Economical Benefits by Contribution of Large Wind Farms to Voltage Control

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Abstract- **Wind energy is the main installed type of renewable energies in Germany. Wind farms owner gets a fix payment for the generated energy. This payment is much higher than the average variable costs of conventional power plants. Wind farms do not participate at voltage control till now. Although, they can supply reactive power into the network. In this study it is assumed, that there is a reactive power market. Large wind farms are connected to high voltage networks. It is shown, that fed reactive power from wind farms can contribute to minimization of the network losses in high and very high voltage networks. This fed reactive power leads to reduction of the complete demanded reactive power to support the voltage control by strong load too. Thereby, a part of costs of transmission system operator will be saved. These saved costs can be a contribution to reduce the fix payment of the generated energy of wind farms.**

I. Introduction

Today, renewable energy plays an important role in energy supply. In some fields the development is still growing, especially at wind energy. It is to be expected, that the installed wind power in Germany until 2020 reaches 60 % of the German total load [1].

In Germany the renewable energy is extra supported by a governmental act (Renewable Energy Sources Act; EEG) [2]. Thus, wind farms owner gets a priority feed-in into the network, where transmission system operator (TSO) must take-over the energy. Based on EEG and before the appearance of wind energy trader, the TSO has to pay a fix payment (EEG payment) to wind farms owner for the generated energy (Fig. 1). This payment is much higher than the average variable costs of conventional power plants.

TSO is responsible for a sure operation of the electrical network. Therefore, he has to support the voltage control [3]. TSO gets a part of the demand reactive power to support the voltage control from the conventional power plants (CPP). In this study it is assumed, that there is a reactive power market. Thus, the TSO has to pay to the CPP owners the price of delivery of reactive energy (Fig. 1).

TSO is responsible for energy transmission between power stations and load. The transmission of the electrical energy causes network losses. TSO gets the demanded active energy to cover the network losses from CPP. TSO has to pay to CPP owners the price of the demand active energy to cover the network losses (Fig. 1).

The TSO forwards the cost based on EEG (EEG payment), cost of delivery of reactive energy to support the voltage control and the cost of cover of network losses to the customers (Fig. 1). These costs are a part of network access price.

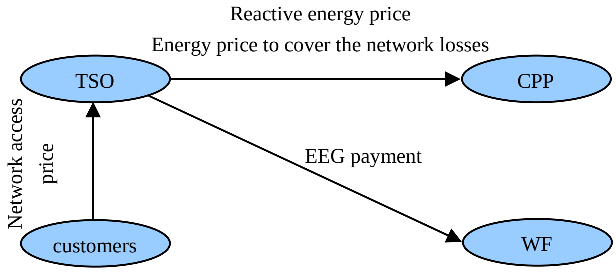

Figure 1. Observed money flow

II. Participation of Wind Farms at Voltage Control

Modern wind power plants are implemented either with double fed induction generator or synchronous generator in combination with full-converter. These two types of wind power plants can supply reactive power into the network [4, 5]. New planned large WF are to be connected to the high voltage network [1]. These large WF do not participate at voltage control till now. In this study it is investigated, which economical benefits can be caused to the customers, by reducing the access price, through participation of large WF at voltage control.

III. Test Model

The test model consists of a 380-kV- and two subordinate 110-kV-networks (Fig. 2 - 4). To the first 110-kV-network, 200 MW wind power are connected in four WF. These WF are implemented with double fed induction generators. To the second 110-kV-network, 700 MW wind power are connected in eight WF. These wind farms are implemented with synchronous generators in combination with full-converter. Total strong load of the network is 4.2 GW. Utilization period of WF is 1810 h/year and 6600 h/year of the load.

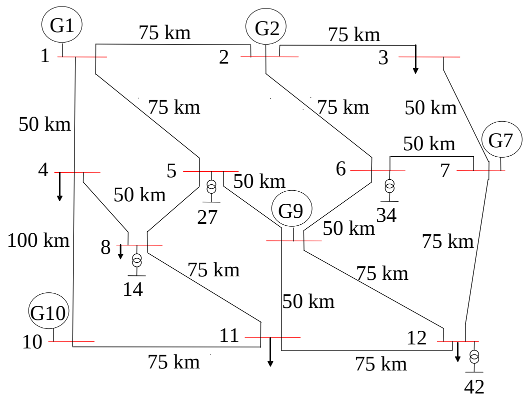

Figure 2. 380-kV-network

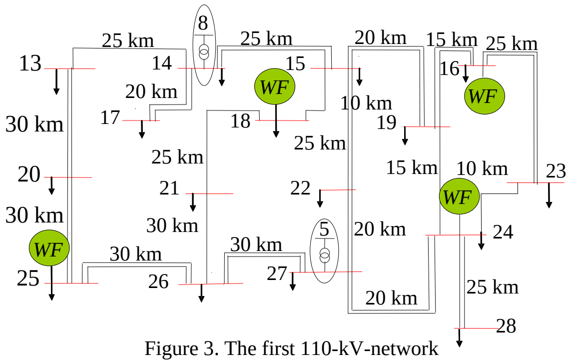

Figure 3. The first 110-kV-network

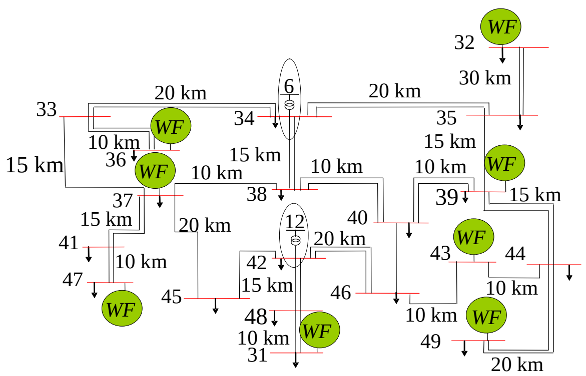

Figure 4. The second 110-kV-network

IV. Test Results

In this study, the two types of wind power plants (all attached WF) supply reactive power into the network. The network losses and the complete demanded reactive power to support the voltage control are compared with and without reactive power supply of WF. The network is tested for different load and wind velocity cases. In this paper, only two cases are investigated briefly: a week day in winter by weak wind (strong load & weak wind) and a sunday in summer by strong wind (weak load & strong wind). In this work, reactive power supply are adjusted to get minimum network losses.

A. *Strong Load & Weak Wind*

By strong load, inductive reactive power is required to support the voltage control. In this study, this necessary reactive power is delivered from CPP at 380-kV-network. WF are connected to 110-kV-networks. Thus, a part of the necessary inductive reactive power for the voltage control can be fed from these WF locally. Thereby, overhead lines and transformers can be released from a part of the transmitting inductive reactive power. Thus, the complete fed reactive power of WF and CPP is less than the fed reactive power of CPP alone (Fig. 5). E.g. the fed reactive power can be reduced 8 % approximately at the time between 11:00 and 12:00 o'clock. As a result, with reactive power supply of WF the network losses can be reduced too (Fig. 6). E.g. the network losses can be reduced 6 % at the time between 11:00 and 12:00 o'clock.

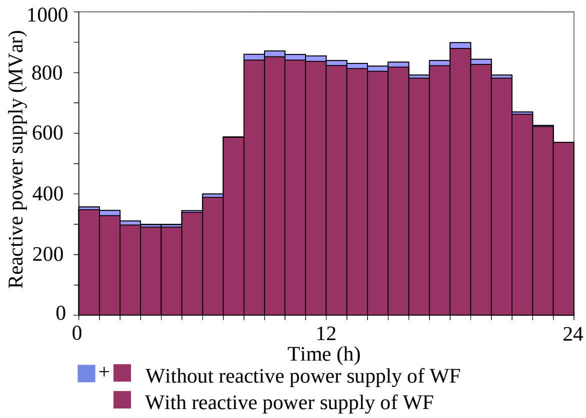

Figure 5. Complete delivered reactive power

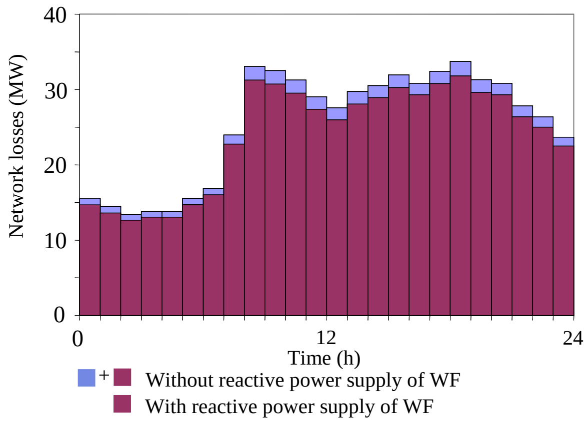

Figure 6. Complete network losses

B. *Weak Load & Strong Wind*

Early in the morning by weak load and strong wind, the fed active power of WF and CPP into the network is larger than the load. WF have feed in priority. Thus, many CPP have to be disconnected from the network to avoid a power surplus, e.g. from 05:00 to 07:00 o'clock the load is very low. Hence, CPP G10, G2 and G7 have to be disconnected from the network. The CPP, which remain at the network, have to produce the necessary (capacitive) reactive power to support the voltage control. Thus, a high reactive power flow can be caused and the possibilities to minimize the network losses are limited.

Reactive power supply of WF offers more possibilities to support the voltage control and to minimize the network losses simultaneously. Thus, the complete delivered reactive power of WF and CPP is larger than the complete delivered reactive power of CPP alone in weak load (in the morning and evening, Fig. 7). In this case, WF may supply reactive power, only if the saved costs of network losses are larger than the more costs of delivery of reactive power. Through reactive power supply of WF, the network losses can be reduced, e.g. 5 % approximately at the time from 11:00 to 12:00 o'clock (Fig. 8).

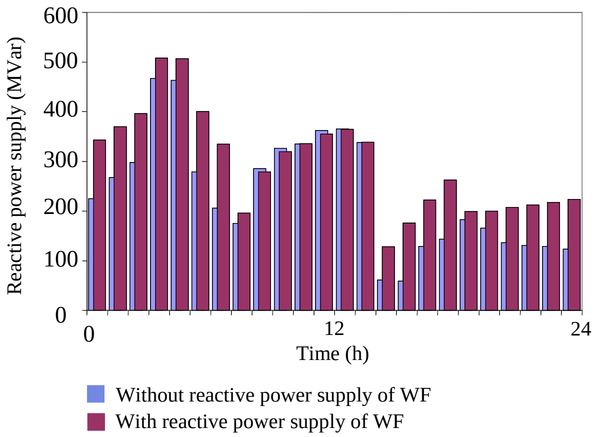

Figure 7. Complete delivered reactive power

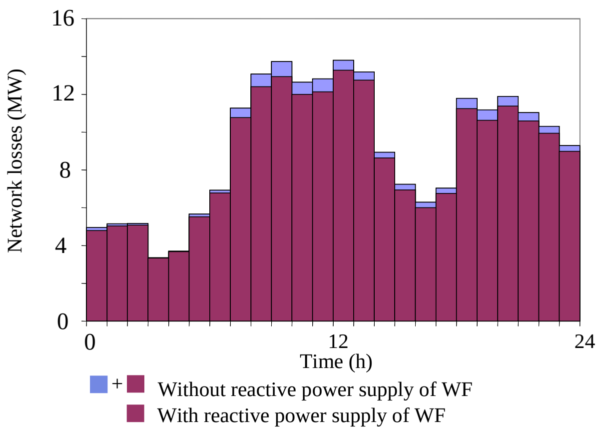

Figure 8. Complete network losses

C. *Economical Benefits by Contribution of Wind Farms to Voltage Control for one Year*

Tables I and II show the prices of reactive energy delivery to support the voltage control and the prices of active energy delivery to cover the network losses. High tariff (HT) prices by active energy delivery have to be paid from 08:00 to 20:00 o'clock on a week day, else the delivered energy should be paid in low tariff (LT).

Through the contribution of WF at voltage control for one year, the TSO saves a part of costs of covering of network losses (0.52 m€) and a part of costs of delivery of reactive energy (0.13 m€). WF owner gets more income (1 m€) through delivery of reactive energy, because there is a reactive power market.

TABLE I
PRICES OF REACTIVE ENERGY DELIVERY TO SUPPORT THE VOLTAGE CONTROL

		Price (€/MVarh)
Reactive Energy	Inductive	1
	Capacitive	0.5

TABLE II
PRICE OF ACTIVE ENERGY DELIVERY TO COVER THE NETWORK LOSSES

		Price (€/MWh)	
		HT	LT
Voltage Level	380 kV	50	50
	110 kV	80	60

D. *Economical Benefits for Customers*

In this study, the EEG payment is 87 €/MWh. In addition to that, it is assumed, that the total income of WF owner and costs of TSO with and without participation of WF at voltage control may not be changed. Therefore, the more income of WF owner and the saved costs of TSO should be transferred to the WF owner as a part of the fix payment (EEG-payment) for the observed year. This leads to reduction of the EEG payment. Thus, the EEG payment can be reduced from 87.00 to 85,98 €/MWh (-1,17 %) in the observed year (Fig. 9).

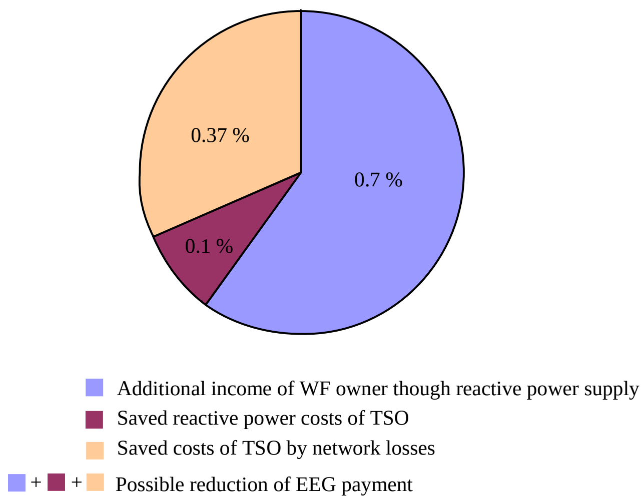

Fig. 9. Possible reduction of EEG payment in the observed year

EEG payment should be paid for 20 years. This payment is not constant for the 20 years, it has a degression. Thus, this payment was 83.76 €/MWh in the year 2007 [2], and the delivered energy of wind farms in Germany reached 39500 GWh in the same year [6]. So based on EEG, customers should pay for this generated energy 3.3 b€. The reduction of EEG payment with 1.17 % means that, customers should pay 56 m€ less.

V. Conclusion

In this study it is assumed, that there is a reactive power market. Wind farms owner gets additional income through participation of wind farms at voltage control. This participation leads to reduction of network losses and the demanded reactive power to support the voltage control by strong load. This means, the transmission system operator saves a part of the demanded costs to cover the network losses and delivery of reactive power to support the voltage control. The additional income of wind farms owner and the saved costs of transmission system operator can be a contribution to reduce the EEG payment, where wind farms owner and transmission system operator should have the same income and costs with and without participation of wind farms at voltage control. Thus, customers pay less for energy of wind farms.

The new research should help to reduce the EEG payment of wind power plants. The new researches show, that wind power plants can support the frequency control too [7]. Contribution of wind power plants to frequency control leads to reduce the EEG payment too. This reduction is clearly larger than the reduction by participation of wind power plants to the voltage control.

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