

Dynamic Assignment of Renewable Energy Tokens in a Collaborative MicroGrids

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Abstract—Nowadays, electrical energy consumption and energy prices have increased. Thus, the microgrids (μ Gs) rely on renewable energy receive more attention from consumers. New neighborhoods opt for green philosophy where the most consumed energy comes from renewable generation. Indeed, each residence could be supplied from its own solar and wind generation or from centrally located power plant. However, the latter present many problems in efficiency and reliability. This paper proposes a new approach based on a dynamic assignment of renewable energy tokens (DARET) algorithm to add a smart behavior to μ Gs. The proposed algorithm allows residential μ Gs of a small geographic area to dynamically collaborate and share their individual green energy generation in order to supply their overall load. The sharing is dynamically updated in short-term by exchanging data, in terms of individual demands and supplies, between the consumers over wireless links.

Index Terms—Collaborative Grid, Wireless Distributed Management, Micro-Grid, Renewable Energy.

I. INTRODUCTION

Recently, the interest in microgrids (μ Gs) has been growing as a new eco-friendly energy grid in order to avoid the increasing environmental pollutions caused by fossil fuel emissions. thus, sustainability becomes an imperative requirement in electrical field. Generally, the μ G can be defined as a small electrical grid formed by renewable sources, conventional generation, energy storage devices, power conversion systems and different controllers with advanced communication features. The μ G can work in both connected and islanded mode [1].

Many studies have been investigated to manage power in μ Gs operating in connected mode where the connexion to the power grid guarantees the generation/consumption balancing. In [2], an optimization method is applied to minimize energy losses, production cost and carbon emissions in μ G. Another study of power flow management is developed in [3] based on predictive control to reduce the disparity between demand curve and generation curve. For islanded μ G, there is some research focused on improving the management of stochastic supplying and consumers behavior. An optimization algorithm is proposed in [4] to minimize the cost operating schedule of both electrical and thermal supply and demand in a residential microgrid. In [5], a management approach is applied to dynamic demand response and distributed generation (controllable sources such as micro-CHP and uncontrollable wind/ photovoltaic sources) in order to reduce the energy consumption cost of the μ G community. Another work in [6] proposes to couple many μ Gs for improving the reliability and the power quality of the whole system.

This paper presents a dynamic assignment of renewable energy tokens algorithm, based on the schedulability of heavy loads and the individual green energy generation of each μ Gs, especially photovoltaic and wind sources. The goal behind this algorithm is to manage the energy distribution of the whole system in order to maintain the power balancing in a smart collaborative aspect. Each μ G is equipped by smart control panel (SCP) allowing the control of energy consumption behavior via load controllers (LCs). For the proposed approach, it is suitable to use wireless communication infrastructure to exchange all operational information of μ Gs thanks to their attractive advantages.

The reminder of this paper is structured as follows. Section II develops a global formulation of power balance problem in μ Gs. Section III presents the proposed DARET algorithm and its detailed operational steps, including the proposed communication technologies intra and inter μ Gs. Section IV presents the performance results of the proposed algorithm while Section V presents conclusions of this work.

II. PROBLEM FORMULATION

The major electricity problem is that it cannot be stored in large quantities. Thus, the dispatching of power production is done dynamically. With conventional production, generation adjustment was possible (primary, secondary and tertiary) to keep, all the time, the production power at the same level as the demand power. But with the intermittent generation sources, we should apply an efficient process to achieve power balance. We consider, as shown in Fig. 1, a collaborative system composed of many islanded μ Gs where each one has its own green power generation including photovoltaic and wind sources. The whole μ Gs are interconnected between them in order to share the total generated energy for schedulable loads and to share also power consumption information via a wireless communication infrastructure.

To keep balance power in this system, we have to check, in real time, the equality in (1).

$$\sum_{i \in \bullet} P_i^* = \sum_{i \in \bullet} P_i' + P^{***}, \quad (1)$$

where P_i^* is the contribution power, P_i' the consumed power for supplying the all schedulable loads (controllable and non-controllable loads), P^{***} is the total loss power in electrical lines and the dissipated surplus power on dump loads (dissipating resistor).

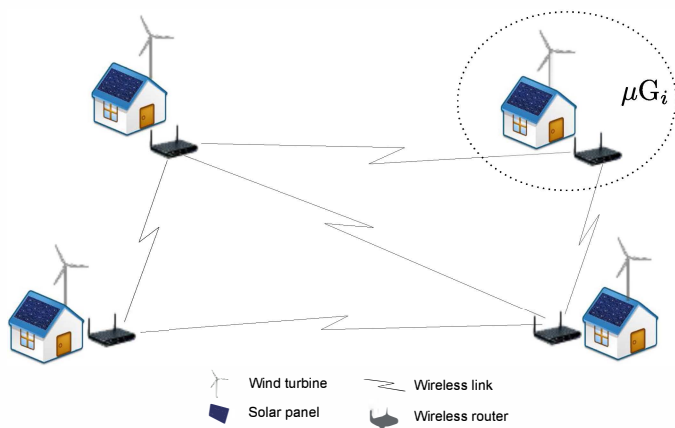


Fig. 1. Microgrids Architecture Scenario

In this study, we neglect losses in electrical lines and we consider $P^{***} = P^{**}$, P^{**} is the dissipated power on dump loads. This power is less than the minimum requested one which is equivalent to one token.

Then, we must control one of the two generated and/or consumed powers to ensure this equality. Since production from intermittent sources is uncontrollable and is very dependent on climatic variation, we propose to push the power demand to be manageable.

We assume that we have a variation $\delta P_c = \sum_{i=1}^N \delta P_i^*$ of generated power, then we must vary the demand accordingly by $\delta P_s = \sum_{i=1}^N \delta P_i^*$.

In order to keep up with the unpredictable energy sources variations, we propose herein a collaborative architecture system where loads of administrative or residential buildings are supplied by a distributed renewable energy sources (RESs).

III. COLLABORATIVE SMART MICROGRIDS

The cost of renewable energy source (RES) technology and its deployment is still expensive. Thus, the collaboration of a number of μG s with smaller and cheaper RESs can supply heavy loads, at the same time, allow a participant to be supplied even if its own system is down.

A. System description

Fig. 2 shows the intra-structure of each μG . It has two kind of supplying: independent part which supplies non-schedulable loads via the battery and collaborative part which supplies schedulable loads in interconnected grid. The latter are classified into controllable and non-controllable loads. We define here the following load classes:

- *Non-Schedulable loads* are loads that we cannot determine its turning on and turning off because they present a paramount need and depend extremely in random behavior of users. Such as lighting, television, computer, fridge, etc.
- *Schedulable loads* are the electrical equipments that are time unconstrained and for which a user can prioritize. Within this category, we distinguish two sub-classes:

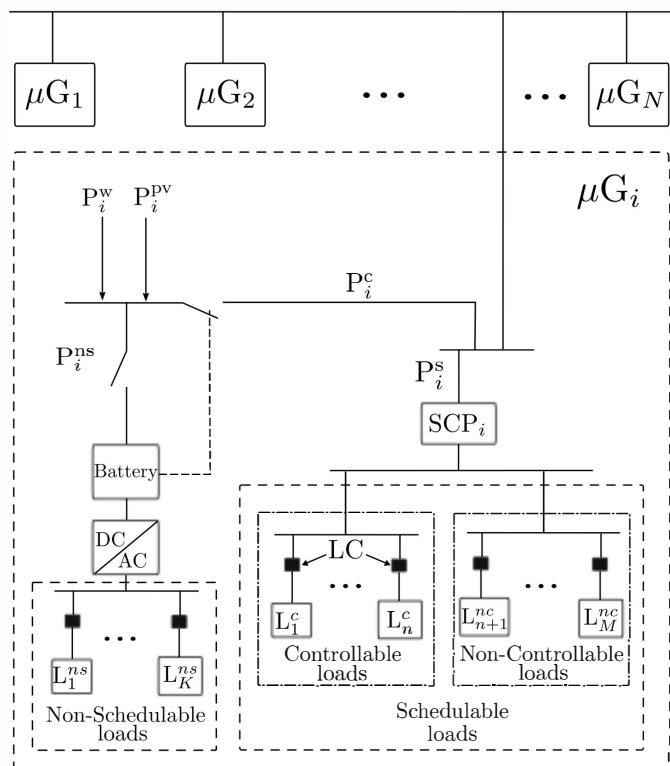


Fig. 2. Electrical power distribution

- *Controllable loads* can be switched on or off through the LCs depending on the available power production. They include electrical equipment that can not be damaged if we turn them off during their operation such as tumble dryer, electrical vehicle, heating circuit, air conditioning, etc.
- *Non-controllable loads* can be switched on but cannot be switched off before the end of their operating time such as washing machine, cooker, oven, etc.

We suppose that we have a number N of residential μG having, each one, a number M of schedulable loads to be supplied by the interconnected grid. Each load has a downstream LC allowing its turning on and turning off depending on SCP decision. As developed in section II, we have (1) where

$$P_i^* = P_i^* + P_i^{**} - P_i^{**}, \quad (2)$$

and,

$$P_i^* = \sum_{j=1}^n L_j^* + \sum_{j=1}^M L_j^{**}, \quad (3)$$

where P_i^* is the photovoltaic power generation, P_i^{**} is the wind power generation and P_i^{**} is the consumed power for supplying non-schedulable loads of μG_i . L_j^* and L_j^{**} , $j = 1, \dots, n$, are the consumed power by controllable and non-controllable loads, respectively.

Each μG is equipped by one SCP and many LCs. In fact, each load has a downstream LC which measures the instant consumed power in order to send it to the SCP. Moreover,

Algorithm 1 Dynamic Assignment of Renewable Energy Tokens

1: **INPUT:** Maximal load power vector P^* , Operating time vector T , Requested load priorities matrix R , Number of μ Gs N , Number of loads per μ Gs M , Forecast individual contribution power P^* .

2: **OUTPUT:** Binary decision matrix $D = \{d_{i,j}\}_{i,j}^{N \times M}$.

3: **PROCEDURE:**

4: $P^* \leftarrow [P_L, P_L, \dots, P_{LM}]$

5: Initialization of the Checking Matrix $C = \mathbf{0}^{N \times M}$

6: $n \leftarrow 0$

7: **while** $C \neq \mathbf{1}^{N \times M}$ **do**

8: $n \leftarrow n + 1$

9: $P^* = \sum_i^N (P_i^*(n) - P_i^*(n))$

10: **while** $P^* < 0$ **do**

11: Switch off the last controllable load m

12: Record the remaining operating time for load m

13: $P^* = P^* + P_{L_m}$

14: $m \leftarrow m + 1$

15: **end while**

16: **for** $j = 1$ to M **do**

17: **for** $i = 1$ to N **do**

18: $k \leftarrow r_{i,j}$

19: **if** $c_{i,k} = 0$ and $P^* - P_{L_k} \geq 0$ **then**

20: $c_{i,k} \leftarrow 1$

21: $d_{i,k} \leftarrow 1$

22: $P^* \leftarrow P^* - P_{L_k}$

23: **end if**

24: **end for**

25: **end for**

26: **end while**

it relies on the SCP decisions to switch on or switch off the connected load. The SCP is the general controller in each μ G, it is designed to collect all the power consumption information sent from LCs of the same μ G and total consumed power from the neighbors SCP. We opt for running the algorithm at each SCP in order to ensure a great redundancy and reduce the time of decisions broadcasting. Besides, it executes the DARET algorithm to make decisions about the consumption behaviour of the whole loads. After the SCP sends the decision to the appropriate LC in order to switch on or off the load.

B. Operation algorithm

We propose integrating the DARET algorithm at SCP of each μ G. We keep in SCPs data about the maximum consumed power by all schedulable loads. Power data is represented in terms of token unit equivalent to one kilowatt. We assume that the SCP is able to have forecasts curve of its own contribution power. Each SCP is equipped by wireless network interface card making it able to communicate with LCs and with the other SCPs.

On one hand, the transmitted information intra- μ G, between a SCP and LCs is done over bidirectional dedicated wireless channels. Indeed, each LC sends the consumed power measure

of its connected load to SCP, and each SCP sends the decisions of turning on or off to the appropriate LCs. On the other hand, the transmitted information inter- μ Gs between SCPs is done over shared channel. Indeed, each SCP broadcasts its local total consumed power (P_i^*) to all SCPs members of the DARET collaborative system. Every night, the consumer of each residential or administrative μ G sets on its local SCP its preferences in terms of needed loads to be turned on during the next day and their priorities. After exchanging these information within the collaborative system. Each SCP runs DARET algorithm, as presented in Algorithm 1, and sends its decisions of turning on or off to its schedulable loads.

C. Proposed communication

Providing a reliable communication is the key of success, efficiency and high power quality in μ G. It is essential to build a robust communication infrastructure with the optimal cost. In fact, there are many wired and wireless communication technologies that can ensure communication infrastructure. In one hand, μ G can be controlled and operated by using communication links such as power line communication (PLC) [7] or Fiber optic lines. However, these communication links present some disadvantages. Indeed, the PLC technology has a gap of supporting high data transmission and causes introduction of errors into the transmitted signal due to interferences, noise or attenuation which can not make the μ G data transmission reliable and robust [8]. Besides, the Fiber Optic link can support high speed in data transmission, latency is exceptionally low with fiber optic. But, in the case of μ G it could take a low deployment and need a large up-front investment comparatively to the amount of the exchanged data [9], [10]. In the other hand, wireless technologies offer several advantages in term of rapid deployment, low cost installation and mobile communications that wired technologies can not offer. In fact, these wireless technologies are structured in two categories, the first for indoor communications and the second for the outdoor communication. Zig Bee IEEE 802.15.4 [11] can be used as an indoor communication to exchange the information between the smart devices (LCs and SCP) within each μ G. Moreover, the cellular technologies 3G/4G [12], Wimax IEEE 802.16 [13] can be used as an outdoor infrastructure for all communications between the SCPs of μ Gs. Finally, wireless mesh network (WMN) and wireless local area network IEEE 802.11 [14] can be used for indoor and outdoor communications.

IV. SIMULATION AND RESULTS

In this section, we demonstrate the simulation results using an example to examine the performance of the proposed DARET algorithm in power management described in the previous sections. We generate, with a step size of 6 minutes, a daily data of the contribution solar and wind power. Fig. 3 considers DARET algorithm for six interconnected μ Gs, in terms of the power consumption (\bullet) and power generation (∇) during 24hours. In this case of a small number of collaborative μ Gs, we note that disparity between the curves of consumption

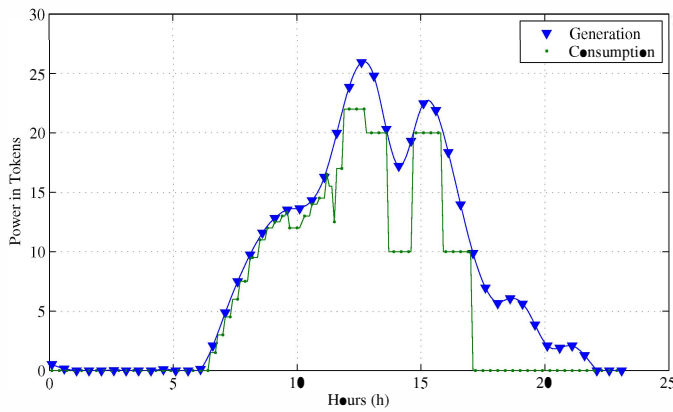


Fig. 3. Total available and consumed power for $N = 6$ Microgrids during 24hours.

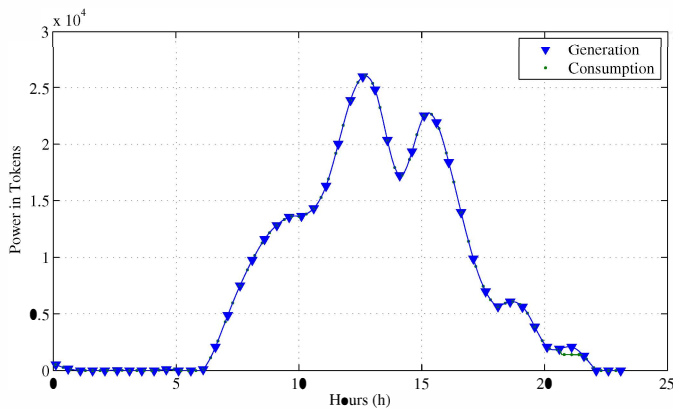


Fig. 4. Total available and consumed power for $N = 6000$ Microgrids during 24hours.

and of generation is important. On the other hand, Fig. 4 considers DARET algorithm for six thousand μ Gs. The disparity is much smaller than the one obtained in Fig. 3. Indeed, in Fig. 5 that shows the variation of loss percentage relatively to the generated power in function of the number of collaborative μ Gs, for $N = 6$ μ Gs we have a loss percentage around 26% while for $N = 6000$ the percentage is less than 0.3%. The latter figure shows that the loss percentage decreases exponentially in term of the number of collaborative μ Gs.

V. CONCLUSION

This paper presents a dynamic assignment of renewable energy tokens (DARET) algorithm in order to add a smart collaborative behavior to a group of μ Gs. The proposed scenario is an islanded μ Gs model which collaborate with the power provided from their individual green energy sources. The role of DARET algorithm is to manage power sharing and to maintain, at the same time, the power balancing in the μ Gs system. Simulation results show the effectiveness of the

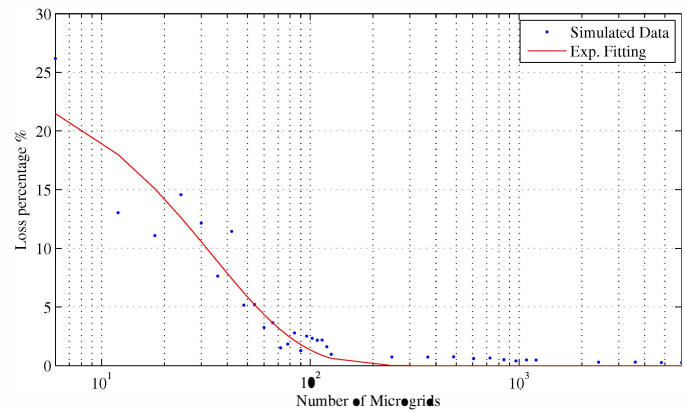


Fig. 5. Power loss percentage in term of number of collaborative microgrids

proposed algorithm, specifically, when the number of the collaborative μ Gs is large which lead to negligible power loss percentage compared to the case with no-collaboration between μ Gs.

REFERENCES

- [1] A. Etxeberria, I. Vechiu, H. Camblong, and J. Vinassa, "Comparison of sliding mode and PI control of a hybrid energy storage system in a microgrid application," *Energy Procedia*, vol. 12, pp. 966–974, 2011.
- [2] E. R. Sanseverino, M. L. Di Silvestre, M. G. Ippolito, A. De Paola, and G. Lo Re, "An execution, monitoring and replanning approach for optimal energy management in microgrids," *Energy*, vol. 36, no. 5, pp. 3429–3436, May 2011.
- [3] A. Hooshmand, H. Malki, and J. Mohammadpour, "Power flow management of microgrid networks using model predictive control," *Computers & Mathematics with Applications*.
- [4] P. O. Kriett and M. Salani, "Optimal control of a residential microgrid," *Energy*, vol. 42, no. 1, pp. 321–330, Jun. 2012.
- [5] B. Jiang and Y. Fei, "Dynamic residential demand response and distributed generation management in smart microgrid with hierarchical agents," *Energy Procedia*, vol. 12, no. 0, pp. 76–90, 2011.
- [6] R. H. Lasseter, "Smart distribution: Coupled microgrids," vol. 99, no. 6, 2011, pp. 1074–1082.
- [7] A. Maneerung, S. Sittichivapak, and K. Hongesombut, "Application of power line communication with OFDM to smart grid system," in *International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), 2011*, vol. 4, 2011, pp. 2239 – 2244.
- [8] H.-M. Kim and Y. Lim, "A communication framework in multiagent system for islanded microgrid," *International Journal of Distributed Sensor Networks*, vol. 2012, pp. 1–7, 2012.
- [9] V. K. Sood, D. Fischer, J. M. Eklund, and T. Brown, "Developing a communication infrastructure for the smart grid," in *Electrical Power & Energy Conference (EPEC), 2009 IEEE*, 2009, pp. 1–7.
- [10] J. Gao, Y. Xiao, J. Liu, W. Liang, and C. P. Chen, "A survey of communication/networking in smart grids," *Future Generation Computer Systems*, vol. 28, no. 2, pp. 391–404, Feb. 2012.
- [11] "IEEE std. 802.15," *IEEE Standard for Information Technology - telecommunications and information exchange between systems - Local and metropolitan area networks*, 2006.
- [12] "ITU global standard for international mobile telecommunications (imt-advanced)." [Online]. Available: <http://www.itu.int/home/imt.html>
- [13] "IEEE std.802.16," *IEEE Standard for Information Technology - telecommunications and information exchange between systems - Local and metropolitan area networks*, 2009.
- [14] "IEEE std. 802.11," *IEEE Standard for Information Technology - telecommunications and information exchange between systems - Local and metropolitan area networks*, 2007.