ROSEN": 0.007
>> Power Lines #52 - "Single": 0.009
>> Power Substations #17 - "NA#3": 0.03
>> Power Substations #36 - "GORLAGO": 0.03
>> Power Plants #7 - "Tavazzano": 0.01
>> Power Substations #19 - "NA#4": 0.015
>> Power Lines #22 - "Single": 0.013
>> Power Lines #20 - "Single": 0.013
>> Power Lines #42 - "Double": 0.027
>> Power Lines #42 - "Double": 0.007
>> Power Lines #184 - "Single": 0.009
>> Power Lines #125 - "Single": 0.004
>> Power Lines #126 - "Single": 0.004
>> Power Lines #130 - "Single": 0.004
>> Power Lines #129 - "Single": 0.004
>> Power Lines #124 - "Single": 0.009
>> Power Lines #123 - "Single": 0.009
>> Power Lines #145 - "Single": 0.008
>> Power Lines #145 - "Single": 0.008
>> Power Lines #147 - "Single": 0.008
>> Power Lines #136 - "Single": 0.004
>> Power Lines #138 - "Single": 0.004
>> Power Lines #85 - "Single": 0.01
>> Power Lines #84 - "Single": 0.01
>> Power Lines #195 - "Single": 0.006
>> Power Substations #26 - "NA#7": 0.005
>> Power Lines #27 - "Single": 0.025
>> Power Lines #33 - "Single": 0.025
>> Power Lines #35 - "Single": 0.025
>> Power Lines #26 - "Single": 0.025
>> Power Lines #35 - "Single": 0.013
>> Power Substations #23 - "PIEVE A": 0.008
>> Power Substations #11 - "VADO L.": 0.008
>> Power Plants #25 - "Presenzano": 0.004
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #89 - "GARIGLIANO S.NE": 0.002
>> Power Substations #89 - "GARIGLIANO S.NE": 0.002
>> Power Substations #83 - "ROMA SUD": 0.005
>> Power Substations #83 - "ROMA SUD": 0.005
>> Power Substations #104 - "MATERA": 0.005

>> Power Substations #94 - "S. MARIA CAPUA V.": 0.002
>> Power Substations #101 - "MONTECORVINO": 0.002
>> Power Substations #58 - "DIVACA": 0.006
>> Power Plants #15 - "Monfalcone": 0.004
>> Power Plants #14 - "Rosen": 0.002
>> Power Lines #51 - "Single": 0.004
>> Power Substations #16 - "NA#2": 0.015
>> Power Substations #18 - "BULCIAGO": 0.015
>> Power Substations #20 - "NA#5": 0.015
>> Power Lines #23 - "Single": 0.007
>> Power Lines #24 - "Single": 0.007
>> Power Lines #11 - "Single": 0.007
>> Power Lines #12 - "Single": 0.007
>> Power Lines #183 - "Single": 0.003
>> Power Lines #131 - "Single": 0.003
>> Power Lines #133 - "Single": 0.003
>> Power Lines #146 - "Single": 0.004
>> Power Lines #155 - "Single": 0.004
>> Power Lines #132 - "Single": 0.002
>> Power Lines #131 - "Single": 0.002
>> Power Lines #154 - "Single": 0.002
>> Power Substations #21 - "BAGIO": 0.002
>> Power Lines #28 - "Single": 0.013
>> Power Lines #32 - "Single": 0.013
>> Power Lines #25 - "Single": 0.013
>> Power Plants #4 - "Ferrera E.": 0.003
>> Power Plants #3 - "Vado L.": 0.003
>> Power Substations #88 - "CEPRANO": 0.002
>> Power Substations #93 - "PATRIA": 0.002
>> Power Substations #105 - "TARANTO NORD": 0.002
>> Power Substations #111 - "LAINO": 0.002
>> Power Substations #93 - "PATRIA": 0.001
>> Power Substations #111 - "LAINO": 0.001
>> Power Lines #25 - "Single": 0.002
>> Power Lines #16 - "Single": 0.002
>> Power Substations #15 - "NA#1": 0.008
>> Power Substations #13 - "SOAZZA": 0.008
>> Power Lines #148 - "Single": 0.002
>> Power Lines #150 - "Single": 0.002
>> Power Lines #156 - "Single": 0.003
>> Power Substations #22 - "NA#6": 0.001
>> Power Lines #29 - "Single": 0.007
>> Power Substations #107 - "S.NE BRINDISI SUD": 0.001
>> Power Substations #108 - "GALATINA": 0.001
>> Power Plants #26 - "Rossano": 0.001
>> Power Lines #171 - "Single": 0.001
>> Power Substations #109 - "MUSIGNANO": 0.004
>> Power Plants #27 - "Roncovalgrande": 0.003
>> Power Lines #149 - "Single": 0.001
>> Power Lines #151 - "Single": 0.001
>> Power Lines #151 - "Single": 0.001
>> Power Lines #152 - "Single": 0.001
>> Power Lines #186 - "Single": 0.001
>> Power Lines #30 - "Single": 0.003
>> Power Lines #31 - "Single": 0.003
>> Power Lines #30 - "Single": 0.003
>> Power Substations #125 - "ROSSANO": 0.001

Number of System Components affected by EIP #2: none

System Table after *Event 1*			
Key	**Name**	**Value**	**Class**
Power Substations	*VADO L.*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Substations	*SOAZZA*	0.008	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.006	Fully Functional
Power Substations	*NA#1*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Substations	*NA#2*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#3*	0.030	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.050	Fully Functional
Power Lines	*Single*	0.038	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*BULCIAGO*	0.015	Fully Functional
Power Substations	*NA#4*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#5*	0.015	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Substations	*BAGIO*	0.002	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*NA#6*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*PIEVE A*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Substations	*VIGNOLE B.*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#7*	0.005	Fully Functional
Power Lines	*Single*	0.009	Fully Functional
Power Substations	*TAVAZZANO*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*LA CASELLA*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*NA#8*	0.059	Fully Functional
Power Lines	*Single*	0.050	Fully Functional
Power Lines	*Single*	0.098	Fully Functional
Power Substations	*NA#9*	0.029	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*PIACENZA*	0.058	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Lines	*Single*	0.096	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*CAORSO*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Substations	*CREMONA*	0.058	Fully Functional
Power Lines	*Single*	0.096	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*NA#10*	0.029	Fully Functional
Power Substations	*NA#11*	0.003	Fully Functional

Power Lines	*Single*	0.003	Fully Functional
Power Lines	*Single*	0.005	Fully Functional
Power Substations	*GORLAGO*	0.032	Fully Functional
Power Lines	*Double*	0.034	Fully Functional
Power Substations	*PIAN CAMUNO*	0.008	Fully Functional
Power Lines	*Double*	0.014	Fully Functional
Power Substations	*S. FIORANO*	0.016	Fully Functional
Power Lines	*Double*	0.014	Fully Functional
Power Lines	*Double*	0.014	Fully Functional
Power Lines	*Single*	0.027	Fully Functional
Power Substations	*NA#12*	0.006	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Substations	*FLERO*	0.012	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Substations	*NAVE*	0.032	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Substations	*LONATO*	0.052	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*PARMA VIGHEFFIO*	0.052	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*RUBIERA*	0.101	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Substations	*S. DAMASO*	0.199	Fully Functional
Power Lines	*Single*	0.332	Partially Disabled
Power Substations	*BARGI STAZIONE*	0.199	Fully Functional
Power Lines	*Single*	0.332	Partially Disabled
Power Lines	*Single*	0.169	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Substations	*POGGIO A CAIANO*	0.052	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Lines	*Single*	0.088	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Substations	*MARGINONE*	0.026	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Lines	*Double*	0.022	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Substations	*LA SPEZIA*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.058	Fully Functional
Power Substations	*ACCIAIOLO*	0.013	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Substations	*NOGAROLE ROCA*	0.101	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Substations	*OSTIGLIA*	0.024	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Lines	*Single*	0.040	Fully Functional
Power Substations	*DUGALE*	0.199	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Lines	*Single*	0.169	Fully Functional
Power Lines	*Single*	0.332	Partially Disabled
Power Substations	*SANDRIGO*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*CORDIGNANO*	0.052	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Substations	*UDINE OVEST*	0.026	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Substations	*REDIPUGLIA*	0.012	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.020	Fully Functional

Power Substations	*DIVACA*	0.006	Fully Functional
Power Substations	*PLANAIS*	0.013	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Substations	*SALGAREDA*	0.010	Fully Functional
Power Lines	*Single*	0.016	Fully Functional
Power Substations	*VENEZIA NORD*	0.019	Fully Functional
Power Lines	*Double*	0.031	Fully Functional
Power Substations	*DOLO*	0.019	Fully Functional
Power Lines	*Double*	0.031	Fully Functional
Power Substations	*CAMIN*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*RFX CNR*	0.052	Fully Functional
Power Substations	*ADRIA SUD*	0.255	Partially Disabled
Power Lines	*Double*	0.217	Partially Disabled
Power Lines	*Double*	0.425	Partially Disabled
Power Substations	*PORTO TOLLE*	0.255	Partially Disabled
Power Lines	*Single*	0.217	Partially Disabled
Power Lines	*Double*	0.425	Partially Disabled
Power Substations	*FERRARA FOCOMORTO*	0.255	Partially Disabled
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.217	Partially Disabled
Power Substations	*MARTIGNONE*	0.390	Partially Disabled
Power Lines	*Single*	0.650	Out of Order
Power Substations	*COLUNGA*	0.390	Partially Disabled
Power Lines	*Single*	0.650	Out of Order
Power Substations	*CALENZANO*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*TAVARNUZZE*	0.052	Fully Functional
Power Substations	*FORLI ORAZIANA*	0.765	Out of Order
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.867	Out of Order
Power Substations	*RAVENNA CANALA*	0.500	Out of Order
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.425	Partially Disabled
Power Lines	*Single*	0.425	Partially Disabled
Power Substations	*S. MARINO IN XX*	0.255	Partially Disabled
Power Lines	*Single*	0.217	Partially Disabled
Power Lines	*Single*	0.217	Partially Disabled
Power Substations	*FANO E.T.*	0.260	Partially Disabled
Power Lines	*Single*	0.221	Partially Disabled
Power Substations	*CANDIA*	0.133	Fully Functional
Power Lines	*Single*	0.113	Fully Functional
Power Substations	*PIAN DELLA SPERANZA*	0.026	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Substations	*SUVERETO*	0.026	Fully Functional
Power Lines	*Double*	0.022	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Substations	*ROSEN*	0.007	Fully Functional
Power Lines	*Single*	0.006	Fully Functional
Power Substations	*MONTALTO*	0.018	Fully Functional
Power Lines	*Double*	0.015	Fully Functional
Power Lines	*Single*	0.030	Fully Functional
Power Lines	*Double*	0.015	Fully Functional
Power Lines	*Double*	0.015	Fully Functional
Power Substations	*AURELIA*	0.009	Fully Functional
Power Lines	*Single*	0.019	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Substations	*ROMA OVEST*	0.010	Fully Functional

Power Lines	*Single*	0.009	Fully Functional
Power Lines	*Single*	0.009	Fully Functional
Power Substations	*ROMA SUD*	0.014	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*LATINA NUCLEARE*	0.005	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*VALMONTONE*	0.009	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Substations	*ROMA EST*	0.012	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Substations	*ROMA NORD*	0.013	Fully Functional
Power Substations	*CEPRANO*	0.002	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Substations	*GARIGLIANO S.NE*	0.004	Fully Functional
Power Lines	*Single*	0.005	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Substations	*VILLAVALLE*	0.035	Fully Functional
Power Lines	*Single*	0.058	Fully Functional
Power Substations	*ROSARA*	0.068	Fully Functional
Power Lines	*Single*	0.113	Fully Functional
Power Substations	*PATRIA*	0.003	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*S. MARIA CAPUA V.*	0.002	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*S. SOFIA*	0.005	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*PRESENZANO*	0.010	Fully Functional
Power Lines	*Single*	0.009	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Substations	*BENEVENTO 2*	0.009	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Substations	*VILLANOVA*	0.068	Fully Functional
Power Lines	*Single*	0.058	Fully Functional
Power Substations	*LARINO*	0.035	Fully Functional
Power Lines	*Single*	0.030	Fully Functional
Power Substations	*FOGGIA*	0.018	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Substations	*MONTECORVINO*	0.002	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*ANDRIA*	0.018	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Substations	*BARI O.*	0.009	Fully Functional
Power Lines	*Single*	0.016	Fully Functional
Power Substations	*MATERA*	0.005	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*TARANTO NORD*	0.002	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*BRINDISI*	0.009	Fully Functional
Power Substations	*S.NE BRINDISI SUD*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*GALATINA*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*MUSIGNANO*	0.004	Fully Functional

Power Substations	*LAINO*	0.003	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Substations	*SERMIDE*	0.047	Fully Functional
Power Lines	*Single*	0.078	Fully Functional
Power Substations	*ROSSANO*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Plants	*Vado L.*	0.003	Fully Functional
Power Plants	*Ferrera E.*	0.003	Fully Functional
Power Plants	*Tavazzano*	0.010	Fully Functional
Power Plants	*Piacenza*	0.020	Fully Functional
Power Plants	*La Spezia*	0.010	Fully Functional
Power Plants	*Ostiglia*	0.008	Fully Functional
Power Plants	*Edolo*	0.006	Fully Functional
Power Plants	*San Fiorano*	0.006	Fully Functional
Power Plants	*Bargi Centrale*	0.068	Fully Functional
Power Plants	*Rosen*	0.002	Fully Functional
Power Plants	*Monfalcone*	0.004	Fully Functional
Power Plants	*Porto Tolle*	0.087	Fully Functional
Power Plants	*Enipower Ravenna*	0.170	Fully Functional
Power Plants	*Porto Corsini*	0.170	Fully Functional
Power Plants	*Piombino Termica*	0.009	Fully Functional
Power Plants	*Montalto C.le*	0.015	Fully Functional
Power Plants	*Torrevaldaliga Nord*	0.003	Fully Functional
Power Plants	*Torrevaldaliga*	0.003	Fully Functional
Power Plants	*Presenzano*	0.004	Fully Functional
Power Plants	*Rossano*	0.001	Fully Functional
Power Plants	*Roncovalgrande*	0.003	Fully Functional
Power Plants	*La Casella*	0.010	Fully Functional
Power Plants	*Sermide*	0.087	Fully Functional
Power Plants	*Dolo*	0.034	Fully Functional

Full Simulation Report for *EVENT 2*

THE SYSTEM

DEFINITION

Component Types: 3
 > Power Lines
 > Power Plants
 > Power Substations

Infrastructure Failure is considered:
 > 'Acceptable', if 0 < (W)IFI < 0.2
 > 'Partially Acceptable', if 0.2 <= (W)IFI < 0.5
 > 'Unacceptable', if 0.5 <= (W)IFI <= 1
where:
 - (W)IFI - the (Weighted) Infrastructure Failure Index.

The weights for computing WIFI:
 > Fully Functional: 0.1
 > Partially Disabled: 0.5
 > Out of Order: 1

A System Component (SC) is
 > 'Fully Functional', if 0 < II < 0.2
 > 'Partially Disabled', if 0.2 <= II < 0.5
 > 'Out of Order', if 0.5 <= II <= 1
where:
 - II - the Incapability Index of the component.

STATUS

THE INFRASTRUCTURE

Infrastructure Failure LEVEL: "ACCEPTABLE", based on
 Infrastructure Failure Index (weighted)=0.140456

Infrastructure Failure LEVEL: "UNACCEPTABLE", based on
 Infrastructure Failure Index=0.837607

THE SYSTEM COMPONENTS

Number of System Components reached: 326

Reached Components by Type:
 Power Lines - 166, representing 47%
 Power Plants - 25, representing 7%
 Power Substations - 103, representing 29%

Reached Components by Functionality Level:
 From "Power Lines"
  > 4 components 'Out of Order'
  > 21 components 'Partially Disabled'
  > 141 components 'Fully Functional'
 From "Power Plants"
  > 1 components 'Out of Order'
  > 0 components 'Partially Disabled'
  > 24 components 'Fully Functional'
 From "Power Substations"
  > 2 components 'Out of Order'
  > 13 components 'Partially Disabled'
  > 88 components 'Fully Functional'

Overall Incapability Index of the system: 0.0709373

Most Affected System Component(s): 1, with the Incapability Index: 0.869
> Power Lines #98: "Single"

THE ERROR INJECTION POINTS

Number of System Components affected by EIP #1: 314
>> Power Substations #73 - "RAVENNA CANALA": 0.5
>> Power Lines #92 - "Single": 0.425
>> Power Lines #89 - "Double": 0.425
>> Power Lines #90 - "Single": 0.425
>> Power Lines #91 - "Single": 0.425
>> Power Lines #99 - "Single": 0.425
>> Power Lines #97 - "Single": 0.425
>> Power Lines #96 - "Single": 0.425
>> Power Substations #67 - "FERRARA FOCOMORTO": 0.255
>> Power Lines #88 - "Double": 0.425
>> Power Substations #66 - "PORTO TOLLE": 0.255
>> Power Plants #18 - "Porto Corsini": 0.17
>> Power Plants #17 - "Enipower Ravenna": 0.17
>> Power Substations #74 - "S. MARINO IN XX": 0.255
>> Power Lines #100 - "Single": 0.425
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Lines #93 - "Single": 0.217
>> Power Substations #65 - "ADRIA SUD": 0.255
>> Power Lines #181 - "Single": 0.217
>> Power Lines #98 - "Single": 0.217
>> Power Lines #101 - "Single": 0.217
>> Power Lines #102 - "Single": 0.217
>> Power Substations #72 - "FORLI ORAZIANA": 0.255
>> Power Lines #95 - "Single": 0.65
>> Power Lines #98 - "Single": 0.65
>> Power Plants #33 - "Sermide": 0.087
>> Power Lines #87 - "Double": 0.217
>> Power Plants #16 - "Porto Tolle": 0.087
>> Power Substations #75 - "FANO E.T.": 0.13
>> Power Substations #75 - "FANO E.T.": 0.13
>> Power Substations #68 - "MARTIGNONE": 0.39
>> Power Lines #191 - "Single": 0.65
>> Power Lines #189 - "Single": 0.078
>> Power Lines #103 - "Single": 0.221
>> Power Lines #86 - "Single": 0.332
>> Power Lines #190 - "Single": 0.332
>> Power Lines #62 - "Single": 0.332
>> Power Substations #69 - "COLUNGA": 0.39
>> Power Substations #123 - "SERMIDE": 0.047
>> Power Substations #76 - "CANDIA": 0.133
>> Power Substations #53 - "DUGALE": 0.199
>> Power Substations #46 - "BARGI STAZIONE": 0.199
>> Power Substations #45 - "S. DAMASO": 0.199
>> Power Lines #94 - "Single": 0.04
>> Power Lines #114 - "Single": 0.113
>> Power Lines #67 - "Single": 0.169
>> Power Lines #76 - "Single": 0.169
>> Power Lines #80 - "Single": 0.169
>> Power Lines #75 - "Single": 0.169
>> Power Lines #74 - "Single": 0.169
>> Power Lines #61 - "Single": 0.169
>> Power Lines #63 - "Single": 0.169
>> Power Substations #52 - "OSTIGLIA": 0.024
>> Power Substations #98 - "VILLANOVA": 0.068
>> Power Lines #182 - "Single": 0.113
>> Power Substations #51 - "NOGAROLE ROCA": 0.101
>> Power Substations #54 - "SANDRIGO": 0.101
>> Power Substations #63 - "CAMIN": 0.101
>> Power Plants #13 - "Bargi Centrale": 0.068
>> Power Substations #70 - "CALENZANO": 0.101

>> Power Substations #44 - "RUBIERA": 0.101
>> Power Substations #32 - "CAORSO": 0.101
>> Power Lines #65 - "Single": 0.02
>> Power Lines #64 - "Single": 0.02
>> Power Lines #113 - "Single": 0.058
>> Power Lines #139 - "Single": 0.058
>> Power Substations #92 - "ROSARA": 0.068
>> Power Lines #66 - "Single": 0.086
>> Power Lines #77 - "Single": 0.086
>> Power Lines #81 - "Single": 0.086
>> Power Lines #82 - "Single": 0.086
>> Power Lines #73 - "Single": 0.086
>> Power Lines #105 - "Single": 0.086
>> Power Lines #60 - "Single": 0.086
>> Power Lines #55 - "Single": 0.086
>> Power Plants #10 - "Ostiglia": 0.008
>> Power Substations #40 - "FLERO": 0.012
>> Power Substations #90 - "VILLAVALLE": 0.035
>> Power Substations #99 - "LARINO": 0.035
>> Power Substations #42 - "LONATO": 0.052
>> Power Substations #55 - "CORDIGNANO": 0.052
>> Power Substations #64 - "RFX CNR": 0.052
>> Power Plants #34 - "Dolo": 0.034
>> Power Substations #71 - "TAVARNUZZE": 0.052
>> Power Substations #47 - "POGGIO A CAIANO": 0.052
>> Power Substations #43 - "PARMA VIGHEFFIO": 0.052
>> Power Lines #54 - "Single": 0.086
>> Power Lines #173 - "Single": 0.01
>> Power Lines #48 - "Single": 0.01
>> Power Lines #54 - "Single": 0.01
>> Power Lines #112 - "Single": 0.03
>> Power Lines #140 - "Single": 0.03
>> Power Lines #49 - "Single": 0.044
>> Power Lines #78 - "Single": 0.044
>> Power Lines #177 - "Double": 0.031
>> Power Lines #194 - "Double": 0.031
>> Power Lines #104 - "Single": 0.044
>> Power Lines #104 - "Single": 0.044
>> Power Lines #109 - "Single": 0.044
>> Power Lines #107 - "Single": 0.044
>> Power Lines #72 - "Single": 0.044
>> Power Lines #59 - "Single": 0.044
>> Power Lines #57 - "Single": 0.096
>> Power Substations #31 - "PIACENZA": 0.058
>> Power Substations #39 - "NA#12": 0.006
>> Power Substations #41 - "NAVE": 0.006
>> Power Substations #80 - "MONTALTO": 0.018
>> Power Substations #100 - "FOGGIA": 0.018
>> Power Substations #41 - "NAVE": 0.026
>> Power Substations #56 - "UDINE OVEST": 0.026
>> Power Substations #61 - "VENEZIA NORD": 0.019
>> Power Substations #62 - "DOLO": 0.019
>> Power Substations #77 - "PIAN DELLA SPERANZA": 0.026
>> Power Substations #78 - "SUVERETO": 0.026
>> Power Substations #48 - "MARGINONE": 0.026
>> Power Substations #33 - "CREMONA": 0.058
>> Power Lines #53 - "Single": 0.049
>> Power Lines #40 - "Single": 0.049
>> Power Lines #58 - "Single": 0.049
>> Power Lines #174 - "Single": 0.049
>> Power Lines #47 - "Single": 0.005
>> Power Lines #45 - "Single": 0.027
>> Power Lines #175 - "Double": 0.015
>> Power Lines #118 - "Double": 0.015
>> Power Lines #115 - "Double": 0.015
>> Power Lines #141 - "Single": 0.015
>> Power Lines #142 - "Single": 0.015

>> Power Lines #135 - "Single": 0.015
>> Power Lines #79 - "Single": 0.022
>> Power Lines #179 - "Single": 0.016
>> Power Lines #110 - "Single": 0.022
>> Power Lines #106 - "Single": 0.022
>> Power Lines #111 - "Double": 0.022
>> Power Lines #108 - "Single": 0.022
>> Power Lines #106 - "Single": 0.022
>> Power Lines #70 - "Double": 0.022
>> Power Lines #71 - "Single": 0.022
>> Power Lines #56 - "Single": 0.049
>> Power Substations #28 - "LA CASELLA": 0.029
>> Power Lines #39 - "Single": 0.049
>> Power Lines #38 - "Single": 0.049
>> Power Lines #37 - "Single": 0.049
>> Power Substations #49 - "LA SPEZIA": 0.029
>> Power Plants #8 - "Piacenza": 0.02
>> Power Substations #35 - "NA#11": 0.003
>> Power Substations #38 - "S. FIORANO": 0.016
>> Power Plants #20 - "Montalto C.le": 0.006
>> Power Substations #85 - "VALMONTONE": 0.009
>> Power Substations #81 - "AURELIA": 0.009
>> Power Substations #102 - "ANDRIA": 0.009
>> Power Substations #102 - "ANDRIA": 0.009
>> Power Substations #97 - "BENEVENTO 2": 0.009
>> Power Substations #59 - "PLANAIS": 0.013
>> Power Substations #60 - "SALGAREDA": 0.01
>> Power Substations #87 - "ROMA NORD": 0.013
>> Power Plants #20 - "Montalto C.le": 0.009
>> Power Plants #19 - "Piombino Termica": 0.009
>> Power Substations #50 - "ACCIAIOLO": 0.013
>> Power Lines #69 - "Single": 0.022
>> Power Substations #34 - "NA#10": 0.029
>> Power Lines #50 - "Single": 0.025
>> Power Substations #30 - "NA#9": 0.029
>> Power Lines #38 - "Single": 0.049
>> Power Substations #29 - "NA#8": 0.059
>> Power Substations #27 - "TAVAZZANO": 0.029
>> Power Lines #192 - "Single": 0.025
>> Power Lines #69 - "Single": 0.025
>> Power Lines #68 - "Single": 0.025
>> Power Lines #46 - "Single": 0.003
>> Power Lines #44 - "Double": 0.014
>> Power Lines #172 - "Double": 0.014
>> Power Lines #43 - "Double": 0.014
>> Power Lines #128 - "Single": 0.008
>> Power Lines #127 - "Single": 0.008
>> Power Lines #120 - "Single": 0.008
>> Power Lines #117 - "Single": 0.008
>> Power Lines #121 - "Single": 0.008
>> Power Lines #116 - "Single": 0.008
>> Power Lines #122 - "Single": 0.008
>> Power Lines #176 - "Single": 0.008
>> Power Lines #143 - "Single": 0.015
>> Power Lines #144 - "Single": 0.015
>> Power Lines #134 - "Single": 0.008
>> Power Lines #137 - "Single": 0.008
>> Power Lines #180 - "Single": 0.011
>> Power Lines #83 - "Single": 0.009
>> Power Lines #119 - "Single": 0.011
>> Power Lines #117 - "Single": 0.011
>> Power Lines #153 - "Single": 0.011
>> Power Lines #69 - "Single": 0.011
>> Power Plants #32 - "La Casella": 0.01
>> Power Lines #34 - "Single": 0.05
>> Power Lines #41 - "Single": 0.05
>> Power Lines #193 - "Single": 0.025

>> Power Lines #36 - "Single": 0.025
>> Power Plants #9 - "La Spezia": 0.01
>> Power Substations #25 - "VIGNOLE B.": 0.015
>> Power Substations #36 - "GORLAGO": 0.002
>> Power Plants #11 - "Edolo": 0.006
>> Power Plants #12 - "San Fiorano": 0.006
>> Power Substations #37 - "PIAN CAMUNO": 0.008
>> Power Substations #96 - "PRESENZANO": 0.005
>> Power Substations #84 - "LATINA NUCLEARE": 0.005
>> Power Substations #86 - "ROMA EST": 0.005
>> Power Substations #82 - "ROMA OVEST": 0.005
>> Power Plants #21 - "Torrevaldaliga Nord": 0.003
>> Power Substations #82 - "ROMA OVEST": 0.005
>> Power Plants #22 - "Torrevaldaliga": 0.003
>> Power Substations #103 - "BARI O.": 0.009
>> Power Substations #106 - "BRINDISI": 0.009
>> Power Substations #96 - "PRESENZANO": 0.005
>> Power Substations #95 - "S. SOFIA": 0.005
>> Power Lines #83 - "Single": 0.011
>> Power Substations #57 - "REDIPUGLIA": 0.012
>> Power Substations #86 - "ROMA EST": 0.007
>> Power Substations #79 - "ROSEN": 0.007
>> Power Lines #52 - "Single": 0.009
>> Power Substations #17 - "NA#3": 0.03
>> Power Substations #36 - "GORLAGO": 0.03
>> Power Plants #7 - "Tavazzano": 0.01
>> Power Substations #19 - "NA#4": 0.015
>> Power Lines #22 - "Single": 0.013
>> Power Lines #20 - "Single": 0.013
>> Power Lines #42 - "Double": 0.027
>> Power Lines #42 - "Double": 0.007
>> Power Lines #184 - "Single": 0.009
>> Power Lines #125 - "Single": 0.004
>> Power Lines #126 - "Single": 0.004
>> Power Lines #130 - "Single": 0.004
>> Power Lines #129 - "Single": 0.004
>> Power Lines #124 - "Single": 0.009
>> Power Lines #123 - "Single": 0.009
>> Power Lines #145 - "Single": 0.008
>> Power Lines #145 - "Single": 0.008
>> Power Lines #147 - "Single": 0.008
>> Power Lines #136 - "Single": 0.004
>> Power Lines #138 - "Single": 0.004
>> Power Lines #85 - "Single": 0.01
>> Power Lines #84 - "Single": 0.01
>> Power Lines #195 - "Single": 0.006
>> Power Substations #26 - "NA#7": 0.005
>> Power Lines #27 - "Single": 0.025
>> Power Lines #33 - "Single": 0.025
>> Power Lines #35 - "Single": 0.025
>> Power Lines #26 - "Single": 0.025
>> Power Lines #35 - "Single": 0.013
>> Power Substations #23 - "PIEVE A": 0.008
>> Power Substations #11 - "VADO L.": 0.008
>> Power Plants #25 - "Presenzano": 0.004
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #89 - "GARIGLIANO S.NE": 0.002
>> Power Substations #89 - "GARIGLIANO S.NE": 0.002
>> Power Substations #83 - "ROMA SUD": 0.005
>> Power Substations #83 - "ROMA SUD": 0.005
>> Power Substations #104 - "MATERA": 0.005
>> Power Substations #94 - "S. MARIA CAPUA V.": 0.002
>> Power Substations #101 - "MONTECORVINO": 0.002
>> Power Substations #58 - "DIVACA": 0.006
>> Power Plants #15 - "Monfalcone": 0.004
>> Power Plants #14 - "Rosen": 0.002

\>> Power Lines #51 - "Single": 0.004
\>> Power Substations #16 - "NA#2": 0.015
\>> Power Substations #18 - "BULCIAGO": 0.015
\>> Power Substations #20 - "NA#5": 0.015
\>> Power Lines #23 - "Single": 0.007
\>> Power Lines #24 - "Single": 0.007
\>> Power Lines #11 - "Single": 0.007
\>> Power Lines #12 - "Single": 0.007
\>> Power Lines #183 - "Single": 0.003
\>> Power Lines #131 - "Single": 0.003
\>> Power Lines #133 - "Single": 0.003
\>> Power Lines #146 - "Single": 0.004
\>> Power Lines #155 - "Single": 0.004
\>> Power Lines #132 - "Single": 0.002
\>> Power Lines #131 - "Single": 0.002
\>> Power Lines #154 - "Single": 0.002
\>> Power Substations #21 - "BAGIO": 0.002
\>> Power Lines #28 - "Single": 0.013
\>> Power Lines #32 - "Single": 0.013
\>> Power Lines #25 - "Single": 0.013
\>> Power Plants #4 - "Ferrera E.": 0.003
\>> Power Plants #3 - "Vado L.": 0.003
\>> Power Substations #88 - "CEPRANO": 0.002
\>> Power Substations #93 - "PATRIA": 0.002
\>> Power Substations #105 - "TARANTO NORD": 0.002
\>> Power Substations #111 - "LAINO": 0.002
\>> Power Substations #93 - "PATRIA": 0.001
\>> Power Substations #111 - "LAINO": 0.001
\>> Power Lines #25 - "Single": 0.002
\>> Power Lines #16 - "Single": 0.002
\>> Power Substations #15 - "NA#1": 0.008
\>> Power Substations #13 - "SOAZZA": 0.008
\>> Power Lines #148 - "Single": 0.002
\>> Power Lines #150 - "Single": 0.002
\>> Power Lines #156 - "Single": 0.003
\>> Power Substations #22 - "NA#6": 0.001
\>> Power Lines #29 - "Single": 0.007
\>> Power Substations #107 - "S.NE BRINDISI SUD": 0.001
\>> Power Substations #108 - "GALATINA": 0.001
\>> Power Plants #26 - "Rossano": 0.001
\>> Power Lines #171 - "Single": 0.001
\>> Power Substations #109 - "MUSIGNANO": 0.004
\>> Power Plants #27 - "Roncovalgrande": 0.003
\>> Power Lines #149 - "Single": 0.001
\>> Power Lines #151 - "Single": 0.001
\>> Power Lines #151 - "Single": 0.001
\>> Power Lines #152 - "Single": 0.001
\>> Power Lines #186 - "Single": 0.001
\>> Power Lines #30 - "Single": 0.003
\>> Power Lines #31 - "Single": 0.003
\>> Power Lines #30 - "Single": 0.003
\>> Power Substations #125 - "ROSSANO": 0.001

Number of System Components affected by EIP #2: 176
\>> Power Plants #23 - "Brindisi Sud": 0.75
\>> Power Lines #149 - "Single": 0.675
\>> Power Substations #107 - "S.NE BRINDISI SUD": 0.405
\>> Power Lines #148 - "Single": 0.344
\>> Power Lines #151 - "Single": 0.344
\>> Power Substations #105 - "TARANTO NORD": 0.206
\>> Power Substations #108 - "GALATINA": 0.206
\>> Power Lines #146 - "Single": 0.175
\>> Power Lines #150 - "Single": 0.175
\>> Power Lines #150 - "Single": 0.175
\>> Power Lines #152 - "Single": 0.175
\>> Power Substations #104 - "MATERA": 0.105
\>> Power Lines #147 - "Single": 0.089

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>> Power Lines #155 - "Single": 0.089
>> Power Substations #106 - "BRINDISI": 0.053
>> Power Substations #111 - "LAINO": 0.053
>> Power Lines #145 - "Single": 0.045
>> Power Lines #144 - "Single": 0.045
>> Power Lines #154 - "Single": 0.045
>> Power Lines #156 - "Single": 0.045
>> Power Substations #103 - "BARI O.": 0.027
>> Power Substations #102 - "ANDRIA": 0.027
>> Power Substations #101 - "MONTECORVINO": 0.027
>> Power Plants #26 - "Rossano": 0.018
>> Power Lines #143 - "Single": 0.023
>> Power Lines #141 - "Single": 0.023
>> Power Lines #143 - "Single": 0.023
>> Power Lines #142 - "Single": 0.023
>> Power Lines #138 - "Single": 0.023
>> Power Lines #186 - "Single": 0.016
>> Power Substations #100 - "FOGGIA": 0.014
>> Power Substations #100 - "FOGGIA": 0.014
>> Power Substations #95 - "S. SOFIA": 0.014
>> Power Substations #125 - "ROSSANO": 0.01
>> Power Lines #140 - "Single": 0.024
>> Power Lines #135 - "Single": 0.024
>> Power Lines #136 - "Single": 0.012
>> Power Lines #137 - "Single": 0.012
>> Power Lines #157 - "Single": 0.009
>> Power Substations #99 - "LARINO": 0.014
>> Power Substations #97 - "BENEVENTO 2": 0.014
>> Power Substations #94 - "S. MARIA CAPUA V.": 0.007
>> Power Substations #97 - "BENEVENTO 2": 0.007
>> Power Substations #113 - "SCANDALE": 0.005
>> Power Lines #139 - "Single": 0.012
>> Power Lines #134 - "Single": 0.018
>> Power Lines #132 - "Single": 0.006
>> Power Lines #131 - "Single": 0.006
>> Power Lines #158 - "Single": 0.004
>> Power Substations #98 - "VILLANOVA": 0.007
>> Power Substations #96 - "PRESENZANO": 0.011
>> Power Substations #93 - "PATRIA": 0.004
>> Power Substations #89 - "GARIGLIANO S.NE": 0.004
>> Power Substations #114 - "RIZZICONI": 0.002
>> Power Lines #114 - "Single": 0.006
>> Power Lines #113 - "Single": 0.006
>> Power Lines #128 - "Single": 0.009
>> Power Lines #184 - "Single": 0.009
>> Power Lines #133 - "Single": 0.003
>> Power Lines #183 - "Single": 0.003
>> Power Lines #133 - "Single": 0.003
>> Power Lines #129 - "Single": 0.003
>> Power Lines #130 - "Single": 0.003
>> Power Lines #159 - "Single": 0.002
>> Power Substations #76 - "CANDIA": 0.004
>> Power Lines #182 - "Single": 0.006
>> Power Substations #90 - "VILLAVALLE": 0.004
>> Power Substations #85 - "VALMONTONE": 0.005
>> Power Plants #25 - "Presenzano": 0.004
>> Power Substations #88 - "CEPRANO": 0.002
>> Power Substations #84 - "LATINA NUCLEARE": 0.002
>> Power Substations #84 - "LATINA NUCLEARE": 0.002
>> Power Substations #115 - "SORGENTE": 0.001
>> Power Lines #103 - "Single": 0.003
>> Power Substations #92 - "ROSARA": 0.004
>> Power Lines #112 - "Single": 0.003
>> Power Lines #118 - "Double": 0.004
>> Power Lines #127 - "Single": 0.004
>> Power Lines #120 - "Single": 0.004
>> Power Lines #125 - "Single": 0.003
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>> Power Lines #126 - "Single": 0.003
>> Power Lines #127 - "Single": 0.003
>> Power Lines #160 - "Single": 0.001
>> Power Substations #75 - "FANO E.T.": 0.002
>> Power Substations #80 - "MONTALTO": 0.002
>> Power Substations #80 - "MONTALTO": 0.002
>> Power Substations #86 - "ROMA EST": 0.002
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #83 - "ROMA SUD": 0.002
>> Power Substations #116 - "PATERNO": 0.001
>> Power Lines #102 - "Single": 0.002
>> Power Lines #101 - "Single": 0.002
>> Power Lines #175 - "Double": 0.003
>> Power Lines #115 - "Double": 0.003
>> Power Lines #119 - "Single": 0.002
>> Power Lines #123 - "Single": 0.003
>> Power Lines #124 - "Single": 0.003
>> Power Lines #161 - "Single": 0.001
>> Power Substations #74 - "S. MARINO IN XX": 0.001
>> Power Substations #74 - "S. MARINO IN XX": 0.001
>> Power Plants #20 - "Montalto C.le": 0.001
>> Power Substations #81 - "AURELIA": 0.002
>> Power Substations #87 - "ROMA NORD": 0.001
>> Power Substations #82 - "ROMA OVEST": 0.002
>> Power Substations #82 - "ROMA OVEST": 0.002
>> Power Substations #117 - "CHIARAMONTE GULFI": 0.001
>> Power Lines #98 - "Single": 0.002
>> Power Lines #99 - "Single": 0.002
>> Power Lines #111 - "Double": 0.001
>> Power Lines #117 - "Single": 0.002
>> Power Lines #121 - "Single": 0.002
>> Power Lines #116 - "Single": 0.002
>> Power Lines #122 - "Single": 0.002
>> Power Lines #176 - "Single": 0.002
>> Power Lines #117 - "Single": 0.001
>> Power Lines #110 - "Single": 0.001
>> Power Lines #122 - "Single": 0.003
>> Power Lines #121 - "Single": 0.003
>> Power Lines #162 - "Single": 0.001
>> Power Substations #72 - "FORLI ORAZIANA": 0.001
>> Power Substations #73 - "RAVENNA CANALA": 0.001
>> Power Lines #100 - "Single": 0.002
>> Power Substations #78 - "SUVERETO": 0.001
>> Power Plants #21 - "Torrevaldaliga Nord": 0.001
>> Power Plants #22 - "Torrevaldaliga": 0.001
>> Power Substations #77 - "PIAN DELLA SPERANZA": 0.001
>> Power Lines #95 - "Single": 0.001
>> Power Lines #96 - "Single": 0.001
>> Power Lines #97 - "Single": 0.001
>> Power Lines #100 - "Single": 0.001
>> Power Lines #92 - "Single": 0.001
>> Power Lines #89 - "Double": 0.001
>> Power Lines #90 - "Single": 0.001
>> Power Lines #91 - "Single": 0.001
>> Power Lines #97 - "Single": 0.001
>> Power Lines #96 - "Single": 0.001
>> Power Lines #106 - "Single": 0.001
>> Power Lines #107 - "Single": 0.001
>> Power Lines #108 - "Single": 0.001
>> Power Lines #109 - "Single": 0.001
>> Power Substations #68 - "MARTIGNONE": 0.001
>> Power Lines #191 - "Single": 0.001
>> Power Substations #67 - "FERRARA FOCOMORTO": 0.001
>> Power Lines #88 - "Double": 0.001
>> Power Substations #66 - "PORTO TOLLE": 0.001
>> Power Substations #48 - "MARGINONE": 0.001
>> Power Substations #47 - "POGGIO A CAIANO": 0.001
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>> Power Substations #47 - "POGGIO A CAIANO": 0.001
>> Power Lines #86 - "Single": 0.001
>> Power Lines #190 - "Single": 0.001
>> Power Lines #62 - "Single": 0.001
>> Power Substations #69 - "COLUNGA": 0.001
>> Power Lines #93 - "Single": 0.001
>> Power Substations #65 - "ADRIA SUD": 0.001
>> Power Lines #181 - "Single": 0.001
>> Power Lines #72 - "Single": 0.001
>> Power Lines #70 - "Double": 0.001
>> Power Lines #71 - "Single": 0.001
>> Power Lines #105 - "Single": 0.002
>> Power Lines #104 - "Single": 0.002
>> Power Lines #72 - "Single": 0.002
>> Power Substations #53 - "DUGALE": 0.001
>> Power Substations #46 - "BARGI STAZIONE": 0.001
>> Power Substations #45 - "S. DAMASO": 0.001
>> Power Lines #87 - "Double": 0.001
>> Power Substations #50 - "ACCIAIOLO": 0.001
>> Power Lines #69 - "Single": 0.001
>> Power Substations #70 - "CALENZANO": 0.001
>> Power Substations #71 - "TAVARNUZZE": 0.001
>> Power Lines #67 - "Single": 0.001
>> Power Lines #76 - "Single": 0.001
>> Power Lines #80 - "Single": 0.001
>> Power Lines #75 - "Single": 0.001
>> Power Lines #74 - "Single": 0.001
>> Power Lines #61 - "Single": 0.001
>> Power Lines #63 - "Single": 0.001
```

System Table after *Event 2*			
Key	**Name**	**Value**	**Class**
Power Substations	*VADO L.*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Substations	*SOAZZA*	0.008	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.006	Fully Functional
Power Substations	*NA#1*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Substations	*NA#2*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#3*	0.030	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.050	Fully Functional
Power Lines	*Single*	0.038	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*BULCIAGO*	0.015	Fully Functional
Power Substations	*NA#4*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#5*	0.015	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Substations	*BAGIO*	0.002	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*NA#6*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*PIEVE A*	0.008	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Substations	*VIGNOLE B.*	0.015	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Substations	*NA#7*	0.005	Fully Functional
Power Lines	*Single*	0.009	Fully Functional
Power Substations	*TAVAZZANO*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*LA CASELLA*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*NA#8*	0.059	Fully Functional
Power Lines	*Single*	0.050	Fully Functional
Power Lines	*Single*	0.098	Fully Functional
Power Substations	*NA#9*	0.029	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*PIACENZA*	0.058	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Lines	*Single*	0.096	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*CAORSO*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Lines	*Single*	0.170	Fully Functional
Power Substations	*CREMONA*	0.058	Fully Functional
Power Lines	*Single*	0.096	Fully Functional
Power Lines	*Single*	0.049	Fully Functional
Power Substations	*NA#10*	0.029	Fully Functional
Power Substations	*NA#11*	0.003	Fully Functional
Power Lines	*Single*	0.003	Fully Functional
Power Lines	*Single*	0.005	Fully Functional
Power Substations	*GORLAGO*	0.032	Fully Functional
Power Lines	*Double*	0.034	Fully Functional
Power Substations	*PIAN CAMUNO*	0.008	Fully Functional
Power Lines	*Double*	0.014	Fully Functional

Power Substations	*S. FIORANO*	0.016	Fully Functional
Power Lines	*Double*	0.014	Fully Functional
Power Lines	*Double*	0.014	Fully Functional
Power Lines	*Single*	0.027	Fully Functional
Power Substations	*NA#12*	0.006	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Substations	*FLERO*	0.012	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Substations	*NAVE*	0.032	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Substations	*LONATO*	0.052	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*PARMA VIGHEFFIO*	0.052	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*RUBIERA*	0.101	Fully Functional
Power Lines	*Single*	0.170	Fully Functional
Power Substations	*S. DAMASO*	0.200	Partially Disabled
Power Lines	*Single*	0.333	Partially Disabled
Power Substations	*BARGI STAZIONE*	0.200	Partially Disabled
Power Lines	*Single*	0.333	Partially Disabled
Power Lines	*Single*	0.170	Fully Functional
Power Lines	*Single*	0.170	Fully Functional
Power Substations	*POGGIO A CAIANO*	0.054	Fully Functional
Power Lines	*Single*	0.088	Fully Functional
Power Lines	*Single*	0.090	Fully Functional
Power Lines	*Single*	0.045	Fully Functional
Power Lines	*Single*	0.045	Fully Functional
Power Lines	*Single*	0.047	Fully Functional
Power Substations	*MARGINONE*	0.027	Fully Functional
Power Lines	*Single*	0.045	Fully Functional
Power Lines	*Double*	0.023	Fully Functional
Power Lines	*Single*	0.023	Fully Functional
Power Substations	*LA SPEZIA*	0.029	Fully Functional
Power Lines	*Single*	0.025	Fully Functional
Power Lines	*Single*	0.059	Fully Functional
Power Substations	*ACCIAIOLO*	0.014	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Substations	*NOGAROLE ROCA*	0.101	Fully Functional
Power Lines	*Single*	0.170	Fully Functional
Power Substations	*OSTIGLIA*	0.024	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Lines	*Single*	0.040	Fully Functional
Power Substations	*DUGALE*	0.200	Partially Disabled
Power Lines	*Single*	0.170	Fully Functional
Power Lines	*Single*	0.170	Fully Functional
Power Lines	*Single*	0.333	Partially Disabled
Power Substations	*SANDRIGO*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*CORDIGNANO*	0.052	Fully Functional
Power Lines	*Single*	0.044	Fully Functional
Power Substations	*UDINE OVEST*	0.026	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Substations	*REDIPUGLIA*	0.012	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Substations	*DIVACA*	0.006	Fully Functional
Power Substations	*PLANAIS*	0.013	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Substations	*SALGAREDA*	0.010	Fully Functional
Power Lines	*Single*	0.016	Fully Functional
Power Substations	*VENEZIA NORD*	0.019	Fully Functional
Power Lines	*Double*	0.031	Fully Functional
Power Substations	*DOLO*	0.019	Fully Functional
Power Lines	*Double*	0.031	Fully Functional
Power Substations	*CAMIN*	0.101	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*RFX CNR*	0.052	Fully Functional

Power Substations	*ADRIA SUD*	0.256	Partially Disabled
Power Lines	*Double*	0.218	Partially Disabled
Power Lines	*Double*	0.426	Partially Disabled
Power Substations	*PORTO TOLLE*	0.256	Partially Disabled
Power Lines	*Single*	0.218	Partially Disabled
Power Lines	*Double*	0.426	Partially Disabled
Power Substations	*FERRARA FOCOMORTO*	0.256	Partially Disabled
Power Lines	*Single*	0.426	Partially Disabled
Power Lines	*Single*	0.218	Partially Disabled
Power Substations	*MARTIGNONE*	0.391	Partially Disabled
Power Lines	*Single*	0.651	Out of Order
Power Substations	*COLUNGA*	0.391	Partially Disabled
Power Lines	*Single*	0.651	Out of Order
Power Substations	*CALENZANO*	0.102	Fully Functional
Power Lines	*Single*	0.086	Fully Functional
Power Substations	*TAVARNUZZE*	0.053	Fully Functional
Power Substations	*FORLI ORAZIANA*	0.766	Out of Order
Power Lines	*Single*	0.427	Partially Disabled
Power Lines	*Single*	0.427	Partially Disabled
Power Lines	*Single*	0.428	Partially Disabled
Power Lines	*Single*	0.869	Out of Order
Power Substations	*RAVENNA CANALA*	0.501	Out of Order
Power Lines	*Single*	0.426	Partially Disabled
Power Lines	*Single*	0.426	Partially Disabled
Power Lines	*Single*	0.427	Partially Disabled
Power Substations	*S. MARINO IN XX*	0.257	Partially Disabled
Power Lines	*Single*	0.219	Partially Disabled
Power Lines	*Single*	0.219	Partially Disabled
Power Substations	*FANO E.T.*	0.262	Partially Disabled
Power Lines	*Single*	0.224	Partially Disabled
Power Substations	*CANDIA*	0.137	Fully Functional
Power Lines	*Single*	0.119	Fully Functional
Power Substations	*PIAN DELLA SPERANZA*	0.027	Fully Functional
Power Lines	*Single*	0.023	Fully Functional
Power Substations	*SUVERETO*	0.027	Fully Functional
Power Lines	*Double*	0.023	Fully Functional
Power Lines	*Single*	0.023	Fully Functional
Power Substations	*ROSEN*	0.007	Fully Functional
Power Lines	*Single*	0.006	Fully Functional
Power Substations	*MONTALTO*	0.022	Fully Functional
Power Lines	*Double*	0.018	Fully Functional
Power Lines	*Single*	0.033	Fully Functional
Power Lines	*Double*	0.019	Fully Functional
Power Lines	*Double*	0.018	Fully Functional
Power Substations	*AURELIA*	0.011	Fully Functional
Power Lines	*Single*	0.022	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Lines	*Single*	0.010	Fully Functional
Power Substations	*ROMA OVEST*	0.014	Fully Functional
Power Lines	*Single*	0.012	Fully Functional
Power Lines	*Single*	0.012	Fully Functional
Power Substations	*ROMA SUD*	0.018	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Substations	*LATINA NUCLEARE*	0.009	Fully Functional
Power Lines	*Single*	0.015	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Lines	*Single*	0.007	Fully Functional
Power Substations	*VALMONTONE*	0.014	Fully Functional
Power Lines	*Single*	0.017	Fully Functional
Power Lines	*Single*	0.012	Fully Functional
Power Substations	*ROMA EST*	0.014	Fully Functional
Power Lines	*Single*	0.013	Fully Functional
Power Substations	*ROMA NORD*	0.014	Fully Functional
Power Substations	*CEPRANO*	0.004	Fully Functional
Power Lines	*Single*	0.006	Fully Functional
Power Substations	*GARIGLIANO S.NE*	0.008	Fully Functional
Power Lines	*Single*	0.011	Fully Functional
Power Lines	*Single*	0.009	Fully Functional

Power Substations	*VILLAVALLE*	0.039	Fully Functional
Power Lines	*Single*	0.064	Fully Functional
Power Substations	*ROSARA*	0.072	Fully Functional
Power Lines	*Single*	0.119	Fully Functional
Power Substations	*PATRIA*	0.007	Fully Functional
Power Lines	*Single*	0.008	Fully Functional
Power Substations	*S. MARIA CAPUA V.*	0.009	Fully Functional
Power Lines	*Single*	0.016	Fully Functional
Power Substations	*S. SOFIA*	0.019	Fully Functional
Power Lines	*Single*	0.020	Fully Functional
Power Lines	*Single*	0.027	Fully Functional
Power Substations	*PRESENZANO*	0.021	Fully Functional
Power Lines	*Single*	0.018	Fully Functional
Power Lines	*Single*	0.026	Fully Functional
Power Substations	*BENEVENTO 2*	0.030	Fully Functional
Power Lines	*Single*	0.039	Fully Functional
Power Substations	*VILLANOVA*	0.075	Fully Functional
Power Lines	*Single*	0.070	Fully Functional
Power Substations	*LARINO*	0.049	Fully Functional
Power Lines	*Single*	0.054	Fully Functional
Power Substations	*FOGGIA*	0.046	Fully Functional
Power Lines	*Single*	0.038	Fully Functional
Power Lines	*Single*	0.038	Fully Functional
Power Substations	*MONTECORVINO*	0.029	Fully Functional
Power Lines	*Single*	0.047	Fully Functional
Power Substations	*ANDRIA*	0.045	Fully Functional
Power Lines	*Single*	0.061	Fully Functional
Power Lines	*Single*	0.060	Fully Functional
Power Substations	*BARI O.*	0.036	Fully Functional
Power Lines	*Single*	0.061	Fully Functional
Power Substations	*MATERA*	0.110	Fully Functional
Power Lines	*Single*	0.097	Fully Functional
Power Lines	*Single*	0.179	Fully Functional
Power Lines	*Single*	0.093	Fully Functional
Power Substations	*TARANTO NORD*	0.208	Partially Disabled
Power Lines	*Single*	0.346	Partially Disabled
Power Lines	*Single*	0.352	Partially Disabled
Power Substations	*BRINDISI*	0.062	Fully Functional
Power Substations	*S.NE BRINDISI SUD*	0.406	Partially Disabled
Power Lines	*Single*	0.676	Out of Order
Power Lines	*Single*	0.346	Partially Disabled
Power Substations	*GALATINA*	0.207	Partially Disabled
Power Lines	*Single*	0.176	Fully Functional
Power Substations	*MUSIGNANO*	0.004	Fully Functional
Power Substations	*LAINO*	0.056	Fully Functional
Power Lines	*Single*	0.048	Fully Functional
Power Substations	*SCANDALE*	0.005	Fully Functional
Power Lines	*Single*	0.009	Fully Functional
Power Lines	*Single*	0.004	Fully Functional
Power Substations	*RIZZICONI*	0.002	Fully Functional
Power Lines	*Single*	0.002	Fully Functional
Power Substations	*SORGENTE*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*PATERNO*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*CHIARAMONTE GULFI*	0.001	Fully Functional
Power Lines	*Single*	0.001	Fully Functional
Power Substations	*SERMIDE*	0.047	Fully Functional
Power Lines	*Single*	0.078	Fully Functional
Power Substations	*ROSSANO*	0.011	Fully Functional
Power Lines	*Single*	0.017	Fully Functional
Power Plants	*Vado L.*	0.003	Fully Functional
Power Plants	*Ferrera E.*	0.003	Fully Functional
Power Plants	*Tavazzano*	0.010	Fully Functional
Power Plants	*Piacenza*	0.020	Fully Functional
Power Plants	*La Spezia*	0.010	Fully Functional
Power Plants	*Ostiglia*	0.008	Fully Functional
Power Plants	*Edolo*	0.006	Fully Functional
Power Plants	*San Fiorano*	0.006	Fully Functional
Power Plants	*Bargi Centrale*	0.068	Fully Functional
Power Plants	*Rosen*	0.002	Fully Functional

Power Plants	*Monfalcone*	0.004	Fully Functional
Power Plants	*Porto Tolle*	0.087	Fully Functional
Power Plants	*Enipower Ravenna*	0.170	Fully Functional
Power Plants	*Porto Corsini*	0.170	Fully Functional
Power Plants	*Piombino Termica*	0.009	Fully Functional
Power Plants	*Montalto C.le*	0.016	Fully Functional
Power Plants	*Torrevaldaliga Nord*	0.004	Fully Functional
Power Plants	*Torrevaldaliga*	0.004	Fully Functional
Power Plants	*Brindisi Sud*	0.750	Out of Order
Power Plants	*Presenzano*	0.008	Fully Functional
Power Plants	*Rossano*	0.019	Fully Functional
Power Plants	*Roncovalgrande*	0.003	Fully Functional
Power Plants	*La Casella*	0.010	Fully Functional
Power Plants	*Sermide*	0.087	Fully Functional
Power Plants	*Dolo*	0.034	Fully Functional

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Abstract

InSIEME (*Infrastructure Security In Electricity Markets*) is a GIS-based application that aims at supporting system analysis of complex, highly interconnected systems (i) by determining the reaction of such systems to abnormal initial events that affect their operability state and (ii) by providing visual spatial data representation of the system state.

InSIEME is an application that targets business decision makers, policy makers, other stakeholders, professionals. The application is mainly designed for the evaluation of critical infrastructure systems, which usually are characterized by a large number of components from different, and not necessarily evident related, subsystems. The system under discussion in ***InSIEME*** is the Italian 360 kV Electricity Grid.

InSIEME is developed as a ***CRISA*** (*Critical Infrastructures Security Assessment Assistant*) project, which confers increased capabilities of analysis of complex system architectures, as well as of the functionality, capabilities and interconnectivity of constituent parts, based on various types of data characterizing the system. In addition, two models - of *error dispersion* and *influence flow* were developed and implemented, in order to enhance the capabilities of the project in assisting decision making processes.