AGENT-BASED APPROACH FOR ELECTRICITY DISTRIBUTION SYSTEMS

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Abstract: This paper describes how semantic web and agent technologies could be used in enhancing the electricity distribution systems. The paper starts by a brief overview of functioning of electricity distribution systems. The introduced approaches aim at improving functionality of electricity distribution network systems and assisting the experts by supporting automating of routine tasks in daily operations. We focus on GUN (Global Understanding Environment) framework proposed by IOG (Industrial Ontologies Group) for intelligent services on industrial resources. The resources and infrastructure of the electricity power network are distributed. The interoperability, automation and integration features of GUN allow us to joint and arrange cooperation among heterogeneous resources in electricity network domain. The interaction and cooperation among resources in GUN platform are realized via resource agents. Based on discussions held with the domain experts we also decided to use agent approach for automated collection of additional information from heterogeneous resources and integrate this information to the operator interface (Dashboard). This context information supports expert in decision making processes.

1 INTRODUCTION

The power electricity network is a complicated structure and control of the networks' processes is a highly complicated and dynamic task. The software engineering systems that exist nowadays provide facilities for management of the power network. In order to manage the power network the operator needs to use several software systems and use appropriate system tools according to the case specific needs. By case we mean here a practical implementation of a power electricity network. As a tool to enhance the functionality of the electricity network management systems via cooperation among case specific software we are going to use the latest IT solutions, such as semantic web and agent technologies.

In the last years agent technology has been an area of active research on the wide range of application domains. Agents have been used to solve different problems (Jennings & Wooldridge, 1998). Especially agent technology was used in industrial applications, where conventional software systems and teams of human experts are assisted and supported by agents to cope with the demands of continuously changing and complex industrial environment. Agents are helping to perform the work of the power network operators and arrange cooperation and communication among different software systems.

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The overall topic of using agent technology in electricity network domain was already analyzed by different research groups (Hines et al., 2005; Kezunovic & Latisko, 2005). One of the frameworks that was proposed by Cockburn is CIDIM (Cooperating Intelligent Systems for Distribution Systems Management) (Cockburn et al., 1992). Their solution proposes to use the agent layer to arrange cooperation and sharing of information among different electricity domain expert systems. The usage of semantic web allows to structure the information and to represent it in machine understandable way. The framework proposed by IOG is to create an environment, which could unite different industrial resources. GUN environment (Kaykova et al., 2005) allows linking different resources and making them co-operate. The producers of electrical equipment have come up with there own frameworks. ABB proposed the AIP framework (Garcia et al., 2003).

The usage of semantic web and agent technology can help to enhance the functionality on such areas as fault detection and fault location. In general the fault detection and fault location functions are complicated tasks. In order to get accurate result a lot of parameters need to be taken into account. In fault detection such information as status of each node of the electricity network, network structure and description of the electricity network components should be taken into account.

The results of fault location could be more accurate, if further case related context information could be taken into account (Tomita et al., 1998). An example of context information could be physical location of the network and objects nearby (forest, lake, factory, etc.), weather conditions and other on-going activities in the area, where the network fault is to be located. The location of the power network affects to fault diagnostics. In case if electricity network has a fault and part of the network is situated in the area nearby forest and recently there was a forest fire, then there is a high probability that the fault happened in that region. So, this kind of context information provides the possibility to enhance fault detection and fault location. The supporting context information, which should be used in the fault location and fault diagnosis, is presently already available in the web, but need to be extracted from distributed sources and converted into semantically rich format.

The next chapter explains the basic principles of operation in a power network. This section provides basic information about the electricity network management system and its operation. In the next section we describe the set of technologies, which should bring the added value to existing systems. The next chapter demonstrates multi agent approach and GUN framework in some detail. At the end of this paper we make conclusions about the work and point out the issues, which need to be addressed in the future.

2 OPERATING ELECTRICITY DISTRIBUTION SYSTEMS

The common operations for the operator of distribution systems are: monitoring, control, fault analysis, restoration and maintenance. In order to access full network's status information in existing systems the operator requires to use several software applications. One of the leaders in electrical distribution field ABB company comes up with their own tools, which may be used in other domains as well. The monitoring and control operations are performed mainly using MicroSCADA Pro Control System SYS 600, whereas fault analysis and restoration occur via MicroSCADA Pro Distribution Management System DMS 600. In process of work operator may need information from additional systems. The composition of this information gives to the user a more clear picture about the current system status. The information from SYS and DMS systems can be used by external application for other purposes like energy or asset management of power network.

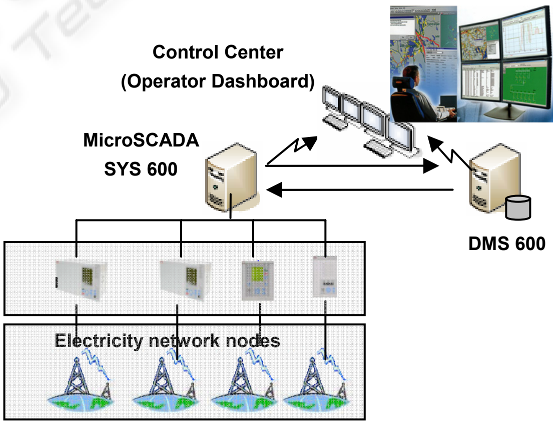

Figure 1: The system and its network operator Control Center.

The Figure 1 shows the structure of the typical power management system and network operator's interface, which includes the following technical elements: DMS 600 network diagram, Trends lines, Event list and Process displays from the SYS 600. SYS and DMS systems provide on-line information about the power network status, i.e. switching state information and network topology colored by voltage level specific colors (ABB, 2003; ABB, 2005). When a fault occurs in the power network, the situation will be indicated by these systems and the related fault analysis can be made by the operator.

Many of the faults in the power network are however such faults, which do not result into a persisting fault into the primary process. These faults are recovered via protection algorithms of Intelligent Electrical Devices (IEDs) in the following way. When a fault is detected by the IED, it performs the automatic recovery (high speed automatic reclosing) of power network according to the parameter setting values for protection and control algorithm. This means that the opened circuit breaker becomes reclosed after some hundred of milliseconds since the original fault detected by the IED. The trial will be used to stop the lightning in the spark gap. If the reclosing is not successful, the IED will try the reclosing once more, now after a few minutes (delayed automatic reclosing). If this second reclosing is not successful, the permanent fault situation is indicated in the network management systems. To analyze the occurred fault situation from the IED point of view, requires that the operator initiates the manual operation to extract the disturbance recordings from the IEDs or then they are triggered automatically by the SYS 600 file system. The analysis of disturbance recording in a graphical tool reveals the technical details of the primary process at the fault time. Otherwise the updated power network status will indicate those areas of the power network, which have been defected by the permanent fault.

Depending on what kind of equipment there appears in the primary process, the exact fault location in the power network may be calculated automatically or then additional switching operations need to be performed by the operator. The results of these additional switching operations indicate the fault location more accurately in the power network. This iteration process is called fault isolation. When fault isolation has been made it is time to apply restoration operation towards the power network. For this, different criteria for the decision making of operator apply. As the above describes there are evidently requirements to get the relevant information out of the underlying devices and different systems to assist the operator in performing the correct actions in the different circumstances. Next, these assistants of operator are briefly described including their role in the electricity distribution process. IEDs control and monitor the primitive equipment of the power network, such as circuit breakers, disconnectors, earth-switches and measurements. Their primary task is to protect the power network and perform the control operations either launched from the IED panel or from the electricity distribution management system. Additionally these devices collect the information from the power network related to the switching states, measurements, faults and power quality harmonics (Vattinen et al., 2005). These devices operate and collect information on the high accuracy level (in milliseconds). This information is then sent to the electricity distribution system, such as SYS 600, based on the filtering definitions made during the IED configuration. For the measurements it is typical that only the values exceeding the configured deadband value in device are sent to the system. However, the switch position indications and other process critical state changes (typically binary) are always sent from the device to system level together with accurate time stamps. This is because these are also meaningful, when the changes in the process are later on investigated from the system history archives.

Additionally DMS contains the accurate information on the physical power network (location of wooden poles, cable types) and customers supplied by specific feeders. This information is then utilized, when DMS participates into fault location process and provides the suggestion of restoration operations to the operator. This functionality is based on the SYS and DMS data exchange, and some information is extracted from the IEDs, too. Next, the applicability of semantic web and agent technologies will be investigated in electricity distribution systems.

3 ENHANCING THE ELECTRICITY DISTRIBUTION SYSTEMS

In the previous chapter we've discussed the practical operation of the electricity network and electricity network management systems. The present systems provide functionality to monitor and partially detect and locate the faults. To address the previously described complexity in operation, we need to exchange information and use external sources of information, too.

3.1 Software Components based Approaches

A step towards integrating systems has already previously been made by ABB company. The AIP (Aspect Integrator Platform) framework provided by ABB provides a mechanism for integration of different layers of information systems and improves interaction among them. The different hierarchical levels of the enterprise processes and systems of AIP can be seen in Figure 2 (Garcia et al., 2003).

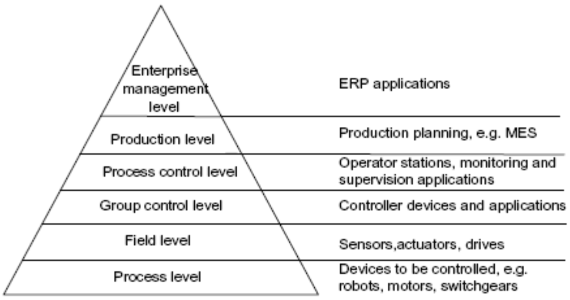

Figure 2: The overall enterprise information systems with its levels.

In our case enterprise here can be seen to be the whole power distribution system with all its automation applications. The first level contains hardware devices, which need to be controlled (e.g. feeders of the electricity network). The second level includes hardware components, which collect data or perform some actions on the process level hardware (IEDs). IEDs contain embedded sensors and actuators together with communication. The Group control level includes components (hardware and software), which provide interoperability for a set of lower level hardware components. The Process control level includes components for interaction among the set of hardware components and allows to monitor and to supervise the processes. The top levels allow us to coordinate and integrate usability of data between different technological and business processes.

The AIP provides means for information representation and navigation as well as interfaces to connect to the actual processes. The main AIP concepts that build up automation applications on this platform are Aspect Objects and Object Types. Aspects and Aspect Types are implemented as COM components with the above hierarchical structure. This architecture is however not fully applicable in electricity distribution domain, but is extensively used in the automation scenarios. At present the interoperability between different system can be provided by OPC (OLE for Process Control) technology only. The main advantage of this standard is that it already allows extraction of data produced by various system devices. The OPC uses XML/SOAP as a standard for communication, and the other necessary open, web based approaches for improving this hierarchical scheme will be addressed next.

3.2 Web Technology based Approaches

As we showed in the previous section the growing complexity of systems together with a wide array of supporting web-based information calls for new means of enabling information sharing between applications. As has been recognized by the technology approaches and solutions proposed above, various interchangeable information descriptions have to be used. XML technologies have been widely accepted by the IT and software vendors to be a unified information description platform for any software. This has today been realized in the two lower levels of Figure 2 only. In communicating this information between interchangeable components web services (with SOAP, WSDL and UDDI) provide integration means only requiring TCP/IP and HTTP/HTTPS readiness in the interacting partners.

However to sufficiently manage and coordinate the higher levels of Figure 2 we need to provide domain specific metadata together with XML based lower level description and web services. This is provided by W3C's open standards on semantic web. We only note here that architecturally we can still work like Figure 2 suggests, but by semantic web, web services and their engineering standard counterparts we improve the information exchangeability towards intelligent industrial services. On the lower level of Figure 2 semantic web proposes new knowledge interchange standards like RDF(Resource Description Framework), OWL(Ontology Web Language) and their extensions that will be used with domain specific ontologies alike IEC 61850 in improving the integration and interoperability of software service-type systems. In the GUN platform these are extended to RSCDF, RGBDF and RPIDF for generic industrial engineering processes and service descriptions. These will enable the multi agent solutions of GUN, which will be described in section 4.2. More technical details for this will be provided in next chapter and in reference (Terziyan, 2003).

To achieve this the existing distribution system components need to be extended to expose their information in a way that it becomes applicable for these new modern technologies. Already now it can be seen that this improves the overall expandability and ability to integrate overall system with other third party add-ons and evolving industry standards like IEC 61850. Hence the semantic web, web services provide new added value and potential benefits for the whole domain. In the next chapter we show how agent-based systems can be readily applied to provide the improved operating of a power distribution network.

4 AGENT-BASED APPROACH FOR ELECTRICITY DISTRIBUTION DOMAIN

4.1 Agents in Multiagent Environment

We assume that the future electricity distribution system uses the previous hierarchical architecture together with open web service interfaces and a structured and semantic description of information contained in the engineering systems as discussed above. A software agent in our case is any component that can operate independently and collaboratively with other components in the electricity distribution system presented on Figure 1. The IEDs discussed previously are not agents yet, because they only work with binary data and do not presently support the improved data standards like XML or RDF with extensions. When several agents exist in one system, they form a MAS(Multiagent system). In general MAS can contain hundreds of agents, but for our demonstration environment (Tsaruk, 2006) we restrict only to three types of agents, which allows us to enhance the fault detection and detection mechanisms. The overall goal of the agent approach is to provide automated means to enhance the electricity distribution systems. In the first stage agents should providing the user additional, domain context aware information. Later this approach can be developed further to automate some of the operator processes described in chapter 2.

The agent technology can bring added value to the existing electricity network management systems. The agent in the GUN platform is more generically a software component, which has such features as: reactivity, proactivity and communication. The reactivity is a feature which allows software components to react to the changes in the environment. The proactivity feature makes it possible to predict the future values of the environment's parameters. The agent needs to have communication ability in order to share collected experience and cooperate with other agents (Hines et al., 2005). The agents collaborate and cooperate in this multi agent environment. What these more complicated features of agents are and how agents can collaborate in MAS we will discuss more precisely in follow up papers.

4.2 GUN Platform

The Global Understanding Environment (GUN) (Kaykova et al., 2005) enables interfacing of heterogeneous resources and arranging interaction among them. With GUN the heterogeneous resources (devices, services, systems, human experts and documents) become web-accessible, proactive and cooperative. The web accessibility feature allows the resource to use functionality of other resources available in the web and provide it's own service facilities. The agent supported resources are able to analyze their state independently from other system components or to acquire such analysis from remote experts or web services. The semantic web

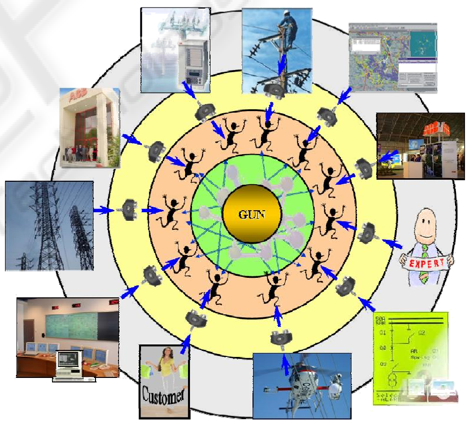

Figure 3: Layers of the GUN architecture: resource, adapter, agent.

technology allows us to realize the interoperability among heterogeneous resources. The usage of agent technologies allows us to monitor and control the status of each node in a highly distributed manner (Wong & Kalam, 1997).

In Figure 3 the agent layer of GUN environment takes care about realization of intelligent, proactive and collaborative behaviour of the resource. The adapter layer performs transformation from and to resource specific format. The proactive feature allows it to monitor and plan its behavior towards efficient functioning. The cooperative feature allows agents to collaborate and share experience with other resources. The functionality of the environment is realized using agent technology as described above.

The whole set of resources within GUN are divided into following types: service consumers, service providers and expert (in our case the operator). All these resources can be artificial (material or abstract) or natural (human or other). The service consumers will be able to proactively monitor their own state over time within the dynamic environment; share experiences and knowledge among other resources; to discover and to use appropriate service providers in order to get some additional functionality or information.

Industrial resources (e.g. devices, experts, software components, etc.) can be linked to above semantic web-based environment via adapters (or interfaces), which include (if necessary) sensors with digital output, data structuring (e.g. XML) and semantic adapter components. A specific agent is assigned to each resource and it is able to monitor semantically rich data about the state of the resource.

This generic GUN framework can be used in various domains. In SmartResource project the GUN concept was used for industrial device maintenance domain see (Terziyan, 2006) for more details. There the GUN platform is used for constant monitoring providing necessary maintenance of the industrial resources. In case if experience and knowledge of a specific agent is not enough the agent discovers other agents in the MAS environment, which represent other components and exchange information to act in the processes and collaborate on further operations that are needed. Implementation of agent technologies within GUN framework allows later highly distributed operation and further system dynamics (like mobility, self configuration and dynamic life cycle) of intelligent service components. These can act between various platforms using decentralized service discovery, FIPA communication protocols utilization, and other advanced MAS-type integration/composition of distributed services.

In software architecture the distributed and service based architectures are beginning to replace the previously popular component-based approaches of section 3.1. Overall, the semantic web technologies provide mechanisms, which allow us to realize seamless integration of different systems. This provides enormous potential for integration of different levels of enterprise processes. It provides possibility to integrate applications of monitoring and controlling network with business and planning. Instead of “reinventing the wheel” the GUN platform proposes to interconnect and interact with systems that exist nowadays. This solution should be suitable for both customers and producers of electricity network management systems. The customer gets benefits of integrating different already existing systems without big investments like ERP systems. This is extremely important since industrial processes are running 24 hours a day and it is often not possible to interrupt the process due to change or upgrade of software. The producer should have a chance to smoothly adapt software systems according to demand of the market.

4.3 Applying the Generic GUN Framework in the Electricity Distribution Domain

The previous section discussed the general concepts of GUN MAS environment. The overall setup of the GUN architecture was done in Figure 3. In the electricity distribution domain the consumer of the service is a Device with an attached GUN agent component (see Figure 3 and previous section 4.1). It is important to note that the Device means both the physical industrial hardware and its complementary agent software component residing in the GUN platform that will supplement the enhanced system functionalities that will be realized in the future. At present, the Device during its life time works and produces online data. This data need to be carefully collected and will only be used in our case if the network has some symptoms of the fault as was discussed in chapter 2. These symptoms should be recognized locally by the IED when ever possible. The request of the Expert(human operator) should be sent for detail description of Device status in the fault detection cases described in chapter 2. As data to the Expert resource Device sends the historical values of relevant Device’s parameters. The process of interaction among Device and Expert is combined by the Service component. This component is a processing unit. Based on the information about the network parameters and previous decision made by the Expert the Service via its agent is also gradually learning the inherent logic of fault detection. When the Service is fully learned it is able to perform similar, routine like tasks as the Expert did originally. The scenario of interaction among resources is presented in the Figure 4.

Using this setting GUN framework can be used in electricity distribution field to address a variety of real world cases in the advanced control and management of the power distribution networks. The experience and diagnosis about fault detection could be shared among agents. In future, the heterogeneous network hardware and software systems allow us to demonstrate the interoperability and added functionality among heterogeneous electricity power network resources and systems. The automation of the operator's routine tasks will also be later done via the previously described MAS system using agent collaboration and learning behaviors.

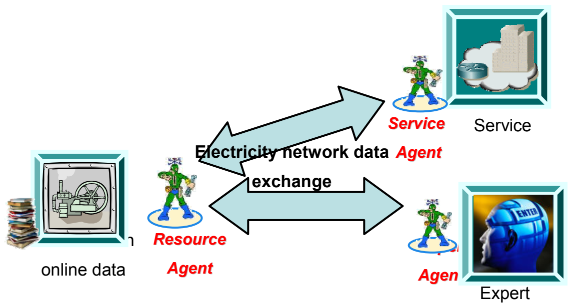

Figure 4: The scenario of interaction among resources according to GUN framework.

According to the GUN platform interaction among resources is organized via adapters and agents realize the behavioral functionality of the resource (proactive, cooperative resources' behavior). In the pilot demo environment the part of electricity network (feeder) represents a device to be monitored and maintained (against system failures and faults) as was described in Figure 4. The architecture and scenario of interaction among components combining Figures 1 and 4 can be found in Figure 5. The agent of the Expert resource interacts, collects and integrates information from other agents. One more function of the Expert agents will be automation of operator's routine work. In case if Expert agent detects that the network operator does the same operation when he gets a specified set of events, next time operator gets the same set of events the agent is going to support the user in performing this operation in a semi automated manner.

The additional case based information is provided by Context Information Providers (CIP). The CIP resources are provide context information about the network (e.g. geographical location of the network, weather conditions, activities in the area of the electricity network, etc.). The CIP resource is a subtype of Service resource. One of the examples of such service could be a shared algorithm for fault detection and location as a web service. Nowadays this functionality is provided by the DMS 600 software system.

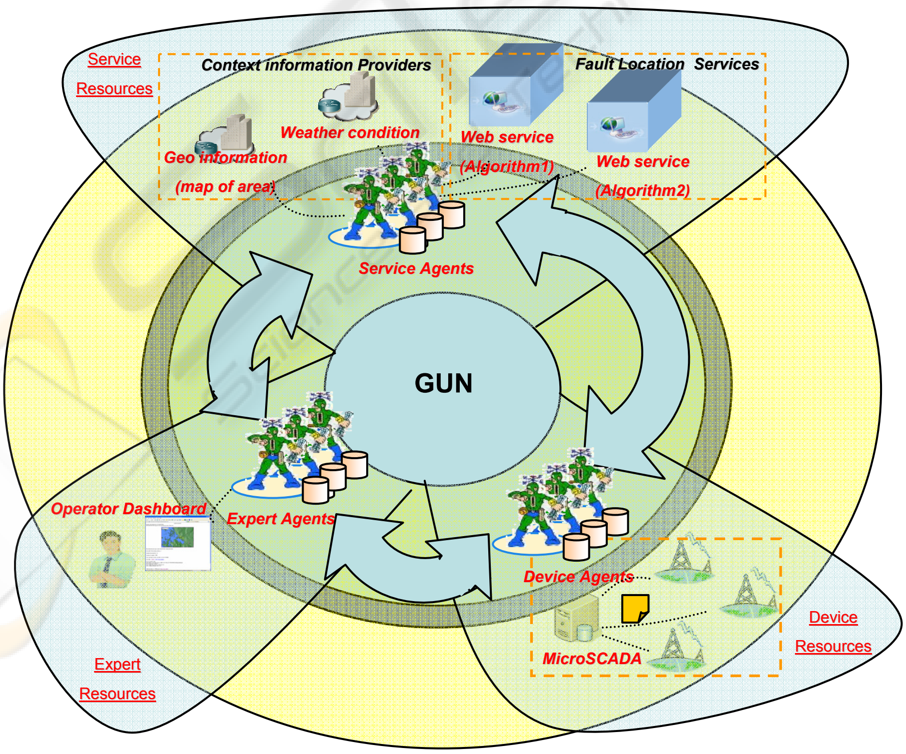

Figure 5: Architecture of multiagent electrical distribution controlling environment.

5 CONCLUSIONS

In this paper we have improved electricity power network management and control with semantic and agent approaches. We used the general GUN platform in establishing a future test bed for building highly distributed and intelligent industrial control systems for the demanding needs of the distributed energy systems. The device agent deployed on each node could enhance the local diagnosis done today by the IEDs based on the shared status of the overall electricity network(current, voltage on the power line). The information should be provided in both directions: import from external sources to electricity distribution systems and export information or functionality of electricity network systems to systems from other domains.

Thanks to agents learning capabilities new types of faults could be detected. The knowledge about new type of faults and their solution could be shared among agents because of agents' communication feature. The information and functionality could be exported to the other systems using SOA (Service Oriented Architecture). The usage of SOA allows simplifying the integration of heterogeneous software systems. The GUN platform used provides a superior platform for developing next generation engineering solutions that transform the heterogeneous industrial resources into smart components that enhance both the engineering and business needs of the distributed energy domain.

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