Agent based Micro Grid Management System

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Abstract—**This paper describes the Micro Grid Management System developed using agent based technologies and its application to the effective management of generation and storage devices connected to a LV network forming a micro grid. The micro grid is defined as a set of generation, storage and load systems electrically connected and complemented by a communication system to enable control actions and follow up surveillance. The effectiveness of the proposed architecture has been tested on laboratory facilities under different micro grid configurations. The performance and scalability issues related to the agent framework have also been considered and verified.**

***Index Terms*-- Energy management, Cooperative systems, Distributed storage and generation, SCADA systems, Power generation scheduling, Power generation control.**

I. Nomenclature

Micro Grid Central Controller (MGCC), Source Controller (SC), Load Controller (LC), Demand Side Management (DSM).

II. Introduction

THIS document describes the Micro Grid Management System developed in MICROGRIDS project (Large scale integration of micro generation to low voltage grids, ENK5-CT-2002-00610) using agent technologies.

A Micro Grid could be defined as a low voltage distribution network with distributed energy sources (micro turbines, fuel cells, PV, diesel …) altogether with storage devices (flywheel, batteries …) and controllable loads. These systems could be operated either interconnected to the main grid or either isolated from it by means of a local management system with communication infrastructure allowing control actions to be taken following any given strategy and objective.

In the recent years inverter technology has increased in both, functionality and efficiency while lowering prices. Most of the micro source and micro storage equipment is connected through power electronic devices providing to some extent features such as active power output management, reactive power control, load balancing, voltage support and fast dynamic response without a significant harmonic distortion.

The implemented management system includes functionality for several micro grid objectives such as measurement data acquisition retrieval, DSM functions for load shifting, load curtailment and generation scheduling. Over this base system a secondary control of generation and storage devices has been developed in order to cope with the active power contribution of the units accordingly to self adjustments after load changes.

At the laboratory micro grid system, each micro grid connected device including generation, storage and loads has its own local controller with its defined aims. These local controllers incorporate communication protocols, based on Internet standards, acting as gateways to the proprietary device interface.

Complementary studies have also been performed in order to ensure the performance and scalability of the agent platform used.

III. Micro Grid Management System

A Micro Grid Management System has been developed in MICROGRIDS project taking advantage of agent technologies.

A. Agent platform

Although there is not a unique definition of what intelligent agents are there is a common view into describing them as a piece of software with: *Autonomy* (operate without the direct intervention, and have some kind of control over their own actions), *Proactivity* (react to external events but also have goal directed behavior) and *Social Ability* (co-operate with other agents by means of some communication language).

An agent platform is a software environment in which software agents run. It consists of the machines, operating system, agent management system and the agents.

The Agent Platform used for the development of Micro Grids Agents is JADE (Java Agent DEvelopment Framework, [2]).

Jade is compliant FIPA 2000 (Foundation of Intelligent Physical Agents, [1]). An overview of core services specified by FIPA standards is:

- Agent Management Service (AMS)
- Directory Facilitator (DF)
- Message Transport Service (MTS)

The work is being supported by the EESD program of the 5th framework of the European Commission under contract nº ENK5-CT-2002-00610

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The AMS service is in charge of maintaining a directory of AID-s (Agent IDentifier), offers white pages services and is also responsible for managing the operation of an Agent Platform (such as the creation, deletion and migration of agents to and from the platform).

The DF service provides yellow pages services to other agents. Agents may register their services with the DF and query the DF to find out what services are offered by other agents or which agents offer certain services.

The MTS is in charge of delivering messages between agents within the same Agent Platform and to agents that are running on other Agent Platforms. FIPA specifies the requirements for the MTS regarding the communications between agents in different agent platforms but does not specify the communications between agents in the same platform, this way, inter-operability between agent platforms is maintained.

B. *Management functions*

The agent based Micro Grid Management System provides the following functionality:

- SCADA like system; it is able to acquire data from the sources inside the micro grid and send parameters.
- Selling bids managing system; the generators can produce selling bids and send them to a central storage backend (based on the Spanish electricity market).
- Power schedule tracking system; the generators' local controller agents retrieve power scheduling information and send the set points to the generators.
- Secondary regulation system; it is in charge of analyzing planned generation targets and real measurements and performing suitable corrections over generation schedules.
- Load shifting system; the load shifting process consists on delaying the time period when a load is effectively connected in accordance with some optimization criteria.
- Load curtailment system; It decreases the power consumption of the loads.

The agent based management system accesses the generation scheduling procedures by means of an external conventional relational database but does not include the schedule calculation itself. This approach allows different generation schedule algorithms or strategies to be used during the research while the management system remains unmodified.

In the same way, load control functions (both shifting and curtailment) have been developed on a separate DSM (Demand Side Management) study but only the data structures and communication infrastructure have been brought to the agent software.

The further addition of generation scheduling and demand side management algorithms performed by other agent should not create any problem other than the algorithm software development itself.

C. *Software architecture*

The Micro Grids Management System is developed on top of Jade Agent Platform; Jade's container architecture allows the deployment of agents in a distributed enviroment. Under normal circunstances, each micro source, storage or load control system has a devoted local controller agent althouth the distributed architecture enables any of those agents to be executed on a phisically diferent hardware.

The management system architecture (see Fig. 1) may be depicted into:

- Relational Data Base Server: It holds real time measurements, generation schedules and demand side management data. It is accessed using standardized and platform independent communication protocols (Java Data Base Connectivity, JDBC).
- Micro Grid Agent Platform: It provides the basic infrastructure and services where the Micro Grid Central Controller (MGCC), Micro Source Controller (SC) and Load Controller (LC) agents are executed.
- Source and Load device controllers: Local device controllers have been adapted to support, not only proprietary protocols but also the XML-RPC standard.

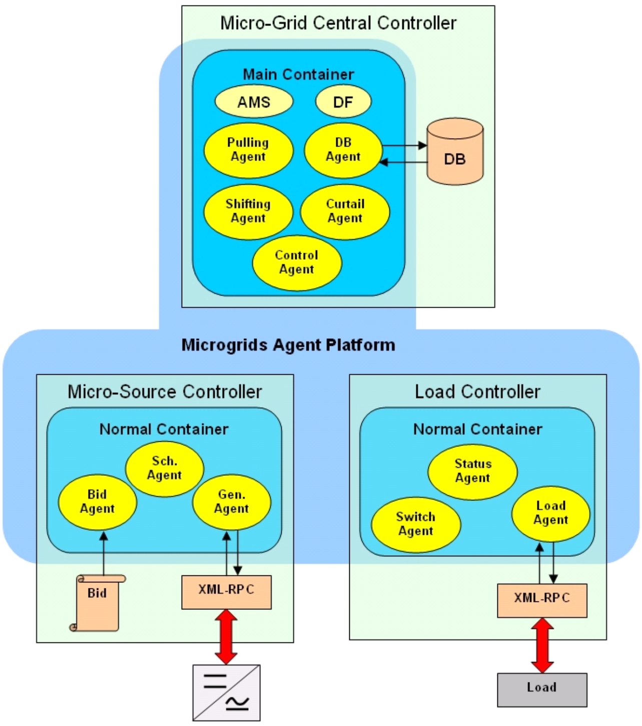

Fig. 1: Management System Architecture

1) *Micro Grid Central Controller*

The MGCC executes the Agent Platform Main Container where the basic DF and AMS are found. It includes the following agents and functions:

- Pulling Agent: It is in charge of getting source measurements (active & reactive power, frequency, voltage and status) and sell bids periodically for database storage. It is also in charge of checking for generation schedules updates at the persistent storage backend.
- Database Agent: It interfaces the relational data base and the remaining agents for measurement, bid, generation schedule and demand side management

data storing, updating and browsing.

- Control Agent: It enables the secondary regulation functions modifying generation schedules on as needed basis.
- Shifting Agent: It manages shiftable load connection requests and assigns a connection period accordingly to the DSM produced schedule.
- Curtailment Agent: It ensures the curtailment actions following DSM output.

2) Micro Source Controller

The MSC executes in an Agent Platform Container:

- Generator Agent: It is used by other agents to access generator data setting and retrieving working parameters as an interface to the XML-RPC server (see Fig. 2).
- Schedule Agent: It is in charge of the active power output tracking to apply the generation schedule.
- Bid Agent: It sends active power selling bids. The default reference implementation reads it from the file system.

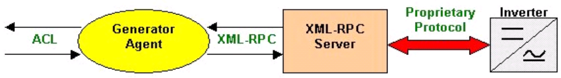

Fig. 2: Generator control architecture.

3) Load Controller

The LC runs in an Agent Platform Container providing:

- Load Agent: It registers shiftable and curtailable loads into the system and enables demand side management actions.
- Status Agent: It controls the on/off status of the load.
- Switch Agent: It is in charge of receiving and executing shifting and curtailment commands.

D. Secondary regulation

The Secondary Regulation Control System is implemented using the developed Agents Software which basic functionalities (data acquisition, scheduling, load curtail and load shifting systems) have already been tested in laboratory environment with real devices.

The implementation is done by adding a new agent (Control Agent running at the MGCC) that collaborates with the previously deployed agents in order to execute the new control functionality.

The secondary regulation control system is in charge of adjusting the current power schedules of the generators taking into account real time measured active power generation, initially planned schedules and micro source configuration settings.

The available schedules and last measurements are retrieved from the database, this data as well as configuration information (such as maximum & minimum power limits and fixed schedule flag) is processed calculating the deviation of the produced power from the planned power output. Then the found error is assigned to each micro source proportionally to each generator power change capacity.

The calculation procedure is as follows:

1) Calculate the total power deviation:

$$\Delta P_{Tot} = \sum (P_i^{sch} - P_i^{meas})$$

Where:

- i: Time step.
- P_i^{sch} is the planned power output for a generator
- P_i^{meas} is the measured active power output.

2) Calculate the total power change capacity of the generators:

$$\Delta P_{Tot}^{\max} = \sum (P_i^{\max} - P_i^{sch})$$

Where:

- $P_i^{\max}$ is the maximum power limit of the generator.
- Repeat the same for minimum power outputs.

3) For each generator the deviation to be assigned over its previous schedule is:

$$\Delta P_i^{Assig} = \frac{(P_i^{\max} - P_i^{sch})}{\Delta P_{Tot}^{\max}} \times \Delta P_{Tot}$$

The solving procedure takes into account non dispatchable sources (for instance renewable and intermittent sources), those with fixed schedules (i.e. units linked to heat demand links or contracted schemes), maximum and minimum limits, and resources availability.

The new generation schedules are produced adding the calculated power correction to the initial planned output and stored into the data base. Updated schedules are managed by other agents without any additional request from the Control Agent.

The secondary regulation control system is designed for the isolated operation of the micro grid but it could be possible to apply it to the grid connected mode by adding a dummy source controller monitoring the power exchange between the micro grid and the mains and then adding the desired import/export balance as its planned schedule. This approach would translate into the effective control of the micro grid sources into satisfying a contracted behavior of the micro grid with the distribution grid.

E. Laboratory micro grid

The experiments where performed at ISET's laboratory (DeMoTec) located in Kassel, Germany. The diagram of the used equipment is shown in Fig. 3..

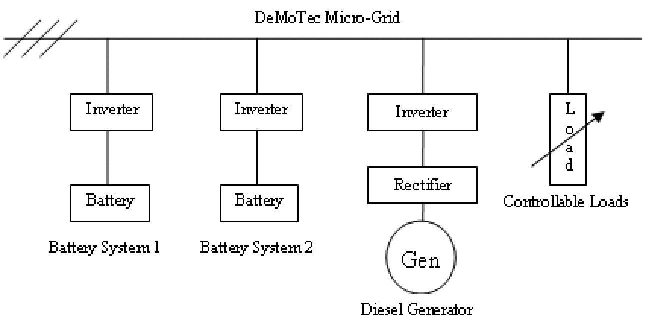

Fig. 3: Electrical Schema of the test bed.

The following devices are used:

- Variable speed diesel aggregate: It consists of a diesel motor (30kW), a synchronous generator (400V, 50 Hz, PME 20kVA) and a three-phase inverter.
- Battery system 1: The system contains three battery

bi-directional inverters (Sunny-Island; each 3.3kW) with battery bank (14 kWh).
- Battery system 2: Same as the previous one.
- Controllable loads: A set of two load banks (lamps, compressor…) remotely controlled.

The diesel aggregate and the two battery systems are controlled by means of standard PCs with Linux operating system. Each control PC is communicated with the inverter control by means of a serial link under a proprietary communication protocol and behaves as a gateway providing XML-RPC access to the data.

The XML-RPC is an Internet standard that encapsulates information under XML (eXtensible Markup Language) and uses HTTP (HyperText Transfer Protocol) as communications protocol.

The controllable load bank uses a Netsyst NetMaster device supporting the XML-RPC protocol to enable and disable individual load consumption.

F. Study Case: Single storage system

The first test consist in taking the diesel aggregate system, one battery inverter and the load bank in grid isolated mode. The battery inverter is configured as voltage source (being responsible for frequency and load following) while the diesel aggregate is working as current source (producing a given power output). Load bank is operated manually connecting and disconnecting individual consumptions at random.

This layout is aimed towards having the battery inverter reacting to consumption changes immediately adjusting its own power output to recover the generation-load balance from the energy stored. Then, the secondary regulation should detect the change in the power output of the battery inverter and assign the difference to the diesel generator.

The data acquisition system is running every 20 seconds, the secondary control system is configured to be executed every 30 seconds; the battery inverter schedule is loaded into the data base to have a fixed cero power output.

The recorded measurements are stored in the data base and exported to a spreadsheet. A summary of the obtained result is shown in Fig. 4

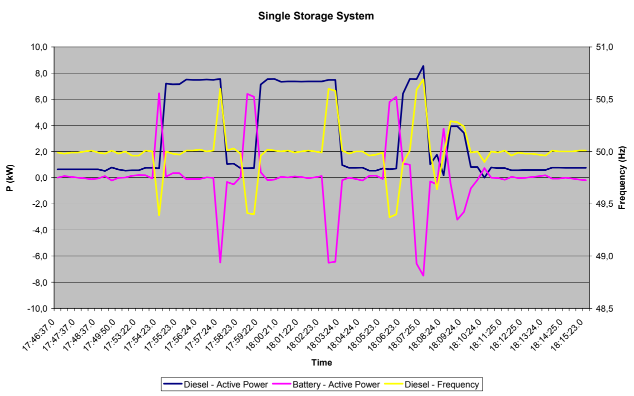

Fig. 4: Single Storage System results

As it can be seen at Fig. 4:
- When a micro grid load changes the battery inverter modifies its power output (magenta line) until the generation-consumption balance is recovered again.
- The frequency drop characteristic of the battery inverter becomes apparent noticing that the battery output and the frequency (yellow line) are mirror images one to the other: as the power output raises the frequency is reduced and opposite. Droop slope characteristic is hidden by the used graph scale effect of both measurements.
- The secondary control is able to restore the desired storage system output.
- Once the new diesel system schedule has been produced and set the unit increases its power output (blue line) following a ramp. An opposite ramp is observed at the battery inverter reducing its power output as there is an excess of power in the system.
- System frequency is recovered automatically once the battery inverter has reached its initial state.

It is worth stressing that the secondary regulation system seems to be requiring two executions to restore the storage output to the planned value. This is apparent misbehavior is due to the secondary regulation coming into operation before the equilibrium has been obtained after the load step (notice that measured battery outputs are systematically lower than the diesel final active power output).

This fact implies that it is possible to reduce the secondary regulation timing in order to lower the use of the battery inverter storage or increase it to allow the full equilibrium before any action is taken. Both approaches would affect the number of cyclic operations of the battery and its long term live.

IV. References

[1] FIPA, http://www.fipa.org/
[2] JADE, http://jade.tilab.com/

V. Biographies

José Oyarzabal was born in Bilbao, Spain, on 1967. He received the M.Sc. degree in Industrial Electrical Engineering, from the University of the Basque Country, Bilbao, in 1992. Since 1994 he has been working in Labein, involved in several applications related to power transmission and distribution control systems as well as protective relays. His special field of interest includes the application of information and communication technologies standards to energy management systems. He is a member of the association of industrial engineers of Bilbao.

Joseba Jimeno was born in Bilbao, Spain, on November 26, 1975. B. Sc. in Electrical Engineering (2001) from the School of Engineering of the University of the Basque Country in Bilbao. Master in Networks, Telematic Services and Internet (2001) from the School of Engineering of the University of the Basque Country in Bilbao. His employment experience included Euskaltel since May 2001 to November

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