ISSN 1392 – 1215 ELECTRONICS AND ELECTRICAL ENGINEERING 2012. No. 2(118)
ELEKTRONIKA IR ELEKTROTECHNIKA

T 190 ELECTRICAL ENGINEERING
ELEKTROS INŽINERIJA

The Problem Issues of Intelligent Monitoring and Control of CIS in Latvia

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crossref http://dx.doi.org/10.5755/j01.eee.118.2.1174

Introduction

Infrastructures such as energy grids, transportation networks, telecommunications systems and water supply networks are critical to the welfare, economy and security of every European country. Protecting these critical infrastructures is one of the main challenges for governments and international organizations. In order to develop robust infrastructure protection strategies, it is important to identify and understand the global behavior and intrinsic weaknesses of these systems and their components, especially in the face of adverse events [1].

From an infrastructure interdependency perspective, power, telecommunications, banking and finance, transportation and distribution, and other infrastructures' are becoming more and more congested and are increasingly vulnerable to failures cascading through and among them. A key concern is the avoidance of widespread failure due to these cascading and interactive effects [2].

Irrespective of the nature of CIS they have the range of common characteristics:

- Strong requirement for safety critical systems;
- Complex, large-scale;
- Data-rich environments;
- Spatially distributed;
- Dynamic, time-varying,
- Similarities the underlying dynamics;
- Similarities in the impact of failures;
- Need to develop information processing methodologies to extract meaning and knowledge out of the data.

Key issues to be addressed in order to intelligent monitor and control critical infrastructures: system identification, prediction, optimization, feedback control, coordination and cooperation among CIS operators and fault processing and isolation [3].

In particular, it is necessary to model and analyze the mutual relationships that exist within an infrastructure and between infrastructures [4]. These dependencies are often implicit, hidden and poorly understood by infrastructure owners and operators as well as domain experts. Moreover, as the level of detail of the critical infrastructure modeling framework is increased, the model becomes harder to validate primarily due to the lack of quantitative data of the appropriate granularity.

The failure of one infrastructure can result in the disruption of other infrastructures, which can cause severe economic disruption and loss of life or failure of services, which impede public health and well-being [5].

It is not surprising, why in the past few years; many researchers have concentrated on the modeling and analysis of interdependent infrastructures [6]. The scientific and application interest in interdependencies research is growing, which according to Fig. 1, the percentage of papers published in the field has increased significantly since 2001 and has so far reached peak values in 2007, 2008, and 2009. In fact, 95 % of all papers in infrastructure interdependencies have been published within the last 10 years alone [7].

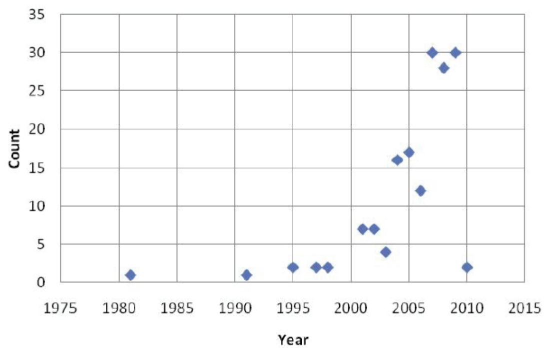

Fig. 1. Frequency of literature on interdependent infrastructures published every year [7]

The purpose of this research is to observe the scope existing practice and research agenda in the area of monitoring, control and interdependence character of critical infrastructures in Latvia, to identify constrains preventing intelligent monitoring and control CI and to justify the methods and approaches for further research of interdependencies of CI. The overview of Latvian Critical infrastructures will be provided in the next chapters.

Power supply systems

Nowadays Latvian Power Company faces a slow, but continuous increase in power consumption, so loading of power transmission lines gradually reaches the limits of its maximum transfer capacity; therefore power systems are much more sensitive to the different disturbances of operational conditions. Hence, there is the need for development of control systems by elaborating new, more complete control principles and new control tools [8].

In order to fulfill automated monitoring and control functions compact, comprehensive management scheme of the functions of distribution systems are developed at "Distribution Network" company, which is based on Geographical Information System (GIS), System Control and Data Acquisition (SCADA) and Customer Service and Billing System. Combination and interconnection of these multimodal and multifunctional systems enables such network control functions as technical information centralized storage, power distribution network proper identification and automation of control of commutation process, optimization of dispatchers functions [9].

Existing emergency automation providing the change of generation or load in the power system basically operates with a pre-determined algorithm; it cannot adapt to all possible emergency situations and is not adaptive to a process of definite emergency situation.

To resolve the problem it is proposed a method [8] for determination *of adaptive control actions,* which is based on the application of active power deficiency or surplus value calculated in real-time in normal and emergency operational conditions' control automation. Dosing method is elaborated for application of calculated active power deficiency (surplus) value in frequency and power control automation, emergency load shedding automation, and stability disturbance prevention automation.

J. Barkans [10] proposed a universal technical solution for blackout prevention in a power system, which combines the means for its optimal short-term sectioning and automatic self-restoration to normal conditions. The key element of *self-restoration is automatic synchronization.* The authors show that for this purpose it is possible to use automatic re-closing with a device for synchronism-check.

The traditional network has a radial structure with unilateral power supply, but the growing number of new power suppliers fosters the transition from unilateral to dispersed electro energy production. The task of optimization of network operation regime becomes multi criteria and more difficult due to the task of minimization of voltage deviation on average weighted and necessity to reduce lost of electro energy that derives because of splitting reactive power among suppliers. The author of the research [11] offers the methods of criterion coherence and consistency analysis.

An overall view at diagnostic and control of mechatronic systems is discussed in A.Patlins at al. [12] job. In view of the power distribution networks configuration it could be recognized as combination of mechatronic systems, therefore the concurrent *use of automated diagnostic systems using sensors* is the way how to handle machinery-maintenance and process-control operations. Sensor-fused intelligent control systems should be used to evaluate and control the manufacturing process, and to provide a link to basic design [12].

Transport infrastructure

Methods of control transport infrastructure and methods of consideration impact of different factors at reliability of transport services are researched in several works. Krumiņš [13] in his work described a form of traffic participants that can be easy implemented in computing environment, suitable for true real-time operation, and serves as a backbone for high accuracy models. The author proposed the principle of ITS realization aiming to interpret a flow on the road with tiny cyclic processes, where any is described with simple algorithms that do required calculations about: vehicles correct location coordinate; direction, speed, acceleration; location schedule and possible interaction with other traffic participants etc.

One of the prerequisites of creation ITS, is ubiquity of wireless network to ensure interchange of data between systems participants.

The issue of interrelation between two critical infrastructures is considered in the work [14]. The suggested methodology ensures a decision making procedure for electric power supply and transport logistics tasks solution in the conditions of Baltic region's liberal market by using mathematical models of software agents. A complex of nine mutually related models has been analyzed in the work for the development and investigation of software agent models of electric power supply and transport logistics, for example: functional model of feedstock supply system, functional model of a transport system for power systems of feedstock supply and others models.

In order to ensure such interrelation between electro energy suppliers, customers and transport logistics, they have to have interconnections between IT systems.

Water infrastructure

Nowadays most of WDN use Supervisory Control and Data Acquisition systems (SCADA) for control water pump stations. Nevertheless water utilities and its clients still are facing problems related to losses of tap water during extraction, distribution and consumption. Despite of the fact that between 47% and 99% of residents premises are equipped with water meters the difference between individual meter's figures and billed volume differs city by city, but anyway it could be 20% or even more. The reason of such discrepancies mainly resides from low quality of existing meters, leakages in housing water-supply, resident's fraud, manual data collection and the lack of reliable actual data.

As an example could serve Riga city water supply system, where most of water pump stations do not equipped with water flow meters. Moreover, water pumps utilization efficiency is about 30% due to low load (below 70%) and obsolete regulation way, with damper instead of variable frequency which is more effective.

A research [15] offered an automatic meters reading system for water consumption and distribution in Latvian districts (Fig. 1).

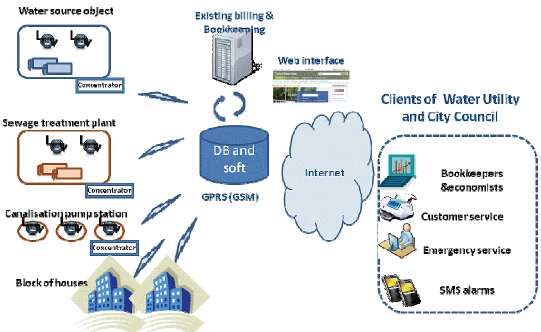

Fig. 2. Recommended automated meters reading (AMR) system for water consumption and distribution in Latvian districts

The system to be composed of water flow and pressure meters and sensors to be installed at main water preparation, distribution and consumption WDN points as well as at waste water treatment plants, sewage treatment plants, at the inputs at the offices, block of building, resident premises etc. The metering data via wire of wireless networks could be collected and processed at the central WDN server. Application of SOA approach could enable creating of services for housing services companies, business and residents.

The project implemented by Micro Dators, IT House and Ventspils University together with Talsi City Council and Talsu Water in 2009-11 could serve as an example of AMR system in practice [16]. AMR system implemented in Talsi, which applies two stage data collection and processing system (sensors transmit data to concentrators using SRD band 868 MHz; in its turn the traffic between concentrators and central server is ensured by GPRS), provides opportunities to collect data and to monitor and plot metering data on the chart observing them by hours, days, month or years.

District heating infrastructure

District heating (DH) as a part of city's CI is technology that transports energy in the form of hot water or steam from a central heat plant to customers used mainly for collective heating systems in residential quarter of blocks with dense buildings. DH supply is based on using the heat-supply pipe lines for supplying heat energy from the sources of its generation (cogeneration heat and power plants, boiler-houses and others) to buildings. DH in Latvia satisfies demands of significant part of the customers both residents and industrial clients: 28,7% [17].

In order to improve effectiveness of DH the main problem issues across district heating domain to be resolved:

- *System's balancing*. The relationship between outdoor temperature and primary supply is often assumed to be linear (colder outdoor air leads to a warmer primary supply), however, different factor, such wind, solar radiation or picks in hot water consumptions can notably impact relationship between outdoor and primary supply temperature [18].
- *Evaluation the state of equipment*. Control valves in the district heating substation often possess inappropriate dimensions, resulting in intermittent control, pressure shocks, and high return temperatures. Therefore, an error in the control valve may be unnoticed for a considerable amount of time.
- *Small leaks* in distribution pipes could remain unheeded for a long time thus causing lost of hot water. It is not easy to identify places of the leaks, because the inspection is time consuming and is not always successful.
- *Client's fraud* especially tampering of hot water meters causes lost of revenue and encourages practice, when honest clients are forced to pay the bills that include stolen amount of hot water. Usually fraudulent behavior could be noticed only by inspection at client site [15].
- *Customer services improvements*. The clients of heating companies: business and residents are eager to have data about heat consumptions and the cost not only for paying bills, but also for monitoring of their behavior in order to save expenses. Housing services providers needs to have data for rapid billing of clients in case, when they leave premises, or for analysis of possible leaks of client's fraud [15].
- *Dynamic load balancing and intersystem's cooperation* is a method used to remove heat load peaks and divide power consumption between buildings. Dynamic load balancing is based on the presence of a large thermal time constant of each building, therefore the heating system can be turned off when the price of heat is high or during peak energy hours without causing any harm to clients. Such balancing is impossible without online automatic auction system to be used to decide which buildings will be shut down or provided a limited amount of thermal power [19].

The project implemented in "Riga Heat", the utility owned by Riga City Council, and research SME "Micro Dators" in 2009-10 is an example of applying wireless sensor networks (WSN) at DH networks.

The project aimed to install automatic meters reading devices in 28 building heating substations, which had to transmit metering data to the system server once at least per hour and to be able to send data "on demand" within minute after request. The most complex objects were selected for the pilot: heating substations allocated in Riga Old city underground basements [20].

All 28 objects have been equipped with Kamstrup Multical energy meters that for communication with external equipment exploited Multical appropriate protocol at logical level and RS232, M-Bus connection at physical level. For the project purposes connection was selected through the optically isolated RS232 interface. At Fig. 3 one can see a block scheme of the technical solution for automatic metering data reading from energy meters.

Fig. 3. A block scheme of technical solution for automatic metering data reading from energy meters

Conclusions: The methods of monitoring and control reviewed above are relevant mostly to particular CI domain only. Therefore impact of interdependences of critical infrastructures should be in agenda of future research.

Moreover effective monitoring and control of CIS is not possible without actual, trustworthy metering data about the state of particular CIS, therefore application of sensor networks for data collection becomes crucial.

Observation of analysis and simulation methods

As four critical infrastructures have been described in previous chapters, the next task is to define framework for analysis method in order to research interdependences between critical infrastructures.

Dudenhoeffer et al. [21] proposed categorization of CI, which could be used for further analysis:

- Physical – direct linkage between infrastructures as from a supply/consumption/production relationship;
- Geospatial – co-location of infrastructure components within the same footprint;
- Policy – a binding of infrastructure components due to policy or high level decisions;
- Informational – a binding or reliance on information flow between infrastructures.

Many authors have used several types of mathematical modeling methods to analyze and simulate infrastructure interdependencies as part of their studies. According to [7] there are four attributes in this category: Agent Based, input-output, network or graph theory, and all other emerging models.

In *Agent Based modeling*, components in an infrastructure (such as electric transformers or generators, water distribution network elements, along with users and institutions) are represented by individual agents defined by a specific set of rules that determine the actions the agent will take in response to the actions by other agents. The synergy between agent-based modeling and semantic technologies holds promise for the resolution of challenges posed by a broad range of complex systems, in particular cyber-physical systems (CPSs), where embedded computing and communication capabilities are used to streamline and fortify the operation of a physical system [22]. In CPSs, sensors collect information about the physical operation of the system, and communicate this information in real-time to the computers and embedded systems used for intelligent control.

Inoperability input-output models (IIM) analyze how perturbations on an initially affected infrastructure propagate to other infrastructures through the exchange of input and output commodities that link them. The input-output analysis is based on Wassily Leontief's original model used for studying equilibrium conditions in the economy. Leonteif's model is based on equation (1)

$$x = Ax + c \leftrightarrow \{x_i = \sum_j a_{ij} x_j + c_j\} \forall_i . \qquad (1)$$

Interpreting this equation from an infrastructure view point, the terms of the equation become risks of inoperability, while the functional form of the equation remains the same. In the infrastructure model, x_j is the overall risk of inoperability experienced by infrastructure *j*, and is a measure of both degree of inoperability and its probability, a_{ij} is the probability of inoperability that the *j*th infrastructure contributes to the *i*th infrastructure due to their interconnectedness, and c_j is the additional risk of inoperability that is inherent in the complexity of the *j*th infrastructure. Where a_{ij}, x_j, and c_j are factors in the total risk of inoperability of infrastructure *i*, x_i.

Graph theory are approaches that use nodes and links to directly model different types of infrastructure components and their coupling topology while exploiting the visual representation of the systems for increased adoption and usability.

More generically, nodes are representative of units in the same infrastructure or across multiple infrastructures that consume and/or produce resources while links represent the means by which resources travel to and from units. In [23] nodes and links of water (*W*) and power (*P*) systems are referred to as vertices $v_w \in V_w$ or $v_p \in V_p$ and edges $e_w \in E_w$ or $e_p \in E_p$, which are contained in networks or graphs, $G_w(V_w,E_w)$ or $G_p(V_p,E_p)$ representing the water and power systems, respectively.

Interdependencies within the network system are modeled by interdependent adjacency matrices, which capture the location, direction, and strength of coupling. The effect of the interdependent interface is assessed by running multiple simulations in which vertices are removed, either randomly, targeted, or as a consequence of natural hazards.

The scale of analysis describes the level of granularity the infrastructure interdependencies should be selected. Scales could be grouped into three common levels: system of systems (SoS), network, and advanced network levels.

The highest infrastructure abstraction level (or lowest level of granularity) is the system of systems level. A system of systems contains all the critical infrastructures, including electricity, transport, etc. System of systems analysis is, therefore, the examination of interdependencies between two or more infrastructure systems, each treated as a single entity, usually without distinguishing its constitutive components [6].

The intermediate level (or medium level of granularity) is at the network level. At this level, interactions and interdependencies between the most basic infrastructure units in a system are analyzed. The lowest abstraction (with the highest level of granularity) is the advanced network level which includes elements of the network level previously mentioned [24].

Discussions and future work

For analysis infrastructure systems and their interdependencies the SoS approach through the exploitation of intelligent software agents is used in this article. The benefits of this approach as compared with the methods described above is that these systems are on the one hand much simpler to formulate and on the other hand more flexible and easily extendible [25]. Such solution allows providing alarming of highly related infrastructures in case of any defined situation within the specified territory.

An intensive application of IT tools and sensor networks for data collection and control of CI systems encourages applying agent-based technique within the concept so called system-of-systems.

A complex (Fig. 4) of eight mutually coordinated models comprising software agent's models of water supply, electric power supply and telecommunication system is developed using the approach from the work [26].

- Functional model of the water supply system - *Su;*
- Model power supply system - *Se;*
- Model of telecommunication system - *St;*
- Model of agents which interaction with the water supply system - A^u;
- Model of agents which interaction with the power supply system - A^e ;
- Model of agents which interaction with the telecommunication system - A^t ;

The information collecting functions are provided by Intelligent agents system and the control functions by Supra agents A^s functions (Fig. 4.)

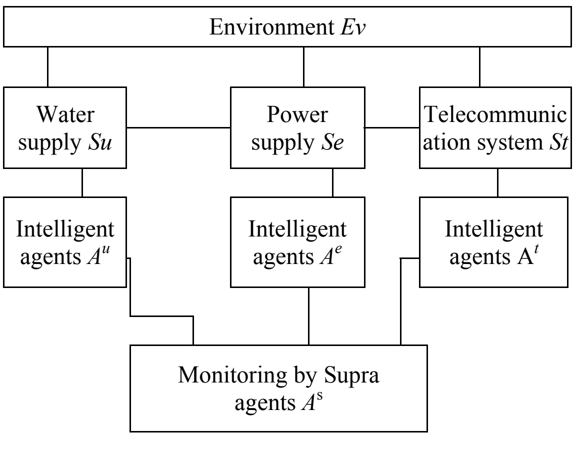

Fig. **4**. Intelligent agent's models

The software agents are denoted as: $A^{i} =\{ A^{i}_{k} , k \in K \}$. In its turn the set of the Supra software agents is denoted as $A^s=\{ A^s_i , i \in 1)\ I\}, 1=\{1, 2, ...,m_j\}$.

The optimization is by the alarm time within the predefined conditions of the systems.

Target function: $G^u=A^u(Su(t)) \times A^e (Se(t)) \times A^t (Ste(t)) \times A^s (Se(t)) \to min$.

The benefits of SoS concept application for analysis of CIS using intellectual agent-based technique is minimization of time spot needed to make CI system control actions.

Conclusion: when the most suitable method is selected for analysis of CI systems, the next step would be research of SoS algorithms and selection of the most proper tool for modeling behavior the systems comprising SoS and interdependences among them.

Conclusions

The field of critical infrastructure interdependency is a new, but rapidly growing area of study with contributions from multiple researchers in various engineering, mathematical and social science disciplines, which is indicated by growing number of research and publications.

Review of publications and projects implemented in Latvia devoted to monitoring and control of critical infrastructures demonstrates growing interest to this area of research, however pointed out the number of problem issues:

1. The methods of monitoring and control reviewed above are mostly relevant only to single critical infrastructure.
2. Critical infrastructures of one domain are considered as a set of independent autonomous systems; however in reality adjustments in one of the system could cause unexpected deviations in other ones evoking imbalance and even damage.
3. The lack of actual data about the state of CIS prevents effective monitoring and control of Latvian CIS. Moreover creation of practical, really working tools for evaluating impact of interdependencies among CIS is not possible without actual, trustworthy metering data about the state of particular CIS; therefore application of sensor networks for data collection is crucial.
4. Hence SoS approach through the exploitation of intelligent software agents is selected for analysis of CI systems, the next step would be research of SoS algorithms and selection of the most proper tool for modeling the systems behavior and interdependences among them.

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Received 2011 09 22
Accepted after revision 2011 12 13

A. Zabasta, N. Kunicina, L. Ribickis. The Problem Issues of Intelligent Monitoring and Control of CIS in Latvia // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 2(118). – P. 57–62.

The field of critical infrastructure interdependency is a new, rapidly growing area of study. Review of researches and projects implemented in Latvia pointed out the number of problem issues, such as the methods of monitoring and control are mostly relevant only to particular critical infrastructure, interdependence of CI is not yet a priority of research and the lack of actual data about the state of CIS prevents effective monitoring and control. The authors of the research justified the methods and approaches for the further research of interdependencies of CI. Ill. 4, bibl. 26 (in English; abstracts in English and Lithuanian).

A. Zabasta, N. Kunicina, L. Ribickis. Latvijos kritinių infrastruktūrų intelektualios kontrolės ir valdymo klausimai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 2(118). – P. 57–62.

Kritinių infrastruktūrų (KI) tarpusavio priklausomybė yra nauja ir sparčiai besiplečianti tyrimų sritis. Tyrimų ir projektų, atliktų Latvijoje, analizė atskleidė nemažai probleminių klausimų, tokių kaip atskirų kritinių infrastruktūrų valdymo ir kontrolės metodų taikymas. Kritinių struktūrų tarpusavio sąveikos tyrimas nelaikomas prioritetiniu. Savo ruožtu faktinių duomenų apie KI būklę nebuvimas trukdo efektyviai kontroliuoti ir valdyti. Pagrįsti tolesnių KI sistemų tarpusavio sąveikos tyrimų metodai ir būdai. Il. 4, bibl. 26 (anglų kalba; santraukos anglų ir lietuvių k.).