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Improving the Power Factor Using D-STATCOM Inverter with FACTS Capability for Distributed Energy System

R.Rashmitha
M.Tech-PE,
Vidya Bharathi Institute of Technology, T.S, India.

M.Kishore
Associate Professor & H.O.D,
Vidya Bharathi Institute of Technology, T.S, India.

Abstract:

The inverter is placed between the wind turbine and the grid, same as a regular wind energy inverter (WEI), and is able to regulate active and reactive power transferred to the grid. This inverter is equipped with the distribution static synchronous compensators option in order to control the power factor (PF) of 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 PF of the distribution lines. Moreover, using the new types of converters with FACTS capabilities will significantly reduce the total cost of the renewable energy application. 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 upon the size of the compensation, multiple inverters may be needed to reach the desired PF. This shows the new way in which distributed renewable sources can be used to provide control and support in distribution systems. A high PF is generally desirable in a power system to decrease power losses and improve voltage regulation at the load. It is often desirable to adjust the PF of the system to near load. It is often desirable to adjust the PF of the system to near 1.0. when reactive elements supply or absorb reactive power near the load, the apparent power is reduced. Therefore, the voltage regulation is improved if the reactive power compensation is performed near large loads. Traditionally, utilities have to use capacitor banks to compensate the PF issues, which will increase the total cost of the system. The Modern way of controlling the PF of these power lines is to use small distribution static synchronous compensators (D-STATCOMs).

The D-STATCOM are normally placed in parallel with the distributed generation systems as well as the power system to operate as a source or sink of the reactive power to increase the power quality issues of the power lines.

Introduction:

The role of power electronics in distribution systems has greatly increased recently. The power electronic devices are usually used to convert the non-conventional forms of energy to the suitable energy for power grids, in terms of voltage and frequency. In permanent magnet(PM) wind applications, a back-to-back converter is normally utilized to connect the generator to the grid. A rectifier equipped with a maximum power point tracker (MPPT), converts the output power of the wind turbine to a dc power. The dc power is then converted to the desired ac power for power lines using an inverter and a transformer.

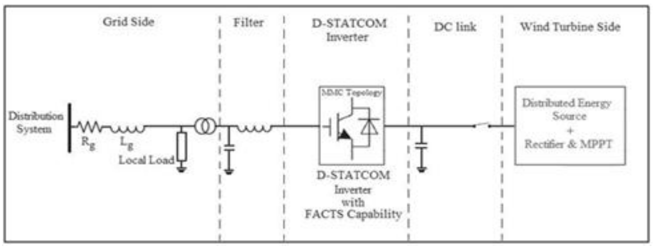

Fig.1. Complete configuration of the proposed inverter with FACTS capability

There are a large number of publications on integration of renewable energy systems into power systems. A list of complete publications on FACTS applications for grid integration of wind and solar energy was presented in, new commercial wind energy converters with FACTS capabilities are introduced without any detailed information regarding the efficiency or the topology used for the converters.

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Power Electronics in Distribution System:

Distributed generation has recently been introduced to modern power systems to avoid generating and transmitting power over a long distance. Relatively small power generators, such as small wind or solar energy systems, are an approach to spread renewable throughout the power systems. Small renewable energy sources are connected to the low side of distribution systems, or in other words, end customers act not only as consumers in modern power systems, but also as active power suppliers to generate electric power. Deployment of small renewable energy sources in distribution systems results in paying more attention to power quality issues at the end point, specifically when the amount of installed renewable energy becomes significant compared to the total power of the system.

Among all power quality concerns, control of active and reactive power transferred to or from the power grid requires major attention. This attention currently is possible through the use of power electronic circuits. Power electronic-based flexible AC transmission systems (FACTS) have been developed in order to enhance control of active and reactive power transfer on feeder lines. FACTS components have been found to be the most efficient and economical method to control power transfer in interconnected AC transmission systems. FACTS systems include a wide range of power electronic devices used in power systems to ensure secure power transmission in AC systems.

MODULAR MULTILEVEL CONVERTER:

The main benefits of the MMC topology are: modular design based on identical converter cells, simple voltage scaling by a series connection of cells, simple realization of redundancy, and possibility of a common dc bus. Fig. 2 shows the circuit configuration of a single-phase MMC and the structure of its SMs consisting of two power switches and a floating capacitor. The output voltage of each SM (vo) is either equal to its capacitor voltage (vc) or zero, depending on the switching states.

The buffer inductors must provide current control in each phase arm and limit the fault currents. To describe the operation of MMC, each SM can be considered as a two pole switch. If Sui, which is defined as the status of the i^{th} sub module in the upper arm, is equal to unity, then the output of the i^{th} SM is equal to the corresponding capacitor voltage; otherwise it is zero. Likewise, if Sli which is defined as the status of the i^{th} sub module in the lower arm, is equal to unity, then the output of the i th lower SM is equal to the corresponding capacitor voltage; otherwise it is zero. Generally, when Sui or Sli is equal to unity, the i^{th} upper or lower SM is ON; otherwise it is OFF.

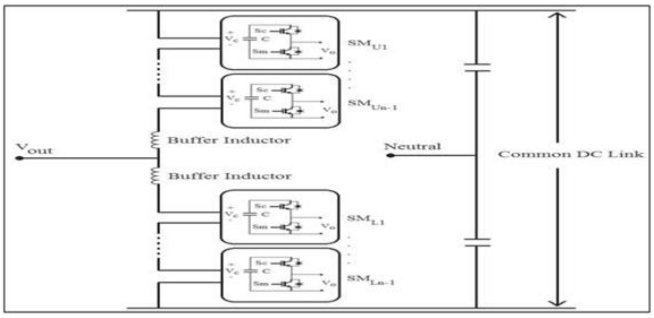

Fig 2:Structure of a single-phase MMC inverter structure

D-STATCOM Inverter:

Power electronic devices, when incorporated into the transmission system, are generally referred to as flexible AC transmission systems (FACTS) devices. There exists a whole family of FACTS devices which have a wide range of uses. However, they all strive to do the same thing which is to provide more control and knowledge of the system. A more detailed explanation of FACTS is given in chapter 4. For now, the discussion of FACTS is limited to one type of device, the static synchronous compensator (STATCOM), which is one of the focuses of this thesis. A STATCOM is the name given to a shunt-connected voltage-source controller that can provide reactive support to a transmission bus. A D-STATCOM is a STATCOM located on the distribution system. The general makeup of a STATCOM is a DC–AC converter that connects a small amount of energy storage such as a capacitor to the AC grid.

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Due to the low energy capacity on the DC side, steady-state operation dictates that the power transfer from the DC to the AC side must remain neutral. This gives the STATCOM device one degree of freedom which it uses to regulate the amount of reactive power it exchanges with the grid. The STATCOM is considered to be the modern static VAR compensator as it performs the same duties but has a faster response rate and wider operating range.

Converter Outline:

The proposed D-STATCOM Inverter described in the thesis is designed to be used with both wind and solar installations. While the D-STATCOM Inverter is the same for both solar and wind installations, the required backends of the overall converter structure are very different. This has to do with the way photovoltaic (PV) and wind turbines operate. PV arrays look like variable current sources while wind turbines look like a variable voltage sources. Both types of installations require a maximum power point tracker (MPPT) to operate efficiently. However, the operation of the MPPT is very different for a solar array than it is for a wind turbine and the outputs are very different as well. The output of a solar MPPT is a fairly stable and constant voltage. The job of the DC–DC Boost stage for a solar converter is to bring the voltage level up to the desired DC link voltage between the DC–DC boost and D-STATCOM Inverter. The output of the MPPT stage of a wind turbine is a variable DC voltage. This makes the job of the DC–DC boost stage much harder as it must boost a variable voltage to a constant DC link value.

Hybrid Multilevel Converter
Cascaded H-Bridges Inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 31.1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources. An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 31.2. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$. For a stepped waveform such as the one depicted in Figure 31.2 with s steps, the Fourier Transform for this waveform follows

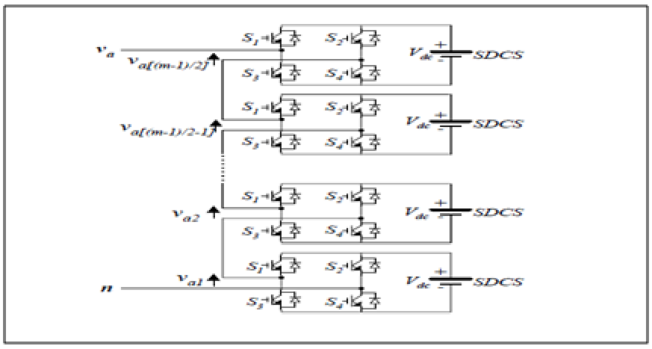

Fig3:Single-phase structure of a multilevel cascaded H-bridges inverter

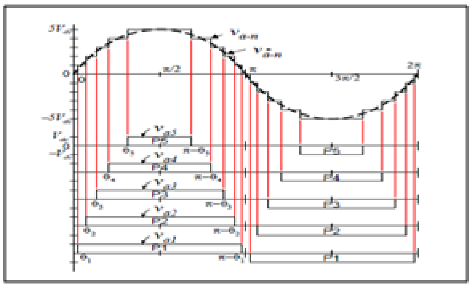

Fig 4: Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

Multilevel Converter PWM Modulation Strategies:

Pulse width modulation (PWM) strategies used in a conventional inverter can be modified to use in multilevel converters. The advent of the multilevel converter PWM modulation methodologies can be

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classified according to switching frequency as illustrated in Figure 31.13. The three multilevel PWM methods most discussed in the literature have been multilevel carrier-based PWM, selective harmonic elimination, and multilevel space vector PWM; all are extensions of traditional two-level PWM strategies to several levels. Other multilevel PWM methods have been used to a much lesser extent by researchers; therefore, only the three major techniques will be discussed in this chapter.

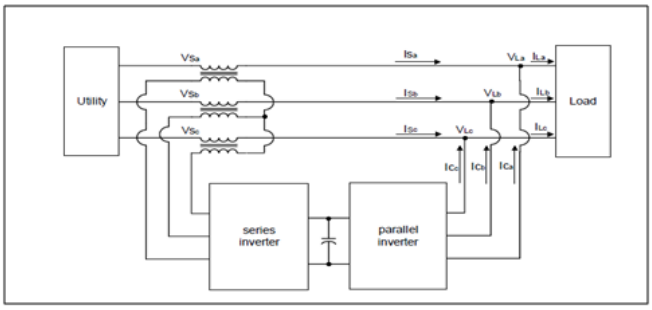

Fig 5:Series-parallel connection to electrical system of two back-to-back inverters

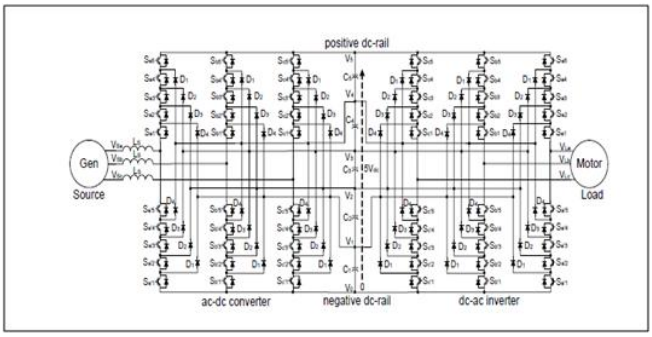

Fig 6:Six-level diode-clamped back-to-back converter structure

PROPOSED CONTROL STRATEGY:

The proposed controller consists of three major functions. The first function is to control the active and reactive power transferred to the power lines, the second function is to keep the voltages of the SMs' capacitors balanced, and the third function is to generate desired PWM signals. Fig. 3 shows the complete proposed controller system.

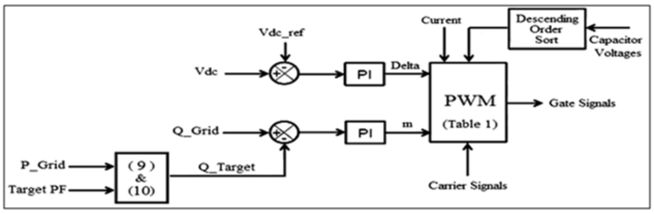

Fig 7: Schematic of the proposed controller system

SIMULATION RESULTS:

The design of an 11-level MMC inverter was carried out in MATLAB/Simulink. The simulation is 20 s long and contains severe ramping and de-ramping of the wind turbine. The goal is to assess the behavior of the control system in the worst conditions. Table II shows the values of the parameters used for the simulation. Before t = 6 s, there is no wind to power the wind turbine; therefore, the dc link is open-circuited. At t = 6 s, the input power of the inverter is ramped up to 12 kW in 5 s, and then ramped down to 3.5 kW 4 s later. Fig. 6 shows the output active power from the wind turbine.

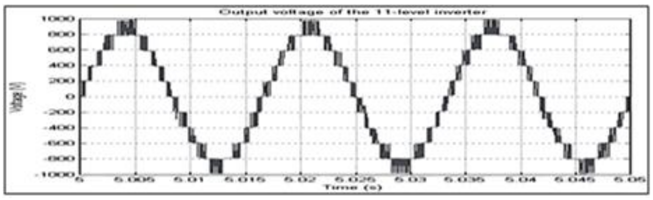

Fig 8: Simulated output voltage of an 11-level inverter

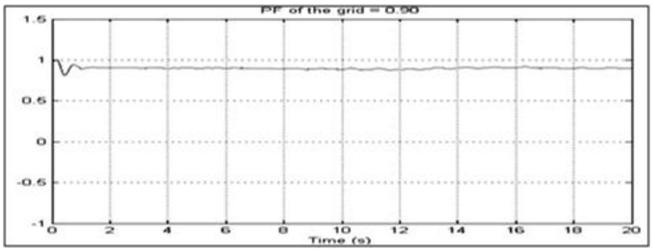

Fig 9: Simulated PF of the grid

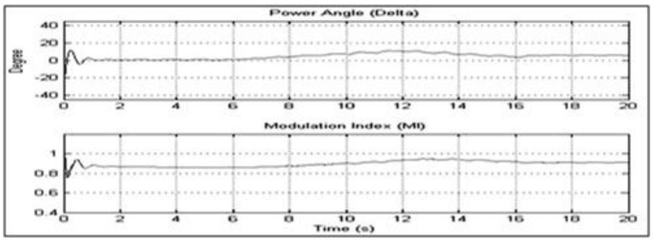

Fig 10: Simulated delta and modulation index of the 11-level inverter

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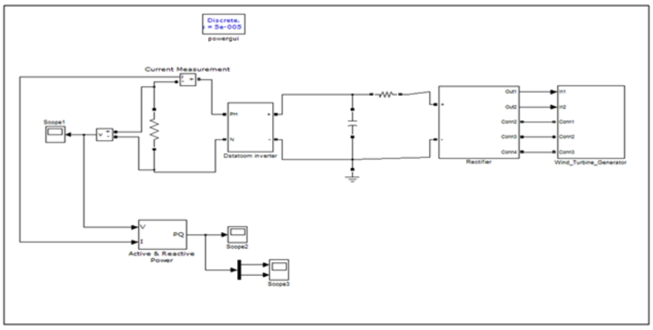
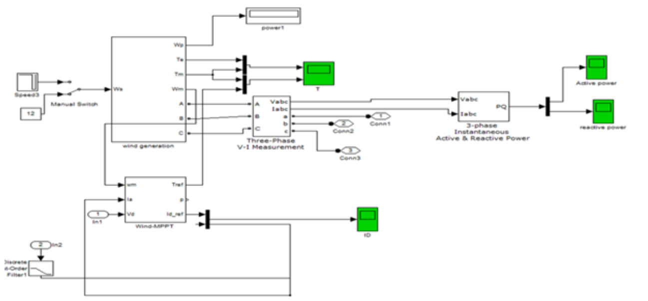
The inverter transfers the whole active power of the wind, excluding its losses, to the grid. The amount of reactive power is dictated by the target PF.

MATLAB Model Diagrams:



Wind Turbine Generator



SCREEN SHOTS

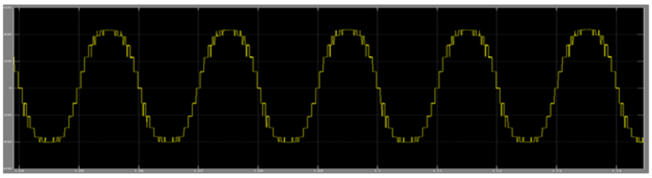


Fig 11: Simulated output voltage of an 11-level inverter

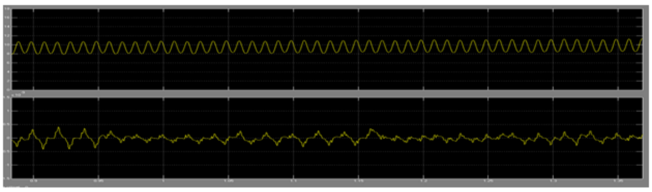


Fig 12: Simulated active and reactive power of the inverter (top graph)

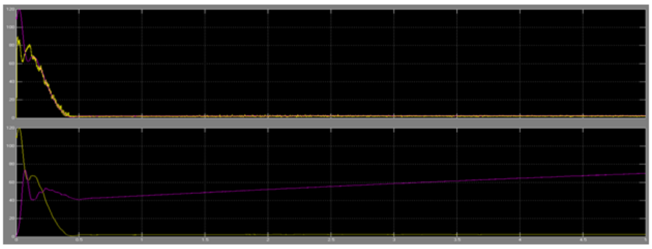


Fig 13: Torque of the wind turbine generator

CONCLUSION:

The concept of a new multilevel inverter with FACTS capability for small-to-mid-size wind installations is presented. 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 proposed controller system adjusts the active power by changing the power angle (delta) and the reactive power is controllable by the modulation index m. The simulation results for 11-level inverters are presented in MATLAB/Simulink. To validate the simulation results, a scaled prototype of the proposed 11-level inverter with D-STATCOM capability is built and tested. Practical results show good performance of the proposed control strategy even in severe conditions.

Future Scope:

This thesis work focuses on space vector pulse wid demodulation based algorithms for multilevel inverters. The SVPWM algorithms proposed have essentially been aimed at reducing the harmonic distortion in the output voltage of multilevel inverters. The performance of all these algorithms can be evaluated in the over modulation zone. Analytical evaluation of harmonic distortion for multilevel inverters can also be carried out. More SVPWM based techniques can be developed for inverter switching at

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much higher frequencies and hardware implementation can also be done. All the proposed algorithms in this thesis are for time-invariant systems. Therefore, it is recommended to eliminate harmonics for time-variant systems. Further to reduce the switching losses of the inverters, discontinuous pulse width modulation algorithms have to be proposed.

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