Harmonic Analysis And Performance Improvement Of A Wind Energy Conversion System Using 84 Pulse STATCOM

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Abstract *— This paper presents novel dynamic controller for the Static Synchronous Compensator (STATCOM) device to stabilize Stand-Alone Wind Energy Conversion Systems (SWECS) using an induction generator. The wind energy conversion system is connected to an electric load through an 84-pulse STATCOM, a flexible A.C. transmission systems (FACTS) device. The proposed strategy allows savings in the number of employed switches.The results demonstrated the effectiveness of the 84 pulse STATCOM device in stabilizing the wind energy conversion system by insuring effective harmonic reduction at generator/load bus voltage regulation and dynamic reactive compensation. This is modeled using MATLAB /SIMULINK software.*

Keywords **-** WECS, FACTS, STATCOM PWM,THD.

1. Introduction:

Along with the increasing demands for wind power, the turbine technologies are improving and thus equipment costs are reducing. Because the wind industry is a well established power house on the renewable market, its prices per kWh are comparable with prices of the conventional energy generations. Unlike gas, coal and oil resources which in future will become scarce, and for which the technologies became mature decades ago, the wind energy is abundant and new improvements on aerodynamics and power electronic devices are still to come. Therefore by 2030 electricity production from wind will inevitably become cheaper than any other source of energy, currently having a high market share. There is a good correlation between wind turbines costs and their sizes. Unlike solar panels, which remain at the same price regardless of array size, wind turbines become cheaper with increased system size. The practical explanation is that the power delivered by the wind turbine depends on the square of the rotor diameter.

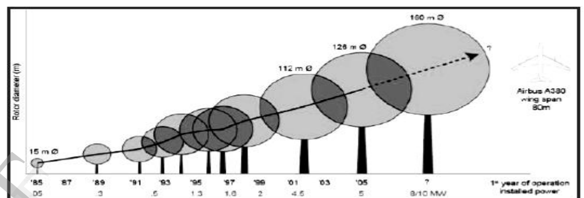

Fig. 1. Increase of wind turbine size over the years

Fig. 1. shows the evolution of wind turbine size with respect to year of production. It is seen that in the last 20 years the rotor diameter has increased by a factor of 10. Today state-of-the-art wind turbines, with 126 m for rotor diameter, produce 5 to 6 MW of power. The amount of energy captured from a WECS depends not only on the wind at the site, but depends on the control strategy used for the WECS and also depends on the conversion efficiency.

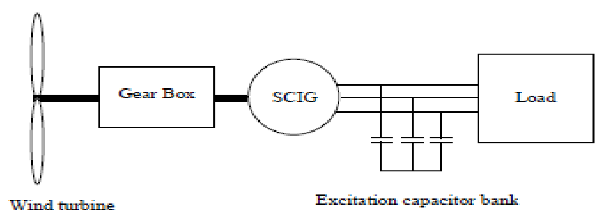

Fig. 2. Wind driven stand-alone SCIG connected to a load

Fig 2. Shows the basic diagram of wind conversion system with capacitor bank connected to load. FACTS is one aspect of the power electronics revolution that happened in all areas of electric energy. These controllers provide a better adaptation to varying operational conditions and improve the usage of existing installations. FACTS controller is defined as a power electronic-based system that

provide control of one or more AC transmission system parameters (series impedance, shunt impedance, current, voltage, phase angle).
Using the advantages offered by the power electronic devices the FACTS controller provides a smoother operation and an increased lifetime of the system(less maintenance), compared to the conventional devices which are mechanical switched.

To enhance the performance of a Wind Power Plant with ability to deliver or absorb reactive power from the grid is to use Static Synchronous Compensation. STATCOM can be treated as a solid state synchronous condenser connected in shunt with the AC system. The output current of this controller is adjusted to control either the nodal voltage magnitude or reactive power injected at the bus. STATCOM is a new breed of reactive power compensators based on VSC. It has a characteristic similar to a synchronous condenser, but because it is an electrical device it has no inertia and it is superior to the synchronous condenser in several ways. Lower investment cost, lower operating and maintenance costs and better dynamics are big advantages of this technology [2].STATCOM consists of one VSC with a capacitor on a DC side of the converter and one shunt connected transformer.

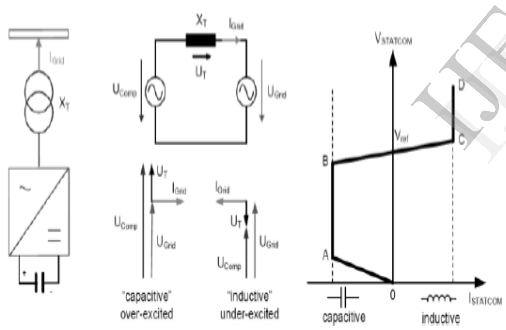

Fig. 3. Schematic representation of working principle of STATCOM

This paper describes a strategy to generate the 84-pulse VSC, assembled with the combination of one 12-pulse converter with a seven-level converter, as well as one reinjection transformer to attain the required performance. This 84 pulse STATCOM is connected to wind energy system .The extra components are: 8 switches, 4 DC voltage sources, and 4 diodes for the seven-level converter. A reinjection transformer is needed, which is able to work properly within a wide range of its turn ratio. This constitutes an attractive array in terms of costs.

2. 84 PULSE STATCOM:

The WECS considered in this work consists of a DFIG driven by a fixed pitch wind turbine. An 84 pulse STATCOM is connected to improve the power quality of WECS .Since the STATCOM may cause interference on the system's fundamental sine wave at frequencies that are multiples of the fundamental one, especial care should be taken to ensure not to pollute the system to prevent further harmonic issues. In general, there are three feasible strategies to assemble a VSC: (*i*) the multi-pulse; (*ii*) the multi-level; (*iii*) and the pulse width modulation (PWM) [9, 10].
The simplest one is by increasing the number of six-pulse converters and the corresponding transformers (4 six-pulses converter results in 24-pulse, 8 six-pulse converter results in 48-pulses operation, and so forth). The harmonic cancellation is carried out by the transformer secondary windings arrangement. The weakness of this method is the large size and high cost due to the increased number of bridges and transformers. In order to overcome such difficulty, an auxiliary circuit in the DC link side has been proposed for reinjection [3]. Such topology results through modifying the
DC input on the conventional double bridge twelve-pulses shunt converters through a multi-level auxiliary circuit with an injection transformer [4]. In this paper, an asymmetric 7- level array for the auxiliary circuit is used as a reinjection scheme.
The conventional double bridge twelve-pulse operation is assembled by connecting two identical three-phase bridges to three-phase transformers in a parallel VSC configuration. Each branch in the six-pulse converter must have a displacement of 120° among them. The upper switch is conducting while the lower one is open and vice versa (180° voltage source operation) [5]. A 30° displacement in the firing sequence of both converters should be considered.
Transformer's turn ratios are 1:1 and 1: 3 on the YY and YΔ transformers, respectively. By injecting additional DC pulses via the three-phase bridges' neutral point, an effect of pulse spreading is attained. The auxiliary circuit is common to the three phases, reducing the number of extra components. The configuration description to provide pulse multiplication is detailed in [2]. To apply the seven-level inverter output voltage to feed the standard twelve-pulse converter, special care should be taken to not inject negative voltage into V_Y or $V\Delta$. ; notice the inclusion of the injection transformer between both arrays. Thus, voltages at the six-pulse converter inputs can be regulated by adjusting the injection voltage U_i by:

$$V_Y = V_{DC} + U_i \qquad (1)$$

$$V_\Delta = V_{DC} - U_i \qquad (2)$$

The injection voltage is determined by the seven-level inverter switching pattern and the injection transformer turns ratio. By using voltages V_Y and V_Δ

as inputs to the six-pulse converters, a cleaner VSC's output voltage comes out. Through the 1:1 ratio for the *YY* transformer, 1: 3 for the *Y*Δ transformer, and adding their corresponding output signals, the 84-pulse line-to-neutral signal *VU* emerges (Fig. 6). The corresponding harmonic spectrum is depicted in Fig. 7, illustrated on a linear scale[6].

The 84-pulse signal value (*VU*) depends on the injection transformer turns ratio *a*, which is determined so as to minimize the total harmonic distortion (THD), which is defined by

$$THD_{VU} = \sqrt{\frac{\sum_{n=2}^{\infty} V_{Un}^2}{V_{U1}^2}}$$

Table 1 Minimum THD can be reached through VSC multi-pulses-based

Number of pulses	THD (%)
12	15.22
24	7.38
48	3.8
60	3.159
84	2.358

In high voltage applications, Seven-level inverter is better for VSC based STATCOM [7]. Therefore, we considered seven-level STATCOM based on PWM technique to enhance the stability of wind generator in the simple model system with DOIG. A seven-level PWM based STATCOM is connected with wind farm terminal. PWM control is used as the control methodology of the STATCOM [8]. As wind speed is intermittent and stochastic in nature, the terminal voltage of wind generator fluctuates randomly, which has an adverse effect on the rest of the power system. In this study, it is reported that the STATCOM with reduced capacitor bank can decrease the voltage fluctuations of wind generator terminals. Moreover, it is shown that the STATCOM can also enhance the transient stability of induction and synchronous generators when a network disturbance occurs in the power system[9].

According to the IEEE Std. 519, the distortion limits indicate that the allowed THD voltage is 10% in dedicated systems, 5% in general systems, and 3% for special applications as hospitals and airports .Table 1 presents the voltage's minimum THD generated by several multi-pulse configurations[10]. Through our proposition, the resultant THD allows its use even in applications with stringent quality requirements; it exhibits less dependence to variations in the transformer's turn ratio *a*, which can have a variation until 12.5% to reach a maximum THD lower than 3%. This means that it does not need a strict reinjection transformer turn ratio in order to get the THD for stringent conditions.

3. RESULTS

The proposed 84 pulse STATCOM for wind power plant is simulated using MATLAB/SIMULINK.

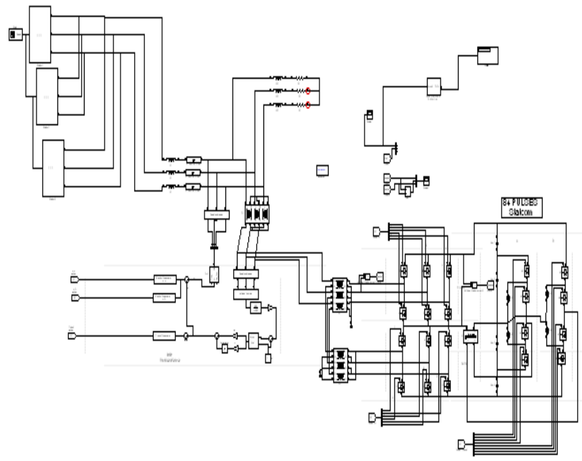

Fig 4. Simulink model of proposed WEC

For a wind speed of 8m/s the Results and wave forms obtained are as follows.

Wind speed	THD
8 m/s	2.3%

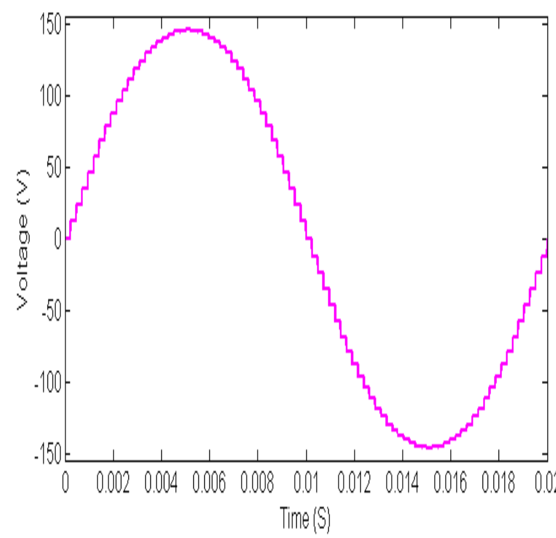

Fig5. 84 pulse STATCOM line to neutral output voltage

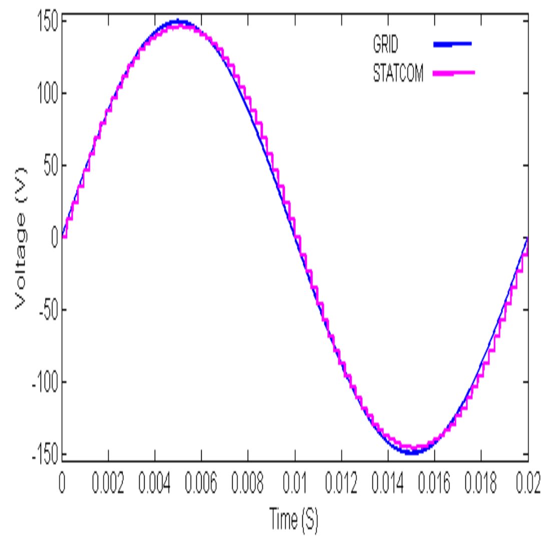

Fig 6. Matching of pure sinusoidal voltage and output voltage of STATCOM

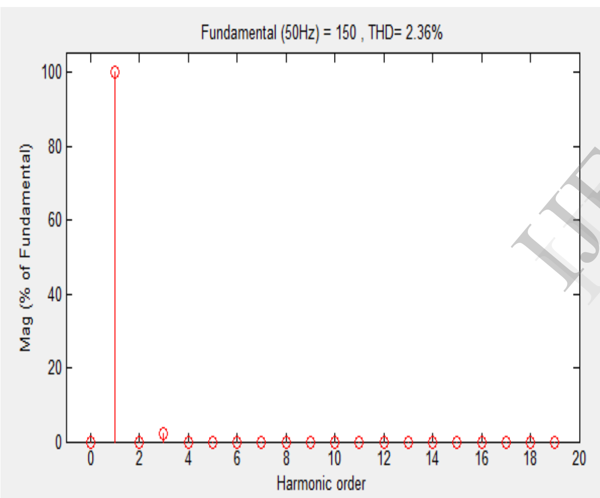

Fig7. FFT analysis of Harmonics in the output voltage

CONCLUSIONS: Application of FACTS controller called Static Synchronous Compensator STATCOM to improve the performance of Wind Farms is investigated .The essential feature of the STATCOM is that it has the ability to absorb or inject fastly the reactive power. Therefore the voltage regulation of the output voltage with STATCOM device is achieved. Observed that STATCOM with reduced capacitor bank can decrease the voltage fluctuations of wind generator terminals. Moreover restoring the stability of the power system having wind farm after occurring severe disturbance such as faults or wind farm mechanical power variation is obtained with STATCOM controller. The dynamic model of the power system having wind farm controlled by proposed 84 pulse STATCOM is developed. The results prove the effectiveness of the proposed 84 pulse STATCOM controller in terms of fast damping the power system oscillations and restoring the stability of wind energy conversion system for wind speed of 8 m/s is tested. This can be extended for different wind speeds

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