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C6-203

CIGRE 2008

Semantic Web technology for Grid control

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SUMMARY

Today, semantic technologies are deployed in the representation of knowledge and the development of inference engines that can incorporate reasoning capabilities to the systems.
The S-TEN technology is extending the Semantic Web technologies for applications in industrial sectors. In the field of active distribution networks several objectives are addressed: to enable an automatic re-configuration of a microgrid, to improve the integration of dispersed generation by enhanced monitoring and control processes and to facilitate the integration of demand resources into the control of the grid using market mechanisms.
The grids of the electrical network of the future will need to be highly automated, will require a reduced human intervention and will have a dynamic characteristic. Dynamic characteristic indicates the possibility of the equipment connected in the network to connect, disconnect and provide services to the central controller for managing the network. This capability will require plug and play capabilities that need the specification of standard protocols and data exchange models. But apart from

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this it also requires to provide self-describing capabilities to the devices and inference capabilities to the grid controller.
Within the EU project S-TEN, co-funded by the European Community's Sixth Framework Programme (FP6), three applications will be developed in the area of power systems, two of them being presented in this paper. One application is dedicated to microgrid control and the other one focuses on the mechanisms for demand side bidding and resources dispatch. A description of the third application committed to the monitoring and control of distributed energy resources is given in [2].

1. Microgrid control application
   The application that is going to be developed is related with the secondary control of a microgrid, but taking into account that the knowledge about the components that can be controlled makes the re-configuration of the network simpler. This advantage of adjustable operation facilitates the penetration of renewables, and makes possible an intelligent and distributed reaction to disturbances that can deviate the operation of the microgrid from its intended purpose. In the paper, the components of the microgrid will be described as well as the normal operation scenario and a set of disturbances or deviations from a normal scenario. The kind of disturbances that will be considered are failures of generation sources, the shutdown of modules in charge of scheduling the resources or the failure of generators to give the assigned power to the network. Besides, it will show the ontology used for the self-description of one of the components.

2. Demand-Side Bidding
   Demand-Side Bidding (DSB) enables the supplier to adjust his Spot Market bids. Such optimized exploitation of loads during the planning phase requires appropriate measures during the operation phase in order to guarantee a balanced system.
   Today DSB is only applied to dedicated large single consumers or groups of large consumers with similar behaviour. An appropriate Control, Metering and Communication (CMC) infrastructure is customized based on a case by case analysis.
   The S-TEN approach suggests a more generic CMC infrastructure based on Semantic Web technologies. It reduces costs and enables wider DSB participation of smaller consumers.
   S-TEN technology will support the self-description of devices and the publishing of services on the web, e.g. storage capabilities of heating and cooling devices could be published dynamically on the web. This information will be exploited for improved bids on one hand and a balanced system within a trading period on the other hand.

Additional information on the applications and on the project is provided at the project’s website: www.s-ten.eu.

KEYWORDS

Web – Semantics – Self-describing network components – Reasoning – Microgrid – Demand-Side Bidding

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1. INTRODUCTION

Evolutionary changes occurring during last years, such as the liberalisation of the electricity market, the emergence of small price competitive generating systems, the focus on renewable sources as an important generation alternative and the need to reduce the emission of green house gases to the atmosphere have changed the vision about how the electricity has to be generated, transported and consumed. The SmartGrids Consortium views the future electricity networks as highly distributed and composed of actors that generate and consume energy at any level, breaking with the traditional view of energy consumption taking place at lower voltage levels and power flowing from high voltage levels to lower consumption levels. This view identifies microgrids, demand participation and Information and Communication Technologies (ICTs) as three of the foundations for the SmartGrids of the future.
The EU project S-TEN, co-funded by the European Community's Sixth Framework Programme (FP6), contributes to this view on future electricity networks by developping two applications relevant to this field applying Semantic Web [1] technology and reasoning support. One application is dedicated to microgrid control and the other one focuses on the mechanisms for demand-side bidding and resources dispatch. This paper describes the two applications and gives an overview of the S-TEN technology implemented in both applications.

2. THE S-TEN TECHNOLOGY

The aim of the S-TEN project is to exploit the “Semantic Web” for scientific and engineering applications and to provide an automated network management in a massively distributed and continuously changing network of intelligent self-describing devices. This includes the provision of support for decision makers based upon the application of process knowledge bases to measurements, human observations and design information published on the Web.
An S-TEN network may consist of various components ranging from very simple and dumb components such as sensors to very complex systems such as electrical plants. In order to cope with such a variety of network components the architecture [2] has to be flexible and scalable and needs to support self-configuration of the network. That is, if components are added to the network or withdrawn from the network their status has to be updated. Besides, such systems need to be able to exchange information and control commands among each other in order to execute the functions implemented for them.

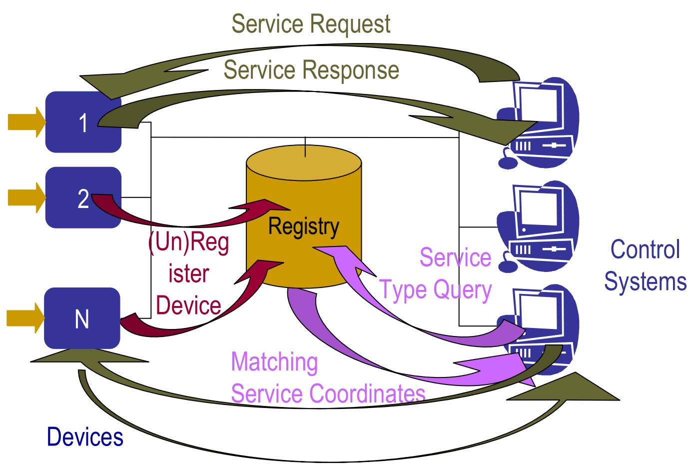

Figure 1 : Overview of the S-TEN system

Figure 1 gives an overview of the S-TEN system with its actors: Registry, Devices (device may also cover more complex network components) and External Systems. A device has a semantically interpretable self-description containing relevant information about the device such as its type, location, measured values and the parameter it controls. This self-description is uploaded into the S-TEN registry when a device registers itself in the registry. An external system can query the registry for a particular service. The registry response contains relevant information to access the services offered by the device and to link services elements with the S-TEN ontology [3]. With this information the external system can directly go to the device of interest and consume the provided services, e. g. data monitoring or command execution. A crucial aspect is that the data of a device is not held within a centralised database but that each device has its own intelligence, is able to register in the network autonomously and publishes information about its position, services and data. The current status of the network is provided by a search operation, which determines which components are part of it, how they are connected and what they are currently doing.

The S-TEN ontology describes all S-TEN system components in a computer understandable way (see Figure 4) and provides the semantics necessary for exchanging messages (see Figure 3) between the different components of the S-TEN system including those coming from external users and the ones used internally by the system. The advantage of having such an ontology is that automated reasoning can be applied to the data of the network components. Within S-TEN, rules supporting system operations are developed and applied to information available in the Web, e.g. measurements. Rules may trigger corresponding alarms and generate Best Practice Advice for the system operator based on the currently valid state of the network. Different organisations (fire brigade, police, control center operators, etc.) may have different views on the same data. River flows, for example, will be handled differently by a fire brigade and a research institute. Therefore each organisation may have their own rule-bases to generate appropriate Best Practice Advice according to the nature of the environmental hazard - i.e. the state of the environmental system.

3. SECONDARY CONTROL OF A MICROGRID

The Consortium for Electric Reliability Technology Solutions (CERTS) proposes that the potential for small DER (distributed energy resources) to meet Customers' and Utilities' needs can be captured by organizing these resources into microgrids [4]. A microgrid according to this view is an aggregation of loads and microsources operating as a single system providing both heat and power. The control flexibility of a microgrid allows it to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security. The microgrid concept relies on local power electronic control and has modular, dynamic adaptability. Dynamic adaptability means that components can be added/removed without manual re-configuration. Dynamic adaptability and plug&play capabilities are concepts familiar in the field of ICTs, but which are not so common in the electrical sector [5]. Standards' development is a key issue for facilitating plug&play functionality, nevertheless higher levels of functionality and reaction to unknown events can be achieved with the representation of understandable knowledge about the operations and services that the components of the microgrid can provide.

The approach within the project explores the use of the IEC-61850 Standard and semantics to improve the reliability of the microgrid when facing failures or unexpected situations. This added layer of semantics gives rise to new functional requirements at the component level, and at the microgrid controller level to be able to anticipate undesired situations and modify the management of the network based upon the online acquired knowledge of the

components. To demonstrate the validity of the approach, a demonstrator has been built for managing the dispatchable units of a microgrid laboratory (see Figure 2) in a way to react to sudden load increases in the system by dispatching the convenient generators and by monitoring the operation of the components to take decisions about other actions in case that some components are not able to fulfil their obligations due to failures and/or previously unknown local constraints.
The main components of the microgrid test bed set up at LABEIN premises are:

- Controllable resistive loads of 150 and 50 kW with a 30 and 20 kW step function for connecting and disconnecting load.
- A flywheel that provides continuous power protection against surges, sags during 15 seconds at nominal capacity (250 kVA)
- A battery bank of 1925 AH..
- 2 diesel generators with a maximum power output of 55 kW each and steps of 5 kW.
- A micro turbine with a maximum power output of 50 kW and steps of 5 kW.

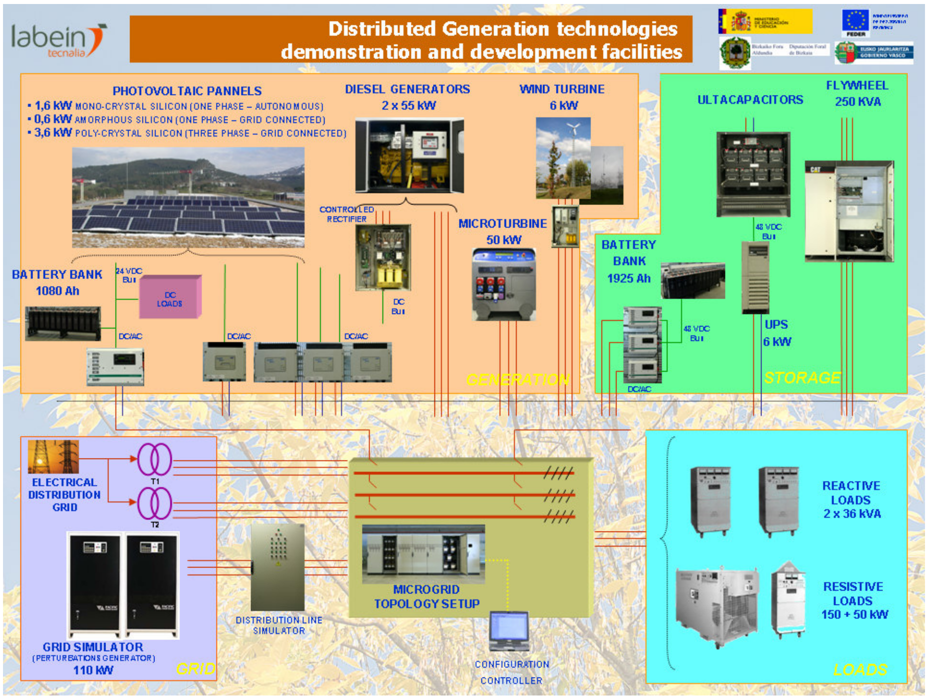

Figure 2 : Electrical Schema of the microgrid test bed

One of the experiments to be performed within the laboratory can be described according to the following scenario:

- The microgrid is isolated from the distribution network and works according to a planned schedule, in which the connected load is consuming 70 kW, one of the diesel generators is generating 35kW, the other diesel generator 20 kW and the micro turbine the remaining 15 kW.
- Suddenly a load of 20 additional kW is connected to the system and the flywheel reacts to supply the demanded capacity.
- A scheduler detects the situation and signals the need to update the dispatch of the generation units.
- The dispatching planner decides to raise the power output of the micro turbine to an additional 20 kW.

- The event generator is monitoring the operation of the system and the scheduling planned and detects that the output of the micro turbine gets stabilized at 30 kW and raises an alarm announcing that the micro turbine is not able to meet the objectives and asking for a new scheduling to achieve the equilibrium between generation and consumption.
- The dispatching planner looks at the characteristics of the available resources, the monitored constraints and decides that the best thing is to increase the output of the second diesel generator. Then, it schedules its generation to an amount of 30 kW.

```
<wsdl:message name="operaterequest-input">
   <wsdl:part name="control-data" type="impl:ControlData">
   </wsdl:part>
   <wsdl:part name="device" type="impl:Device">
   </wsdl:part>
</wsdl:message>
<wsdl:message name="operaterequest-output">
   <wsdl:part name="operaterequest-result" type="xsd:string">
   </wsdl:part>
</wsdl:message>

<wsdl:portType name="generator-control">
   <wsdl:operation name="operaterequest"
      <sawsdl:attrExtensions
      sawsdl:modelReference="http://jass.hevs.ch/s-ten/sten#Operate">
     <wsdl:input name="operaterequest-input" message="impl:operaterequest-input">
     </wsdl:input>
     <wsdl:output name="operaterequest-output" message="impl:operaterequest-output">
     </wsdl:output>
   </wsdl:operation>
</wsdl:portType>
```

Figure 3 : WSDL code excerpt for raising the active power output of the diesel generator

The information about the capabilities of the different DER resources is exposed to the external world using SAWSDL (Web Services with annotated Semantics), as can be seen in Figure 3 : for the case of a micro turbine. In this case the figure represents the service that allows raising the active power output of the generator and specifies the file where the semantics associated with the operation are described. The input and output would also be described with associated semantics, in the same way as before.

The ontology of the components of the microgrid shows the OWL [6] description of the components of the system that can be used by the event detector and the scheduler to get knowledge about the services provided by the different components of the microgrid. In Figure 4 the micro turbine is defined, as well as some of the properties that apply to it like the power raising ramp which amounts to 0.1 Watts/second.

```
<owl:Class rdf:ID="Microturbine_01">
   <rdfs:type rdf:resource="#generator" />
   <rdfs:comment xml:lang="en">Microturbine existing in the laboratory.</rdfs:comment>
  </owl:Class>

  <sten:physical_property rdf:ID="total_active_power">
   <rdfs:range rdf:resource="#active_power" />
  </sten:physical_property>
  <owl:Class rdf:ID="active_power">
   <rdfs:comment xml:lang="en">Active power.</rdfs:comment>
   <rdfs:subClassOf rdf:resource="http://jass.hevs.ch/s-ten/sten#physical_quantity_space" />
  </owl:Class>
  <owl:Class rdf:ID="active_power_per_second">
   <rdfs:comment xml:lang="en">Active power ramp.</rdfs:comment>
   <rdfs:subClassOf rdf:resource="http://jass.hevs.ch/s-ten/sten#physical_quantity_space" />
  </owl:Class>

  <sten:physical_property rdf:ID="nominal_active_power_ramp">
        <rdfs:domain rdf:resource="#Microturbine_01" />
   <rdfs:range>
        <sten:physical_quantity_space rdf:resource="#active_power_per_second">
          < sten:scale rdf:resource="#wattspersecond">
                <sten:real_number>
                   <sten:decimal
                rdf:datatype="http://www.w3.org/2001/XMLSchema#string">0.1</sten:decimal>
                </sten:real_number>
          </ sten:scale >
        </ sten:physical_quantity_space >
   </rdfs:range>
  </sten:physical_property>
```

Figure 4 : OWL ontology for the micro turbine

As it has been shown, the S-TEN technology increases the representation capability of the components of the Microgrid and in this way facilitates the implementation of an intelligent behaviour for the system.

4. DEMAND-SIDE BIDDING

Demand Side Bidding (DSB) is another emerging application in the focus of the S-TEN technology. The S-TEN technology may support the automated management of a massively distributed network of dynamic electrical loads in an open market environment.

DSB enables the supplier to produce selling bids and send them to a central market manager. Such optimized exploitation of loads during the planning phase requires appropriate measures during the operation phase in order to guarantee a balanced system. In [7] DSB is defined as the short time response of consumers to the needs of the operator of an electrical transmission network.

The S-TEN approach suggests a generic CMC (Communication, Monitoring and Control) infrastructure based on Semantic Web technologies for both the planning phase and the subsequent operation phase where dynamic loads may support the secondary control of the network. Of course the approach is applicable to dynamic generation as well.

Figure 5 illustrates the support of secondary control functionality during the operating phase by dynamic loads. The approach is based on S-TEN CMC infrastructure. A dynamic load provides its «flexibility» by publishing the feasible range of energy consumption for the remaining of the actual trading period (e.g. 1 hour) plus its requirements for the subsequent trading periods (e.g. next 24 hours). Many such dynamic loads form a self organising (S-TEN) network.

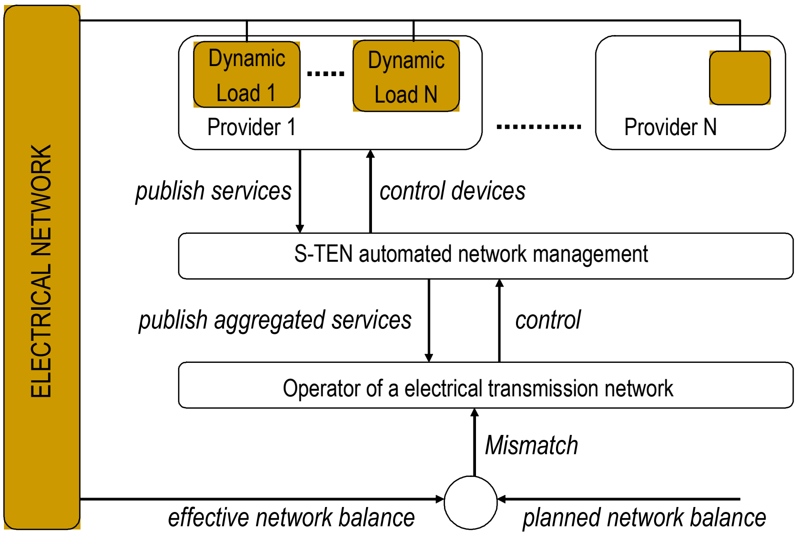

Figure 5 : Support of secondary control by dynamic loads with S-TEN CMC infrastructure

The S-TEN automated network management bundles the offers of all individual dynamic loads. This overall flexibility is offered as a service to an operator of an electrical network or to a trading unit in charge of the balancing of their schedules. They profit from the flexible energy consumption profile and may switch on and off the loads in order to obtain an optimised overall balance and taking into account the constraints given by the requirements which have been published by the loads.

Such a smart system prevents a network operator or a trading unit from paying penalty fees for deviation from schedule or calling expensive reserve generators and therefore will optimise the overall system efficiency.

On the other side the owner of the dynamic load gains financial reward, e.g. reduced energy prices, direct payments or availability payments (for the promise). Usually such «flexibility» does not belong to the core business and must not disturb the main business processes.

Based on a penalty fee of 10 €/MWh for positive or negative deviations from the schedule such an approach appears economically feasible for loads providing an annual flexibility above 100 MWh. The threshold decreases when security issues and increasing energy prices are taken into account. In addition the investment costs per device can be significantly reduced when DSB is considered as one service in the context of ubiquitous computing.

The S-TEN technology supports the self-description of devices and the publishing of services on the web, e.g. storage capabilities of heating and cooling devices could be published dynamically on the web. This information will be exploited for improved bids on one hand and a balanced system within a trading period on the other hand. In the long term it will reduce costs and enables wider DSB participation of smaller consumers.

5. CONCLUSIONS

The web gives the opportunity to make things readily available, independent of location and at a low price. Semantics are seen as the key to smarter forms of collaboration and process control. In the electricity industry, security reasons and real time requirements have delayed the uptake of this technology. Nevertheless, future power systems with significant share of power generated by DERs have to be managed in an intelligent way.

This paper presents the work that is being done for the use of technologies that have proved successful in other fields and that can provide the functionality required by the grid of the future.

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