Dynamic Optimisation for Power Dispatch in Microgrids

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***Abstract*—The increasing growth of non-dispatchable renewable energy sources (RES) such as solar and wind and the upcoming plug-in electric vehicles (PEVs) makes the secure power dispatch a challenging optimisation. In this paper, a coordinated power dispatch strategy in microgrids with a battery management system is proposed. The power dispatch strategy dynamically fits the power production to the power demand by appropriately dispatching the controllable distributed energy resources (DER). A strategy is presented where an active battery scheduling system includes the load and generation profiles of the microgrid and the electricity prices of the spot market in order to maximise the microgrid revenue.**

***Index Terms*—Microgrid, power dispatch, multi-objective optimisation, energy management.**

I. Introduction

Distributed generation (DG) and storage become part of the modern energy structure. Unfortunately, conventional energy grids are not designed for the bidirectional power flows in the distribution networks. Moreover, the aging electrical distribution networks are not actively managed, i.e., they are conceived as passive facilities of the transmission network in which the control and stability is achieved. The challenge of ensuring a reliable and sustainable electricity supply is driving the need for technology improvements in electricity networks. Besides, the enormous efforts in the pursuit of low-carbon economy have led to a huge boom in the use of intermittent renewable energy sources (RES). The increasing growth of distributed electricity production and the unpredictability of electricity consumption could lead to grid congestion problems. As these techniques grow in popularity, so do the challenges. Control strategies for the coordinated power dispatch of distributed energy resources (DER) gain importance [1]. The microgrid concept, with a more reliable and more sustainable framework, is a promising approach and forms a solution to this challenge. A microgrid is an active distribution network defined as an integrated power delivery system. It consists of a low-voltage (LV) network including DG units, storage devices and (controllable) loads and behaves as a single controllable entity. A microgrid can provide both power and heat and may be operated to achieve several objectives, such as market participation, reducing the electricity cost through flattening of the load profile, and CO_2 reduction by maximising the use of RES. The priority goals of a microgrid are to provide a coordinated integration of DG in the electric power system, to improve the reliability, and to allow a more efficient use of energy [2]. Due to the dynamics of RES, different generator power dispatch levels and external grid characteristics, a microgrid can be characterised by specific operations and limitations [3]. Taking into account these criteria, the microgrid needs a flexible energy management system (EMS) [4], [5]. In this paper, a coordinated power dispatch strategy in microgrids with a battery management system is proposed. For the development of the dynamic optimisation for power dispatch in microgrids, we have further improved the microgrid environomic scheduling approach we have developed in our earlier work [6]. The power dispatch strategy aims to fulfill the time-varying energy demand at lowest cost and lowest emission, and presents a battery scheduling systems which takes into account the load and generation profiles and the electricity prices on the spot market. This paper is organised as follows: Section II describes the microgrid power dispatch in which an existing environomic dispatch strategy is described briefly, followed by an introduction of a microgrid battery management system. Section III describes the formulation of the optimisation problem. The implementation of the algorithm is presented in Section IV.

II. Microgrid power dispatch

A. Environomic power dispatch

In [6] we developed an environomic microgrid scheduling approach where the focus was on the dynamic response of the microgrid in terms of dispatching the power among different DER in an economically and environmentally sound way. Due to the intermittency of the RES involved and the multiple objectives that needed to be satisfied, the power dispatch system calculates the generator setpoints quickly and continuously. Operational constraints such as generator limits and power the balance were satisfied. The microgrid concept, used in this work, is presented in Fig. 1. It consists of an industrial park including fuel-based thermal generators (micro turbine, diesel generator and fuel cell), renewable energy production by wind turbines and photovoltaics, a battery device, and two manufacturing companies with a varying demand profile. To improve the matching performance of the power generation and consumption in the microgrid, the power dispatch application dynamically fits the power production to the power demand by optimally dispatching the controllable DER and the storage device. Additionally, the microgrid features a storage unit. Stored energy was controlled to balance the power generation of renewable sources, to cover the overall microgrid demand and to optimise the overall power exchange between utility grid and microgrid. Simulations were carried out with real measurement data of Ghent University and were performed over one day with a sampling time of 15 minutes. The microgrid demand and the renewable energy production is presented in Fig. 2. In order to meet the microgrid demand, the micro sources were dispatched according to the minimum operating costs and minimum emissions. The power dispatch profile, which is presented in Fig. 3, follows the shape of the microgrid demand profile. Between 5 p.m. and midnight, the surplus of the energy produced by RES (presented in Fig. 2), while feeding the requiring loads, was stored. Within this period, the microgrid demand is covered by RES and the micro sources are dispatched to zero. Stored power was used during periods when no sun and no wind are available, and was used instead of using power from the utility grid, as shown in Fig. 4. The proposed scheduling approach reduces the microgrid operating costs and emissions, and reduces the power exchange with the utility grid.

B. Battery

In the application described above, the storage unit participates passively in the optimisation strategy. It will only be charged with the surplus of renewables and discharged to minimise the use of the utility grid. The charging and discharging process of the storage device does not consider the electricity price of the spot market.

The main contribution of this paper is the improved power dispatch strategy for microgrids in a emission-constrained competitive environment. The optimisation method finds the optimal trade-off between maximising profit (or equivalently minimising the microgrid operating cost) by managing the micro sources without excessive emissions [7]. Additionally an active battery scheduling system considers the load and

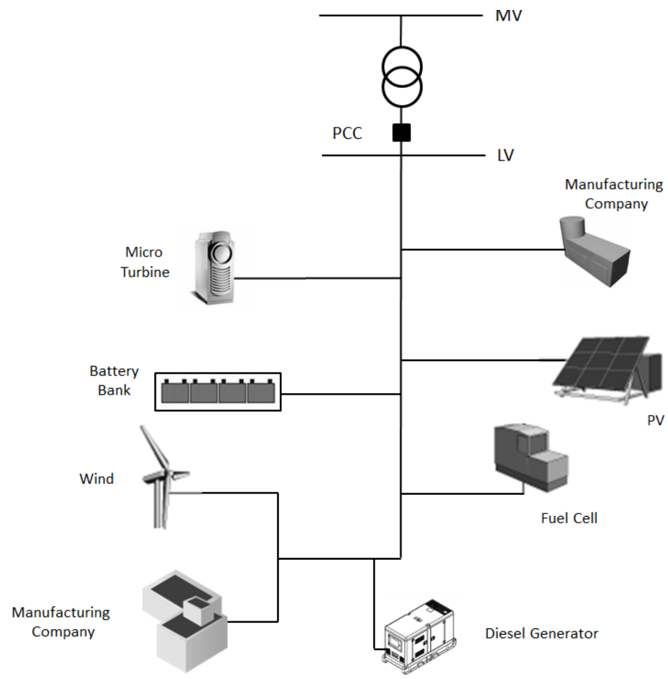

Fig. 1. Microgrid concept

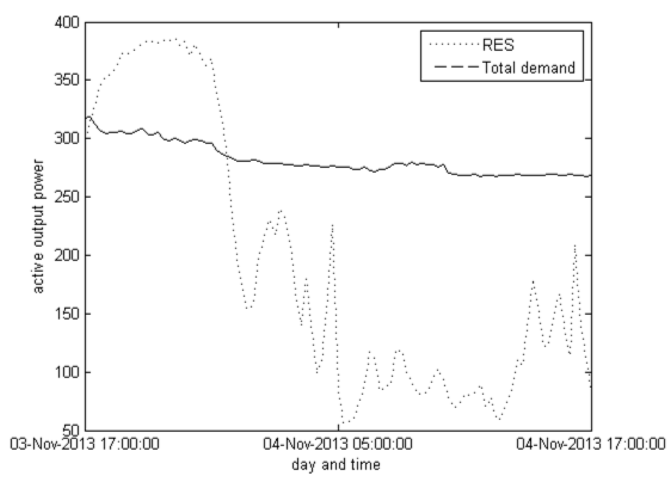

Fig. 2. Microgrid demand and renewable energy production

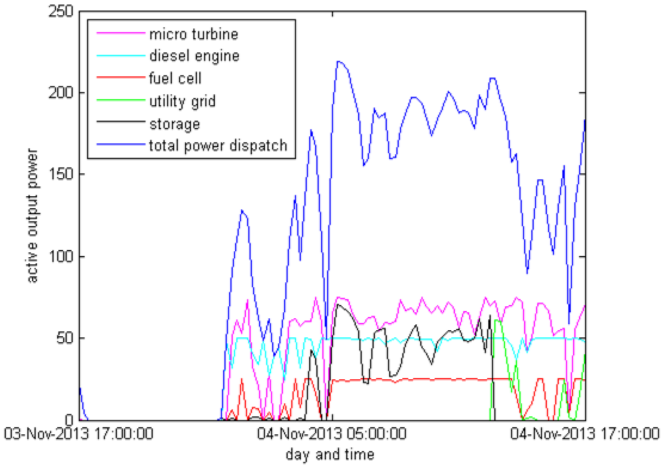

Fig. 3. Microgrid environomic power dispatch

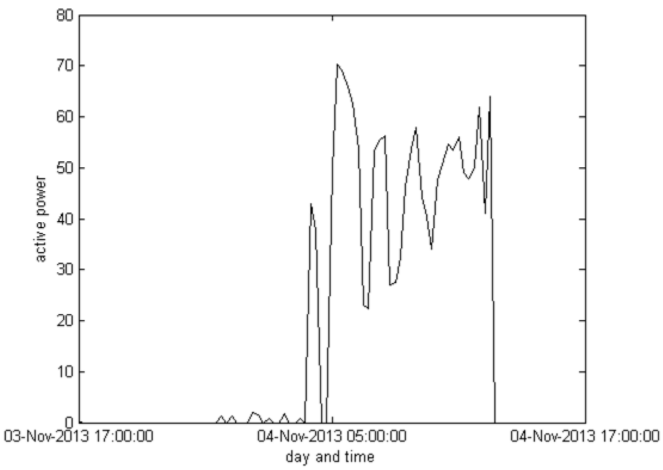

Fig. 4. Battery discharge

generation profiles and the electricity prices in order to maximise the microgrid revenue [8].

A similar microgrid model, as presented in Fig. 1, will be used for the dynamic optimisation strategy. The microgrid operates in grid-connected mode, and can sell and purchase electricity to and from the utility grid. Local energy is produced by DG units and RES, and energy can be stored using the storage device. Two manufacturing companies provide a varying energy demand profile and are considered as non-controllable loads. The microgrid coordinated power dispatch strategy minimises the overall microgrid operating cost and the CO_2-emissions while satisfying operational constraints. The battery management system will further reduce the overall microgrid operating cost by importing power during the cheap hours and exporting power during more expensive hours.

III. Formulation of the optimisation problem

A. Mathematical battery model

An efficient storage scheduling strategy for a microgrid battery system takes in to account the load and generation profiles, and electricity price for every 15 minutes. By optimal scheduling the charging and discharging process of the battery system, the microgrid operating cost can be further reduced [9], [10]. The optimisation of the storage device can be described as

$$\min_{b(k)} \sum_{k=1}^{N} E_{grid}(k).C(k) \tag{1}$$

Where k is a single unit of time (here 15 minutes will be considered). N is the total number of repetitions of the 15-minute intervals (here, 96 time steps will be considered which form a 24-hour simulation). $C(k)$ is the market price of electricity in €/kWh for k. E_{grid} is the exchanged energy with the utility grid, where negative values stands for energy export to the utility grid. Local production by RES and the dispatchable generators, as well as the microgrid demand and the charged and discharged energy from the battery are incorporated in E_{grid}.

$$E_{grid}(k) = E_{gen}(k) - E_{demand}(k) + b(k) \tag{2}$$

where, $b(k)$ is the charged (+) and discharged (-) energy of the microgrid battery in one time period. $b(k)$ forms the decision variable of optimisation problem which is bounded by charge and discharge rates and the lower and upper bounds of the energy level stored in the battery.

$$E_{battery}(k+1) = E_{battery}(k) + b(k) \tag{3}$$

$$E_{lb} < E(k) < E_{ub} \tag{4}$$

IV. Algoritm implementation

Considering the objective function bounded by several constraints, which have a linear decision variable $b(k)$, the optimisation strategy can be defined as a linear programming (LP) optimisation problem. Linear programming involves the minimisation of the objective function, described in (1), bounded by linear equality and inequality constraints, described in (3) and (4). The linear programming formulation of the mathematical battery model has the advantage of being easy to be solved by the Matlab optimisation toolbox. In several practical applications, such as operational optimisation or profit maximisation, the linear programming method reformulates the problem which makes it easy to implement. To determine the effectiveness of the proposed battery scheduling system, this optimisation method will be implemented using the MatLab *linprog* function and integrated in the existing environomic dispatch model. This creates a multi-level optimisation, where different models of a system will be used. The first level will cover the microgrid demand at the lowest cost and lowest emission, bounded by its constraints. Subsequently, a second level controls the battery management system, which aims to reduce the microgrid operational cost, taking into account the price of electricity.

V. Conclusion

Simulation results of the microgrid power dispatch system confirms the effectiveness of the environomic scheduling system with reduced microgrid operating costs and emissions. Still, there is room for improvement by integrating an active battery management system and participation in the electricity market. This paper analysed how a battery unit can actively participate in the dispatch strategy of a micro grid. A strategy is described where an active battery scheduling system includes the load and generation profiles of the microgrid and the electricity prices of the spot market in order to maximise the microgrid revenue. Simulations are in progress and results will be published in the another paper.

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