21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

D2-305

CIGRE 2016

MAGIC – A Microgrid AGent Intelligent Control Device

N. HATZIARGYRIOU[1], A. DIMEAS[1], I. VLACHOS[1], I. KOUVELIOTIS-LYSIKATOS[1], D. KOUKOULA[1], S. MAKRYNIKAS[2], M. KOUVELETSOU[2]
[1]National Technical University of Athens
[2]Hellenic Electricity Distribution Network Operator S.A.
Greece

SUMMARY

The transition of the traditional power network to the Smart grid requires the application of computer intelligence and advanced communication infrastructures in order to make sure the efficient and robust coordination of the various grid components. Subsequently, the use of Intelligent Electronic Devices (IEDs) communicating with one another, facilitates the accomplishment of tasks formerly done manually. The Microgrid AGent Intelligent Control (MAGIC) system provides an exciting real-world example specifically designed for such applications.
The controller is intended to be easily installed in households offering a range of possibilities for controlling the appliances but also for the communication with the various grid entities. Furthermore, is able to monitor the total electrical consumption of the house and of each appliance. In the case that Distributed Generation (DGs) units are installed in the premises of the household, the controller efficiently accommodates their optimal management according to the goals set by the user.
The MAGIC system has been successfully installed and deployed in the Meltemi summer camp. Meltemi is a seaside camping in Rafina near the city of Athens, consisting of 170 cottages used mostly for summer holidays. Due to the small size of each cottage, its electrical consumption is lower than an ordinary house in Greece. Moreover, the ecological awareness of its inhabitants and the electrical structure (all houses connected to the same MV/LV transformer) of the settlement make it ideal for use as a test bed, for functions related to emergency and critical grid situations. A number of Distributed Generators (DGs) are installed, including a 40kVA diesel generator, 4.5 kW photovoltaic panels and small residential wind turbines that can partially support the Meltemi camping load in islanded Microgrid operation.

Acknowledgments: This work was supported by the DREAM Collaborative Project funded by the European Commission under FP7 grant agreement 609359.

KEYWORDS

Demand Response, Smart Grids, Distributed Generation, Multi-Agent System

nh@power.ece.ntua.gr

INTRODUCTION

The transition of the traditional power network to the Smart grid requires the application of computer intelligence and advanced communication infrastructures in order to make sure the efficient and robust coordination of the various grid components. Subsequently, the use of Intelligent Electronic Devices (IEDs) communicating with one another, facilitates the accomplishment of tasks formerly done manually. The Microgrid AGent Intelligent Control (MAGIC) system provides an exciting real-world example specifically designed for such applications.

The controller is intended to be easily installed in households offering a range of possibilities for controlling the appliances but also for the communication with the various grid entities. Furthermore, is able to monitor the total electrical consumption of the house and of each appliance. In the case that Distributed Generation (DGs) units are installed in the premises of the household, the controller efficiently accommodates their optimal management according to the goals set by the user.

In the context of the smart grid, the responsibility of Distribution System Operators (DSOs) to provide reliable energy to end-users, can be translated into the aggregation of possible available local flexibilities; the usage of which under certain circumstances can be seen as ancillary services to the upstream power grid. The controller accommodates the end-users flexibility mediating for the support of the grid's real-time operation (e.g. congestion management and voltage control). The enhanced communication and coordination capabilities of the controller offer a variety of operational modes. For example, it can be used for the decentralized control of the grid since it is equipped with sophisticated distributed algorithms providing strategies that drive the grid to an optimized technical and economical operation using local communication interactions (i.e. peer-to-peer communication structure). The controller supports the FIPA compliant, Java based, JADE platform and implements a multi-agent system (MAS) that enables the coordination of the negotiating entities along with the calculation of the operational strategies.

On the hardware side, the MAGIC system follows a modular architecture. The heart of the system is based on a powerful micro processing running Linux that is responsible for all communicational and functional capabilities of the controller. The unit also includes a smart metering module, as well as wired and wireless communication interfaces. Modbus TCP/IP is also supported for remote control and data acquisition, thus offering industry standard communication capabilities. Moreover, the controller is expandable with several serial and a USB port and has the ability not only to control but also to monitor several appliances. It is designed for both indoor and outdoor installation and is equipped with a display in order to present messages directly to the consumer. In addition, the consumers are informed online about the status of the system, their consumption and energy costs. This information is also available through a web portal. This information is critical, since consumers accept them easily when they visualize the potential for energy savings cost benefits.

The MAGIC system has been successfully installed and deployed in the Meltemi summer camp. Meltemi is a seaside camping in Rafina near the city of Athens, consisting of 170 cottages used mostly for summer holidays. Due to the small size of each cottage, its electrical consumption is lower than an ordinary house in Greece. Moreover, the ecological awareness of its inhabitants and the electrical structure (all houses connected to the same MV/LV transformer) of the settlement make it ideal for use as a test bed, for functions related to emergency and critical grid situations. A number of Distributed Generators (DGs) are installed, including a 40kVA diesel generator, 4.5 kW photovoltaic panels and small residential wind turbines that can partially support the Meltemi camping load in islanded Microgrid operation.

SYSTEM ARCHITECTURE

Hardware

The heart of the MAGIC controller is the a fully customizable Single Board PC (SBPC), the Alix2d2 from PC Engines (illustrated in Figure 1 below). The specification and technical characteristics of the SBC are listed below.

- CPU: 500 MHz AMD Geode LX800
- DRAM: 256 MB DDR DRAM
- Storage: CompactFlash socket, 44 pin IDE header
- Power: DC jack or passive POE, min. 7V to max. 20V
- Expansion: 2 miniPCI slots, LPC bus
- Connectivity: 2 Ethernet channels (Via VT6105M 10/100)
- I/O: DB9 serial port, dual USB port
- Board size: 6 x 6" (152.4 x 152.4 mm)

Figure 1. The Alix2d2 router board from PC Engines.

The SBPC is also equipped with one wireless card supporting the IEEE802.11a/b/g/ standard, which provides the required connectivity with the Wi-Fi router that is installed in the customers' premises.

Two other components that are included in the MAGIC controller are the energy metering module and the Microcontroller Unit (MCU). The energy metering module carries out the task of continuously monitoring the power line of the consumer and gather the required information, such as voltage and current measurements, active and reactive power readings, energy consumption etc. that are subsequently fed into the "DREAM Framework" that will be presented later in this paper. The coordination and communication between the energy meter module and the SBPC is handled by the MCU, that consists of an Atmel ATmega2560 microcontroller, equipped with necessary digital and analog inputs and outputs, as well as with the relays and circuit breakers required for controlling and interfacing with the customer's loads. The communication between the various functional blocks of the MAGIC controller is based on the TCP/IP and Modbus protocols and an overview of this architecture is depicted in Figure 2.

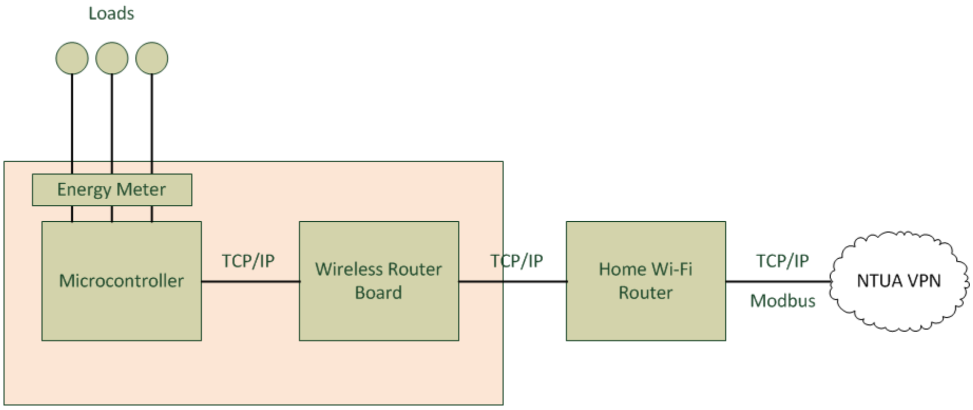

Figure 2. MAGIC communication architecture.

Software

The MAGIC controller firmware is based on the OpenWrt OS. OpenWrt is described as a Linux distribution for embedded devices. Instead of trying to create a single, static firmware, OpenWrt provides a fully writable filesystem with package management. The user interface for the MAGIC is implemented through a web interface, where the experienced user can have access to all components of the controller and can carry out any low- or high-level customization and configuration.

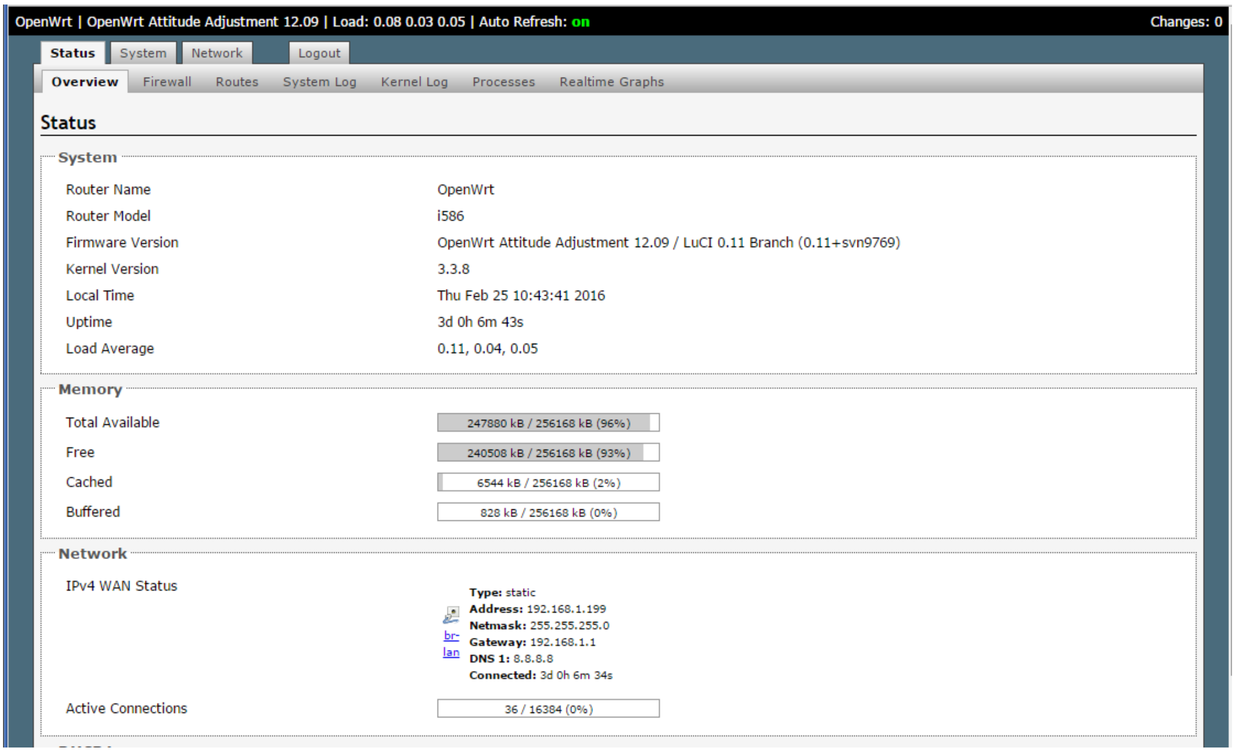

Figure 3. The MAGIC web user interface.

THE MAGIC SYSTEM AS A SMART GRID COMPONENT

The controller accommodates the end-users' flexibility mediating for the support of the grid's real-time operation (e.g. congestion management and voltage control). The flexibility essentially constitutes the possibility and willingness of the grid users to alter their consumption (or production in the case of a DG owner), in order to participate in the optimization of the grid operation. It presents enhanced communication and coordination capabilities and a variety of operational modes. The controller can operate as a home gateway for the DSO, forming a centralized coordination scheme while the consumer is always in the loop, or in a distributed fashion. In the second case, the grid operation moves towards a more self-organized structure, where every household actively participates in the global optimization of the grid operation and simultaneously takes into account the grid constraints as they are posed by the operator. Those distributed techniques drive the grid to an optimized technical and economical operation using local only communication interactions (i.e. peer-to-peer communication structure). The motivation for such a scope for the grid operation has numerous aspects. In the first place, many advantages accrue from a distributed architecture compared to a centralized one, such as increased robustness (avoidance of the single point-of-failure), privacy of the end-user, reduced computation and communication cost but most importantly scalability ("Plug-and-Play" capability). Furthermore, additional attention is drawn from the ever-growing prospect of utilizing technologies such as the Power Line Communication (PLC) that seem particularly suitable, since they enable neighbouring grid nodes (which are electrically connected) to exchange information using the pre-existent grid infrastructure.

The MAGIC system is designed for Smart Grid applications and for this reason is inspired from an insight for the future distribution grid. As presented in Figure 4, the DSO actor and the prosumer actor are defined in order to model their interaction even through a high-level use case description. Also, the role of an aggregator that maintains a portfolio of customers and trades energy and ancillary services seems interesting.

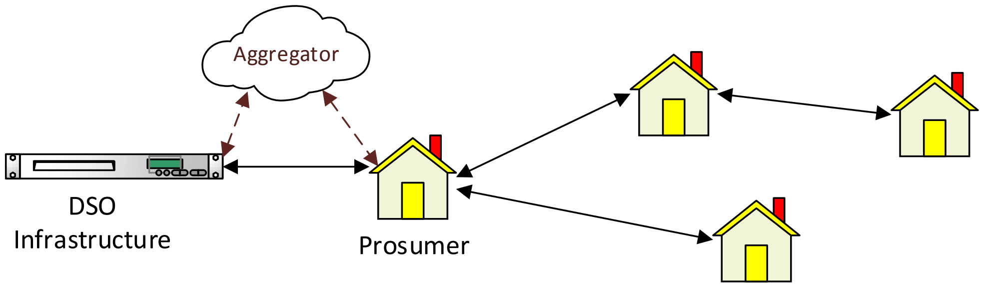

Figure 4. Peer-to-peer network of the households equipped with the MAGIC controller and the DSO front-end IED. A simplified demonstration of a LV feeder. Black arrows represent communication links which coincide with the electrical topology in this case. The aggregator groups the prosumers for grid support functionalities.

REAL-TIME DISTRIBUTION GRID OPERATION SUPPORT

Next, a presentation is given, from a high-level perspective, of the algorithms integrated in the MAGIC system, related to supporting the real-time operation of the distribution grid.

For the case that a voltage problem is detected (either by the DSO IED or a Load Controller) a negotiation is triggered between nearby households by the node that first detected the deviation. Due to the nature of the distributed architecture, the node that triggers the negotiation is indifferent to the final result. The negotiation is based on a distributed algorithm that coordinates the participants using peer-to-peer communication and after a bounded time interval provides a final decision. At this point each entity becomes aware of the action he should perform in order for the voltage problem to be resolved. The DSO is also aware about the actions to be performed, since it is possible to participate in the negotiation with monitoring role. This way, he has always the possibility to approve the actions proposed by the algorithm, judging from the state that his network will be driven to, and without knowing the specific action of each single node. The role of the aggregator is to group customers and trade the provision of customer's flexibility. If the problem persists or the DSO needs to take specific actions due to a critical situation in the grid, conventional control actions are possible to be taken by the DSO such as direct load shedding.

The congestions/overloading of the components of the distribution grid are handled based on the same principle. The actively participating nodes monitor the state of the grid by calculating locally several physical quantities, e.g. active power. The nodes also calculate their share/contribution to a potential overload by comparing internal values with the general state estimated before. The problem is being solved locally taking into account the constraints of the grid and the constraints of loads/DG. The DSO upon detection of overload/congestion informs the related aggregators or prosumers to take action. This action is calculated by the distributed algorithm and evaluated -as discussed previously- by the DSO. If the problem persists or the situation is very critical, conventional control actions can be taken by the DSO.

SOFTWARE ARCHITECTURE

In Figure 5, the software architecture of the MAGIC system is presented. The controller supports the FIPA compliant, Java based, JADE platform [1] and the software package "DREAM framework" [2]. The core of the system is the MAS that implements the functionalities described in the previous chapter and other coordination schemes.

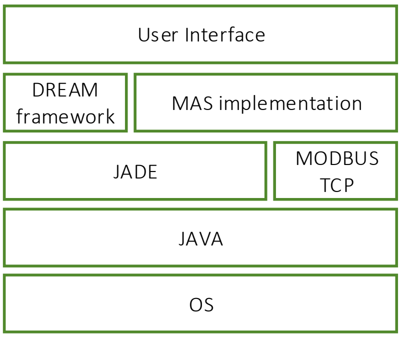

Figure 5. Software packages of the Load Controller.

The distributed algorithms integrated in the MAGIC system are presented in detail in [3] and [4] and they are specially adapted in order to be able to cope with congestion management and voltage control in LV distribution grids. The load controller monitors and controls the consumption of the household appliances and communicates with each other (on the application layer) utilizing the JADE and DREAM framework services. Furthermore, it decides internally and based on the priorities set by the customer, which appliances should be turned on or off in order to maintain the total consumption of the household in the level that is calculated by each negotiation.

DEMONSTRATION SCENARIO

In order to prove the applicability and efficiency of the controller various demonstration scenarios where planned and are being tested in the Meltemi Smart Grid test site. In the specific scenario 10 households under the same feeder, equipped with the load controller, are picked to participate in the demonstration. Screenshots of the JADE application as well as the peer-to-peer message exchange is given in Figure 6.

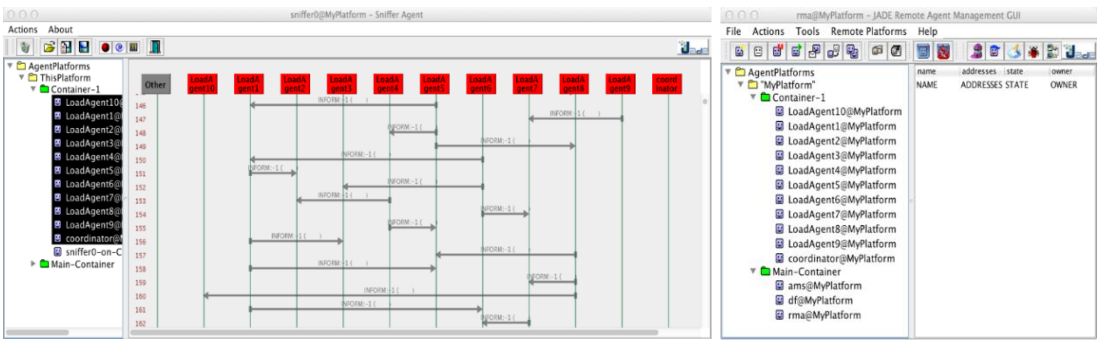
Figure 6. Screenshots of the JADE application.

The scenario under study, aims at altering the consumption of the households in a timeframe of 6 hours with the negotiations occurring within a time interval of one hour. For simplicity reasons, the initial trigger is given each time by the DSO interface that sets the maximum total consumption of the feeder. The negotiation reaches the optimal solution in terms of maximizing the utility functions that derive from the preferences of the consumers.

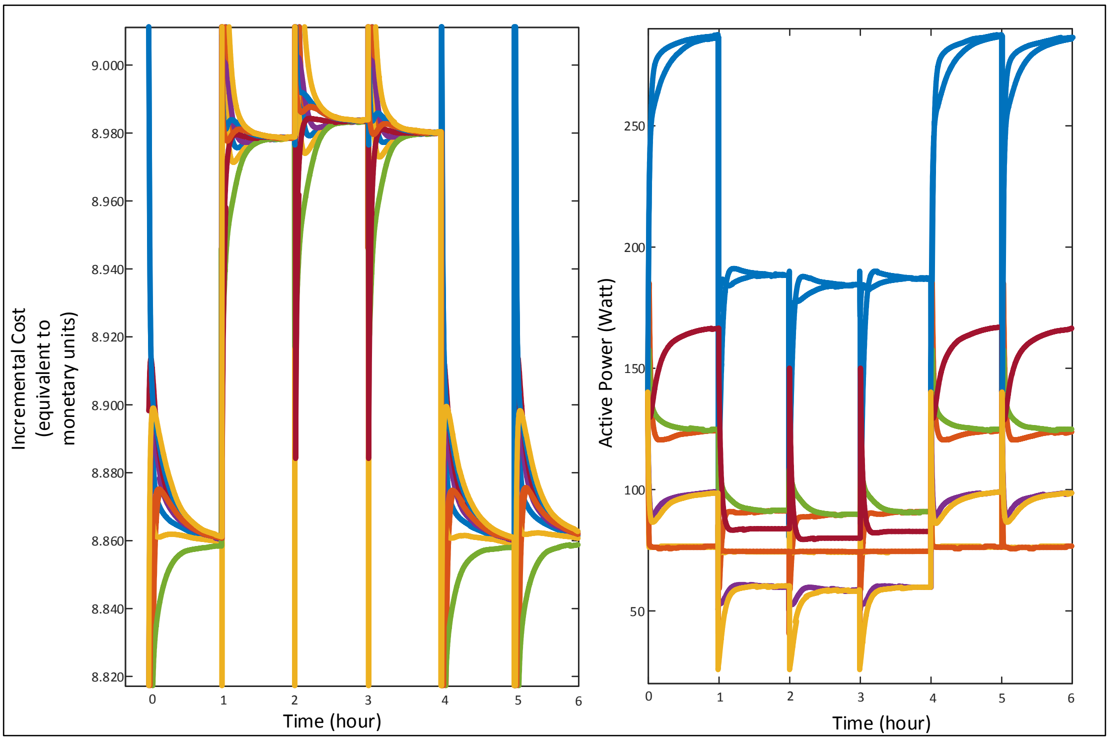

Figure 7. Results of the test scenario with 10 households participating in the demonstration.

In Figure 7, the left diagram presents the internal synchronization variable of the negotiations while the right the total consumption calculated per household for the next hour.

ACKNOWLEDGEMENTS

This work was supported by the DREAM Collaborative Project funded by the European Commission under FP7 grant agreement 609359.

BIBLIOGRAPHY

[1] Bellifemine, Fabio, Agostino Poggi, and Giovanni Rimassa. "JADE–A FIPA-compliant agent framework." Proceedings of PAAM. Vol. 99. No. 97-108. 1999.

[2] Kamphuis, R.; Wijbenga, J.P.; van der Veen, J.S.; Macdougall, P.; Faeth, M., "DREAM: An ICT architecture framework for heterarchical coordination in power systems," in PowerTech, 2015 IEEE Eindhoven , vol., no., pp.1-4, June 29 2015-July 2 2015

[3] Kouveliotis-Lysikatos, I.; Hatziargyriou, N., "Decentralized economic dispatch of distributed generators based on population dynamics," in Intelligent System Application to Power Systems (ISAP), 2015 18th International Conference on , vol., no., pp.1-6, 11-16 Sept. 2015

[4] Koukoula, D.I.; Hatziargyriou, N.D., "Convergence acceleration of gossip protocols applied for decentralized distribution grid management," in PowerTech, 2015 IEEE Eindhoven , vol., no., pp.1-6, June 29 2015-July 2 2015