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Dynamic Optimisation for Environomic Power Dispatch in Microgrids

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As a result of the increasing number of distributed energy resources (DER) in the electrical grid and their commitment to future market participation, control strategies for the optimal operation of DER gain importance. For this scenario a microgrid is a promising approach and forms a solution to this challenge. Microgrids are subsystems of the distribution grid including distributed generation (DG) units, storage devices and controllable loads, and can operate either connected or isolated from the utility grid. Ensuring a smooth, reliable and economic operation of a microgrid requires an energy management system that dynamically fits the production to the consumption in combination with storage. Quick response of the energy management strategy is crucial for a microgrid as compared to a conventional energy system. In this paper, a formulation of the environomic power dispatch approach in microgrids is proposed which uses multiobjective optimisation. The application aims to fulfill the time varying energy demand while minimising the costs and emissions of the local production and imported energy from the utility grid. With the introduction of a storage device, stored energy is controlled to balance the power generation of renewable sources, cover the overall microgrid demand and to optimise the overall power exchange between utility grid and microgrid. Operational constraints such as generator limits, start-up, operation and maintenance costs and the intermittency of renewable energy sources (RES) are to be satisfied. A representative microgrid structure is studied as an example and some simulation results are presented to demonstrate the performance of the microgrid environomic power dispatch approach.

1. Introduction

The deployment of microgrids becomes an essential part in the evolution toward smart grids. Microgrids are considered as an approach to deal with the integration of decentralised unpredictable power sources, the aging grid infrastructure and the increasing power consumption. Microgrids are small-scale electricity networks, consisting of an aggregation of DG units, (controllable) loads and storage elements, that are connected to the utility network through a single point of connection, the point of common coupling (PCC) (Vandoorn and Vandevelde, 2014). In a microgrid, the energy is generated near the loads, enabling the use of small-scale generators, which reduces the power line losses and feeder losses and increases the reliability of power supply. In order to optimise the power flow within the microgrid, distributed dispatchable generators and controllable loads can be coordinated by a local energy management system (EMS). Due to the single connection point between the microgrid and the utility network, microgrids can operate in two conditions; grid-connected and islanded mode. Depending on the operating mode, the microgrid can manage several technical challenges, such as power quality (Gorbe and Magyar, 2011), reliability, peak load limitation (Ghoneim, 2012), cost and emission reduction, etc. The efficiency of the microgrid operation strongly depends on the storage capacity and scheduling process. Storage devices can be used as an energy buffer during islanded mode and to improve the microgrid resilience in the moments subsequent to islanding (Moreira and Lopes, 2013). Coordinating energy storage can be crucial to mitigate the intermittency of renewable energy production (Wu et al., 2013). Compared to conventional approaches such as fast ramping generation, energy storage is much more environmentally friendly. Additionally,

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energy storage has the potential to reduce the system cost by reducing the curtailment of renewable energy sources (Qin and Rajagopal, 2013).

Managing distributed energy resources in an economical and environmental way, requires a multi-objective microgrid control (Abido, 2006). This paper addresses the dynamic optimisation for environomic (environmental/economical) power dispatch in microgrids. In (Deckmyn et al., 2014), a study was done and demonstrated on a distribution grid model based on a campus of Ghent University. The environomic scheduling approach accounts for the minimisation of the fuel costs and the CO_2-emission of the locally generated energy. In this paper, compared to (Deckmyn et al., 2014), storage is included. With the introduction of a storage device, the stored energy is controlled to balance the power generation of renewable energy sources, cover the overall microgrid demand and to optimise the overall power exchange between utility grid and microgrid. The load flow equation and several operational constraints are to be satisfied. Data sets of demand and renewable energy production were used, and the optimisation has been implemented in Matlab/Simulink. The paper is organised as follows: Section II describes the formulation of environomic power dispatch problem. Section III describes the microgrid dynamic optimisation. A microgrid case study is presented in section IV. A demonstration and validation is given in Section V.

2. Environomic power dispatch

The environomic power dispatch problem involves the minimisation of two competing multi-component objective functions, fuel cost and CO_2-emission, subject to a set of constraints. The problem is formulated as follows:

2.1 Problem formulation

The generator fuel cost and the CO_2-emission can be described as quadratic functions. Both are a function of the generator output power and include cost and emission coefficients. Aggregating both objectives and the constraints, the microgrid dispatch problem can be mathematically formulated as a nonlinear constrained multi-objective problem.

$$Min\left(C_j\left(P_{gi}\right), E_i\left(P_{gi}\right)\right) \tag{1}$$

where $C_i(P_{gi})$ presents the fuel cost as a function the generated power in €/h of the dispatchable thermal generators (i.e. diesel generators, gas micro turbines, biomass power plants and fuel cells). $E_i(P_{gi})$ forms the emission function, where E_i is the emission in kg/h and P_{gi} is the power generated in kW.

The minimisation is subjected to linear equality and inequality constraints including power balance and generation active power limits.

$$P_D^a + P_L - \sum_{i=1}^{N_G} P_{GI} = 0 \tag{2}$$

Where P_D^a, is the actual demand and P_L are the losses in the power lines. P_{gi} is the active power output of the ith generator and N_g is the number of generators.

$$P_{GI}^{\min} < P_{GI} < P_{GI}^{\max} \tag{3}$$

P_{GI}^{min} and P_{GI}^{max} are respectively the active power limits of each generator. The power dispatched among the different generators must cover the actual demand P_D^a and the losses P_L in the power lines in order to ensure a power balance. With the introduction of a storage device, stored energy E_{st} is controlled to balance the power generation of renewable sources, cover the microgrid loads, and to optimise the overall power exchange between utility grid and microgrid. The surplus of energy produced by RES during the available period T_a , while feeding the requiring loads in order to obtain a stable system operation, can be stored. Stored power P_{st} can be used during unavailable periods T_u, when no wind and no sun is available. Since RES, such as PV and wind, producing power at zero running cost and zero emissions, their output dpower can be treated as a negative load. Therefore, the stored power P_{st} and the power generated by renewables P_{RES} are deducted from the total demand P_D^t. Figure 1 presents the power produced by the RES, and the total demand. To obtain the actual demand P_D^a, the stored power P_{st} during T_u will be deducted from P_D^t.

$$P_D^a = P_D^t - P_R - P_{st} \tag{4}$$

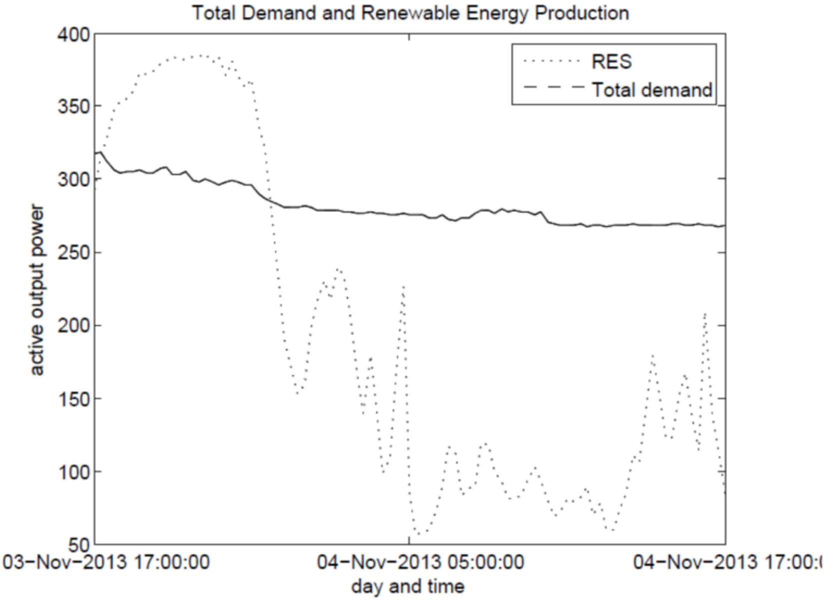

Figure 1: Total demand and renewable energy production

3. Microgrid dynamic algorithm

3.1 Optimisation Method

Minimising more than one objective function simultaneously can be performed by using the multi-objective decision making methods. Due to the competing objectives, the optimisation method has to find an optimum point between cost and emission. The method, which is used in this paper, is called the Pareto solver, based on genetic algorithm. This method finds the local Pareto front for the cost and emission functions. The Matlab multi-objective genetic algorithm function is robust and causes less computational burden. By defining the different decision variables, each imposed with bound constraints, the algorithm determines at each iteration the optimal use of the generators. In order to cover the actual demand, the method will dispatch the power, between their limits, among the different generators. In practice, generators usually have a lower bound which is not equal to zero. As a result, every generator will always be dispatched and no zero dispatch possible. To circumvent this drawback, the optimal point was found for every combination of generators and afterwards, the solution with lowest cost and lowest emission could be found from every optima.

4. Microgrid case study

4.1 Microgrid model

The microgrid, investigated in this paper, is presented in Figure 2. The low-voltage (LV) microgrid consists of 4 LV feeders connected downstream from MV/LV distribution transformer. The microgrid load consist of a small manufacturing plant and a commercial building. Energy is generated by a 25 kW Solid Oxide fuel cell, a 75 kW microturbine and a 50 kW diesel generator. Renewable energy is produced by a 20 kWp rated photovoltaic (PV) and three 130 kW wind turbines. Serving the microgrid load, electric power can be produced either by the dispatchable microsources, RES, or the storage device. The production profiles of the wind turbines and photovoltaic panels were obtained through measurement data. The actual demand profile, for the case no storage was implemented, is presented in Figure 3. Due to the overproduction of the RES, a negative actual demand can be observed on 11/03/2013 between 17:30:00 and 23:30:00.

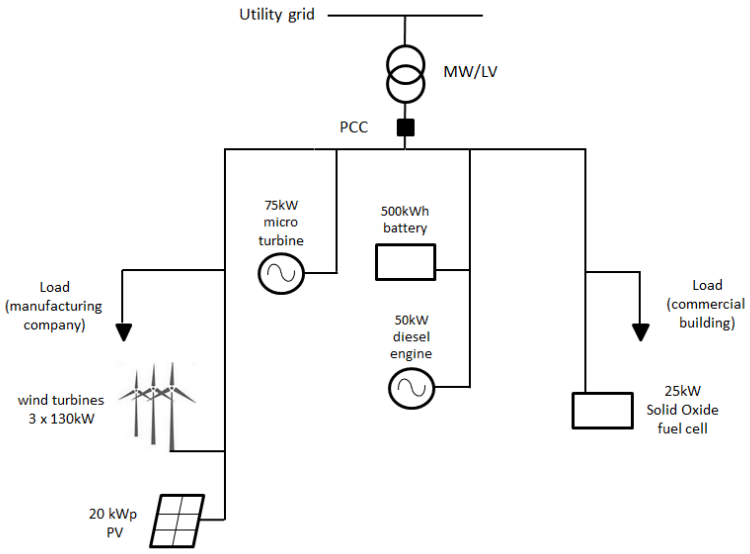

Figure 2: Microgrid model

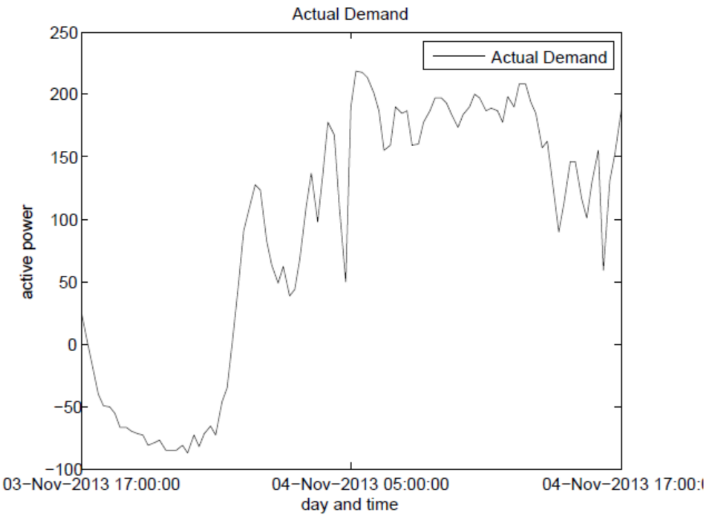

Figure 3: Actual microgrid demand

4.2 Storage

In order to optimise the use of the RES and the overall power exchange between utility grid and microgrid, a storage device was implemented in this work. Based on the negative actual demand in Figure 3, a 250 kW, 500 kWh zinc-bromide battery (Fu et al., 2012) was implemented. Whenever the supply of the RES exceeds the microgrid load demand, energy will be stored in the battery. The battery will be discharged (treated as a negative load) when the produced power of the RES is insufficient to serve the microgrid load, and to reduce the use of power from the utility grid. Discharging the battery instead of using power from the utility grid, will reduce the microgrid operational cost and emissions.

5. Demonstration and validation

Simulations were done with real measurement data of Ghent University, containing production profiles of wind and PV, and a demand profile. The produced power by the wind turbines and the photovoltaics is used to cover the total load, and determines the actual demand profile. Subsequently, the algorithm dispatches the power, subjected to the constraints, among the generators to serve the actual load. In a first simulation, no storage was used, whereby the overproduction produced by RES (negative actual demand) will be injected into the utility grid. The curves presented in Figure. 4 shows the power set-points dispatched by the algorithm without using a storage device. In this work, a storage device was added whereby the surplus of energy produced by RES during the available period T_a, while feeding the requiring loads, can be stored. Stored power P_{st} can be used during unavailable periods T_u and can be used instead of using power from the utility grid. Simulations are performed over one day with a sampling time of 15 min. The power dispatch profile, which is presented in Figure 5, follows the shape of the demand profile. As a result, the power exchange with the utility grid is now captured by the storage device. Between 5 p.m. and midnight, the overproduction coming from the RES will be stored and used when local production cannot cover the total demand. On 11/04/2013 at 1 p.m., the storage unit is completely discharged and the shortage of locally produced energy will be supplemented by the utility grid.

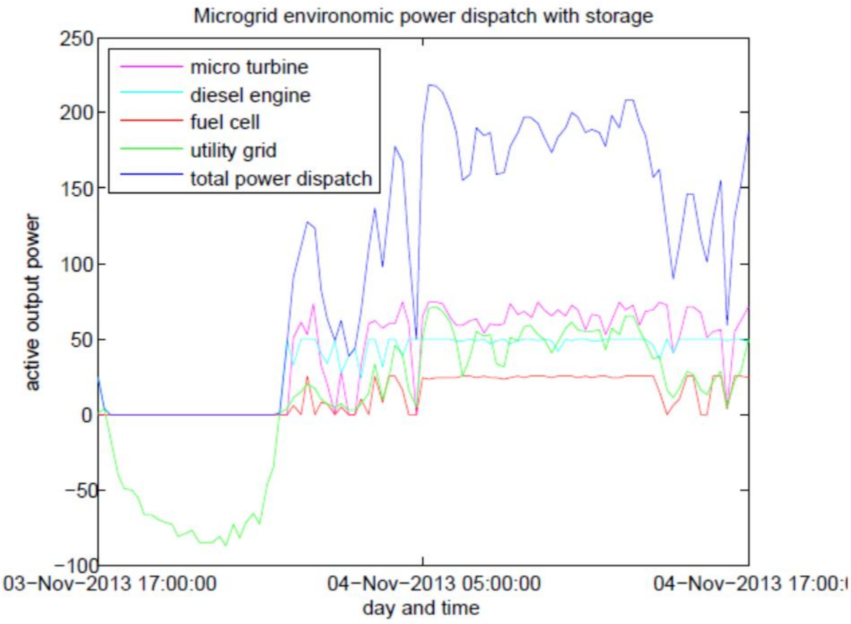

Figure 4: Microgrid environomic power dispatch without storage, in kW

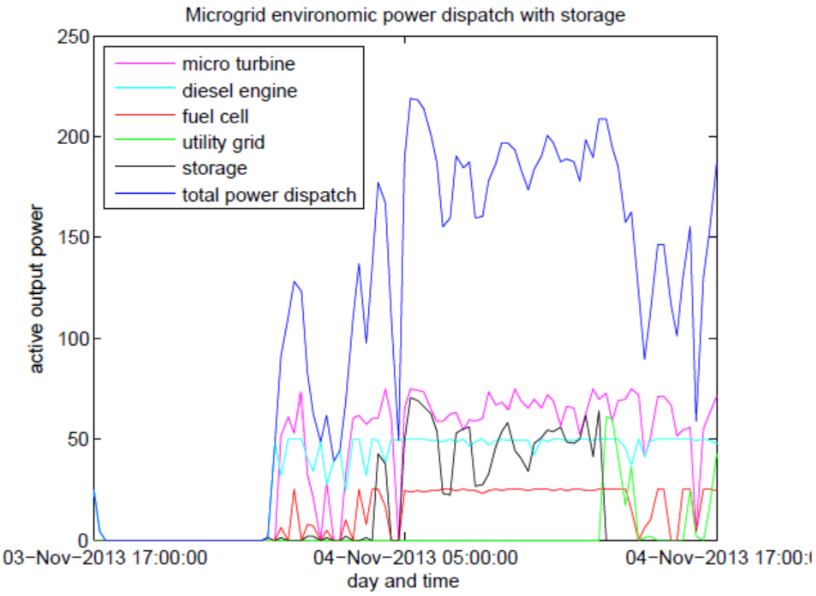

Figure 5: Microgrid environomic power dispatch with storage, in kW

6. Conclusions

In this paper, a power dispatch method for microgrids has been further improved. The efficiency of the microgrid operation strongly depends on the storage capacity and scheduling process. Due to the intermittency of the RES involved and with the introduction of a storage device, the stored energy can be controlled to balance the power generation of renewable sources and to optimise the overall power exchange between utility grid and microgrid. Adding storage minimises the power exchange with the utility grid and minimises the overall microgrid operating cost. The simulation results proved the effectiveness of the proposed scheduling system with reduced microgrid power exchange. The model can be used for different microgrid scenarios with different RES and demand profiles. The concept of the environomic scheduling system can be extended or further improved with market conditions, which changes the microgrid control into a profit based control.

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