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Power Quality Improvement of Wind Farms Using STATCOM: A Review

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Abstract: *Today, the nation's development depends on the availability and usage of electrical power. Electrical energy produced by wind farms are cleaner than the conventional power sources, and don't produce any type of pollution. And since the wind farm's operational cost is low and once it has been installed they are highly economical in power generation. The most important issue with the uninterrupted operation of wind turbines are voltage instability caused by various factors. Hence, this paper reviews certain power quality problems and its improvement in the wind farms using STATCOM (static synchronous compensator). STATCOM is the most popular device used among many other FACTS devices such as static VAR compensator (SVC), to improve voltage stability. The primary objective of STATCOM in power system is to improve the voltage control ability at the grid terminals to compensate reactive power variation. It helps in maintaining the various power quality parameters as well as power flow in the system.t goes here.*

Keywords: *FACTS, Power quality, STATCOM, Voltage stability, Wind energy*

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I. Introduction

In recent years the world is more concern about environmental pollution and increasing demand of electrical energy, this leads the world's interest in the renewable energy sources and new ways of generating electrical power using renewables. For hundreds of years humans have been utilizing wind energy in one way or another. Efficiency in the conversion rate and lack of any kind of gas emissions makes the wind energy a rapidly growing electrical energy source. The property of wind power is that, it is random and variable in nature and because of this a huge penetration of power may cause important problems and can also affect the characteristics of the wind generators [1], [2]. There are many technical issues which need to be addressed before integrating wind power into the existing power system infrastructure. These various issues includes voltage stability, voltage regulations and other power quality issues such as reactive power compensation, voltage transient, voltage flicker and harmonics [3]-[5]. Hence one of the most important challenges is to maintain the quality of power generated by wind farms in an acceptable pre-existing range.

Nowadays the use of technology such as capacitor banks and SVC to compensate reactive power is not justifiable, when there are shunt FACTS devices like STATCOM are already developed to put in use to improve the operation of wind power stability [6], [7]. This paper reviews the roll, a STATCOM plays in the uninterrupted operation of a fixed speed wind turbine during faults as well as improving the power quality. The STATCOM is reactive power compensating, shunt-connected device which is capable of handling sudden increase and decrease of reactive power by absorbing as well as generating reactive power [8], [4], [9]. It has been established by many useful applications, that when it comes to improving power quality as well as stability of wind turbines, STATCOM is the fastest responding device available [10].

The primary objective of this paper is to review various control strategies used, to overcome the power quality problems. This challenges the high percentage of penetration of wind power into the existing power system structure.

II. Power Quality Problems

In this section, various power quality problems are discussed. Power quality of electricity can be termed as the physical characteristics or its basic properties. In Power system power quality is more often refers to the wave form of power distribution bus parameter like voltage and current at rated frequency and magnitude which needs to be maintained at near sinusoidal length [11], [12]. The quality of the voltage must match the minimum required standard of national and international codes. These generalized codes include parameters like voltage interruption, which can further be divided into problems like harmonics distortion, voltage transient and flicker. Because of variable characteristics of wind and use of Induction generators (reactive power) these power quality problems are faced during the wind power generation and that is the main reason behind the low level of wind power penetration in existing power system [13], [14].

2.1 Voltage variation

Wind farm electrical power can be highly variable in nature at many different time periods, like hourly, daily or seasonally. Variations also exist annually, but it is not as significant as other. It is very important that generation of electricity and consumption of it remain in balance all the time to maintain the grid stability, if not then this unbalance can present significant challenge to include large amount of wind power into power system [15]. The operators have to calculate a day ahead forecasting to meet the demands.

2.2 Reactive Power Consumption

In most of the wind farms, induction generators are used because of the low maintenance requirement and economical aspects [3]. The reason behind consumption of reactive power on the wind farm side is the basic principle of induction generator, which requires reactive power in order to generate real power. In addition to that, because of step-up transformer magnetization current the reactive power consumption grows extensively. Reactive power is also required by different types of load to convert the flow of electron into beneficial work and should be enough to lower the voltage sag [19].

2.3 Voltage Transient

In wind turbines, capacitors are provided for compensation of reactive power. To compensate the right amount of reactive power to wind turbine generator (WTG), mechanical switchers were used in some capacitor banks previously. These switches could cause a large amount of voltage transient into wind farms because the amplitude and frequency of those transient were enormous to handle with [4], [20]. Sensitive electronic equipment of wind farm can get damaged if the voltage transient happens frequently, which can lead to premature failure. In addition to that, wind turbine blades are vulnerable to lightning strikes, which can cause an overvoltage in WTG [3], [21].

2.4 Flicker

Flicker is a phenomenon in which due to voltage fluctuation a lightning disturbance is produced. Mostly flicker it takes place when voltage fluctuates in the range of 10 Hz to 35Hz. In wind farms flicker is caused because of the variable nature of wind, which is responsible for voltage fluctuation [4]. Flicker, in wind farms has become a concerning issue. According to a study performed on various types of wind turbine and results shows that in certain cases flicker emission exceeded the limits which are mandatory according to grid codes [22], [23].

2.5 Harmonics Distortion

Harmonic distortion can cause some serious damage to equipment of wind farm, it can reduce lifetime of equipment, power losses, heating of transformers, malfunctioning of sensitive equipment and many other issues [4], [24]. It is important to understand the harmonic behavior of turbine at wind farm in order to study their effects on grids of power system where they are connected. For study we can refer to [25] which analyses the harmonic current emission using extensive measurement performed on a variety of commercially available variable speed turbine.

III. Overview Of Statcom

When connected in shunt connection with the power system a STATCOM can provide transient stability by compensating the reactive power at the point of common coupling [4]. STATCOM is capable of performing many tasks such as it can absorb as well as generate reactive power accordingly and it can also vary its output in order to control various power system parameters [5], [26]. STATCOM can be understood by its various properties which are; it does not significantly change the existing system impedance, it is an ideal synchronous machine which has no inertia and is practically instantaneous, and can internally generate reactive power of both natures, capacitive and inductive [27]-[30]. A STATCOM is much more capable than just reactive power compensation; it can improve power system performance in areas as follows:

- Transient stability [31]
- Voltage flicker control [32]
- Power oscillation damping in power transmission systems [33]
- Dynamic voltage control in transmission and distribution systems [34]
- With the addition of a DC energy source it can control not only reactive power but also active power in connected line if needed [35]-[37].

We can understand the functioning and use of STATCOM with the help of the block diagram in Figure (1). In this scheme STATCOM is configured with an energy source, which helps maintaining the reference active and reactive power respectively.

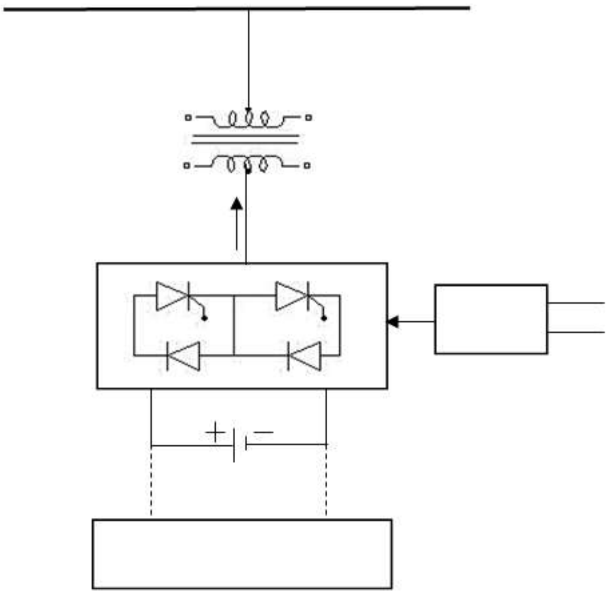

Figure1: Functioning of STATCOM in power quality improvement.

In [3] an example of 10 MVA STATCOM is put in use which is studied in [38] and found enough for protecting the wind turbine from de-synchronizing with the connected power system under different disturbances. Parameters which are to be considered for selecting STATCOM are given in Table 1.

Table 1. STATCOM Parameters

Parameters	Data
Rating	3 MVA
Operation Mode	Volt Regulation
PCC reference voltage	25 KV
Voltage DC linked	4000 V
Capacitor inside DC link	3.75 mF
Synchronous link inductance	6.6 mH, 0.04Ω

IV. Control Strategy Of Statcom In Wind Generation

This section explains the different control strategies used in wind generation with STATCOM. More productive and efficient configuration is using STATCOM with an external energy storage system to overcome the previously stated power quality problems in wind farms, some configurations are also tested and simulated in [4] and [39]. In [9] the author also used battery energy storage system (BESS) and STATCOM configuration and tested the simulation for two applications such as improving power quality and stability of the wind farm turbines. System behavior of both the cases were analyzed and discussed with the help of a study state equivalent circuit representation. This is also supported in [40]-[42].

Figure (2) shows schematics of a grid power system connected to a wind farm system with the control strategy of BESS and STATCOM configuration [43].

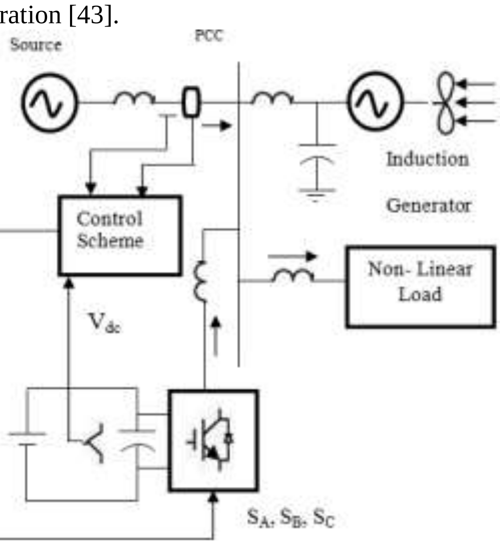

Figure 2: STATCOM control scheme with BESS in a grid system [5], [43]

External energy storage unit is connected to the DC capacitor of STATCOM in parallel arrangement. This is used to level the power fluctuation by discharging and again charging the capacitor [44]-[48].

Grid synchronization is also important to control strategy. This ensures that the current source is controlled to be sinusoidal [49]. There are two control strategies mentioned in [43] and [50]; bang-bang controller or current control and logic controller or fuzzy logic controller.

4.1 Current Control Technique

The bang-bang controller is a hysteresis current controlled technique to inject current into the grid as shown in figure (2). In this, the current controller block subtracts received actual current from reference current so as to activate the operations of STATCOM [51]. The reference current is generated according to equation (1) and sensors are used to measure actual current and are removed before attaining any current faults for a hysteresis based bang-bang controller.

$$i_{sa}^* = I^* U_{sa},\ i_{sb}^* = I^* U_{sb},\ i_{sc}^* = I^* U_{sc} \qquad (1)$$

Thus, hysteresis regulator is main reason for ON/OFF switching signals for IGBTs of STATCOM. The switching function SA for phase 'a' is expressed as:

$(I_{sa} – I_{sa}^*) < HB = SA = 1$

$(I_{sa} – I_{sa}^*) > HB = SA = 0$

Same for phase 'a' and 'b'.

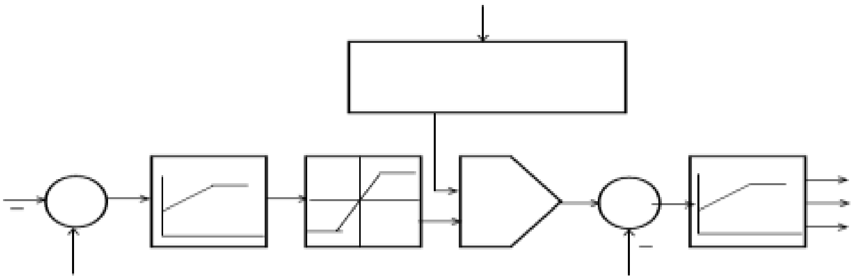

Figure 3: Current controlled technique to inject current [50]

4.2 Logic Controller (Fuzzy logic)

The evolution of a set of linguistic rules is the determining force of control action in a fuzzy logic controller. Represented design shows, that firing angle for the STATCOM switches are controlled by fuzzy controller. In this configuration, STATCOM has changes in two input parameters, voltage (ΔV), and current (ΔI), and has one control output [52], [53].

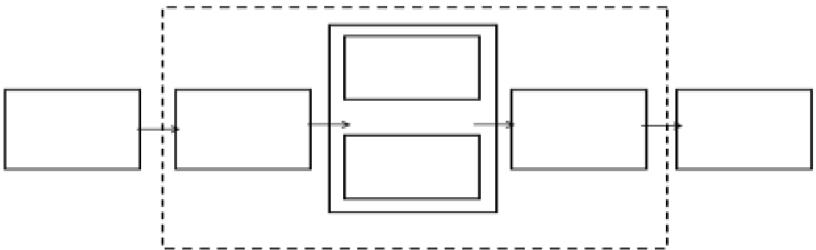

Figure 4: Fuzzy Control block diagram [16]

Converting input values to the fuzzy variables is initial process, termed as fuzzification. After this, fuzzy inputs pass through basic rules or interface engine and the outputs are directed to defuzzification to estimate the final outputs. This procedure is demonstrated in Figure (3).

The majority of wind farms these days are equipped with doubly fed induction generators (DFIG). Most concerning issues with DFIG is the grid fault or low voltage ride-trough capability. Therefore, it is crucial to maintaining voltage stability for uninterrupted operation of DFIG equipped wind farms [54]. By controlling rotor side controller (RSC) and grid side controller (GSC) of the frequency controller (VFC), Control of DFIG can be achieved [55]-[57].

Rolf Grünbaum, in his papers [58]-[60] concluded that, for wind power to contribute in the main stream power system, it has to act upon same rules [61] as conventional generating power plants. It includes, not influencing power system stability in anyway and also "fault ride-through" capability of wind turbines. In order to achieve this use of FACTS devices like SVC or Light SVC (STATCOM) was suggested [62]. With the help of SVC light and BESS, stored active power can inject back into the grids if necessary.

V. Conclusion

In this paper, role of STATCOM is reviewed in mitigating various power quality problem related to wind energy. In recent years, with the increase in electrical power requirement, there is an imminent need to increase the contribution of non-conventional energy in power system to balance out the demand, curbing the pollution. But as promising as wind power is to the power system, it has a certain limitation which needs to be overcome before a significant contribution can be made by it. These issues are mostly related to power quality as well as response to fault occurrences. STATCOM has the capability of cancelling out the portions of load current which contains harmonics, by doing so it is able to sustain current and source within phase and support the demand of reactive power for wind farm and load at PCC in power system. Thus, it helps in improving the utilization factor of power system transmission line. STATCOM has proven to be one of the best solutions of these problems, whether it is used with DFIG or FSIG.

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