RISK LEVEL ESTIMATION IN INTERDEPENDENT CRITICAL INFRASTRUCTURES USING INTELLIGENT RAO SIMULATOR[*]

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Risk level estimation is one of important issues in critical infrastructures management. Moreover, new challenges arise in critical infrastructures interdependency. To estimate risks, various models are used. The paper describes an approach based on the interdependent critical infrastructures modeling with RAO-method and Intelligent RAO simulator. Common model of three infrastructures (electrical, communication and SCADA) is presented along with demonstrative simulation run results.

Introduction

Improving the security of European critical infrastructures (CIs) has become a top priority. Significant actions are underway to assess and reduce vulnerabilities to potential threats, to plan for and practice response to emergencies and incidents and to develop new security technologies to detect security breaches.

In this respect, MICIE (www.micie.eu) project aims to improve the CI protection capability through the design and implementation of a MICIE alerting system that identifies, in real time, the level of possible threats induced on a given CI by undesired events happened in the reference CI and/or in other CIs which are interdependent with the reference CI.

The MICIE alerting system compute, in real time, the CI risk levels basing on designed CI models (taking into account indicators of the mutual interdependency among CIs). An important part of risk estimation is the estimation of consequences of adverse events in the current CIs state.

1. State of the art

Different approaches for modeling interdependent infrastructures [Mili et al., 2004], [Rinaldi et al., 2001], [Brown et al., 2004] are proposed. Among them:

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agent-based simulations [North et al., 2006], input-output analysis, traditionally used to model the interactions of sectors of the economy and to forecast the effects of changes in one part of the economy on performance in other sectors [Haimes et al., 2001], and network models. The latest use Markov and semi-Markov processes to model evolving system. Petri nets and their extensions, such as Stochastic Activity Networks, are used as higher level formalism to represent Markov and semi-Markov processes.

According to [Eusgeld et al., 2008] the well known “classical” methods of reliability and risk analysis which are widely applied to single complicated systems increase in difficulties when applied to model and analyze the behavior of highly complex systems or even large scale interconnected infrastructures. Powerful methods are needed to describe the behavior of such a system as a whole (not as a sum of single systems) while taking into account various kinds of threats and failures, different nature of CIs as well as contextual factors.

Therefore, the approaches required to capture this holistic view should be based on “system thinking” and should use an unique modeling method for all interdependent CIs. Using the RAO method of complex discrete systems modeling and the intelligent RAO simulator [Artiba et al., 1998] for interdependent CIs modeling and simulation are discussed in this paper.

2. CIs Modeling

We model the three interdependent CIs (electrical (ECI), communication (CCI) and SCADA) as well as behavior arising from the CIs interdependencies using the same and unique approach - the RAO method. The model aims to simulate various reference scenarios and to estimate the influence of CIs parameters and interdependency factors on the important indicators of quality of service (QoS) for customers, contributing to estimate risks.

2.1. Reference scenario. For the model testing and validation, the Fault Isolation and System Restoration (FISR) process involving all three CIs is selected by Israeli Electric Corporation (IEC). The process is triggered when a breaker trips due to a fault (short circuit) on a transmission line. Correspondent fragment of electrical grid is spitted into seven segments. The FISR process consists of re-energizing step by step ECI segments from the feeder downstream. Once it comes to the segment containing faulty line, the breaker trips again, thus signaling the faulty segment is found. If on the step 6 where is still no breaker trip, SCADA concludes that the faulty line is located in segment 7. Once the fault is localized, the faulty segment is isolated, the faulty line is repaired and the normal configuration of the ECI is restored by toggling line switches in their normal state.

2.2. ECI elements and structure modeling. The ECI is composed of the following elements and equipment of importance (Figure 1): substations, feeders, breakers, nodes, remote terminal units (RTUs), transmission lines, switches and customers. We model these elements with the following objects in our RAO model: an_HV_MV_substation with Telco room, a_Feeder, a_Line, a_Grid_node and a_Customer. Missing elements are modeled by means of additional state variables of other elements. So, breakers are considered a part of feeder model, RTUs are included in the greed node model and switches are a part of a transmission line model.

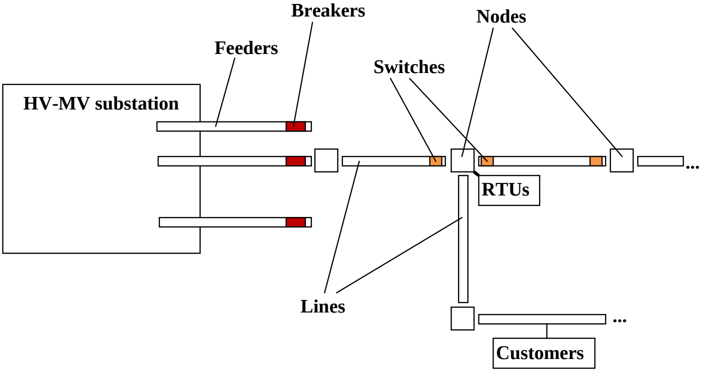

Figure 1. Elements composing the ECI model.

Electrical grid is modeled as a graph. The edges of the graph represent transmission lines. The lines are connected to nodes, in common case they have two switches, one at each extremity. Switches can be manual or remotely controlled by means of an RTU connected to the adjacent node. Nodes represent important points of the electrical grid (lines intersection, switches, grid segments,...) Along with lines, nodes allow to model the topology of the electricity distribution network at the necessary granularity level.

The ECI fragment considered by reference scenario is modeled by two substations, two feeders (named Zuriel and Hanita), 41 nodes, 44 lines, 14 RTUs, 18 switches and 13 MV customers as shown on animation screen in Figure 2. On the screen, the part of the grid normally supplied from Zuriel is colored in green, the part normally supplied from Hanita - in magenta.

At each time step, depending on current state of substations, breakers and switches, the model calculates for each transmission line, greed node and customer whether it is energized or not, along with calculation of total supplied power. Other parameters of objects are actualized, namely service state, outside and in-door temperature, UPS state and energy level for RTUs and for telecommunication rooms at substations, etc.

2.3. SCADA modeling. To model the SCADA behavior, the following object types are used - a_Fault, a_FIP_step, a_Command and a_SCADA. Objects of a_Fault type are introduced to trigger faults and to calculate some QoS indicators related to a given fault. With these objects, one can define various scenarios to evaluate with simulation.

The FISR process is modeled in six steps each consisting of a number of sub steps. In its turn, a sub step consists in opening or closing a breaker or a switch. FISR founds and isolates one of seven segments of ECI part normally provided by Zuriel feeder. During fault reparation, a segment can be temporary fed by Hanita feeder if possible. This is done by closing the switch 72/212R.

To model the FISR process, objects of type a_FIP_step are introduced. These objects store the information about all steps and sub steps of both fault localization and fault isolation processes.

The objects of a_SCADA type model SCADAs. There is one object of this type in our model representing Wizcon SCADA control center of IEC.

2.4. The CCI modeling. For CCI modeling, a a_Command type of objects is introduced. An object of this type is created by SCADA each time an action is to be performed by SCADA on a breaker or a switch while SCADA executes FISR process. For the fault localization and isolation processes, commands are generated on the basis of a_FIP_step objects. The a_Command object represents control commands sent by SCADA over CCI. These objects allow the CCI service modeling. The command travels over the CCI and depending on the current CCI state can be delivered rapidly, can be delayed due to reduced quality of service or can be not delivered at all.

The CCI itself has a complex structure including various communication equipment, such as gateways, field interface units, base stations (for radio transmission), fiber optic cables etc. Part of the equipment, important from the QoS point of view, is represented in our model by corresponding objects. The CCI model is capable to calculate depending on current state of important CCI elements if the given command can be delivered from SCADA to a given RTU and how much time it takes. The possibility of control remotely line switches and command delivery delay influences dramatically the FISR duration and thus QoS indicators. If the command cannot be delivered by CCI, a maintenance team must control the line switches manually. This takes much more time because of transport.

3. Simulation runs

3.1. Quality of Service indicators. Four major QoS indicators used by IEC are calculated by the model:

- Tn - equivalent time of interruption of energy supply;

- SAIDI - System Average Interruption Duration;
- SAIFI - System Average frequency Interruption;
- CAIDI - Customer Average Interruption Duration.

Also, the model gives detailed indicators, for example percentage of time during which a grid element is energized or de-energized, average energy level in the UPS battery of RTUs etc.

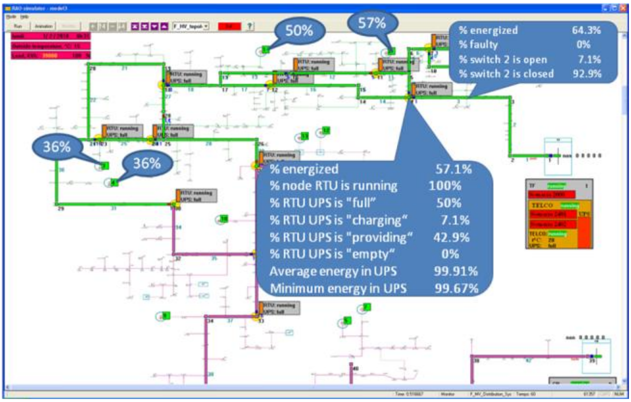

Figure 2. Reference scenario ECI fragment with QoS indicators.

3.2. Test run. A test run of the model simulates a fault on the line 27 belonging to ECI segment number 5. Faulty line reparation time is assumed for this run to be equal to 5 minutes.

Totally the process lasts for 14 time steps (in our model time step is 1 minute). Five minutes for automatic reclosing cycle and for data gathering from costumers before starting FISR process, four minutes for four additional steps of localization process and five minutes for reparation. It is supposed that the faulty segment isolation process as well as the initial ECI configuration restoration process have no duration. This is true in case of normal CCI functioning.

In these conditions, the QoS indicator Tn is equal to 7.26 min (other three indicators have sense for a long period, not for a single fault). Detailed indicators for some ECI elements are presented on **Figure 2**.

Results for transmission lines belonging to all 7 segments of reference ECI part with normally operating CCI and SCADA are given in Table 1(Tn as well as energized time percentage for customers). Table 2 gives Tn values in case of reduced service level (increased delivery times) of one of base stations of CCI.

Table 1.

Indicator	Serment number						
	1	2	3	4	5	6	7

Duration	10	11	12	13	14	52	16
Tn, min	5.28	8.19	6.9	7.09	7.26	20.87	8.58
Customer 1	54.5%	45.5%	0%	46.2%	50%	86.5%	56.3%
Customer 2	54.5%	0%	50%	53.8%	57.1%	88.5	62.5%
Customer 3	54.5%	45.5%	41.7%	38.5%	36%	9.6%	0%
Customer 4	54.5%	45.5%	41.7%	38.5%	36%	0%	37.5%

Table 2.

Indicator	Serment number						
	1	2	3	4	5	6	7
Duration	14	15	18	20	20	59	20
Tn, min	7.28	10.07	9.06	10.59	9.0	24.25	10.13

Conclusion and perspectives

The intelligent RAO simulator allows one to develop integrated model of interdependent CIs. The model takes into account CI interdependencies (in our reference scenario the interdependence is what the SCADA FISR process duration in ECI depends on command delivery time in CCI) contributing to risk level estimation. Next step is to transform our model in on-line one and to connect it to MICIE alerting system.

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