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Optimization of a microgrid with renewable energy and distributed generation: a case study

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***Abstract*—In this paper an optimization algorithm is applied on a microgrid with renewable energy and distributed generation. The intermittent electricity in Lebanon leads to widely use diesel generator groups and to install renewable energy in private places in order to cover the consumption during the power cut. The proposed case study consists of three energy hubs integrating renewable energy, diesel engines, and batteries. These three energy hubs cooperate and exchange extra power if needed by applying the proposed algorithm while minimizing the use of diesel engine groups.**

***Index Terms*—Microgrid, optimization, control, distributed generation, hubs.**

I. Introduction

Nearly 25 years after the Civil War ended, the state-owned electricity company, Electricite du Liban (EDL), is still unable to keep the lights on around the clock, despite promises by successive governments to provide a constant supply [1], [2]. In summer 2013, Beirut, the capital, have suffered nine rather than the usual three hours of cuts. People in rural areas go even longer without power [3]. A global national strategy must be conducted that includes radical solutions combined with a serious political will that aims at rehabilitating and developing the electricity sector [4]–[6]. Waiting these solutions, Lebanese try to find other alternatives like using private generators and renewable energy [7] in order to have power for 24 hours a day.

Universite de technologie et de sciences appliquees Libano-Francaise (ULF) is a university traditionally connected to EDL. However, as mentioned above, the reliability of the power of the national network is debatable. Indeed the university suffers daily power cuts lasting several hours. In an attempt to overcome this problem, the university possesses an autonomous power system consisting of wind turbines, solar panels, batteries, and diesel generators. ULF wants to increase its autonomy from the Lebanese electricity network, while reducing its carbon footprint. A theoretical study has been performed on the university power system. It consists in modeling and optimization of electrical production system. As a result of this work, the owner hopes reliable electricity supply of buildings in order to improve the conditions and quality of education. But the solution is expensive and needs more renewable energy production units to be added. This motivates the study of other approaches dedicated to micro-grids with distributed generation and storage units and with renewable energy source integration.

In [8], a feedback control strategy to solve the OPF problem in smart micro-grids with high penetration of DRES is proposed. In [9], a multi-objective optimization algorithm, the NSGA-II, is applied to manage EES (Electrical Energy Storage) systems, and to minimize the total electricity generation cost and the greenhouse gas emissions of the grid of an existing islanded distribution network supplying the Island of Pantelleria (Italy). In [10], a cooperative control strategy is applied to a microgrid in both grid-connected mode and islanded operation mode. This strategy is evaluated experimentally in [11]. The authors of [12] have proposed a long term scheduling optimization of a grid-connected renewable energy microgrid with hybrid energy storage. Model predicitve control (MPC) is also used in this field. One can cite the work of [13], [14] where an MPC-based algorithm is used to determine the future scheduling of power exchanges among dispersed microgrids as well as the charge and discharge in each local storage system.

In this paper, a new solution for the ULF electricity problem with a small cost using only its existing production units is proposed. The objective is to optimize the electrical production in order to cover the consumption.

The paper is organized as follows. In section II, the ULF power system is given in details. The optimization problem is given in section III. Simulation results are given and commented in section IV. The paper ends with conclusions and perspectives.

II. The ULF grid

In this section, we will give a description of the ULF sites. The first site **ULF1** is equipped with a photovoltaic system of 3 kW, a storage system of 3 kW, a diesel generator of 20 kW. The second site **ULF2** is equipped with a photovoltaic system of 3 kW, a storage system of 3 kW, a diesel generator of 10 kW. The third site **ULF3** is equipped with wind turbine of 2.6 kW, a storage system of 2 kW. All the sites are connected also to EDL with intermittent time which it can reach 12 hours/day.

To find a model of this microgrid, we have inspired from the modelling procedure proposed by [15] where each site is considered as an energy hub (see figure 1). The inputs of the energy hub are the resource flows, F, whose nature depends on the type of generation system. For instance, the resource flow for the PV is the solar irradiance while for the case of diesel generator power, the resource flow is the diesel mass flow. The notation of variable F includes subscripts which identify the energy hub and the input, e.g., $F_{a,H}$ is the resource flow of input H in the energy hub a. The hub outputs are the power flows, P, supplied to other hubs or consumers.

Each generation system is modeled by the so-called converter, ε, which accounts for the conversion efficiency of the resource to power. The storage is also modeled by a converter which has two different values corresponding to charge status and discharge status. The power which is consumed or supplied by the storage is denoted by $P^s_{h,g}$ where the subscripts identify the hub and the storage, respectively. The power stored in the storage is defined negative while the power supplied by the storage to the grid is positive. The interconnecting variables are defined as power flows and denoted as P_{in} or P_{out} depending if the power is sent to a neighbor hub or received from a neighbor hub. In addition, other subscripts are included to identify the hub receptor or emitter, so that $P_{in,n\rightarrow m}$ is the energy received by hub m from hub n.

Hence, the energy balance of energy hub 1 is:

$$\begin{pmatrix} P_{out,1\rightarrow 2} \\ P_{1,1} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} & \varepsilon_{14} & -1 \end{pmatrix} \begin{pmatrix} F_{1,1} \\ F_{1,2} \\ F_{1,3} \\ P^s_{1,4} \\ P_{1,out} \end{pmatrix} + \begin{pmatrix} 0 \\ 1 \end{pmatrix} P_{in,3\rightarrow 1}$$

A similar modelling can be used for the other energy hubs. One get the energy balance of energy hub 2:

$$\begin{pmatrix} P_{out,2\rightarrow 3} \\ P_{2,1} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} & \varepsilon_{24} & -1 \end{pmatrix} \begin{pmatrix} F_{2,1} \\ F_{2,2} \\ F_{2,3} \\ P^s_{2,4} \\ P_{2,out} \end{pmatrix} + \begin{pmatrix} 0 \\ 1 \end{pmatrix} P_{in,1\rightarrow 2}$$

and for the energy balance of energy hub 3:

$$\begin{pmatrix} P_{out,3\rightarrow 1} \\ P_{3,1} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} & -1 \end{pmatrix} \begin{pmatrix} F_{3,1} \\ F_{3,2} \\ P^s_{3,3} \\ P_{3,out} \end{pmatrix} + \begin{pmatrix} 0 \\ 1 \end{pmatrix} P_{in,2\rightarrow 3}$$

III. Optimization problem

This model obtained in the previous section will be used to construct our control scheme. Our goal is to assure the local consumption, to maximize the power stored in the batteries, and to minimize the use of diesel generator. For each energy hub this goal can be achieved by controlling the charge/discharge of the batteries, starting or stopping the diesel engine, and receiving power from a hub neighbor. All of this will lead to minimize of the cost of power production used. For that, in this paper we have used a genetic optimization for each energy hub in order to fulfill its goal. Let's define the decision variables for each energy hub :

- The decision variable u_1 is related to the diesel group power. This input will be 0 when the diesel group is off and 1 when it is on.
- The decision variable u_2 related to the battery can take three values: -1 for charging, 0 for stability, and 1 for discharging.
- The decision whether to share or not the extra power among the energy hubs is related to the following decision variable denoted by u_3

A cost (price) is allocated to each type of production denoted by C_i where the subscript depends on the source of power. The C value is different from a production unit to another, it defines the cost of each one of them. If the value of C is high comparing to another production unit, the corresponding unit will be forbidden by the genetic algorithm. Now we can state the general optimization problem that is solved localy at each energy hub by:

$$\begin{aligned} \min(&-C_{EDL}P_{EDL} - C_{PV}P_{PV} - C_{wind}P_{wind} - u_1 C_{ge}P_{ge} \\ &-u_2 C_{Bat}P_{Bat} + u_3 C_x P_{x\rightarrow y} + consumption) \end{aligned} \quad (1)$$

subject to the following constraints:

$$0.3P_{bat} < P_{bat} < 0.95P_{bat}$$
$$production > consumption$$

IV. Simulation results

The optimization problem explained above is applied using real measurements taken from ULF sites for a spring day of march (for 24 hours). The measurement period is 10 min. The numerical values of the costs used in the optimization problem are $C_{EDL} = 4$, $C_{PV} = 1.2$, $C_{wind} = 1$, $C_{ge} = 20$, and $C_{Bat} = 2.5$

As one can see, the cooperation is activated between the storage system, the diesel generator, and the different energy hubs of the ULF sites. For an example, in figure 3, between 12 oclock and 16 o'clock the power coming from EDL is interrupted. At the same time the PV unit can't cover the consumption. Usually, the diesel generator must be on to feed ULF1. But as result, and by using the optimization, the diesel generator is off and the storage system with the PV unit feed the energy hub of ULF1. In addition, inspecting the decision variables values of ULF1 to ULF2 (see figure 2) at the same time of our optimization is equal 1, meaning that ULF2 gets the extra power of ULF1.

V. Conclusion

Regarding the results obtained in this paper, the optimization algorithm of fulfills the main objective; i.e. minimizing the use of diesel engine. As a result, the production cost in each hub is minimized as well. In addition, the consumption is covered with minimum possible cost using the existing renewable energy unit of each hub and the extra power of the neighbor hubs. These results lead us to apply this optimization on a bigger hub size or on another grid with different production unit. Another perspective to this work is to integrate the operational cost and the degradation of the energy storage system.

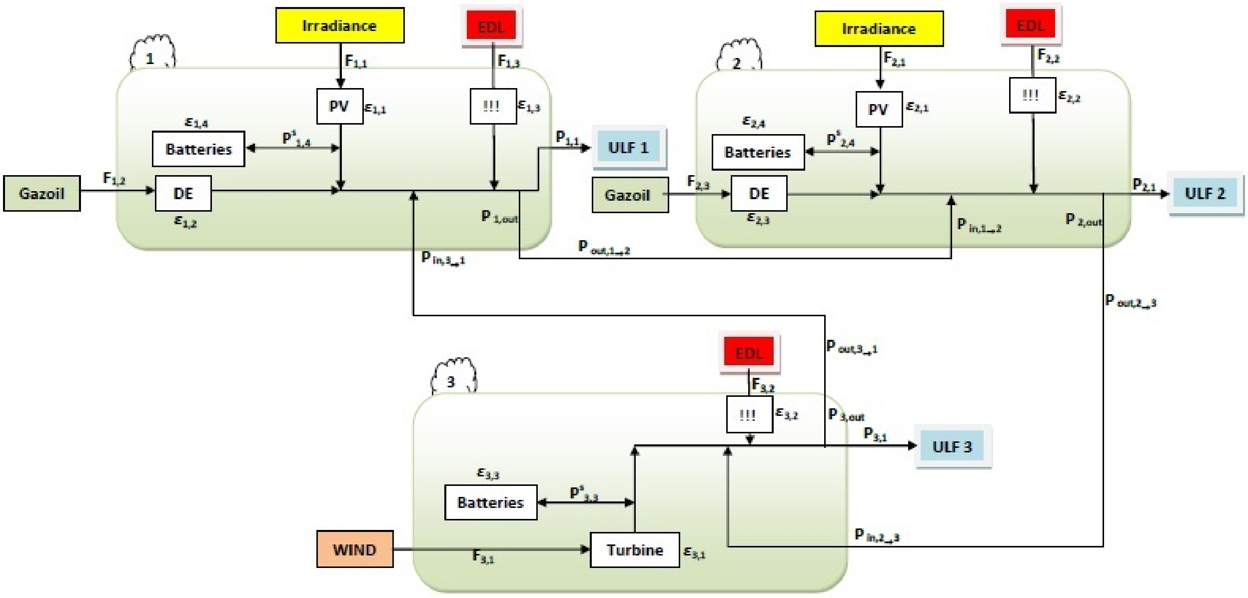

Fig. 1: The ULF grid and the interaction between each energy hub.

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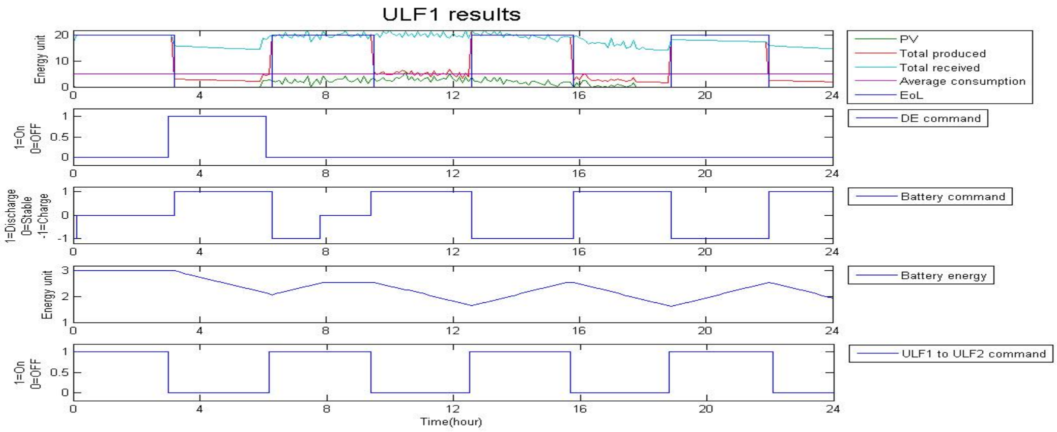

Fig. 2: ULF1 optimization results.

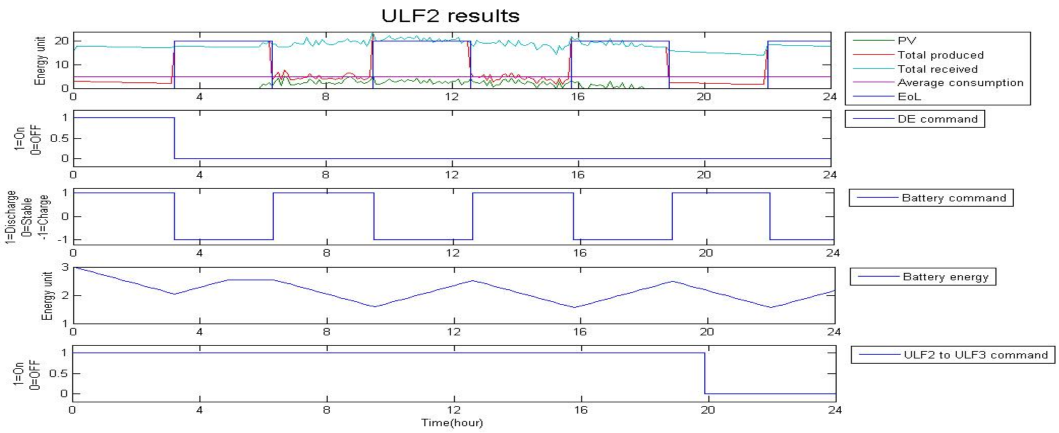

Fig. 3: ULF2 optimization results.

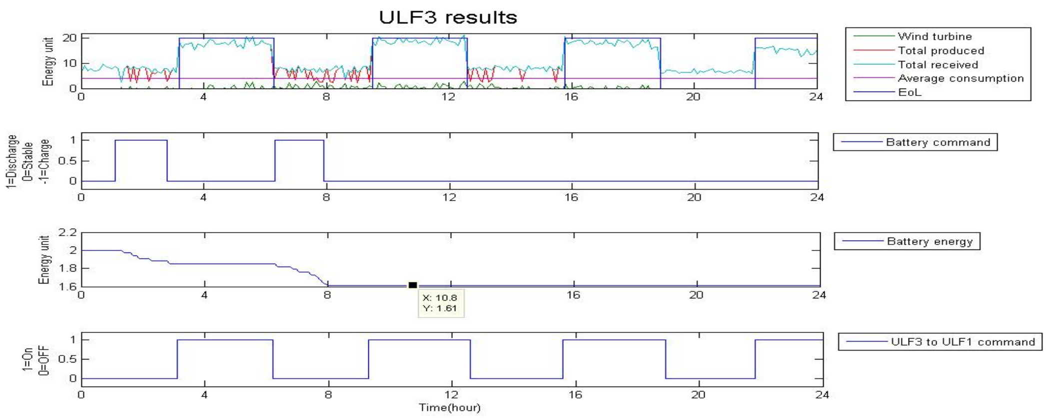

Fig. 4: ULF3 optimization results.