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Optimal scheduling of a renewable micro-grid in an isolated load area using mixed-integer linear programming

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ABSTRACT

In the energy management of the isolated operation of small power system, the economic scheduling of the generation units is a crucial problem. Applying right timing can maximize the performance of the supply. The optimal operation of a wind turbine, a solar unit, a fuel cell and a storage battery is searched by a mixed-integer linear programming implemented in General Algebraic Modeling Systems (GAMS). A Virtual Power Producer (VPP) can optimal operate the generation units, assured the good functioning of equipment, including the maintenance, operation cost and the generation measurement and control. A central control at system allows a VPP to manage the optimal generation and their load control. The application of methodology to a real case study in Budapest Tech, demonstrates the effectiveness of this method to solve the optimal isolated dispatch of the DC micro-grid renewable energy park. The problem has been converged in 0.09 s and 30 iterations.

1. Introduction

Keeping the balance between load and generation is the basic rule of all power systems. In the autonomous power supply systems, as spacecrafts, airplanes or small islands, the critical amount of fuel and specific program of the generation capability give the scheduling problem special importance.

In the power system the daily load curve can be well forecasted. The forecast is based on statistical, analytical or technological models.

Characteristics of the system elements:

- Load – The power system contains controlled and uncontrolled loads. The time curve can be well forecasted.
- Generator – The generators have many constraints that are minimal/maximal capacity, fuel amount (total generated energy) and speedup ratio.
- Storage – A large amount of electricity can't be stored economically. Only small systems use super condensers and batteries, the greater systems contain pumped water storage, pressurized air, hydrogen generator, etc. The storage units have double characteristics: these are loads with limited capabilities, and later they may turn into generators. Due to the losses of transformation the storage has never 100% efficiency.

The scheduling problem exists in all power systems [1]. In the autonomous isolated renewable power systems and in the isolated micro-grids for the limited power source, the dynamic portfolio management is really important.

Nowadays there is an upward tendency for using small isolated power systems, against central power producing system when regarding rural and distant places [2].

In this type of system the most important producers are the renewable sources of energy (e.g, photovoltaic panels (PV), fuel cells, wind turbine, etc.) in combination with diesel generators. These small power producing networks need a distributed and autonomous power generation control [3–4].

Interest in small isolated power systems is also attractive for power utility companies, since they can help in improving the power quality and power supply flexibility. Also, they can provide spinning reserve and reduce the transmission and distribution costs, and can be used to feed the customers in the event of an outage in the primary substation [5].

Although the advantages of using small power systems are considerable, the systems that subsist only from a unique renewable energy source, have their differences because if the source considered is wind power it has more availability than one using photovoltaic panels. Adding storage capability increases the availability more for solar-based systems [6].

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2. VPP operation

The aggregation of DG plants gives place to a new concept: the Virtual Power Producer (VPP). VPPs are multi-technology and multi-site heterogeneous entities. In the scope of a VPP, producers can make sure their generators are optimally operated. At the same time, VPPs will be able to commit to a more robust generation profile, raising the value of non-dispatched generation technologies [7].

The VPP can also operate in isolated networks. In this type of installation the VPP can detain the system management and equipment functioning responsibility.

VPP can reduce maintenance and operation costs of the isolated system and increase its efficiency.

The system management is made at distance, providing the possibility of controlling the aggregated producer's generation that is connected to the network and at the same time all the isolated power system (generation and consumption) [8]. It's possible to manage several isolated grids at the same time.

This type of management has many particular specifications, implying some adjustments to the VPP.

One of the differences is the aggregation goal. The "normal" VPP was as primary goal combine the generation of aggregated producers to sell the biggest quantity of energy in the market, to remunerate the producers and profit to it self. When VPP is managing isolated grids the most important goal is to deliver the necessary energy to assure the optimal function of loads. Therefore, it's necessary to manage the reserves and good operation of controllable generation units (fuel cells and micro-turbines).

Other important aspect that VPP has to consider in the isolated grids is the need to control the generation and the consumption. Since the system is isolated, some times, VPP has to disconnect some loads, to maintain the system balance, when the generation isn't enough.

The VPP can develop DSM (Demand Side Management) strategies to advert the users of the problems that can arise because of wrong electric energy usage.

In isolated grids, the VPP has control of all the system, therefore has to have voltage and frequency control methods and mechanisms that permits to adjust these parameters to obtain an adequate quality service to the consumers demands.

The existence of many isolated grids, that are geographically near and that are managed by the same VPP, can provide an interconnection of these systems, increasing more resources, dimension and stability for all systems [9].

The associated costs of these interconnections are proportional to the distance between grids, being an important restrain to this type of application. These interactions have to be done in MV to maintain a good voltage level and to reduce the transmission losses.

These installations can be useful to develop strategies and methodologies for VPP use, where there is the possibility of island actuation in incident situations, considering the of active networks utilization.

3. Budapest Tech equipment

In the Budapest Tech exists a small renewable system that has a wind turbine, photovoltaic panels and a fuel cell. The test system is implemented at the roof [10] (Fig. 1).

The equipment of generation has the following characteristics:

- Photovoltaic panel(s) – type: DS 40; Nominal power: 40 W; Expected production of 4 panels 150 W peak
- Wind turbine – type: Air-X 401; Nominal power: 400 W at 11.5 m/s; Daily production (day and night) approx. 800 Wh

Fig. 1. Budapest Tech renewable system.

- Fuel cell – type: Flexiva; Nominal power: 80 W
- Load – Practically lighting bulbs; Nominal power: 20–100 W (controllable)
- Storage – Storage maximum charging capacity: 200 W; Storage maximal discharging capacity: 50 W

Many of them generate power in the form of direct current (e.g. PV, fuel cells) or in the form of alternate current at a different frequency from the required 50 Hz (e.g. wind generators, micro-turbine). Therefore, the system containing these sources requires a power electronic interface. The system can be represented with the following scheme (Fig. 2).

The system can be operated connected to grid or in isolated system. In both situations, the control of all equipment is done with a centralized system for measurement and control. With this control system, it's possible to measure the generated energy by the wind turbine, photovoltaic panels, fuel cell, storage discharging and the energy consumed by the load. With the central control is possible regulate the fuel cell, the storage and the load, for balancing the system in according with the defined strategy [11].

It's also possible compare the forecast values of wind turbine and photovoltaic panels generation with the real values. This possibility allows a better system management.

The generation capability of the different units will be on-line monitored, and remotely switched by the scheduler.

When there is unbalance between active power generation and active power load demand, the frequency deviates from its nominal value. Therefore, the isolated system should be able to maintain frequency in an acceptable operating range to ensure power quality [12].

In a further extension the remote switches will be realized on IP base, so the physical micro-grid will be extended to virtual micro-grid (Fig. 3).

4. Problem formulation

For the formulation of the problem we take a real case of the Budapest Tech system and develop a VPP operation in the isolated grid as following structure. Fig. 4 presents the structure of real case study system.

For the optimal operation system, the VPP same information needs, to define the amount of energy generated by wind energy, photovoltaic energy, fuel cell and the storage battery charging and discharging taking into account the following considerations: