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Power Quality Disturbances and its Mitigation in Wind Energy Generation Interface to Grid System

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Abstract— **The integration of wind energy system into the grid can have a significant impact on the power quality. The voltage fluctuations, reactive power compensation and harmonics distortion are the main aspects of power quality issues and these are measured according to national and international guidelines. This paper discusses the power quality problems due to installation of wind turbine with the grid and the main used techniques for their mitigation such as the Flexible AC transmission systems (FACTS) devices. The Static Synchronous Compensator (STATCOM) is studied for its impact on power system during normal and faulty conditions. The intended results in MATLAB/SIMULINK environment relive the performance of the STATCOM to power quality improvement.**

***Keywords*— FACTS; power quality; reactive power compensation; STATCOM; wind power integration.**

I. INTRODUCTION

For the past few decades, the use of renewable energy has been gradually growing due to the environmental and economic issues in our society. Wind energy is one of the fastest growing renewable sources because of its technological maturity, good infrastructure and relative cost competitiveness [1]. According to the World Wind Energy Association, the worldwide wind capacity reached 456,486 MW by the end of June 2016 and all wind turbines installed by mid-2016 can generate 4,7% of the electricity demand. These growth trends can be linked to the multi dimensional benefits associated with wind energy.

However, wind energy can affect the power system due to the fluctuation nature of the wind. These fluctuations increase the problems related to the integration of wind farms into power networks, making their contribution rather difficult to manage. The biggest problem faced during integration of the wind power systems into the grid is the power quality disturbances such as voltage variations, Flickers, reactive power and harmonics [2].

For the successful grid integration of wind farms, different techniques are adopted. Flexible AC transmission systems (FACTS) technologies is among the possible solutions proposed by researchers. According to the IEEE, FACTS is defined as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability". The FACTS technology started with Static VAR Compensator (SVC) system where it was installed in 1975 in Nebraska-USA by General Electric [3]. Afterwards, a group of devices like Thyristor Controlled Series Compensator (TCSC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) were proposed for power flow control, voltage regulation and mitigation of system oscillations [4].

Considerable research efforts have been dedicated to develop and improve the quality power produced from the wind power production systems using FACTS technologies. L. Lei et al. [5] used the STATCOM to mitigate the voltage fluctuations. The simulation results show that the use of this device adjusts the fluctuant power from the wind turbine and makes the power injected smoother. In [6], STATCOM is used to reduce the harmonic pollution and to enhance power transmission in a grid interface to wind power. SVC device can be also used to improve the power quality by reducing harmonics in the grid current. But it has less reactive power compensation [7].

In [8], a comparative study of UPFC and SVC towards voltage profile improvement of grid connected wind energy is proposed. The result reveals that UPFC takes less time to eliminate the transient effects than SVC, so the study demonstrates that UPFC works better.

Reference [9] presents a comparison between STATCOM and UPFC in integrating wind farm into traditional network. From the simulation results, the author concluded that UPFC provides more stable voltage during fault condition comparing by STATCOM.

In [10], the improvement in the voltage profiles using the SSSC device is presented. The result shows that SSSC helps to regulate the active and reactive power for the power system.

The objective of this paper is to study the impact of FACTS devices on power quality due to integrating wind energy resources into the grid.

This paper is organized as follows. In Section II, different power quality problems like, voltage sag/swell, Flickers, harmonics, reactive power are discussed. Section III, is related to power quality improvement techniques and here the application of FACTS technologies is presented. Section IV describes a modeling wind generation power system

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connected to the grid for power quality improvement using STATCOM device. Simulation results and conclusions are given in section V and section VI respectively.

II. Power Quality Issues

The integration of wind energy into the grid can have a significant effect on the power quality. Due to the nature of wind resources, the wind farms generate fluctuating electric power. The voltage fluctuations, reactive power compensation and harmonics distortion are the main aspects of power quality issues. This situation requires new strategies for operation and management of electric grid. There are certain standards which specify the manner to conduct power quality measurement and the level limits. The International standards developed by the working group of Technical Comitee-88 of the International Electro-technical Committee (IEC) are specified as follow:

TABLE I
IEC Standards

Standards	Description
IEC 61400-21	Wind turbine generating system, part-21. Measurement and Assessment of power quality characteristic of grid connected wind turbine.
IEC 61400-13	Wind Turbine—measuring procedure in determining the power behavior.
IEC 61400-3-7	Assessment of emission limit for fluctuating Load.

A. Voltage Sags

The Voltage sag is a brief reduction in voltage to a value between 1% and 90%, typically lasting 1ms to 1 min. The start up of wind turbine is among the causes of this problem. The decrease of nominal voltage change, due to switching operation of wind turbine, is calculated as:

$$d = 100 K_u \psi_k \frac{s_n}{s_k^*} \tag{1}$$

Where d is the relative voltage change, $K_u\psi_k$ is the voltage change factor, s_n is the rated apparent power of wind turbine and s_k^* is the short circuit apparent power of grid.

B. Voltage Swells

Voltage swell is a brief increase in voltage to a value between 1% and 90%, typically lasting 1ms to 1 min. the voltage swell (Δu) at the point of common coupling can be approximated as a function of maximum apparent power s_{max} of the turbine, the grid impedances R and X and the phase angle , as given in the following equation:

$$\Delta u = s_{\max}(R\cos\phi - X\sin\phi)/U^2 \tag{2}$$

C. Flickers

Flicker is the periodic voltage amplitude variations occurring at frequencies between 0.5 Hz and 25 Hz. It is caused by load flow changes in the grid or generators such as wind generators [11]. According to IEC61000-21 standard, the voltage fluctuation caused by wind turbines is divided into two components: the continuous operation and the switching operation. First operation results from the variation of active and reactive power due to wind speed variations, the wind gradient and the tower shadow effect [12]. Second operation results from the fast changes of power due to switching between wind generators [13].

According to IEC61000-4-15 standard, Flicker is quantified by the Probability short term (Pst) measured over a 10 minutes period and the Probability long term (Plt) measured for an average of 120 minutes [14]. The maximum amounts for these two variables are generally specified in the technical rules for the connection of wind turbines into the grid.

Among the different technologies of wind generators, squirrel cage asynchronous generators are the ones that cause the most flicker problems. However, the regulation of the angle attack can be a solution for reducing the flicker effect and improving the performances of this type of generators. For doubly fed induction generators and synchronous generators, the use of power electronics converters makes it possible to filter the power variations and adjust the voltage in order to reduce the flickers [15].

D. Reactive Power

The induction generators in wind turbines consume a large amount of reactive power. According to IEC standard, reactive power of wind turbine is specified as 10 minutes average value as function of 10 min [7]. At no load, the consumption of the reactive power is between 35% and 40% of the rated active power, and increases to around 60% at rated power [16].

The use of a capacitor bank or a controlled inverter may compensate the reactive power needed from the induction generators [17]. For a large scale wind turbine, FACTS devices may be used to provide a smooth reactive power regulation.

E. Harmonics

In power system, harmonic disturbances are associated with the distortion of the voltage or current's waveform. This distortion is produced by nonlinear elements especially power electronic devices and reactive power compensators [1]. The injection of harmonics in the network can lead to reduction in the efficiency of electric energy generation and malfunction in protection devices [18]. Generally, variable speed wind turbines with converters inject more harmonics than fixed speed wind turbines. However, in the case of modern power electronic converters with high switching frequencies, advanced control algorithms and filtering techniques, Total Harmonic Distortion (THD) would not be a main problem [19]. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. The total harmonic distortion of voltage is given by the following equation:

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{V_n^2}{V_1}} 100 \tag{3}$$

Where V_n is the nth harmonic voltage and V_1 is the fundamental frequency. The THD limit for 132 KV is < 3%.

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THD of current is given by the following equation:

$$I_{THD} = \sqrt{\sum_{h=2}^{40} \frac{I_n^2}{I_1}} 100 \quad (4)$$

Where I_n is the nth harmonic current and I_1 is the fundamental frequency. The THD of current limit for 132 KV is < 2.5%.

III. Power Quality Improvement Techniques

In order to overcome the problems mentioned above FACTS devices can be used. With the availability of forced-commuted power electronic devices such as GTOs, IGBTs and IGCTs, FACTS technologies can supply and absorb active and reactive power. By the way they are connected to power system, FACTS devices can be categorized as a shunt, series and shunt-series types [20].

The detailed description and comparison of different FACTS family are proposed in the literature [21]. Table 1 summarizes the services and the performance level of each device of different FACTS technologies [21]. From this comparison, we can see that UPFC is the most performed device in term of harmonics reduction. Also we can clearly see that both the STATCOM and The UPFC are the most performed pieces of equipment in term of reactive power compensation and voltage control. Until we are not interested in harmonic issues, we choose to work with the STATCOM in the next sections.

TABLE III
Comparison of FACTS Devices Performance

Service \ FACTS Technology	SVC	STATCOM	TSCS	SSSC	UPFC
Reactive power generation / absorption	Good	Excellent	Limited	Excellent	Excellent
Voltage control	Good	Excellent	Limited	Limited	Excellent
Flicker mitigation	Good	Excellent			Excellent
Harmonics reduction		Good		Good	Excellent

Legend: Excellent Good Limited

IV. Modeling of the System Operation

In this section, a model of wind energy generating system connected to the grid will be presented to study the impact of STATCOM device on power quality and its improvement.

A. *Wind Energy Generating System*

In wind generation power system, induction generators transform the power captured by the wind turbine into electrical power. The available power of wind turbine energy system is given by the following equation [22]:

$$P_w = \frac{1}{2}.\rho.S.v^3 \quad (5)$$

Where ρ is the air density (ρ = 1.225kg /m^2), m is the mass flow rate per second and v is the wind speed.

The power converted by the wind turbine depends on a power coefficient $C_p(\lambda,\beta)$ which expresses the aerodynamic efficiency of the turbine. The mechanical power produced by the wind is expressed by:

$$P_w = \frac{1}{2}.C_p(\lambda,\beta).\rho.\pi.R^2.v^3 \quad (6)$$

Where λ is the tip speed ratio, β is the pitch angle of the rotor blades and R is the radius of the blade.

B. *STATCOM*

The STATCOM is a shunt device of the FACTS family. It is used to regulate the voltage by controlling the reactive power injected into the grid or absorbed from it. As shown in figure 2, a Voltage Sourced Converter (VSC) connected on the secondary side of coupling transformer is used to perform the variation of reactive power. The capacitor connected on the DC side of the VSC acts as a DC voltage source.

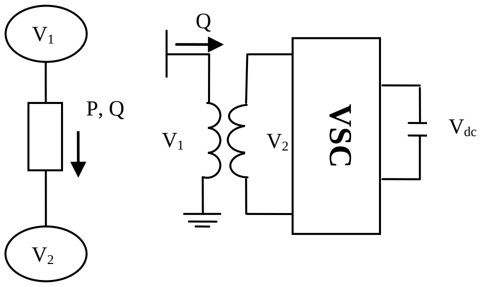

Fig. 1 Basic structure of STATCOM

In our case, the reactive power is expressed as follows:

$$Q = \frac{V_1(V_1 - V_2)}{X} \quad (7)$$

Where V_1 is the system voltage to be controlled and V_2 is the voltage generated by VSC.

The detailed description, mathematical model and the control system of STATCOM device are proposed in the literature [23].

V. Simulation and Results

A. *Case Study*

In this case study, a 9 MW wind farm equipped with induction generators is presented. It consists of six 1.5 MW wind turbines. The stator winding is coupled directly to the grid and the rotor is driven by a variable pitch wind turbine. A part of the reactive power absorbed by the induction generators is compensated by capacitor banks and the rest is regulated by a STATCOM. The figure 2 contains a STATCOM device connected to the grid coupled with wind farms. The model was developed in MATLAB/Simulink environment in order to mitigate the power quality problems.

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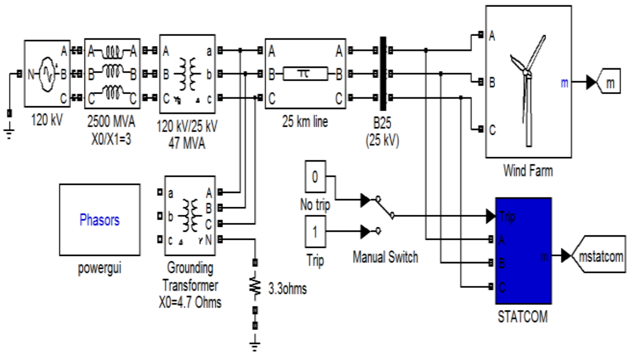

Fig. 2 Grid connected system for power quality improvement

In this part of section, two scenarios of wind farm integrated to the grid are simulated. In the first one, the global system is simulated in normal condition and in the second one, the system is under three phases fault.

B. *Normal Condition*

In order to study the impact of STATCOM on power quality, we first enable manually the STATCOM block.

From figure 3, we can observe that due to the reactive power support, the system voltage is close to 1 p. u. Also the active power reaches the 9MW after 12ms. However, by disabling the STATCOM, the grid voltage dropped below 0.91 p.u . The active power decreases to 6 MW as shown in figure 4.

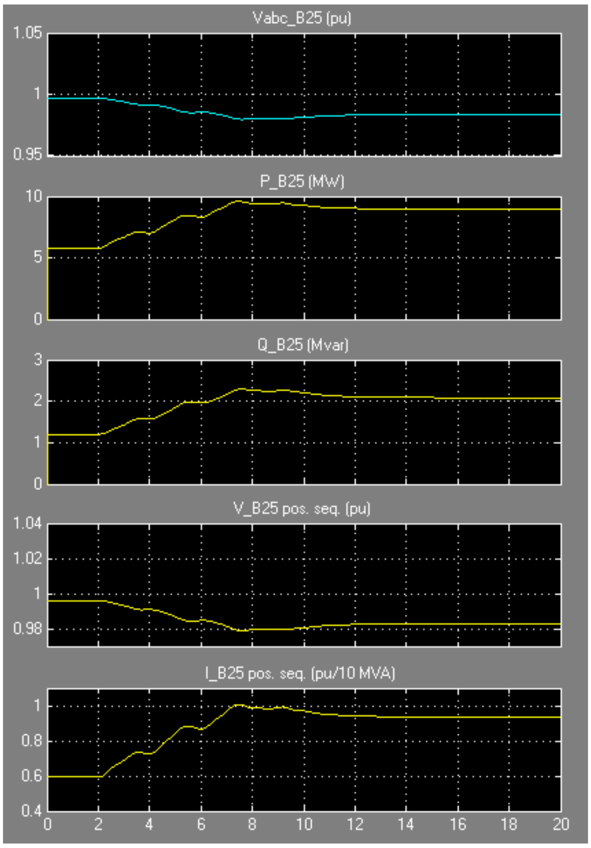

Fig. 3 System with STATCOM in normal condition

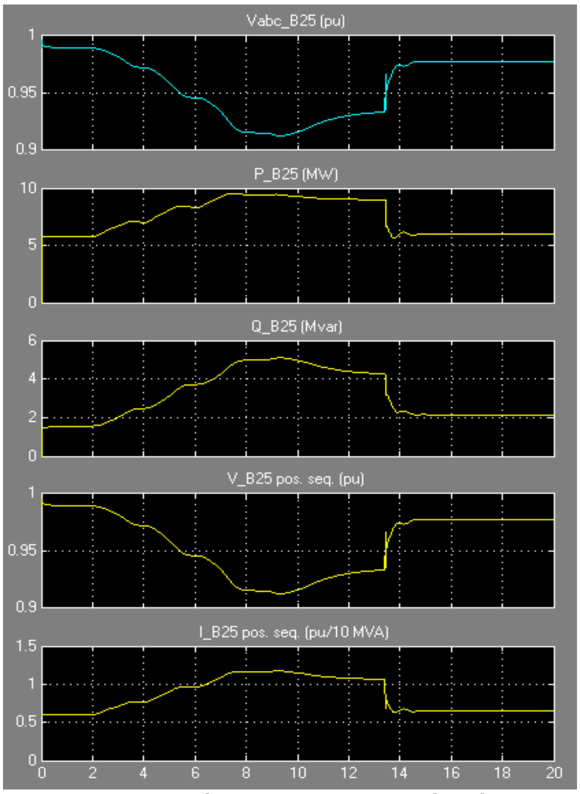

Fig. 4 System without STATCOM in normal condition

C. *Faulty Condition*

Now, the system is under three phases fault. The simulation results are shown in figure 5 and figure 6 .

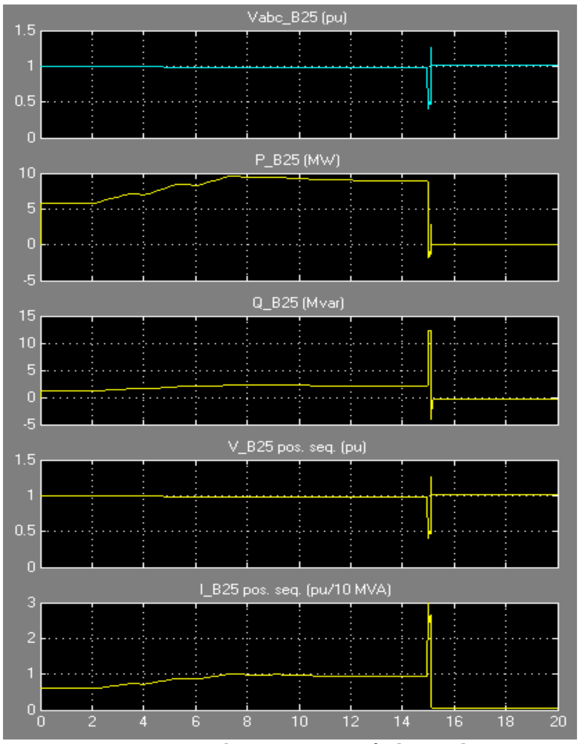

Fig. 5 System with STATCOM in faulty condition

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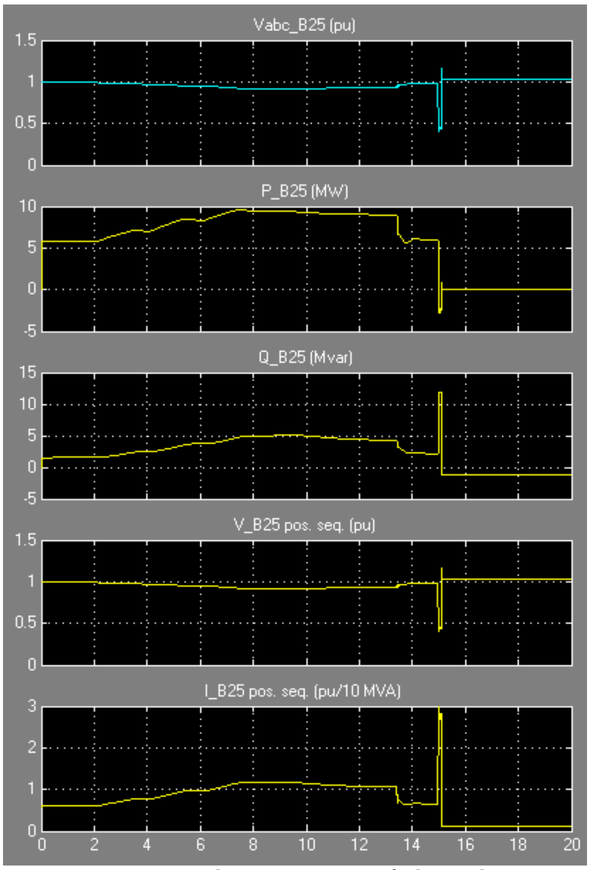

Fig. 6 System without STATCOM in faulty condition

Figure 5 shows the voltage measurements of the grid system and the power generated at the wind turbine during the fault with the STATCOM enabled. We can observe that the voltage during the fault is stable and close to 1.0 p. u. due to the reactive current compensation.

As comparison, Figure 6 shows the voltage measurements of the grid system and the power generated at the wind turbine during the fault condition without the STATCOM. It can be clearly seen that the voltage fluctuates due to disabled STATCOM.

From the comparison results of the four cases above, we can conclude that with the presence of STATCOM, steady voltage could be obtained and power quality is improved in normal and faulty conditions.

VI. Conclusion

This paper analyzes the functional contribution of power electronic devices, like FACTS technology, to the operation improvement of power quality system. The STATCOM is one of the most important FACTS devices for reactive power compensation. Simulation results show that STATCOM improve the power quality in grid connected wind generating system. It maintains the voltage stability and support the reactive power demand for the wind generator in the grid system. The integrated wind turbine and STATCOM FACTS device have shown the outstanding performance.

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