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Multi-agent oriented solution for forecasting-based control strategy with load priority of microgrids in an island mode – Case study: Tunisian petroleum platform

Mohamed Ghaieth Abidi [a,b], Moncef Ben Smida [c], Mohamed Khalgui [a,b,*], Zhiwu Li [d,e,**], Naiqi Wu [d]

[a] School of Electrical and Information Engineering, Jinan University (Zhuhai Campus), Zhuhai 519070, China
[b] LISI Lab, INSAT Institute, University of Carthage, Tunisia
[c] LSA Lab, Tunisia Polytechnic School, University of Carthage, Tunisia
[d] Institute of Systems Engineering, Macau University of Science and Technology, Macau
[e] School of Electro-Mechanical Engineering, Xidian University, Xi'an 710071, China

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ABSTRACT

To improve the power supply availability in an island microgrid, this paper proposes a new approach that integrates distributed energy sources economically, reliably and efficiently. In an island mode, a microgrid must ensure its self-sufficiency of energy production since it cannot make an energetic exchange with a main grid. However, in this mode, the random behavior of the resources affected by meteorological factors presents a major constraint. The challenge related to the power availability in microgrids is to find a solution that faces the operation of intermittent power sources. The microgrid should guarantee a useful power management in order to achieve a high availability of energy. In this paper, we present a mathematical model to describe the influence of the meteorological factors on the sources production. We propose a multi-agent control strategy based on the production forecasting and load shedding for a high availability of the microgrid power supply. The proposed multi-agent system uses the master-slave model in which the communication and negotiation between the defined agents are performed by a concept of tokens. The developed control system is implemented on Spartan 6 FPGA-Board. The paper's contribution is applied to a Tunisian petroleum platform where several blackouts are recorded between 2012 and 2014. Simulation and experimental results show clearly a high availability as a performance of the proposed control strategy.

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1. Introduction

Nowadays, many human activities depend critically on secure supplies of energy. For many energy consumers, such as hospitals, research centers and military bases, any temporary absence of electrical power can lead to material and human losses. The service quality and mainly the power supply availability are regarded as paramount factors [1]. Due to several technical and economic constraints of conventional electrical networks, using the distributed energy production becomes a necessity [2]. Microgrid is a new generation of electrical networks, which aims to integrate different electrical power technologies efficiently and reliably [3–5] in order to meet the power requirements of consumers [6]. A microgrid is composed of networked generation sources, energy storage devices and loads interconnected and controlled by an energy management system [7,8]. The potential for improving the power supply availability is one of the main motivations behind the development and deployment of microgrids [9,10], especially in an isolated mode [11,12]. In this operation mode, a microgrid becomes an autonomous power system. It should have its self-sufficiency in the power production and should be able to ensure an accepted quality of energy requested by consumers [13,14]. In an island mode with the absence of renewable energy sources, the microgrid is supplied by backup sources. The major constraint to ensure a high power availability is the randomness and intermittent behaviour

* Corresponding author at: School of Electrical and Information Engineering, Jinan University, China.
** Corresponding author at: Institute of Systems Engineering, Macau University of Science and Technology, Macau.
E-mail addresses: khalgui.mohamed@gmail.com (M. Khalgui), zhwli@xidian.edu.cn (Z. Li).

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Nomenclature

PV	photovoltaic cells
WT	wind turbine
B	battery
GE	diesel generator
$P_{Source}(t)$	electrical power exchanged between the source and the rest of the network at time t
$P_{Load1}(t)$	electrical power consumed by a critical load at time t
$P_{Load2}(t)$	electrical power consumed by an uncritical load at time t
$En(t)$	insolation at time t
$V_V(t)$	wind speed at time t
$E_{charge}(t)$	battery charge level at time t
$E_{clim}(t)$	sea state at time t
$N_{Charge}(t)$	level of the fuel in the tank of the diesel generator at time t
E_{clim_0}	nominal sea state
$\psi_k(t)$	electrical power produced by source k at time t
$SBWD$	number of the days during which the renewable energy sources are unavailable
$A_{PS}(\%)$	availability rate of the power supply

of renewable energy sources [15], which can cause an imbalance of the energy between the production and consumption. The availability of the electrical energy in an isolated site presents one of the main problems to be solved.

BARAKA platform is an islanded petroleum platform located at the Tunisian coast. It is supplied by: (i) photovoltaic generators, (ii) wind turbines, (iii) batteries and (iv) diesel generators. This platform presents a real case study for an island microgrid that has suffered several power blackouts. In bad weather conditions, the platform becomes inaccessible for refuelling diesel generators. In this condition, a renewable sources unavailability can cause a total absence of electrical power supply. Between 2012 and 2014, six total stops of production are registered. These stops caused approximately one million dollars of losses for the Tunisian government.[1] These significant losses motivate us to find a solution that improves the availability and minimizes the number of stops.

In order to reduce the influence of intermittent sources behaviour and to ensure the balance between the produced energy and the consumers' demands, several studies are done to analyze the adequate types and capacities of sources. This analysis presents the first step to improve any availability [16,17]. These studies show significant technical results, though their solutions are economically expensive. Some studies explore also how the availability of microgrids is impacted by their topology design. These studies focus on the effect of the system architecture and the converters topology on the system availability [18]. They present acceptable technical results though their influence on the power availability is limited.

A power management strategy also has a significant impact on the energy control optimization [19,20]. As a result, the system is able to deal with dangerous situations. Several studies focus on the impact of the power management strategies on the electrical supply quality in microgrids, especially on its stability and availability [21,22]. The power management can be ensured by various techniques, ranging from a centralized control approach as reported in [23] to a fully decentralized one, depending on the responsibility rates assumed by the central and the distributed microgrid controllers. The centralized control is widely used in connected mode-oriented microgrids. With this type of control, the optimization problems become extremely complex. In fact, any modification of the installation (loads or sources) influences the global control strategy. The decentralized approach suggests that this kind of constraints and sub-problems should be solved at the local level. The main responsibility is given to the microsources to optimize their production and to the local loads to control their consumption. For this kind of control, the multi-agent theory presents an interesting and useful solution that can ensure a self-monitoring for each controllable element [24–26]. Whatever the centralized or decentralized approach is applied, especially in an island mode, a real-time control is insufficient. The microgrid should have a control strategy based on the proactive reaction that takes into account production and consumption predictions to ensure the power balance of networks [27,28].

Although these research works are interesting, no one can solve the BARAKA problem for significant reasons related to the location or the size of the platform. In this paper, we present a novel solution to the BARAKA problem. We propose a new multi-agent power management strategy that can optimize real-time power dispatches [29] in order to face unsafe situations [30,31]. A load shedding strategy based on weather forecasting information is developed. With this information, we predict the production insufficiency. Then, the load shedding method is used to ensure the balance between the available and requested energy by promoting high priority loads [32]. The use of forecasting information in the load shedding decision gives rise to proactive control aspect. This aspect allows the system to make the right decision about the refuelling of diesel generators and the choice between supplying total loads or using the load shedding method in order to increase the autonomy of backup sources (batteries and diesel generators) in the unfavorable weather conditions [33–35]. Forecasting options may have a direct impact on the economic viability and supply availability of microgrids [36]. The proposed control strategy is expected to minimize the negative influence of the intermittent behavior of the renewable sources availability on the platform production [37]. By the proposed model of power management, we develop a new control strategy by which the energy management system is subdivided into two main management parts: production and consumption. For each part, a hierarchical multi-agent system with the master-slave model is used to control load and source penetrations. An agent is used to provide the meteorological forecasting data. The production management is assured by a super master agent, four master agents (master agent for each type of sources), and several slave agents (an agent for a micro source). The super master agent of production is used to choose the type of source to be integrated into the network based on the information collected by the master agents of production. These agents collect the useful information about the availability and autonomy state of their sources. They choose one, among them, that will be integrated into the network while taking into account the decision made by the super master agent. The consumption management is made in a similar way. The communication is made by tokens of information and control that allow to avoid the point-to-point high cost communications. The implementation of this strategy requires several input/output ports. The acquisition of weather forecasting data is periodic [38] and the management of energy flow is real-time. For technical and economic reasons, the FPGA Spartan 6 is chosen as a perfect solution for the multiple input/output control strategy implementations. The contributions of this paper are:

- Proposition of a new control strategy based on weather forecasting and load shedding method. This strategy is supported by a mathematical model that describes the relationship between dif-

[1] Official statistics provided by CIPEM.

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