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Distributed co-generation plants as balancing energy supply

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Abstract: Sustainability in future electricity generation requires the optimisation of the triangle of energy demand, environmental aspects and cost. In Germany, balancing energy is unavoidable due to powerful wind power plants and the so called renewable energy law. This paper discusses balancing energy supplied by small and decentralized co-generation plants considering technical, economical and ecological aspects. Altogether, co-generation plants seem to be promising as balancing energy supply.

Key-Words: co-generation, balancing power, balancing energy, wind power plants, heat demand

1 Introduction

Scientists all over the world expect an increasing demand for electricity. In parallel, the importance of environmental awareness increases. Today's energy production is based on existing assets with huge asset values. These have to be integrated into a new supply scheme in order to avoid stranded investments.

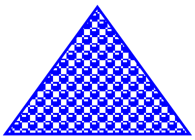

Fig. 1 Optimising the trade-off between ecological aspects, energy demand and cost as future challenge in research

Therefore the challenge of future research activities is to optimise the trade-off between environmental aspects, energy demand and cost (fig. 1).

The German activities in sustainable development are concentrated on building and integrating powerful wind power plants into the existing power system. Today Germany's onshore-installed wind power is 18.5 GW [1]. Moreover, there are several offshore wind parks approved in the German part of the Northern Sea. Per year, each onshore wind turbine is expected to supply maximum power for 1.750 hours and each offshore wind turbine for 3.500 hours. This power supply is stochastic and can be estimated from the weather prognosis. This estimated electricity supply is considered in the power plant schedule. In spontaneously windy or windless periods, grid stability is insecure. Furthermore, there is a lack of both storage capacities and technologies in case of windy periods with low electricity demand.

2 Unavoidability of balancing power and balancing energy in Germany

In Germany, wind farmers are allowed to supply electricity whenever wind blows. The price per kWh is also guaranteed by the German law about giving preference to renewable energies [2]. Unfortunately, wind does not exactly blow as estimated one day before. In this case, the grid supervisor additionally has to order either positive or negative balancing power to keep the balance between electricity supply and consumption. For 15 minutes, transmission system operators automatically provide balancing power on their own. This is the so called primary and secondary reserve. In order to keep this balancing ability, used balancing reserve should be substituted as soon as possible by so called minute reserve or tertiary balance offered in the balancing energy market [3]. The necessary balancing energy E_{BAL} for each 15-minute-period is calculated as follows:

$$E_{BAL} = E_{PPS} - E_{CONS} + E_{WP} - E_{WS} \qquad (1)$$

E_{PPS} is the planned energy supply according to the conventional power plants' schedule. E_{CONS} is the energy which is really consumed and can be well calculated due to long term experience. E_{WP} is the estimated energy output of the installed wind farms. E_{WS} is the real energy output from wind farms. Both the electricity consumption and the supply schedule of conventional power plants have been well planned for years [4]. Therefore, the influence of conventionally produced and total consumed electricity can be neglected and the need of balancing energy within each 15 minute period can be calculated as follows:

$$E_{BAL} = E_{WP} - E_{WS} \qquad (2)$$

In order to minimize the need of balancing energy, one option is to improve the wind power supply estimation. Today, the expected wind power is estimated 48 or even 72 hours in advance accepting an estimation error of 8% [5]. Although wind prognosis tools are improving, balancing energy is still needed now and in future. The German energy agency (DENA) assumes that the positive balancing power demand in the year 2015 will be between 8 and 9 % of the installed wind power [6]. Aiming a total installed wind power of 40 GW, the total installed balancing power has to be 3.2 GW.

Due to the challenge of optimising the trade-off between environmental aspects, energy demand and cost, providing positive balancing energy from small and decentralized co-generation plants seems to be one promising option. Within the following section, this option is discussed considering balancing energy demand, cost and environmental aspects.

3 Decentralized co-generation plants as positive balance energy supply

If the weather spontaneously is windy, but not stormy, the installed wind farms often supply more energy as estimated. In this case, negative balancing energy is needed. That implies a partial shut-down of conventional power plants. If the weather is spontaneously stormy or windless, the wind farms supply less energy than expected. In this case, positive balancing energy is needed. That implies running up additional conventional power plants or decentralized co-generation plants. The last option is discussed in this section. Concerning energy demand, the technical feasibility is evaluated. Furthermore, a cost development estimation based on economic models is performed. Additionally, ecological aspects are determined and considered.

3.1 Technical feasibility study of providing given balancing power demand

Firstly, the balancing energy demand is quantified for a certain region. Secondly, the demand of installed co-generation plants is determined by energy balances based on the quantified balancing energy demand. In this context, the characteristic curves of optional co-generation plant technologies have to be considered in order to achieve highest possible system efficiency. Furthermore, correlations between balancing energy demand and heat demand have to be analysed in order to guarantee highest possible heat use. Moreover, short-circuit-power, load-flow inversion, grid capacity, transmission losses, system reliability and power quality have to be examined before giving a professional opinion on technical feasibility of decentralized balancing energy plants. These additional topics are not discussed in this paper. The reason is that the total installed power in Germany is round about 120 GW and the total need of installed balancing power in Germany is only 2.6 % of all German power plants. Nevertheless, these aspects have to be discussed in detail before realising a concrete balancing plant project.

3.1.1 Analysis of balancing energy demand

In this paper, Vattenfall Europe's system operation area is chosen as concrete regional calculation model. It contains the eastern part of Germany and the city grid of Hamburg. In this region, wind power plants with a total power of 5.4 GW are installed. Furthermore, 18.6 million inhabitants live in this region [7]. Actually, Vattenfall Europe needs 2 GW balancing power and 2.7 TWh balancing energy. The plotted balancing power characteristic is representative for the whole year (fig. 4). Due to the unfavourable proportion of many wind power plants and low population density, Vattenfall Europe usually needs negative balancing energy.

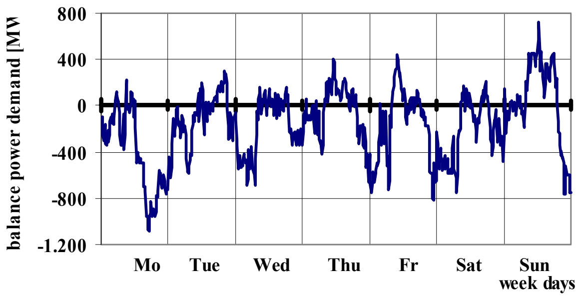

Fig. 2 Vattenfall Europe's demand of balancing power in MW, April 11-17th, 2004 [8]

In general, providing positive balancing energy means to switch on co-generation plants. Providing negative balancing energy means to switch off on demand running co-generation plants. Therefore, providing positive balancing energy is easier. The easiest way to provide negative balancing energy would be a partial shut-down of wind power plants. In Germany, this is only allowed in case of dire emergency [2]. But providing negative balancing energy is not the topic of this paper.

3.1.2 Balancing power potential per kW installed co-generation plant

The most common technology types of co-generation plants offered in the market are combustion engines, micro-turbines and fuel cells. In case of combustion engines and micro-turbines, the maximum of the electrical efficiency curve is reached in full-load operation. Although fuel cell stacks offer maximum electrical efficiency in part-load operation, the total fuel cell system also provides maximal electrical efficiency in full-load operation due to self-consumption of peripheral devices [9]. Therefore, the electrical efficiency characteristic of all named co-generation plants is shaped similarly (fig. 3).

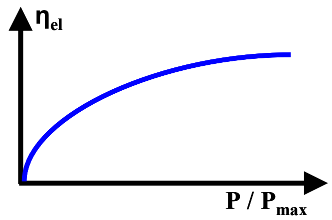

Fig. 3 Principle shape of electrical efficiency curve for each technological type of discussed co-generation plant

The electrical system efficiency is the main criterion for the operational mode of every electricity plant. Due to permanently optimized building insulation and solar heating systems, heat demand of household decreases. Therefore, the electrical efficiency especially of a co-generation plant has to be as high as possible. Respectively, co-generation plants supplying balancing power have to be operated in full-load mode. Due to this, the balancing power potential of a co-generation plant is equal to its installed electrical power. Furthermore, the decentralized power plant can be regulated by switching off single co-generation plants.

3.1.3 Lack of correlation between heat and balancing energy demand

From both ecological and economical aspects, as much as possible heat produced by the co-generation plants has to be used. Heat can either be used directly or stored in additionally installed heat storages. In general, heat demand depends on temperature. Therefore, it varies seasonable (fig, 4, striped bars). The balancing energy demand is dependent from the quality of the wind prognosis. The wind itself may vary seasonably, but the uncertainty of the wind prognosis and the balancing energy demand do not vary seasonable (fig. 4, drawn bars). Therefore, there is no correlation between balancing energy demand and heat demand.

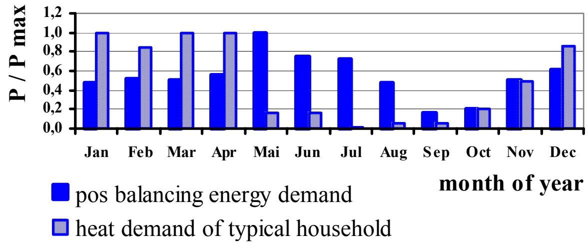

Fig. 4 Monthly heat demand of a typical household and balancing energy demand of Vattenfall Europe operation area in 2004

The main intention of balancing power plant is to provide electrical energy just in time whenever necessary. Due to the lack of correlating demands, an additional heating system, either conventional or solar thermal, is necessary. Nevertheless, heat has to be used with the help of heat storage capacity. From the ecological point of view, as much heat as possible should be used. Further research activities on this topic are planned.

3.2 Cost development estimation of balancing energy based on economic models

Cost of balancing power is estimated using common economic models. The balancing power demand remains constant because it mainly depends on the quality of the wind prognosis. Therefore the only degree of freedom in the balancing energy market is the supply side. Due to this, the economical model of the offer-price-dependence is valid here. In case of constant demand, prices decrease if offers increase [10]. According to this model, prices for balancing energy automatically decrease if balancing energy offers increase. Unfortunately, there are only a few owners of balancing power plants in Germany. With the aim of reducing balancing energy costs, new providers have to be developed. Minimal costs are guaranteed if market saturation is reached [10]. Motivating local power supply companies to enter the balancing energy market seems to be promising to reach the desirable market saturation. Installing small co-generation plants and connecting them to a so called virtual balancing power plant offers local power supplies the option to enter the balancing energy market. Today, balancing energy from small co-generation plants is already profitable. Several technical problems have not been solved yet [11]. In Germany, one company has already specialised on providing balancing energy from medium sized power plants [12]. Altogether, balancing energy from small decentralised co-generation plants is desirable from the perspective of macro-economics.

3.3 Ecological evaluation based on given eco-balances

Eco balancing is a well-known and an internationally accepted method to evaluate ecological efficiency [13]. In order to minimize the negative environmental effects caused by the need of balance power, the ecological impacts of different options to provide balancing power are compared (fig 5).

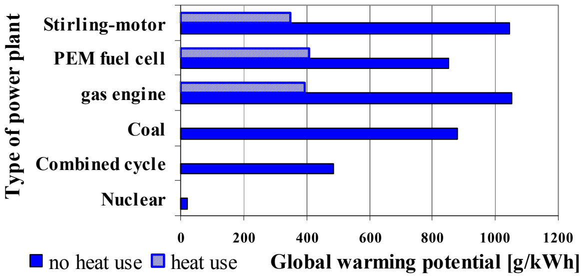

Fig. 5 Power plant options to provide balancing power and their ecological impact on global warming [14] [15]

Pumped storage power plants are also able to supply balancing energy. Their ecological impact refers to the impact of the energy stored in the pumped storage. Therefore, this option is not separately discussed. Concerning the ecological impact of the three co-generation plant types, heat-use (fig. 5, striped) and no-heat-use (fig. 5, drawn) has to be differentiated. If the co-generated heat is used, the global warming potential of all three co-generation technologies is lower than the global warming potential of coal-fired power plants and combined cycle turbines fired with natural gas. If heat cannot be used, combined cycle plants are most promising due to their high electrical efficiency. Although nuclear power plants offer lowest global warming emissions, they will probably be shut down in Germany due to political decisions.

4 Conclusion

In eastern Germany, the need of positive balancing energy is lower than the need of negative balancing energy. If balancing energy is provided by co-generation plants, each has to supply full-load in order to guarantee highest possible electrical efficiency. The lack of correlating heat and balancing power demand causes the need of heat storages. Concerning economical and ecological benefit, balancing energy from small co-generation plants is desirable. At all, this option seems to be promising as balancing power supply. Major future challenges in research are use strategies for co-generated heat and improving heat storages.

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