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Design of a Three Phase Multi-Level Inverter with Facts Capability for Distributed Energy

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Abstract: ***In this work, a wind energy inverter with flexible AC transmission system (FACTS) capability is presented. The proposed inverter is placed between the wind turbine and the grid, same as a regular inverter, and is able to regulate reactive power transferred to the grid. This inverter is equipped with distribution static synchronous compensators option in order to control the reactive power of the local feeder lines. Using the proposed inverter for small-to medium-size wind applications will eliminate the use of capacitor banks as well as FACTS devices to control the reactive power of the distribution lines. The goal of this work is to introduce new ways to increase the penetration of renewable energy systems into the distribution systems. This will encourage the utilities and customers to act not only as a consumer, but also as a supplier of energy. Moreover, designing such inverters with FACTS capabilities will significantly reduce the total cost of the renewable energy application. The inverter is designed in such a manner to meet all the requirements of a power system network such as compatibility with IEEE standards, total harmonic distortion (THD), efficiency, and total cost of the system. Here a three phase multi-level inverter is designed. The proposed control strategy regulates the reactive power using modulation index. PWM modulation technique is used. The function of the proposed inverter is to transfer active power to the grid as well as keeping the reactive power of the local power lines within the satisfactory limit regardless of the incoming active power from the wind turbine. The simulations have been done in MATLAB/Simulink.***

Keywords: D-STATCOM Inverter, PWM Technique etc…

1. Introduction

The renewable energy sources are one of the biggest concerns of our times. High prices of oil and global warming make the fossil fuels less and less attractive solutions. Wind power is a very important renewable energy source. It is free and not polluter unlike the traditional fossil energy sources. It obtains clean energy from the kinetic energy of the wind by means of the wind turbine. The wind turbine transforms the kinetic wind energy into mechanical energy through the drive train and then into electrical energy by means of the generator. Although the principles of wind turbines are simple, there are still big challenges regarding the efficiency, control and costs of production and maintenance.

Voltage fluctuation is a serious issue particularly for direct-connected wind turbines because these turbines produce power dependent on the variations of the wind speed and inject it without conditioning into the grid. Voltage fluctuation disturbs the sensitive electric and electronic equipment. This may lead to a great reduction in the life span of most equipment. This shows the importance of Facts devices. When wind energy is directly connected to grid side then it is necessary to maintain the voltage stability at the grid. A DSTATCOM is a power electronic converter based device connected in shunt with the distribution system. But the use of DSTATCOM like devices increases the cost of the entire system. In this work a new inverter is designed such that it act both as an inverter and a facts device.

Power equations show that P depends on the phase shift Φ mainly and Q depends on the Vc amplitude mainly. Vc is controlled by the modulation ratio m. In light of the above, it is possible to control independently the active and reactive power by adjusting the values of Φ and m respectively. The relationships between Φ and P and between m and Q are basically nonlinear in nature. By changing the modulation index m value only reactive power is varied and it won't affect the active power.

Here in this paper inverter is switched in such a manner that the series injection of output voltage from inverter is fed to the grid side and this won't cause any change in the active power from wind side to the grid. Various modulation techniques such as sinusoidal pulse width modulation (PWM), selective harmonic elimination (SHE), optimized harmonic stepped waveform technique (OSHW), and space vector modulation can be used. PWM technique has been examined. This newly designed inverter will help to replace facts device with a single inverter. By doing this cost of production will be minimized.

2. Literature Survey

In recent years, wind energy has become one of the most economical renewable energy technology. The technological development of recent years, bringing more efficient and more reliable wind turbines, is making wind power more cost-effective[1]. In general, the specific energy costs per annual kWh decrease with the size of the turbine not withstanding existing supply difficulties. Many developing countries and emerging economies have substantial unexploited wind energy potential [2].

When the number of wind energy connected to a weak grid increases it may cause some instability to the power system network. At no load, the reactive power consumption is about 35-40% of the rated active power, and increases to around

60% at rated power. Reactive power imbalance is one of the major causes of voltage instability in the network due to the associated voltage drops in the transmission lines[3]. Power electronic converters used with wind energy sources may result in the presence of harmonics in grid. So voltage stability frequency stability and amount of harmonics at the grid should be regulated. Reactive power compensation at the grid side can be done easily with the help of facts devices[4]. Facts devices are power electronic switching devices so the use of this may result in more harmonic content at grid side. Again the use of facts devices are not economical. The proposed D-STATCOM Inverter in this thesis is designed to replace the traditional inverter of a wind turbine or solar installation and to provide not only active power to the grid but also be able to balance the grid reactive power as well. Design criterion of the inverter also considers the THD value, efficiency of the inverter and cost of inverter.[5]

Proposed configuration consists of a renewable energy source, dc link, inverter and a local grid. Renewable energy source can be either a solar panel or a wind farm. Here in this work a small wind farm of power output 20kW is used[6]. Output from wind farm is rectified and stored in a dc link with the help of a rectifier unit. This stored dc output is fed to the wind energy inverter. This wind energy inverter with facts capability will feed power to the grid in such a manner the reactive power of the grid is maintained within their desirable limit[7].

In a wind farm kinetic energy in wind is converted into mechanical energy by a wind turbine and it again converted into electrical energy by a wind generator. Wind power is proportional to the air density ρ, control area A and the third power of wind velocity[8]. By reducing the speed of an air mass, wind power is converted into mechanical energy. The fluctuation of wind causes fluctuations in the power delivered by the wind farm to the electricity network. Therefore, the development of systems to improve voltage, frequency stability and power quality is an important line of research in the wind power field[9].
The choice of reactive power compensation system is an economic decision considering initial investment and life cycle cost, where the requirements set by the network operator act as an important boundary condition. Annual operating costs comprise losses, maintenance and repair costs. Devices with less power losses will have less investment cost. Most distribution substations rely on capacitor banks for power factor correction if they have that capability at all. Annual expenses for maintenance and repair are usually 1 to 2% of the purchase price of the capacitor. Capacitor units have no moving or wearing parts. Contactors, regulating relays in automatic capacitors banks and breakers in HV banks are the only components that require maintenance. An investment in capacitors will normally be compensate with payment in 0.5 to 2 years through lower losses and reactive power charges. The annual savings for the whole depreciation period are 30 to 100% of the purchase price. Further, it is not economical to install these types of devices on individual feeder lines as the cost is too great. This is the hole that the D-STATCOM Inverter fits into, as it can provide the benefits of a STATCOM device to individual feeder lines without the exorbitant costs.

3. System Description

3.1 The Control Strategy

STATCOM used in distribution side is called as D-STATCOM. The controller of the D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the inverter V_i, is controlled in the same way as the distribution system voltage, V_s. The three basic operation modes of the D-STATCOM output current, I, which varies depending upon V_i are 1) If V_i is equal to V_s , the reactive power is zero and the D-STATCOM does not generate or absorb reactive power. 2) When V_i is greater than V_s, the D-STATCOM 'sees' an inductive reactance connected at its terminal. Hence, the system 'sees' the D-STATCOM as a capacitive reactance. 3) If V_s is greater than V_i, the system 'sees' an inductive reactance connected at its terminal and the D-STATCOM 'sees' the system as a capacitive reactance. The aim of the D-STATCOM Inverter is to replace the inverter of a wind turbine or solar installation with one that gives the utilities additional control. . The active and reactive power flow of the D-STATCOM Inverter and grid is governed by Equations (1) and (2) which are listed below.

$$P_S = \frac{mE_S E_L}{X}\sin\delta \tag{1}$$

$$Q_S = \frac{mE_S E_L \cos\delta - E_L^2}{X} \tag{2}$$

The amplitude of the inverter voltage is regulated by changing the modulation index *m*. Modulation index *m* is the key factor to control the reactive power compensation and its main task is to make the reactive power of the grid equal to the target reactive power. Several assumptions should be considered for the proposed controller which are as: 1) the load on the feeder line should be considered fixed for a small window of time and there is no change in the load during a cycle of the grid frequency, 2) although making a change in *m* has effect on both (1) and (2), it is assumed that a change in the modulation index will predominantly affect *Q*, and not *P*. Q is controlled independently by changing the value *m* and it won't effect the active power.

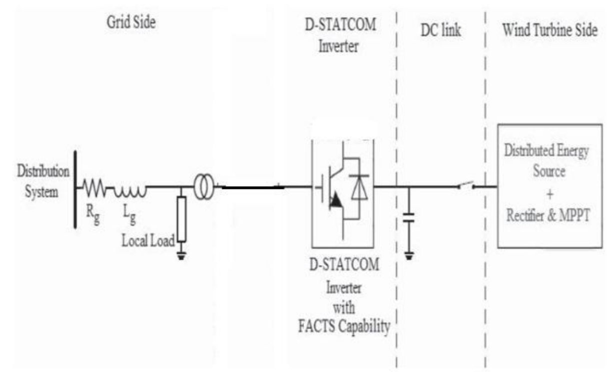

Figure 1: Proposed system

One of the main concerns and performance indicators of an inverter is the level of total harmonic distortion (THD) in its output waveform. Harmonics can greatly reduce the efficiency of an inverter as well as damage other devices that are connected to it. Various harmonic elimination techniques are Sinusoidal Pulse Width Modulation, Space Vector Modulation, Selective Harmonic Elimination, Optimized Harmonic Stepped Waveform Technique.

Sinusoidal Pulse Width Modulation (SPWM) is the simplest of the three techniques. The basic operating principle of SPWM is to compare a reference wave, usually of fixed magnitude but variable frequency, to a sinusoid of desired frequency but controllable magnitude. For a grid connected inverter, the frequency of this sinusoid, often referred to as the control voltage, is set to the frequency of the grid. Under normal operation the switches of the inverter are controlled by the comparison of the triangular wave to the control wave. When the triangular wave is greater than the control wave the inverter outputs a negative voltage and when the triangular wave is less than the control wave the inverter outputs a positive voltage. Usually, the frequency of the triangular waveform is on the order of 7–10 times greater than the frequency of the control waveform. The harmonics can then be easily filtered out using a low-pass filter containing much smaller components.

Equation (3) shows the relation between the target reactive power and the target PF where P_G is the amount of active power on the grid, Q_T is the target amount of reactive power, and PF_T is the target PF desired by the utility. So, Q_T can be calculated as (4). Using (3) and (4), the target reactive power for the grid is determined and is compared with the actual value of the reactive power of the grid. Using a PI compensator will determine the desired value for the modulation index. The power angle is also determined by comparing the actual dc voltage of the inverter with a reference value. A PI compensator determines the desired value for the power angle.

$$P_G = \left(\sqrt{P_G^2 + Q_T^2}\right) \times PF_T \quad (3)$$

$$Q_T = \sqrt{\left(\frac{P_G}{PF_T}\right)^2 - P_G^2} \quad (4)$$

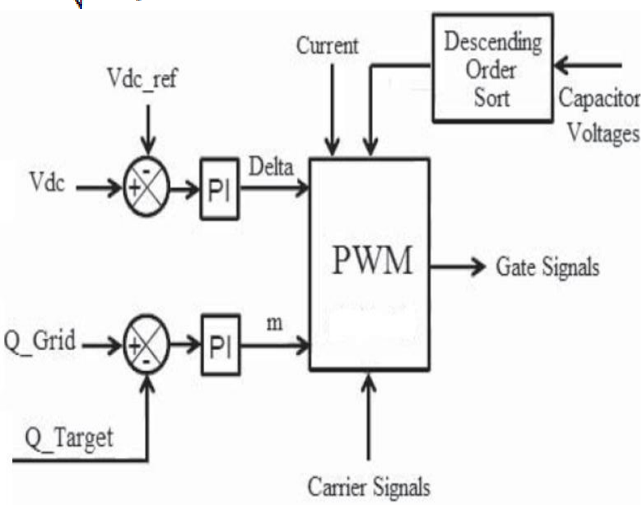

Figure 2: Schematic of the proposed controller system

4. Simulation Result

The design of the D-STATCOM Inverter was carried out in MATLAB/Simulink using the Sim Power Systems toolbox. In this instance, the distributed renewable is modelled as a wind turbine. In the simulation the voltage of the feeder line is supposed to be 7.2 KV and the load on the grid is set to 50 kW and 34.835 kVARs giving a power factor of 0.82 lagging. The voltages for both the DC link are initialized to 1000 V.

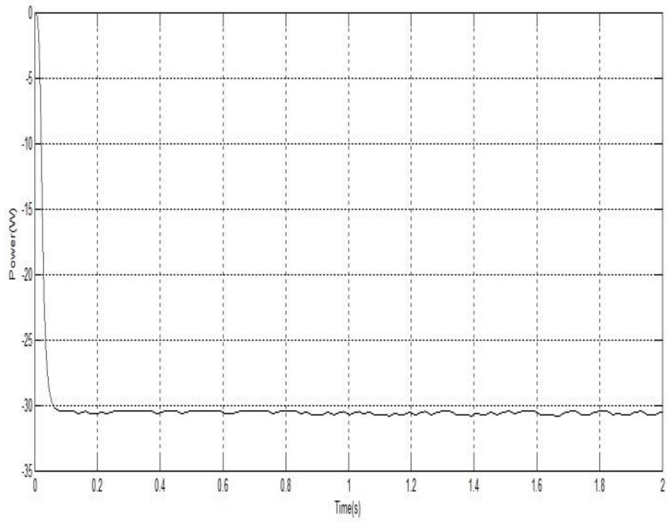

Figure 3: Grid Reactive power without compensation

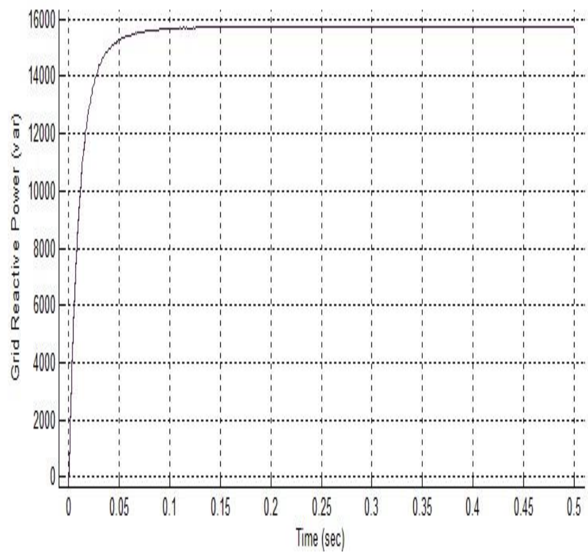

Figure 4: Grid Reactive power with compensation

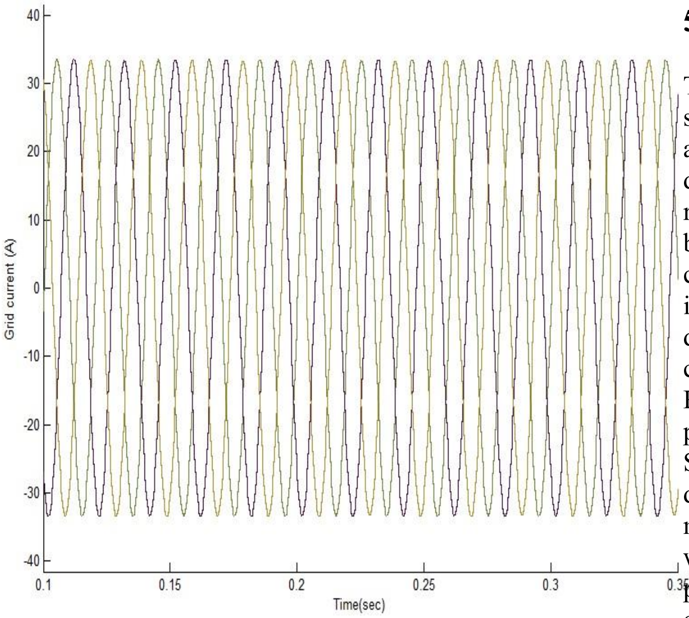

Figure 5: Grid Current after compensation

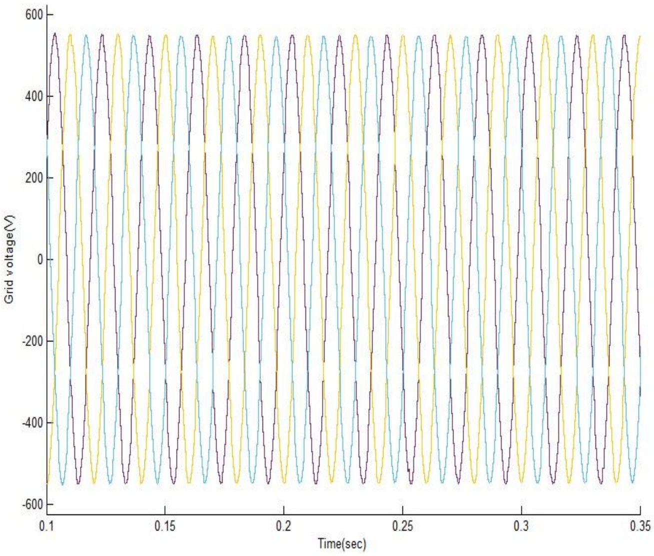

Figure 6: Grid Voltage after compensation

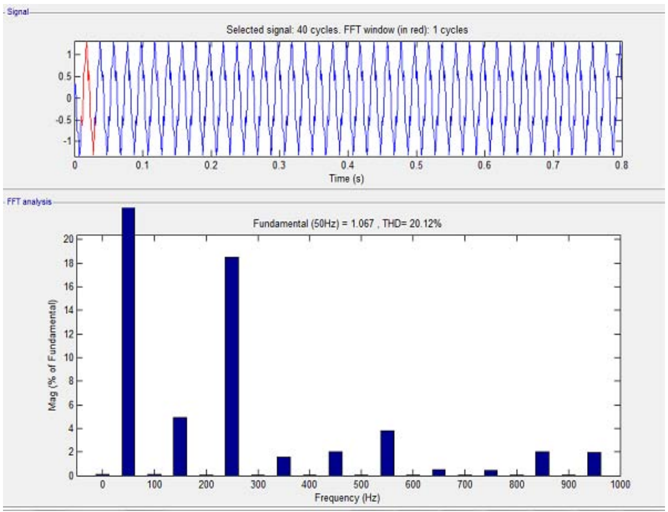

Figure 7: THD value of Grid Current after compensation

5. Conclusion

The concept of a new inverter with FACTS capability for small-to-mid-size wind installations is presented. Utilities are a major barrier to increasing the number of smaller distributed renewable installations. One of the ways that renewable can increase their penetration into these systems is by giving additional control to the utilities. This additional control is done with the help of FACTS devices and this will increase the cost of entire system. The proposed system demonstrates the application of a new inverter with FACTS capability in a single unit without any additional cost. Replacing the traditional renewable energy inverters with the proposed inverter will eliminate the need of any external STATCOM devices to regulate the PF of the grid. Clearly, depending on the size of the compensation, multiple inverters may be needed to reach the desired PF. This shows a new way in which distributed renewable sources can be used to provide control and support in distribution systems. The control strategy of system adjusts the reactive power is controllable by the modulation index *m*. Usage of SHE method will eliminate lower level harmonics and improves the efficiency of the inverter.

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