POWER SCHEDULE OF DISTRIBUTED GENERATION IN CLUSTERED LOW VOLTAGE NETWORK

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ABSTRACT

In this paper the power schedule of distributed generation will be presented in regard to minimise system operation cost of the low voltage (LV-)network and resultant to minimise the power supply by the medium voltage (MV-) network. Therefore, a clustered LV-network has been established in order to implement a different amount of distributed generation units (DGU), here microturbine into the network. The optimisation problem will be introduced with its objective function and constrains to solve the unit commitment. Finally, a case study is given to discuss the technical and economical effects referring the network.

INTRODUCTION

The problem of power schedule is very well known in the electricity industries. During the last years every power supplier has solved the unit commitment to enhance their economics. With the deregulation of the energy market, power generation and system operator have been separated and new independent power producers are getting market access. The concept of pooling distributed generation units is named virtual power plant. New circumstances are taking place and have to be considered, like the implementation of distributed generation into the power schedule of daily forecast.

Actually, the discussion of increasing demand and the simultaneous decrease of installed power and the German back out of the nuclear energy programme, even considering the ageing structure of power plants, an energy gap will be arisen of about 300 GW in Europe until 2020 [1]. To counter steer this process, the application of distributed generation will be a possible resource in supporting the power supply.

In addition to this process, the abidance of carbon dioxide retrenchment according to Kyoto Protocol has to be maintained. Therein distributed generation offers the possibility of combined heat and power and a better fuel utilisation is achieved, which includes a decrease of carbon dioxide.

Finally, the increase of fuel prices of oil and gas as primary energy source can be recognised at the market. Power generation is getting more expensive compared to the past and distributed generation represent nowadays an attractive alternative to traditional thermal power plant and are getting even more economic with rising prices.

CLUSTERED DISTRIBUTED GENERATION

The integration of distributed generation makes great demands on the system operator and the electrical equipment. Different researches have been done to analyse the retroactive effects caused by the mircroturbine and the decentralised power generation. With the clustered distributed generation a clearly arranged method is established for analysing the impact of distributed generation [2]. The model network, based on structural characteristics, consist of three housing units (HU) and their DGU are merged into one cluster. Within the cluster the power ratio of DGU and load demand can very between:

$$0 \le \frac{1}{3} P_{load} \le \frac{2}{3} P_{load} \le P_{load} \qquad (1)$$

Even the operation mode of the DGU can be changed from full load operation to following the load profile of the housing units. A basic structure from MV-network with the cluster is given in Figure 1.

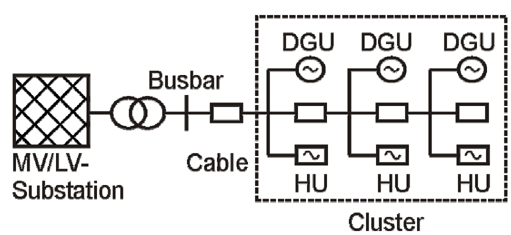

Figure 1: Clustered distributed generation

In different studies the cluster has been connected in serial and parallel, under consideration of different feeding and demand ratios, to locate the technical influences. Considering as reference on power quality EN 50160 to analyse the interactive changes, it can be concluded, that network limits are kept in range during the both operation modes. Only in the mode following load profile, the simultaneous start up of DGU has been identified as most critical factor, because of rapid voltage jump, which has to be avoided. Respectively to the power losses it can be concluded, that a combination of both operation modes will lead to least possible power losses with entire distributed power supply. This combination of different operation modes at different points of time follows to the idea of a virtual power plant and results into a distributed power schedule.

POWER SCHEDULE OF DISTRIBUTED GENERATION

The power schedule is used in daily operation to specify the power generation order from cheapest to dearest generation cost, to satisfy the demand of the customer and to minimise system operation cost. Generally, the forecast horizon constitute 24 hours with an increment of 15 minutes, even so load data has the same division. Within the optimisation process, constrains have to be fulfilled respectively physics and economics of the DGU and the network. First assumption of the power schedule is, that the distributed generation is limited to maximum demand of the LV-network to prevent reverse feeding into the overlaid network. On that account any changes in power protection are needless.

Optimisation problem

The given power system consist of I distributed generation units to be scheduled over the time horizon T, to determine the commitment and generation levels of all DGU and the remaining power from the MV-network, to minimise system operation cost C. The objective function can be formulated as a discrete linear optimisation problem:

$$\min C = \sum_{i}^{I} \sum_{k} \sum_{t}^{T} P_{ik} \cdot c_{ik} \cdot x_{ik}(t) + P_{MV} \cdot c_{MV}(t) \qquad (2)$$

where, P_{ik} is the generation level of unit i in the discrete cost function interval k, c_{ik} is the according generation cost, x_{ik} is binary variable of the cost in a time interval t, P_{MV} is the delivered power from MV-network with its cost c_{mv} in the same time interval t.

The objective function is subject of several constrains such as power generation level, on/off status of the DGU and with respect to power balance equation, which is given as followed:

$$\sum_{i} P_i(t) + P_{MV}(t) = P_d(t) \quad \forall t = 1,2,..,T \ . \qquad (3)$$

According to the Equation 3, the system demand P_d will be supplied by the sum of distributed generation and the medium voltage network, which additionally represents the required system reserve.

Regarding the DGU the following constrains have to be added. The electrical power generation is limited to the boundaries of the DGU, which again depends on construction of the manufacturer. Its Equation is given as next:

$$P_{i\,\min} \le P_i \le P_{i\,\max} \quad \forall i = 1,2,...,I \ . \qquad (4)$$

Taking the on/off status into account, in this paper a different method has been established. Generally, the status is represented by binary variable, whereas in this treatment the status is implemented in the discrete cost function of the DGU.

For completeness two more assumptions have to be considered for the constrains. First one is the number of on/off cycles and the second is the start up function of the DGU. Temporary, there are no information available about the effects in life cycle at a large amount of starting sequences. Information about the start up behaviour are reserved only to the manufacturer. For this reason both constrains are neglected.

Discrete cost function

The main challenge in solving optimisation problems is to handle nonlinear constrains, which are generally existing in the start up function or cost power generation curve. Solving this kind of problems, heuristics in cooperation with optimisation techniques can be required. To get along with this fact, a discrete cost function of a microturbine has been created. Thereby the cost function k_{spec} itself can still remain nonlinear and is given in Equation 5 [3]:

$$k_{spec} = \frac{P_r(\eta) \cdot k_{fuel} + P_r \cdot k_m}{P_r} \qquad (5)$$

In dependency on the rated power P_r to electrical efficiency and its specific fuel cost k_{fuel}, which is result of the fuel cost. In the second term, maintenance cost are given with the product of rated power and specific maintenance cost k_m, whole divided by the rated power.

With the following restriction it has to be accepted, that only increment of power are available in the optimisation process and not any longer continuous power values. Therein, the special case is comprised, either the DGU is turned off or the actual generated power level. These increment of power are arbitrary selectable and the constrain for each generation unit can be expressed as:

$$\sum_{k} x_{ik} = 1 \quad \forall i \ , \qquad (6)$$

where

$$x_k = \begin{cases} 1, \text{ if in array k} \\ 0 \text{ else} \end{cases}$$

Under this point of view, the first expression in Equation 2, the objective function, is linear as well as the second and can simply be solved. Naturally, it is possible to extend the existing problem with additional constrains. As first step for analysing the following case study the formulation of the presented power schedule in mathematical terms is practicable.

CASE STUDY OF POWER SCHEDULE IN CLUSTERED LOW VOLTAGE NETWORK

In this case study, a low voltage network is researched, which is constructed similar to Figure 1 with four clusters connected parallel to the busbar. The study is performed in four steps, where in the first step no DGU is connected to the network. This scenario is the basis for further comparisons and valuations, because it is the actual status in the LV-network. The daily load curve of the first simulation, which will be recorded, is taken as input data of the power balance equation for the next analyses. In three steps, the power ratio of distributed generation to demand is increased according to Equation 1. Hereby, the distributed generation factor $P_i(t)$ in Equation 3 will be taken into account and the optimisation process can be started. Main focus in the technical and economical consideration will be laid on the energy losses and total generation cost in the LV-network. Currently, the benefit in installing DGU is not to be sneezed.

Technical aspects

In connection to the LV-network will only one type of DGU be regarded. These generation units are microturbines, which have been researched in previous work [3]. All typical parameters are given and the microturbine is connected to the LV-network by a power converter. The part load behaviour is limited, naturally, to the maximum rated power and the lower limit is given by the half of it and has a none linear behaviour.
Taking the MV-network into account, surplus power produced from the DGU can be absorbed even so a gap of power will be supplied. A constant frequency is given in any researched case and will kept by the thermal power plant in the transmission network.

Economical aspects

As a last step, some economical parameters have to be determined, like power generation cost in the LV-network and the discrete cost function of the DGU. Actually, the charge of electrical power in the LV-network constitute about 0,15 – 0,2 Euro/kWh depending on power supplier and geographical region. Using distributed generation is only sensible, if an economical benefit will be achieved. Therefore, the base scenario is supplied at an economy-price of 0,15 Euro/kWh. In further simulations, with distributed generation the charge of required power from the MV-network is increased up to 0,2 Euro/kWh. Here, a penalty fee is included in case of disturbances in the DGU and the use of balance energy. Consequently, this payment is the upper limit in the power schedule of distributed generation. If the price of the DGU is higher than this MV-cap, then its economical to turn DGU off and to purchase energy from the overlaid network.
The economic structure and the derived discrete cost functions of the distributed generation units is given as next. Identical economic structures of the DGU have to be avoided in the optimisation process, because of oscillation in the decision whether a DGU is turned on or off [4]. For this reason, the original sample of the discrete cost function in Figure 2 is given by DGU 1 and the remaining DGU are slightly modified.

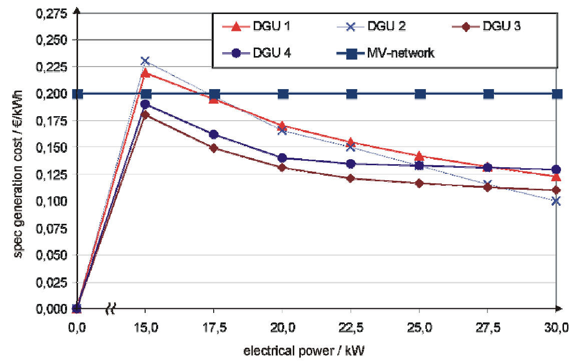

Figure 2: Discrete cost functions of microturbines

The notation of the presented Figure 2 is as followed. On the x-axis the electrical power is scaled beginning at zero, which describes that the DGU is turned off. The next breakpoint is given at 15 kW, which is half of the rated power and is increased in increments of 2,5 kW up to 30 kW, the maximum power output of the microturbine. On the y-axis the specific generation cost is displayed from zero to 0,275 Euro/kWh. The highest generation cost are located at the minimum power output, but the upper limit in the power schedule is given by the least generation cost of the MV-network.

Power Schedule

The minimisation process of the system operation cost in the LV-network has three times being accomplished. As typical case, simulation three is presented. Within this case study the ratio DGU to demand is 2/3, that means 8 microturbines are connected to the LV-network. In Figure 3 the power schedule of the introduced case study is displayed, enclosed by the daily load curve of the LV-network and fragmentation of the DGU.

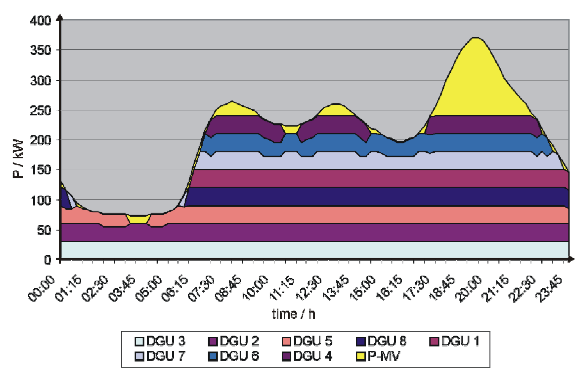

Figure 3: Power schedule of distributed generation

According to the amount of produced energy the DGU are ordered from most to less. Referring Figure 2, the least generation cost are given by DGU 3 at maximum power output, displayed by the blue cross. For this reason DGU 3 is always the first scheduled unit. The remaining power of the load curve in that time interval is responsible for the next classification and the next DGU is chosen with its least generation cost. All possible combinations are analysed within the optimisation process until the least system generation cost are located.

Two special cases within the load curve have to be discussed. At first the weak load situation at night. The demand is decreased down to 72 kW during this time. Two generation units are scheduled with full load and the generation gap is fulfilled by the MV-network. This can be explained on the basis of Figure 2 and the cost function. In the first step DGU 3 is selected at full load with least cost and the remaining power is counted to 42 kW, which has even to be scheduled. Any combination of the remaining DGU is dearer than the presented choice. For this case, it is economic to purchase power from the overlaid network and not to be supplied by distributed generation.

As second during morning, midday and evening peak load, where insufficient power is supplied by the DGU and the MV-network is required to satisfy the demand. All generation units are turned on at full load, but in this case study there is too little distributed power installed, balance energy is required and to be paid at high price.

RESULT & CONCLUSION

The power schedule of distributed generation has four times being performed with different amount of DGU respectively to the case studies. In Figure 4, the results of the technical and economical impact are displayed with the focus on system operation cost and energy losses of the network.

On primary axis the generation cost are given and the referring bars. With the secondary axis energy losses are given respectively to solid line. The x-axis represents the power ratio of produced power of the DGU to power demand. As mentioned before, the first case study is given as base scenario without any connected distributed generation.

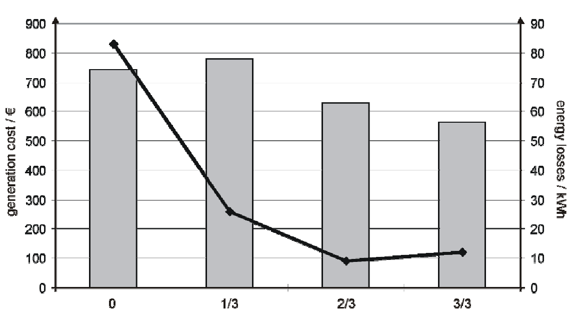

Figure 4: Technical and economical impact in LV-network

In the base scenario, the wholly demand is supplied from the MV-network at low price level and is calculated to 743 €, with energy losses of 83 kWh per day. Final intension in the following studies is to reduce system operation cost as well as energy losses.

Regarding the second case study, four microturbines are connected to the network. Especially in weak load time, the adjustment of the DGU to the load curve is unsatisfying, against to peak load, where all DGU are working at full load and additionally a large amount of expensive balance energy is required. This results in higher system operation cost of about 4.8 %. On the other side, the energy losses have been highly decreased down to 26 kWh per day, which correspond 78 % to the base scenario. This can be traced back on the energy retrenchment of the MV-network, which has a deep impact on the energy losses.

Regarding the third case study, the extension of distributed generation finally leads to a decrease in system operation cost. Balance energy can successfully be reduced and the regarded power systems, existing of 8 micro turbines, is cost effective compared to base scenario. Additionally, the energy losses have been reduced again down to 8 kWh per day.

In the last study 12 microturbines are connected to the LV-network and the adjustment to the load curve is the most suitable. Regarding the economic, the cost have finally decreased down to 565 €. But the energy losses have slightly been increased up to 12 kWh per day, which can be referred to changes in power flow within the LV-network.

Finally, the application of distributed generation has a possible economical and technical benefit. At first noticeable in retrenchment of power losses, afterwards with increased distributed generation in reduced operational cost.

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