Simulation of Single-Phase D-STATCOM Fivelevel Inverter for Wind Applications

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Abstract – This dissertation presents the design of a novel multi-level inverter with FACTS capability for small size (1–2kW) permanent-magnet wind installations using neutral point clamped (NPC) topology. The aim of the work is to design a new type of inverter with DSTATCOM option to provide utilities with more control on active and reactive power transfer of distribution lines. The inverter is placed between the renewable energy sources, specifically a wind turbine, and the distribution grid in order to fix the power factor of the grid at a target value, regardless of wind speed, by regulating active and reactive power required by the grid The inverter is capable of controlling active and reactive power by controlling the phase angle and modulation index, respectively. The unique contribution of the proposed work is to combine the two concepts of inverter and D-STATCOM using a novel voltage source converter (VSC) multi-level topology in a single unit without additional cost. Simulations of the proposed inverter, with 5 levels, have been conducted in MATLAB/Simulink. 5 level inverter is able to fix PF of the grid as well as THD Furthermore, total cost of the prototype model, which is one of the major objectives of this research, is comparable with market prices.

Index Terms – MMC-modular multi-level converter, PF-power factor.

1. INTRODUCTION

The electric utility industry has begun to update more and more in recent years, Relevant issues such as global warming, toxic emissions, energy cost, power market, and increasing energy demand have affected power industry growth over the past decade, utilities have shown decreased willingness to invest in large-scale power plants and, consequently, have shifted to smaller distributed energy sources closer to loads . In addition, power facility upgrades are essential in order to make a profit in the competitive power market. Thus, renewable energy sources such as wind, solar, biomass, and geothermal are attractive alternatives for power utilities With the exception of hydro, wind energy currently has the greatest share in renewable energy sources. The capacity of wind has more than doubled during the last two decades and the cost has decreased by one-sixth . Rapid progress in wind technology has reduced wind energy cost to such an extent that it is competitive with conventional energy. Most commercial wind systems include a horizontal-axis wind turbine, and a generator connected to the grid using power electronic converters. Generally, wind generation systems utilizing permanent magnet (PM) generators possess a rectifier associated with a maximum power point tracker (MPPT) and an inverter. Figure provides the configuration of a PM-based wind system [1]. 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 . One of the most well-known FACTS devices is the static synchronous compensator (STATCOM), a STATCOM is a power electronic device based on a voltage source converter (VSC) [2]. The STATCOM is able to connect in parallel with a power system and act as a source, or sink, of reactive power in order to enhance power quality of the systems. It can also provide active power if connected to a source of power such as a renewable energy source If theSTATCOM is applied on a distribution system, it is called distribution STATCOM (D-STATCOM). The application of D-STATCOM is very similar to a regular STATCOM. STATCOMs are typically utilized on the high-voltage side of the distribution systems because of their high cost. Deploying STATCOMs at the consumer level is not economically feasible. The aim of this work is to combine the two concepts of inverter and D-STATCOM in a single unit in order to enjoy the benefits of an inverter with D-STATCOM capability with no additional cost. The inverter with FACTS (D-STATCOM) capability is a power electronic device that is placed between the renewable energy source and the distribution grid has capability to provide power factor control by regulating active and reactive power control on the system[3][4][5].

2. PRPOSED DESIGN AND STRUCTURE OF THE D-STATCOM

The proposed inverter is able to correct the power factor of the line, especially at the end points of the distribution lines where there is not enough attention to the line behavior. Multiple D-STATCOM inverters on the feeder lines would help utilities increase their knowledge of the distribution system leading to greater efficiency, reliability, and control. The unique work in this paper is the bringing together and combination of several relatively new concepts. The design objectives of the project include: minimize the overall switching frequency of the inverter; minimize the total harmonic distortion in order to maintain compliance with IEEE standards and maximize energy conversion efficiency; and finally, keep the cost of the inverter as low as possible. The D-STATCOM Inverter falls under the category of devices known as custom power electronics. Most of the research on custom power electronics has stemmed from the research done on STATCOM devices that integrate battery energy storage. Generally, the purpose of the D-STATCOM Inverter is to increase the value to the utility of a small wind turbine located on a single-phase feeder line by providing extra control and information. The D-STATCOM Inverter represents one stage of a three-stage power electronics block that makes up the entire converter structure. The first of these first of these stage is wind turbine maximum point tracker (MPPT) This stage transfers the maximum power from wind turbine while transferring Quasi Dc output of permanent magnet generator into uniform dc voltage .The second stage, the DC-DC boost, boost provided by the MPPT to the desired DC link voltage required by the D-STATCOM Inverter The final stage of D-SATCOM inverter focus of this research is the voltage source converter source converter that can provide the grid with VAR control and power factor correction independents of wind turbine production Fig1-shows system structure.

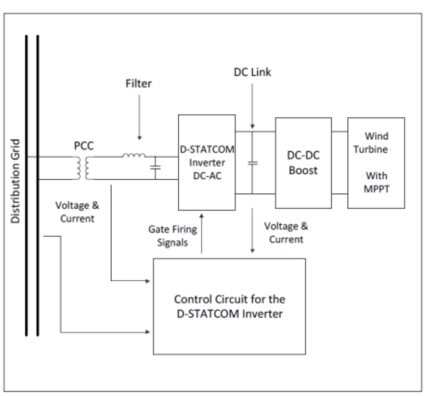

Fig1-System structure

3. PROPOSED CONTROL STRATEGY

This inverter is designed to control the flow of active and reactive power between the wind turbine and the grid. It is able to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. To enhance the reactive power control of the proposed inverter, it is equipped with the additional D-STATCOM option. This option permits the inverter to deliver reactive power fully independent from the wind speed. When the wind speed is too low to generate active power, the inverter acts as a source of reactive power to control the PF of the grid, like a D-STATCOM. The inverter is able to control the active and reactive power regardless of the input active power required by the DC link. Generally, there are two modes of operation for D-STATCOM inverter when it is connected to the grid: 1) when active power is gained from the wind turbine, which is called inverter mode, 2) when no active power is gained from the wind turbine, which is called D-STATCOM mode. The active and reactive power flow of the D-STATCOM is governed by,

$$P = \frac{E_S E_L Sin\delta}{X}$$

$$Q = \frac{mE_S E_L Cos\delta - E_L^2}{X}$$

Where Es, EL, δ and m are the voltage of the STATCOM, voltage of the line, power angle, modulation index, and inductance between the inverter and the grid, respectively. The steady state operation of the D-STATCOM inverter is controlled by adjusting δ and m, so that it provides the desired amount of active power and reactive compensation. The modulation index is used to control the active power while the power angle is used to control the reactive power transferring between the wind turbine and the grid.

4. MULTI-LEVEL TOPOLOGY

Numerous industrial applications require medium to high power capability. Some medium voltage for a medium- to high-voltage power application, rating limitations of power electronic components do not allow to connect only a single power semiconductor switch. Therefore, a multi-level converter can be a suitable alternative for these applications. Multi-level converters can also be a suitable choice for renewable energy systems. During the past three decades, several multi-level topologies have been developed Modular multilevel converter (MMC) topology is a new multi-level topology that recently has gained much attention, specifically for mid- to high-voltage applications. Primary benefits of MMC topology include: modular design based on identical converter cells, simple voltage scaling by a series connection of cells, simple realization of redundancy, and the possibility of a common DC bus. The diode-clamped (DC) Topology, also called neutral-point clamped (NPC), topology is based on the utilization of a number of diodes in order to block small DC sources. The configuration of a single-phase 5-level diode-clamped inverter is shown in Figure 2.

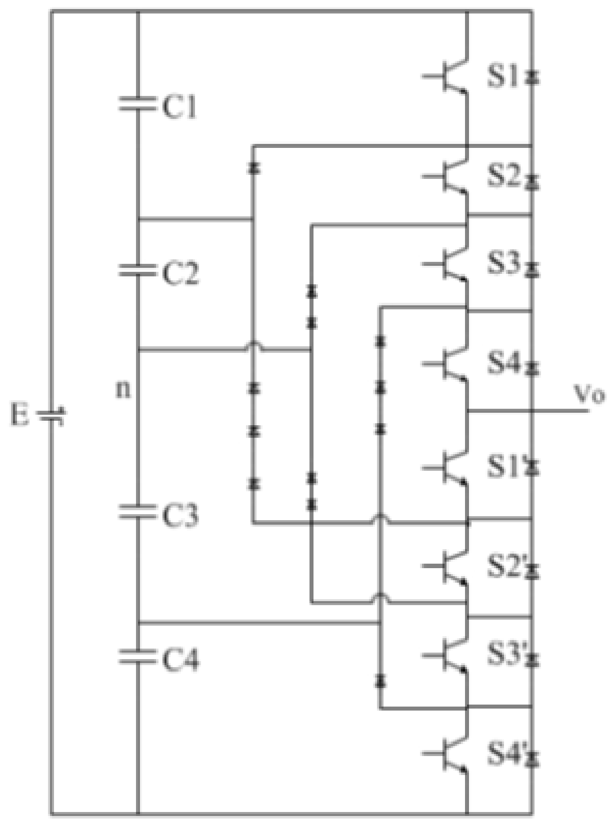

Figure2. Single-phase 5-level DC topology

The DC topology can easily be extended to a generic n-level configuration in a 5-level diode-clamped inverter; the DC bus voltage is split into four equal voltage steps. In this case, the number of diodes required to clamp the voltage changes point by point. Each diode is sized to provide voltage blocking for the voltage across one capacitor. For instance is represented only by one diode, while D1'is represented by three diodes equal to D1,which are in series because it must block voltage across capacitors C2,C3andC4 , meaning that it is allowed to use one diode with higher blocking capability or three diodes in series with equal blocking capability to D1. Considering the diode reverse voltage for an n-level inverter, calculated by Vr=E/n-1, the diode reverse voltage for a 5-level inverter is equal to E/4 , thus demonstrating that increasing the number of levels results in decreased voltage stress on the components. Operation of 5-level NPC topology is shown in Table I.

In Table I, the on-state and off-state of the switches is shown by 0 and1, respectively. Any shortcut should be avoided in each of the switching states, meaning that all switches cannot be turned on simultaneously.

In addition, Si and Si', where i is the number of the switches, should be switched in a complementary way. For instance, when is S1 is on, S1'should be off and vice versa. This has to happen for all the other switches.

Table I: Switching table for the 5-level DC topology

Switches								Output Voltage
S1	S2	S3	S4	S1'	S2'	S3'	S4'	Vo
1	1	1	1	0	0	0	0	+E/2
0	1	1	1	1	0	0	0	+E/4
0	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	-E/4
0	0	0	0	1	1	1	1	-E/2

5. SIMULATION RESULTS

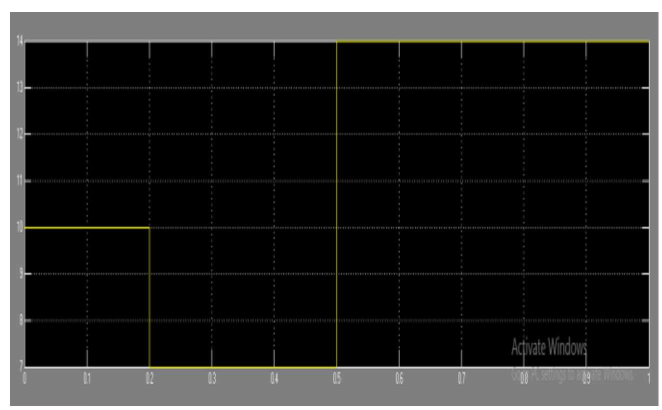

Fig1-Variable wind speed input w.r.t to time

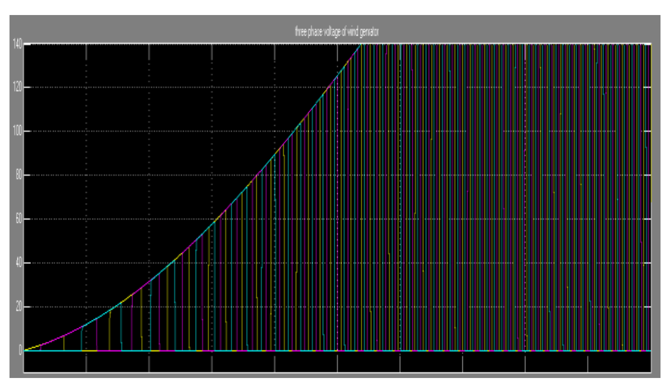

Fig2-Three phase voltage generated by wing generator

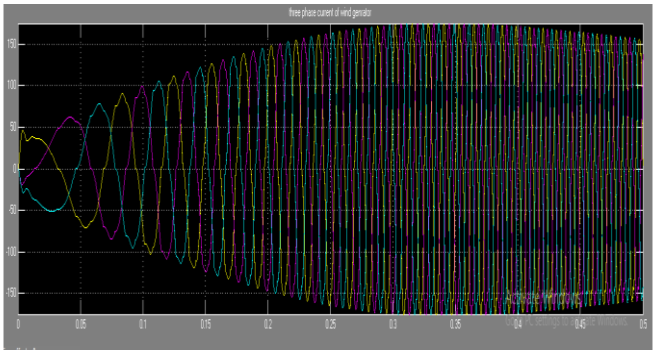

Fig3-Three phase current generated by wing generator

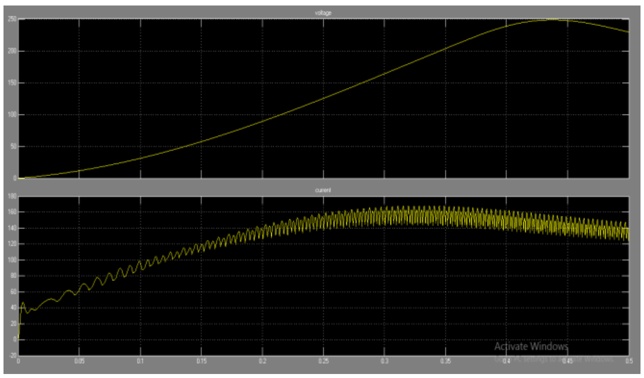

Fig4-torkque and speed waveform of wind generator

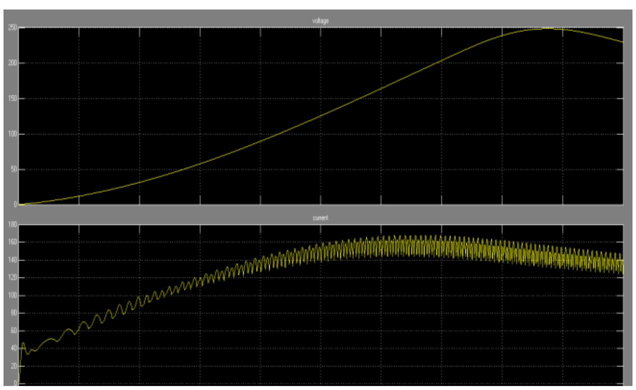

Fig5 –Output voltage and current of bridge rectifier

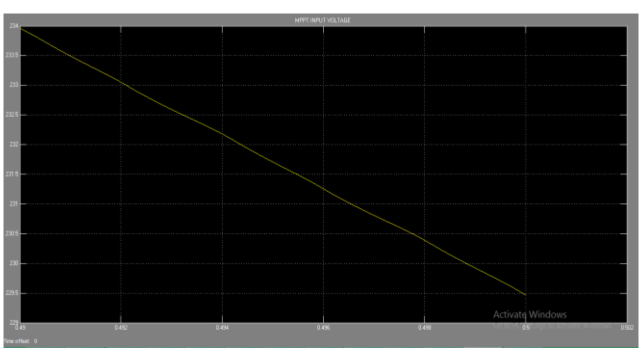

Fig6-MPPT input voltage waveform w.r.t to time

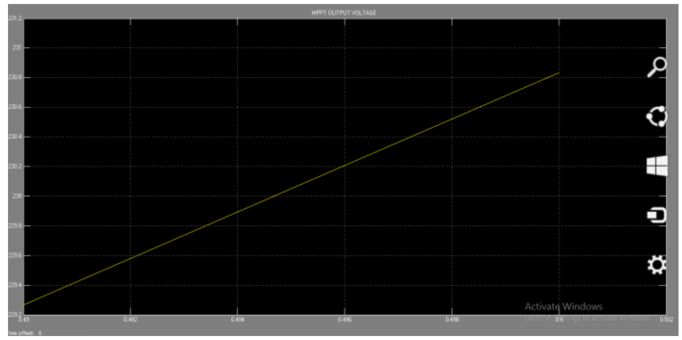

Fig7-MPPT output voltage waveform w.r.t to time

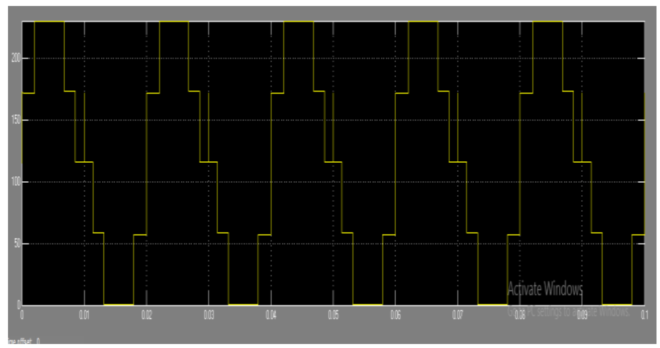

Fig8-Inverter output voltage waveform without filter

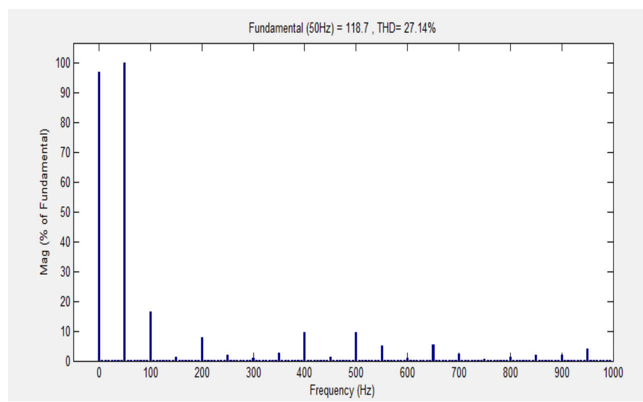

Fig9-THD in inverter output voltage waveform

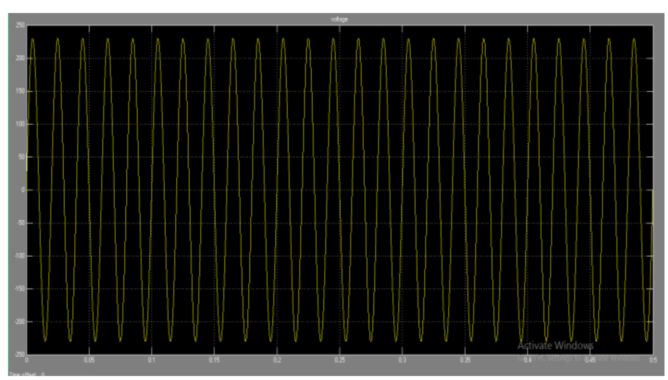

Fig10-Inverter output voltage waveform with filter

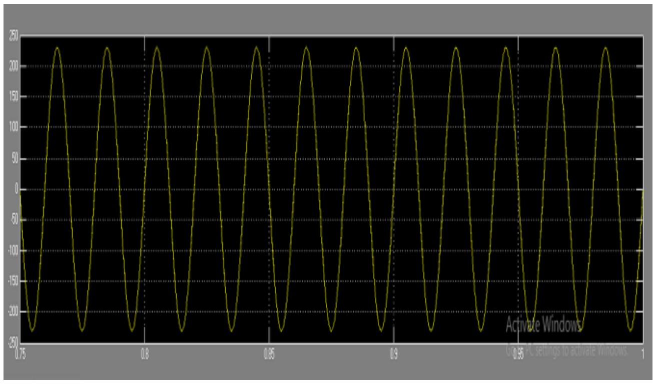

Fig11- output voltage across resistive load

6. CONCLUSION

The proposed D-STATCOM Inverter is used for small size wind turbine for domestic application, Inverter is able to control the power of load by controlling five levels D-STATCOM inverter with SPWM technique, The proposed D-STATCOM Inverter can control the active and reactive power on each single feeder line while the output of the renewable energy source, especially wind is varying. Active power is controlled by shifting the phase angle while reactive power control is achieved by modulation index control. D-STATCOM inverter reduces the total harmonics Distortion up to great extent. The proposed D-STATCOM uses the Diode clamped topology which is also known as Neutral point clamped(NPC) topology and this topology will helps in achieving a good control over the active and reactive power absorb by the load and reduces THD level. And the cost of proposed D-STATCOM inverter is less as the same inverter acts as D-STATCOM.

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