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Intelligent load management in local and wholesale demand response markets
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Laboratorial Microgrid Emulation Based on Distributed Control Architecture

Omid Abrishambaf, Pedro Faria, Zita Vale

GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering - Polytechnic of Porto, Porto, Portugal

Abstract

Power systems worldwide are complex and challenging environments. The increasing necessity for an adequate integration of renewable energy sources is resulting in a rising complexity in power systems operation. Multi-agent based simulation platforms have proven to be a good option to study the several issues related to these systems. This paper presents an emulation of a laboratorial microgrid based on distributed control architecture. The proposed model contains real consumption and generation resources, including consumer load, photovoltaic, and wind turbine emulator. Also, a web-based graphical interface has been designed in order to monitor and control the microgrid. In this system, there are four main agents, which are connected by means of a communication network capable of sharing and exchanging information to achieve the overall system's goal. The performance of the distributed architecture is demonstrated in order to observe the applicability of the agents and their collaboration abilities. The results of the paper show in practice that how a distributed control based microgrid manages its resources, and how it reacts if there is a fault or no activity on them.

Keywords: demand response, load shiting, home energy management system, smart grid

1. Introduction

Nowadays, according to the daily increment of electricity demand, the utilization of Distributed Renewable Energy Resources (DRER) is an opportunity to assist the power distribution network [1]. DRER, such as Photovoltaic (PV) system and wind turbine, are moving the current power grid toward the elimination of centralized power plants [2]. DRER have several benefits for the power grid, namely, they decrease the greenhouse gas emissions, relieves the grid congestion, and decrease the costs related to the electricity production [3]. However, the integration of DRER into the current power grid, leads to have network management and stability problems [4]. The ability of dividing the whole power distribution network into the several subsets, has widely investigated by the research societies to overcome these drawbacks. Therefore, they have come up with a new concept called "microgrid" [5]. Microgrid is referred to a single controllable entity, which operates with respect to the main grid, and consists of several distributed energy resources and local loads [6]. The microgrid is considered as one of the interesting context of the future smart grids, since it can manage the amount of consumption and generation of the local resources [7]. The microgrids can operate in two manners [8]:

- Grid-connected: The microgrid has been connected to the main power grid, which means the local loads can be supplied from the main grid in the case of low generation in local energy resources. In

the case of high energy production, the energy resources can inject the excess of produced power to the grid;
- Islanded-mode: There is no energy transaction between the microgrid and the main grid. The local resources are responsible for feeding the local loads.

Concerning the management of microgrid, two methods can be proposed. The centralized control where a powerful central controller unit and communication between this unit and each single component of the microgrid is required. This is an expensive method and in the case of failure in a component, all of the microgrid may be affected [9]. The second scheme is the distributed control, where the decisions take place in the local controllers based-on the real-time data acquired by the other components [10]. The distributed control method is preferred when comparing with centralized control, since, if microgrid is operating in islanded-mode and a fault occurs, the faulty agent can be easily eliminated and microgrid is able to continue its operation [11]. Additionally, distributed control is more cost-effective [12], tolerant, adaptive, and flexible for microgrid management [13]. Before the massive implementation of business model related to the distributed control for microgrid, the need of laboratorial simulations and survey the behaviour of each components is evident. Intelligent methods such as multi-agent simulations are satisfying for conveying the complex models with dynamic interactions [14].

This paper proposes an implemented laboratorial model of a microgrid based-on distributed control architecture. This model employs several real hardware resources, such as a medium consumer load, a PV arrays, and a wind turbine emulator, that each of which are interconnected to each other as well as the power grid through the four transmission lines. The presented model employs four Programmable Logic Controller (PLC) in order to implement the multi-agent modelling and distributed control. In this microgrid model, all of the agents are conveying information in real-time, and all of controlling decisions are taken place locally. Furthermore, a web-based graphical interface has been designed for monitoring and controlling the microgrid. In this paper it is attempted to survey the controlling decisions of each agent and investigate the behaviour of the microgrid, if there is a fault or no activity (consumption or generation) in the resources. At the end, a case study will be demonstrated in order to test and validate the system capabilities.

The rest of paper is structured as follows: the model description including the implementation, operation, and proposed distributed architecture, is presented in Section 2. In Section 3, the developed web-based graphical interface model will be presented. Section 4 concerns about the case study and the obtained results, and finally, the conclusions are presented in section 5.

2. Distributed based Microgrid Implementation

The model provided in this paper is referred to a laboratorial microgrid simulator based-on distributed control. This system employs several real hardware resources available in GECAD research center ISEP/IPP, Portugal. The model consists of a 30 kW resistive load playing the role of a consumer in the grid, a 7.5 kW PV arrays and a 1.2 kW wind turbine emulator representing the role of renewable energy resources. All of these resources are connected to each other and to the power grid by several transmission lines. The proposed model employs several automation ideas implemented in these resources in order to be managed by one or more controller units. Fig. 1 illustrates the overall view of the system.

The 30 kW resistive load has a switchboard on the front view to control the consumption from 1 kW to 30 kW. In order to implement a fully automated system, four relays have been embedded on this resource. These relays enable the controller unit to automatically control the consumption of the 30 kW resistive load. More details about this process are available in [15].

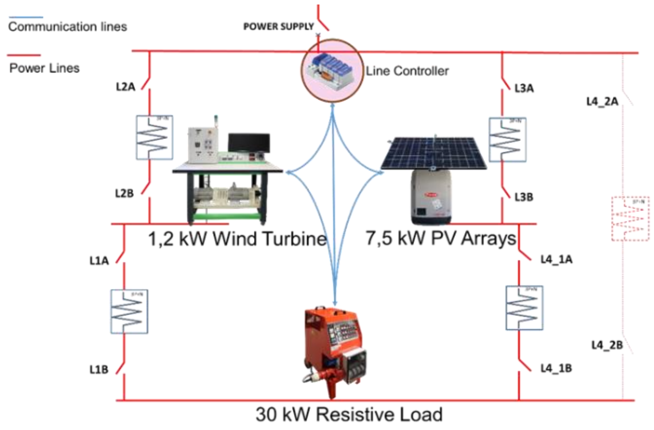

Fig. 1: Overview of the implemented microgrid.

The first renewable resource of this microgrid model is a PV unit with maximum generation capacity of 7.5 kW. Currently, this unit is installed in the GECAD laboratory and its produced energy supplies a significant part of GECAD building's consumption. The data related to the production of this renewable unit is monitored in real-time and also stored in a database using RS-485 interface with MODBUS RTU protocol. According to this information, there are some moments during the day that not only this renewable resource supplies all of the energy demand, but also it injects the rest to the utility grid. Therefore, we can conclude that this unit is an adequate solution for the microgrid model in order to operate in islanded-mode during the day while there is a significant amount of generation. The second renewable resource of this microgrid is a wind turbine emulator with maximum generation capacity of 1.2 kW. In this emulator, there is a three-phase asynchronous motor coupled with an inductive three-phase generator. A speed controller unit is responsible for controlling the speed of motor. Actually, the motor emulates the blade of the wind turbine, which its speed is managed by the speed controller. In this machine, the generator can inject the produced energy to the utility grid, or supply the local loads. More information about this emulator and its automation can also be found in [15].

In the last section of the model, there are four transmission lines responsible for flowing the energy between the system players and the power grid. In each transmission line there are two circuit breakers, one at the beginning and one at the end of the line. Additionally, two energy meters are installed in each line in order to measure and monitor the energy transactions between the system players. As it is demonstrated in Fig. 1, line 1, 2, and 3 have constant position, however, line 4 has two possibilities for its position, the first one is between the consumer and PV unit (L4_1), and the second one is between the consumer and the power grid (L4_2). This enable the microgrid to take appropriate decisions for feeding the consumer unit on critical periods. If, for instance, there is no energy production in the renewable resources, the system supplies the consumer from the power grid by interrupting the line 3 and altering the position of line 4, from L4_1 to L4_2.

Fig. 2 presents the overall system architecture deployed in a distributed fashion. There are four main agents namely, Load, PV, Wind Turbine and Line agent. As also shown in Fig. 3, each agent is equipped with a PLC in order to perform decision making locally and communicate with other agents to fulfil the overall system's goal. The main purpose of the line agent is to supervise the circuit breakers in the transmission line. If, for instance, one of the energy generator agents does not supply energy, it will be interrupted. Moreover, energy meters reside in this agent as well. Suppose that, the load agent broadcasts a message to the agents that its consumption changed to 8500 W. PV agents responds that it can supply up to 5000 W based on its current output power. The rest of the required energy will be provided from the main power grid since there is no wind and hence no energy supplies from the wind turbine agent. Moreover, Fig. 3 presents the deployment diagram which addresses the static realization of the system. In this figure, each agent is represented by its corresponding representation in UML deployment diagram called node.

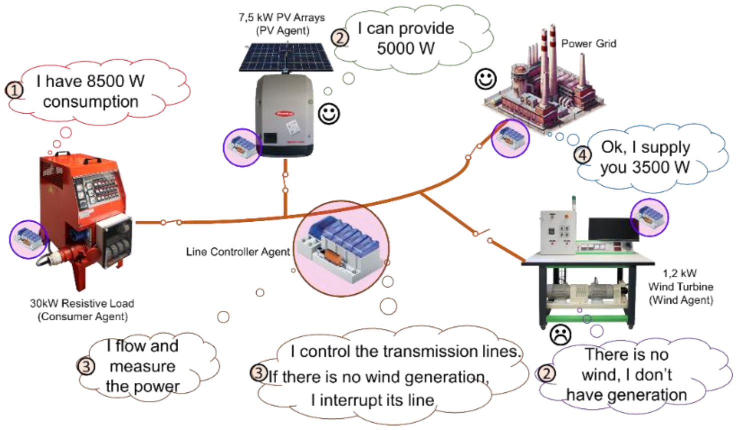

Fig. 2: Distributed control architecture.

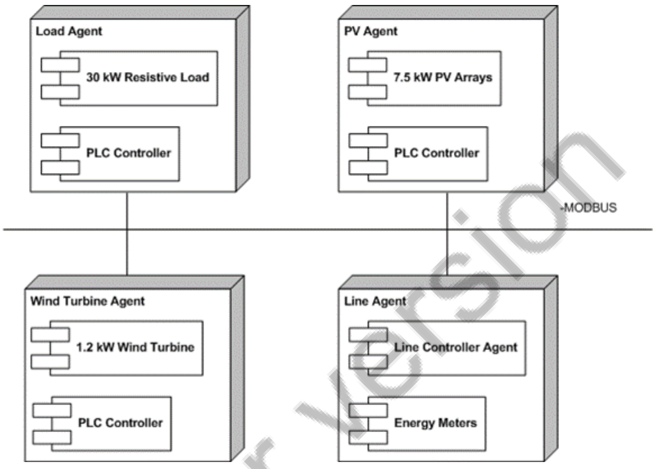

Fig. 3: Agent-based deployment diagram.

A node consists of several components which are the instances of the components shown in Fig. 2. The nodes are communicated via Ethernet interface, with MODBUS TCP/IP protocol. The agents constantly exchange messages in order to share their latest status in the network. This will reduce the response time to any changes in the load agent and hence improve the adaptability. On the other hand, flexibility and reconfigurability are two main important characteristics that an agent-based system offers. For instance, any faulty machine or agent can be easily repaired and replaced without any disruption in the overall system's task. The faulty agent will be registered in the line agent and the system will be reconfigured accordingly.

3. Graphical Interface

Fig. 4 presents the graphical interface designed and implemented in this paper. The overall scheme of this web page consists of four main nodes. The first node is related to the grid connection, which connects the microgrid resources to the utility grid. In this node, there is an energy meter, which measures the energy transactions between the utility grid and microgrid. The second node has owned by the 30 kW resistive load. The interface controls this resource in "Auto" or "Manual" modes. While "Auto" button is ON (green), the real-time consumption of the GECAD building is transmitted to this player, and it attempts to match its consumption with the received value. However, while the "Auto" button is OFF (yellow), the user can manually insert the desirable amount of consumption that intends to be simulated by the 30 kW resistive load.

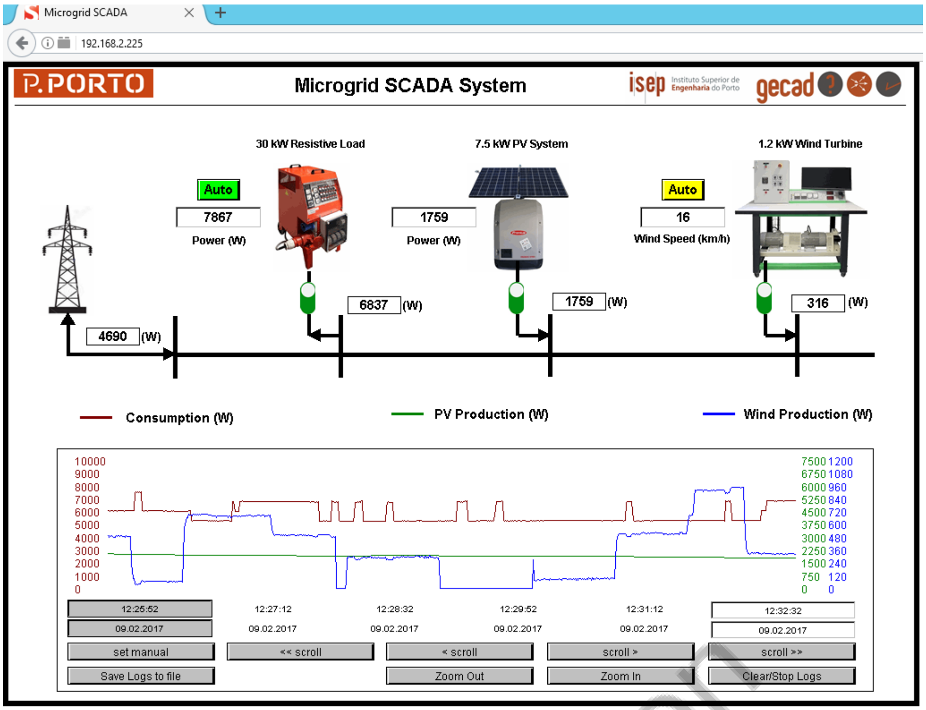

Fig. 4: The graphical interface designed for microgrid control and monitor.

The third node is related to the 7.5 kW PV system. There is no control on this resource, and the system only monitors the real-time amount of generation. The last node is connected to 1.2 kW wind turbine emulator. This energy resource follows the same method as the 30 kW load. However, the difference is when the “Auto” is selected, the real-time wind speed data provided by [16] is transmitted to this resource, and the emulator starts to generate energy regarding to the real-time data. Moreover, the user can turn off the “Auto” button and manually insert the favourable wind speed data. For each one of these nodes, a toggle button has been considered in order to interrupt them from the grid. These buttons are connected to the circuit breakers available in the transmission lines. At the bottom of the interface, there is a trend, which plots the profiles of the consumption and generation of microgrid resources in real-time.

4. Case Study

In this section, a case study will be implemented on the microgrid model provided in this paper in order to test and validate the features and capabilities of the system. For this purpose, the real consumption data of GECAD building has dedicated for the consumer part of this microgrid. The GECAD building is one floor office building including 16 offices, meeting rooms, server rooms, a kitchen, and two bathrooms. In this case study, firstly, the real-time consumption data of the building is provided to the load agent via Ethernet interface, with MODBUS TCP/IP protocol. Afterward, the agent takes several controlling decisions locally in the 30 kW load for matching its consumption to the received value. Regarding the PV agent, the real-time generation profile has been considered for this agent since the PV system is already installed on the GECAD building and it is generating energy now.

In order to provide a complete case study, real-time wind speed data acquired from ISEP Weather Station, Porto, Portugal [16] is transferred to the Wind turbine agent during the case study. For this purpose, a micro-controller unit (Arduino® - www.arduino.cc) has been deployed, which acquires the wind speed data in JavaScript Object Notation (JSON) format, converts it to an integer value, and finally conveys to the Wind turbine agent through Ethernet interface, with MODBUS TCP/IP protocol. While the agent receives this input, it starts generating power according to the real-time wind speed data.

In this case study, the load agent broadcasts it consumption to other agents per second, and simultaneously, the renewable agents (PV and Wind) also broadcast their real-time amount of generation. Therefore, the load agent is aware that how much energy is supplied by the renewable resources and how much energy should be purchased from the power grid. In the meanwhile, the line agent supervises on the power flow and interrupts the line of the faulty agent or the resource that have no activity on the system.

The final results are illustrated on Fig. 5. This case study has executed on a winter day during working hours (10:00 AM to 17:00 PM).

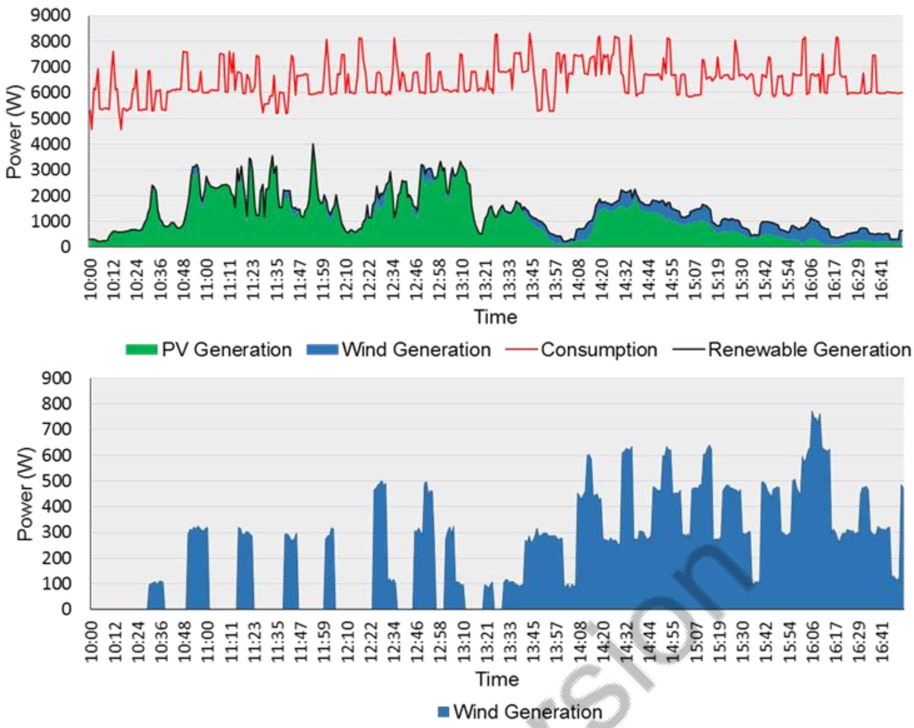

Fig. 5: Consumption and generation profiles of the microgrid simulation during a day.

As it is clear in Fig. 5, the red line stands for the real-time consumption of the GECAD building simulated by the load agent, the green areas refer to the real generation profile of PV arrays mounted on the building, and the blue areas are for the wind generation profile emulated by the wind turbine agent based-on real-time wind speed data. Additionally, the black line is the aggregation of renewable energy production. In another word, the black line is the part of consumption that has been supplied by the renewable energy resources. Moreover, the area between the red and black lines is the power purchased from the utility grid.

5. Conclusion

In this paper, a real-time microgrid simulation based on distributed control architecture has been presented. The system is located in the GECAD Lab, ISEP, Portugal where consists of four main agents. All the agents have their own programmable logic controller in order to process and make decisions locally. One of the agents continuously monitors the status of the all other agents to analyse the overall system's generation and consumptions. If any fault occurs in one of the resources, or system detects there is no activity on that resource, the related agent interrupts it from the system and connects it back while the resource would like to start its activity. Furthermore, a web-based graphical interface was designed and developed, which enabled the microgrid operator to have control and monitor the resources.

The results of this paper demonstrate in practice that distributed control model reduces the response time to any changes in the agents and hence improve the adaptability of the system. Additionally, flexibility and reconfigurability are two main important characteristics that an agent-based microgrid offers. For instance, any faulty machine or agent can be easily repaired and replaced without any disruption in the overall system's task.

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References

[1] P. Faria and Z. Vale, "Demand response in electrical energy supply: An optimal real time pricing approach", *Energy*, vol. 36, no. 8, pp. 5374-5384, 2011.

[2] T. Wang, D. O'Neill, and H. Kamath, "Dynamic Control and Optimization of Distributed Energy Resources in a Microgrid", *IEEE Transactions on Smart Grid*, vol. 6, no. 6, pp. 2884-2894, 2015.

[3] O. Abrishambaf, L. Gomes, P. Faria, J. Afonso and Z. Vale, "Real-time simulation of re-newable energy transactions in microgrid context using real hardware resources", *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, 2016.

[4] Z. Vale, H. Morais, P. Faria and C. Ramos, "Distribution system operation supported by contextual energy resource management based on intelligent SCADA", *Renewable Energy*, vol. 52, pp. 143-153, 2013.

[5] L. Gomes, T. Pinto, P. Faria and Z. Vale, "Distributed intelligent management of microgrids using a multi-agent simulation platform", *2014 IEEE Symposium on Intelligent Agents (IA)*, 20144.

[6] Q. Fu, A. Hamidi, A. Nasiri, V. Bhavaraju, S. Krstic and P. Theisen, "The Role of Energy Storage in a Microgrid Concept: Examining the opportunities and promise of microgrids", *IEEE Electrification Magazine*, vol. 1, no. 2, pp. 21-29, 2013.

[7] L. Gomes, M. Lefrancois, P. Faria and Z. Vale, "Publishing real-time microgrid consump-tion data on the web of Linked Data", *2016 Clemson University Power Systems Conference (PSC)*, 2016.

[8] Y. Kim, E. Kim and S. Moon, "Distributed Generation Control Method for Active Power Sharing and Self-Frequency Recovery in an Islanded Microgrid", *IEEE Transactions on Power Systems*, vol. 32, no. 1, pp. 544-551, 2017.

[9] Qiang Wan, W. Zhang, Y. Xu and I. Khan, "Distributed control for energy management in a microgrid", *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*, 2016.

[10] R. Abrishambaf, M. Hashemipour and M. Bal, "Structural modeling of industrial wireless sensor and actuator networks for reconfigurable mechatronic systems", *The International Journal of Advanced Manufacturing Technology*, vol. 64, no. 5-8, pp. 793-811, 2012.

[11] R. de Azevedo, M. Cintuglu, T. Ma and O. Mohammed, "Multi-Agent Based Optimal Microgrid Control Using Fully Distributed Diffusion Strategy", *IEEE Transactions on Smart Grid*, pp. 1-1, 2016.

[12] X. Chen, Y. Hou and S. Hui, "Distributed Control of Multiple Electric Springs for Voltage Control in Microgrid", *IEEE Transactions on Smart Grid*, pp. 1-1, 2016.

[13] P. Leitão, "Agent-based distributed manufacturing control: A state-of-the-art survey", *Engineering Applications of Artificial Intelligence*, vol. 22, no. 7, pp. 979-991, 2009.

[14] G. Santos, T. Pinto, I. Praça and Z. Vale, "MASCEM: Optimizing the performance of a multi-agent system", *Energy*, vol. 111, pp. 513-524, 2016.

[15] O. Abrishambaf, L. Gomes, P. Faria and Z. Vale, "Simulation and control of consumption and generation of hardware resources in microgrid real-time digital simulator", *2015 IEEE PES Innovative Smart Grid Technologies Latin America (ISGT LATAM)*, 2015.

[16] Meteorologia no Instituto Superior de Engenharia do Porto, 2017. [Online]. Homepage: http://meteo.isep.ipp.pt/.