ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Realization of Modular Multi-Level Inverter Fed Wind System Applications to Various Load Conditions

Radha Devi Pusala
M.Tech Scholar(EPS),
Department of EEE,
Prakasam Engineering College,
Kandukur.

P.Yedukondalu
Assistant Professor,
Department of EEE,
Prakasam Engineering College,
Kandukur.

Abstract

Multilevel inverters have received more attention in industrial application, such as motor drives, FACTS devices and renewable energy systems, etc. Primarily multilevel inverters are known to have output voltages with more than two levels. A modular multilevel converter (MMC) is one of the next-generation multilevel converters intended for high or medium-voltage power conversion without transformers. Compared with the existing multilevel converters, one of the most desirable advantages offered by MMC may be its ability to process both active power and reactive power with its terminals directly connected to directly high-voltage networks. A D-STATCOM (Distribution Static Compensator) is a shunt device which is generally used to solve power quality problems in distribution systems. D-STATCOM is used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. In this project MMC D-STATCOM inverter controls the DC link voltage as well as the active and reactive power transferred between the renewable energy source, specifically wind turbine, and the grid in order to regulate the power factor (PF) of the grid regardless of the input active power from wind turbine. The proposed topology developed by using Matlab/simulink software.

Index Terms— MMC Topology, Power Quality, Renewable Energy Sources, Total Harmonic Distortion.

Introduction

Recently renewable energy power supplied into the utility grid has been paid much attention due to increase in fossil fuel prices, environmental pollution and energy demand boom. Among various renewable energy resources such as solar, wind, tidal, geothermal, biomass etc., the solar photovoltaic system being more attractive and promising green resource because of its abundant availability, safe resource, cost free and eco-friendly [1]. The solar photovoltaic (PV) modules directly converts the light energy into the electrical energy, but energy obtained from the PV module acts as low voltage DC source and has relatively low conversion efficiency. In order to improve the efficiency and convert low voltage DC source into usable AC source, the power electronics converters are used to transform DC into AC.

Deploying small renewable energy sources in distribution systems requires paying more attention to the power quality at the end point, specifically when the amount of installed renewable energy becomes significant compared to the total power of that system. There are numerous benefits to small wind applications such as: it is easier to install in urban landscapes, it requires little to no permitting, and it is easier to finance than large-scale wind. Among all power quality concerns, controlling the active and reactive power transferring to or from the grid requires major attention. Nowadays, this attention is possible using power electronics. Power electronic-based flexible AC transmission System (FACTS) devices have been developed in order to provide more knowledge and control on power systems. FACTS

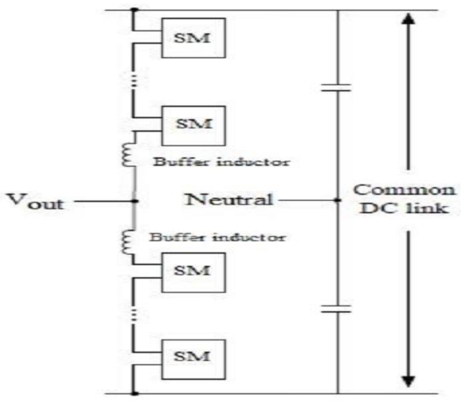
ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

components have been found as the most efficient and economical way to control the power transfer in interconnected AC transmission systems. In this paper, a new single-phase multilevel D-STATCOM inverter is presented.

A D-STATCOM inverter is a power electronic device that is placed between a renewable energy source and the distribution grid not only to provide active power, but to control reactive power on system. The proposed D-STATCOM inverter in this work could replace existing inverters used for renewable energy systems, specifically for small wind applications. Although the history of multi-level inverter goes back to the 1970, conventional two-level topology is still one the most common topologies for power converters. Due to the limits on current and voltage of the semiconductor components, multilevel inverters has recently gained more attention for applications such as large-scale utility applications, electric vehicles (EVs), and inverters for renewable energy systems. A multi-level converter has several advantages compared to the conventional two-level converter. It has the capability to perform at a lower switching frequency, it has lower total harmonic distortion (THD), it has better efficiency, and it possesses less and therefore less voltage stress on the devices [4-8]. The modular multilevel converter (MMC) topology has gained more and more attention specifically for mid- to high-voltage applications. The unique work in this paper is the use of MMC topology for an inverter and a DSTATCOM in a single unit for small to mid-sized wind applications. This paper proposes the overall compensation of power system by using several load conditions by using DSTATCOM topology and dynamically evaluated with the help of Matlab/Simulink Platform.

Concept of MMC Topology

The modular multilevel converter (MMC) is the most advanced topology for large scale commercial deployment. MMC is the topology used by SIEMENS for HVDC Plus technology [9-10]. The structure of this topology is based on several modules in which each module consists of a floating capacitor and two switches. This topology is an ideal choice for FACTS applications if the capacitor voltages maintain balanced. MMC is able to transfer active and reactive power regardless of the load characteristics. The main drawback of this topology is that it requires large capacitors in comparison with similar topologies which may affect the total cost of the inverter. However, this problem can be alleviated by the lack of need for any snubber circuits. 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 [11-13]. Fig. 1(a) shows the circuit configuration of a single-phase MMC. The converter is composed of an arbitrary number of identical sub-modules (SMs). An n-level single-phase MMC consists of a series connection of 2n (n-1) basic SMs and two buffer inductors. Fig.1 (b) shows the structure of each SM consisting of two power switches and a floating capacitor.



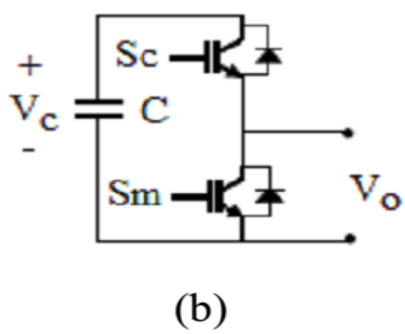


Fig.1. a) Configuration of the MMC topology, b) A sub-module (SM).

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The output voltage of each SM (v_o) is either equal to its capacitor voltage (v_c) or zero, depending on the switching states. The buffer inductors must provide current control in each phase arm and limit the fault currents. The DC link of the MMC is connected to the distributed energy source (i.e., a wind turbine) through a rectifier using maximum power point tracker (MPPT). The output terminal of the MMC is connected to the utility grid through a series-connected second-order filter and a distribution transformer. To describe the operation of MMC, each SM can be considered as a two-pole switch. If s_{ui}, 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 S_{li}, 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 S_{ui} or S_{li} is equal to unity, the i_{th} upper or lower SM is ON; otherwise it is OFF. Therefore, the upper and lower arm voltages of the MMC are as follows:

$$v_{upperArm} = \sum_{i=1}^{n-1}(S_{ui}v_{ci}) + v_{l1} \quad (3.1)$$

$$v_{lowerArm} = \sum_{i=1}^{n-1}(S_{li}v_{ci}) + v_{l2} \quad (3.2)$$

$$v_{dc} = v_{upperArm} + v_{lowerArm} = \sum_{i=1}^{4}(S_{ui}v_{ci}) + \sum_{i=1}^{4}(S_{li}v_{ci}) + (v_{l1+}\, v_{l2)} \quad (3.3)$$

$$v_{out} = {}^{v_{dc}}/_{2} - v_{upperArm} = -{}^{v_{dc}}/_{2} + v_{lowerArm} \quad (3.4)$$

The carrier-based pulse width modulation (CPWM) method [14-15] is used in this paper to control the SMs' voltages. Fig. 2 shows the reference and the carrier waveforms for a 5-level CPWM.

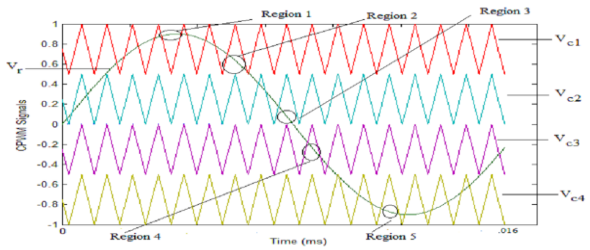


Fig. 2. CPWM waveforms for a 5-level MMC

Fig.2 shows that there are five operating regions for a 5-level MMC defined in table 1:

Table1. Operating regions for a 5-level MMC

Region	Status	$n_{UpperArm}$	$n_{lowerArm}$	V_{out}
1	$v_r \geq v_{c1}, v_{c2}, v_{c3}, v_{c4}$	0	4	${}^{v_{dc}}/_{2}$
2	$v_r < v_{c1}$ $v_r \geq v_{c2}, v_{c3}, v_{c4}$	1	3	${}^{v_{dc}}/_{4}$
3	$v_r < v_{c1}, v_{c2}$ $v_r \geq v_{c3}, v_{c4}$	2	2	0
4	$v_r < v_{c1}, v_{c2}, v_{c3}$ $v_r \geq v_{c4}$	3	1	${}^{-v_{dc}}/_{4}$
5	$v_r < v_{c1}, v_{c2}, v_{c3}, v_{c4}$	4	0	${}^{-v_{dc}}/_{2}$

Where $n_{upperarm}$ and $n_{lowerarm}$ are the numbers of SMs which are ON in the upper arm or lower arm, respectively. The total number of SMs with the status of ON is:

$$n_{upperArm} + n_{lowerArm} = 4 \quad (3.5)$$

The most critical issue to control MMC is to maintain the voltage balance across all the capacitors. Therefore, the SM' voltages are measured and sorted in descending order during each cycle. If the current flowing through the switches is positive, $n_{upperarm}$ and $n_{lowerarm}$ of the SMs in upper arm and lower arm with the lowest voltages are selected, respectively. As a result, 4 capacitors with lowest voltages are chosen to be charged. Likewise, if the current flowing through the switches is negative, $n_{upperarm}$ and $n_{lowerarm}$ of the SMs in upper arm and lower arm with the highest voltages are selected, respectively. As a result, 4 capacitors with highest voltages are chosen to be discharged. Consequently, the voltages of the SMs' capacitors are maintained balanced.

Controller Design

The aim of the designed D-STATCOM inverter is to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. This 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 DSTATCOM inverter when it is connected to the grid: 1) when active power is gained from the wind turbine and it powers the DC link, which is called inverter mode, 2) when no active power is gained from the wind turbine, which is called DSTATCOM mode. The proposed D-STATCOM inverter is able to maintain the PF of the grid at a certain target value whether the DC link capacitors are charged by the current comes from the rectifier or the DC link is open circuited and DC link capacitors are charged by the grid. The power flow between a STATCOM and a line is governed by the same equations that describe the power flow between two active sources separated by an inductive reactance. For normal transmission lines this inductive reactance, modeled by jX in Fig. 3, is the inductance of a transmission line. For a STATCOM the modeled inductance is the inductance of the transformer that connects the STATCOM to the line. In Fig. 3 the RMS voltage of the STATCOM is given as E_S and is considered to be out of phase by an angle of δ to the RMS line voltage: E_L. The active power transferred from the STATCOM to the line is given by (6) and the reactive power transferred from the STATCOM to the line is given by (7).

$$P_S = \frac{E_S E_L}{X} \sin\delta \qquad (3.6)$$

$$Q_s = \frac{E_s E_L \cos\delta - E_L^2}{X} \qquad (3.7)$$

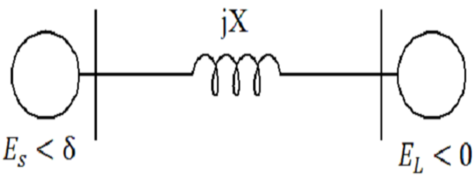


Fig.3 Simple system diagram describing the power flow between two sources

Control over the reactive power provided by the STATCOM is achieved by selecting both the voltage level of the STATCOM and the angle between the two voltages δ. By using power electronics it is possible to control the amplitude of the STATCOM voltage by adjusting the modulation index m and the angle δ adding a delay to the firing signals. Adding the modulation index into (6) and (7) gives:

$$P_S = \frac{mE_S E_L}{X} \sin\delta \qquad (3.8)$$

$$Q_s = \frac{mE_s E_L \cos\delta - E_L^2}{X} \qquad (3.9)$$

These two equations govern the operation of the STATCOM device. The steady state operation of the DSTATCOM inverter is controlled by adjusting m and δ, so that it provides the desired amount of active power and reactive compensation. In this paper, the modulation index is used to control the active power and the power angle is used to control the reactive power transferred between the renewable energy source and the grid. Fig. 4 shows the proposed control system.

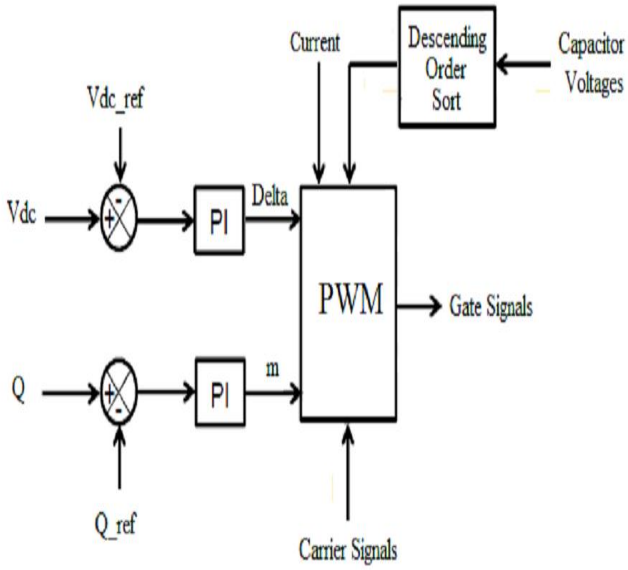


Fig. 4. Control System Schematic

Matlab/Simulink Modeling & Results

Here simulation is carried out in several cases and designed by using Matlab/Simulink environment Tool, in that 1) Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition, 2) Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition, 3)

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Proposed MMC Topology Based DSTATCOM Operated under Variable Load Condition.

Case 1: Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition

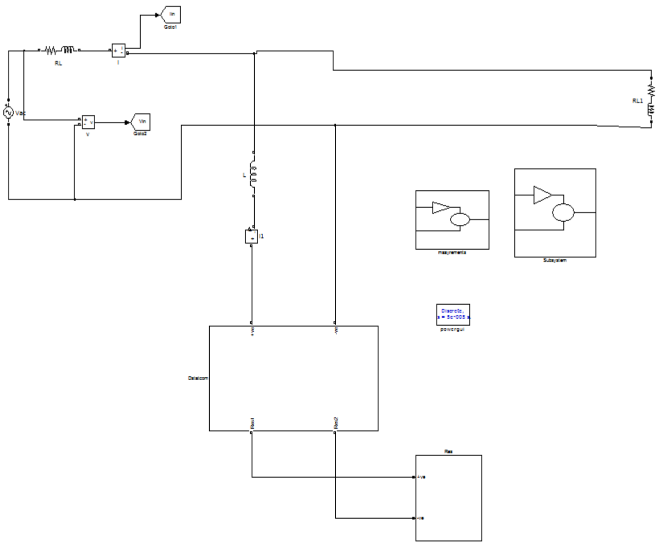


Fig.5 Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition

Fig.5 shows the Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition using Matlab/Simulink Platform.

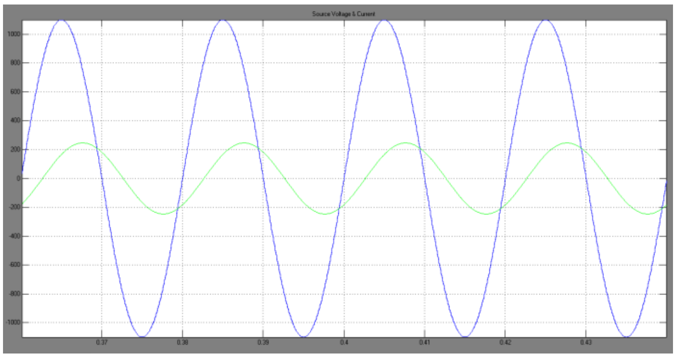


Fig.6 Source Voltage & Current

Fig.6 shows the Source Voltage & Current of Proposed MMC Topology without DSTATCOM Operated under Linear Load Condition.

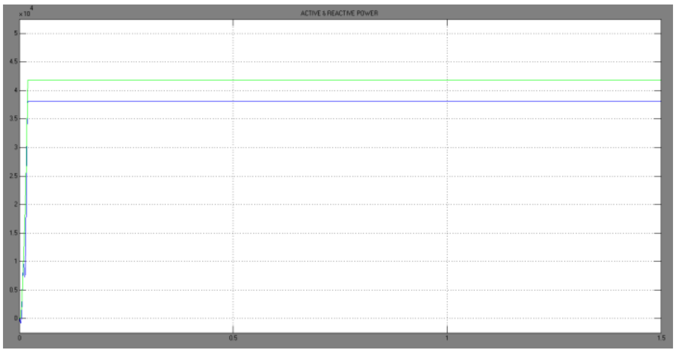


Fig.7 Active & Reactive Power

Fig.7 shows the Active & Reactive Power of Proposed MMC Topology without DSTATCOM Operated under Linear Load Condition.

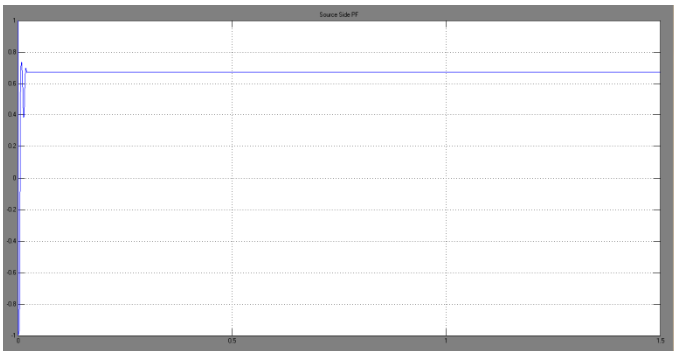


Fig.8 Source Side Power Factor

Fig.8 shows the Source Side Power Factor of Proposed MMC Topology without DSTATCOM Operated under Linear Load Condition.

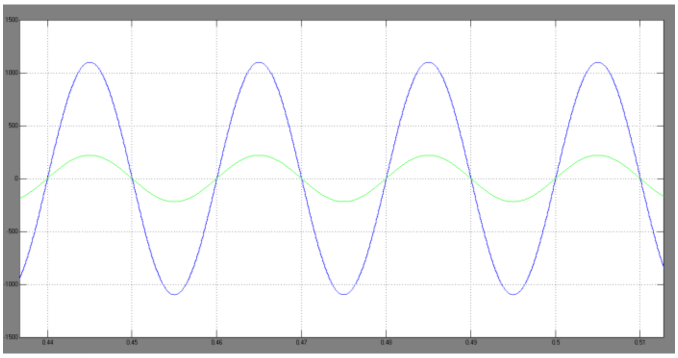


Fig.9 Source Voltage & Current

Fig.9 shows the Source Voltage & Current of Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

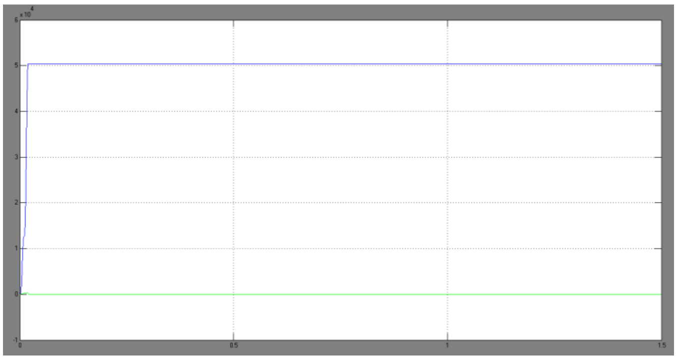


Fig.10 Active & Reactive Power

Fig.10 shows the Active & Reactive Power of Proposed MMC Topology Based DSTATCOM Operated under Linear Load Condition.

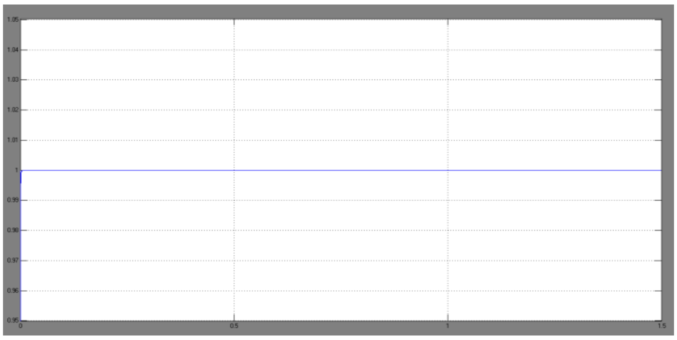


Fig.11 Source Side Power Factor

Fig.11 shows the Source Side Power Factor of Proposed MMC Topology with DSTATCOM Operated under Linear Load Condition.

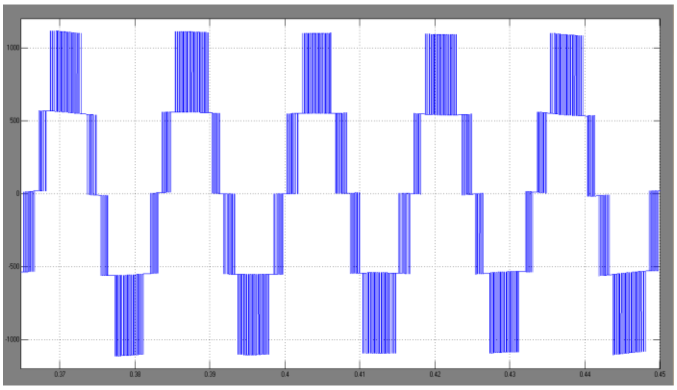


Fig.12 Five Level Output Voltage

Fig.12 shows the Five Level Output Voltage of Proposed MMC Topology with DSTATCOM Operated under Linear Load Condition.

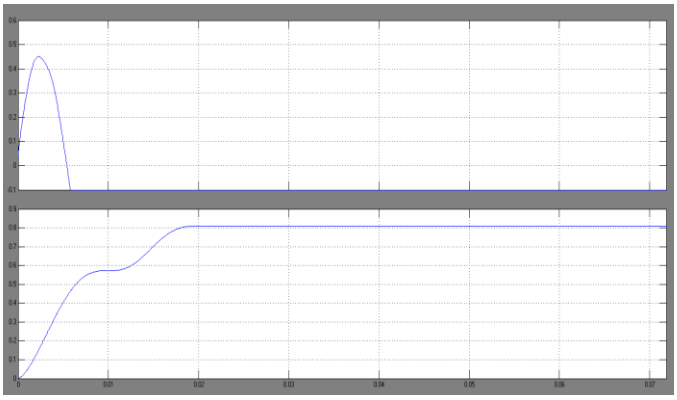


Fig.13 Delta & Modulation Index

Fig.13 shows the Delta & Modulation Index of Proposed MMC Topology with DSTATCOM Operated under Linear Load Condition.

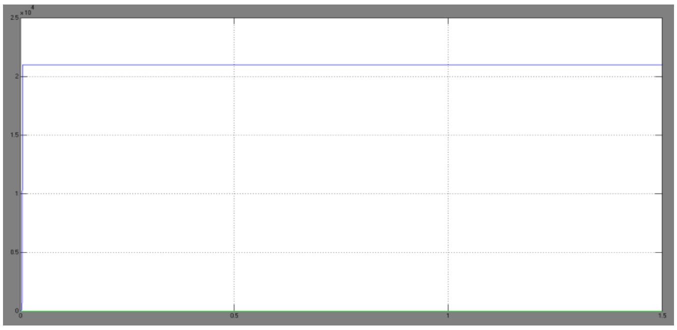


Fig.14 Inverter Injected Active & Reactive Power

Fig.14 shows the Inverter Injected Active & Reactive Power of Proposed MMC Topology with DSTATCOM Operated under Linear Load Condition.

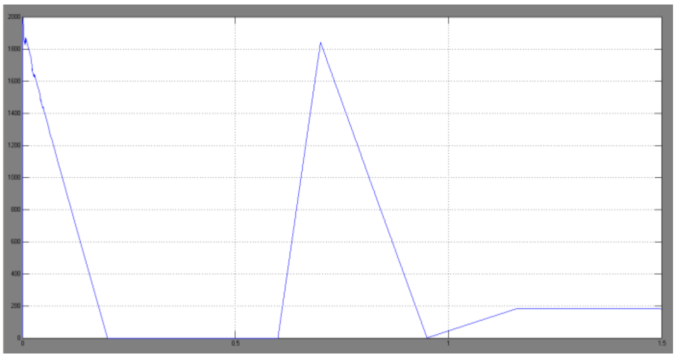


Fig.15 Wind Power

Fig.15 shows the Wind Power of Proposed MMC Topology with DSTATCOM Operated under Linear Load Condition.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Case 2: Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition

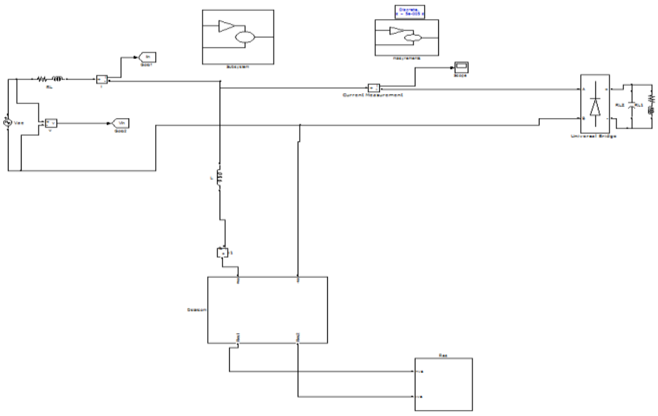


Fig.16 Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition

Fig.16 shows the Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition using Matlab/Simulink Platform.

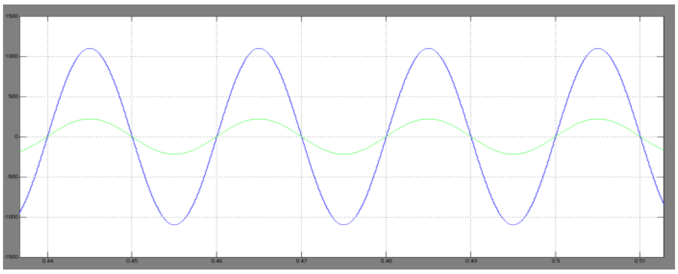


Fig.17 Source Voltage & Current

Fig.17 shows the Source Voltage & Current of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition.

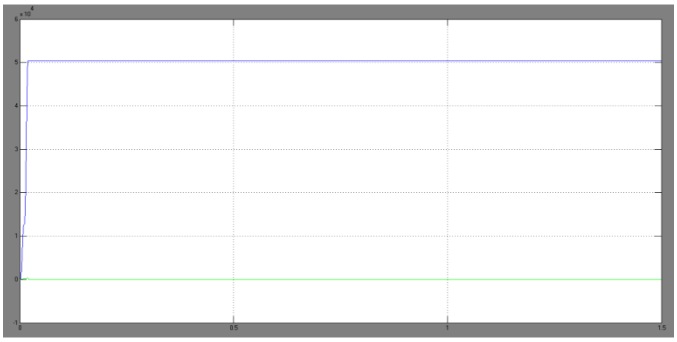


Fig.18 Active & Reactive Power

Fig.18 shows the Active & Reactive Power of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load Condition.

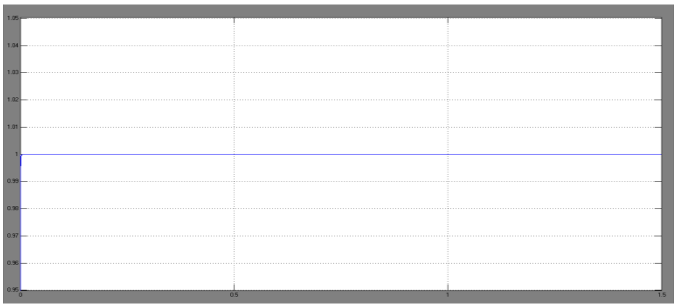


Fig.19 Source Side Power Factor

Fig.19 shows the Source Side Power Factor of Proposed MMC Topology with DSTATCOM Operated under Non-Linear Load Condition.

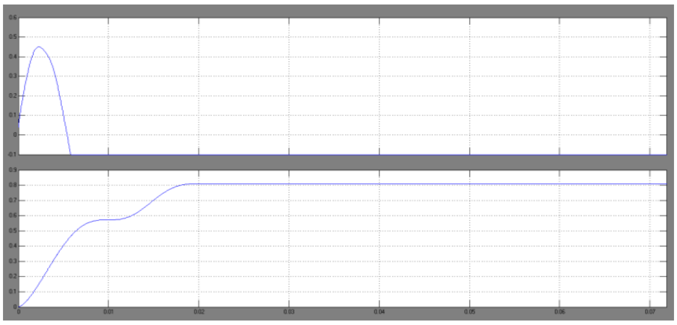


Fig.20 Delta & Modulation Index

Fig.20 shows the Delta & Modulation Index of Proposed MMC Topology with DSTATCOM Operated under Non-Linear Load Condition.

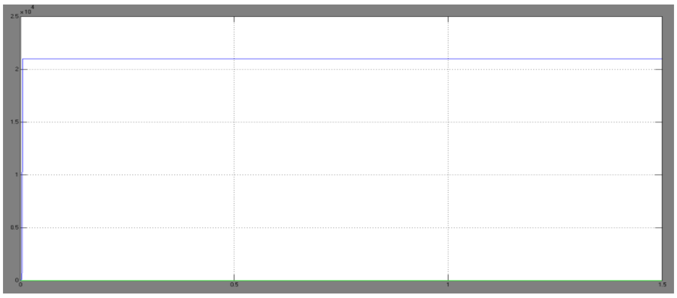


Fig.21 Inverter Injected Active & Reactive Power

Fig.21 shows the Inverter Injected Active & Reactive Power of Proposed MMC Topology with DSTATCOM Operated under Non-Linear Load Condition.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

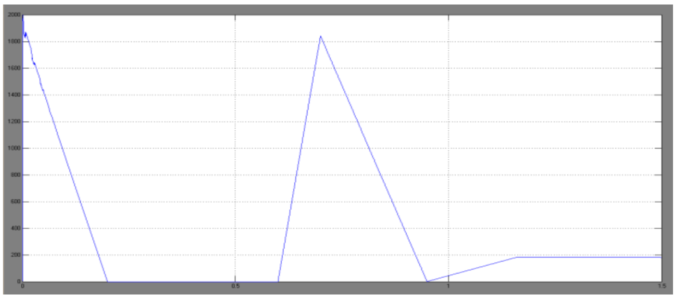


Fig.22 Wind Power

Fig.22 shows the Wind Power of Proposed MMC Topology with DSTATCOM Operated under Non-Linear Load Condition.

Case 3: Proposed MMC Topology Based DSTATCOM Operated under Variable Load Condition

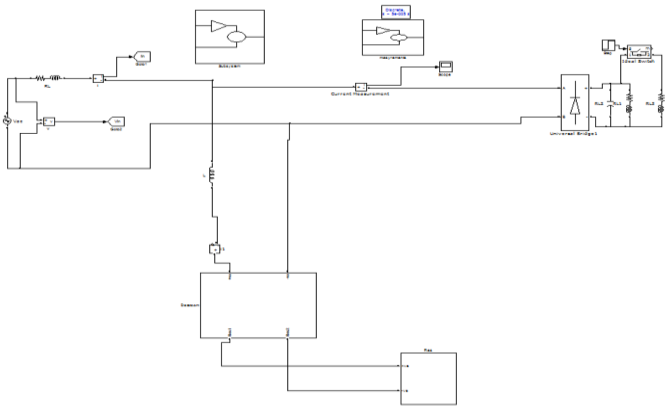


Fig.23 Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load with Variable Condition

Fig.23 shows the Matlab/Simulink Model of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load with Variable Condition using Matlab/Simulink Platform.

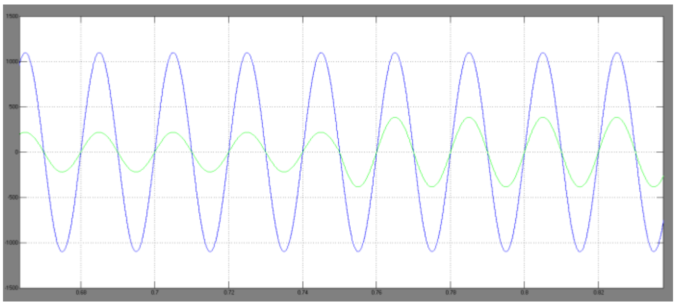


Fig.24 Source Voltage & Current

Fig.24 shows the Source Voltage & Current of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load with Variable Condition.

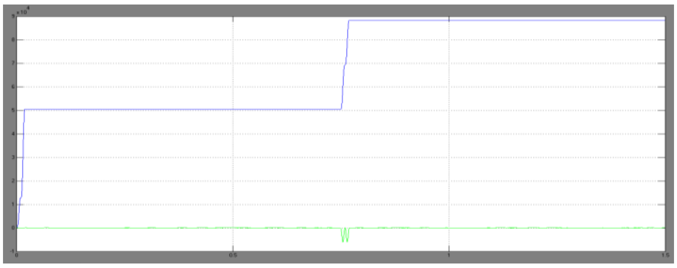


Fig.25 Active & Reactive Power

Fig.25 shows the Active & Reactive Power of Proposed MMC Topology Based DSTATCOM Operated under Non-Linear Load with Variable Condition.

CONCLUSION

Recent developments in power electronics technology have spurred interest in the use of renewable energy sources as distributed generation (DG) generators. The key component in DG generators is a grid-connected inverter that serves as an effective interface between the renewable energy source and the utility grid. The multifunctional inverter (MFI) is special type of grid-connected inverter that has elicited much attention in recent years. The concept of a multi-level D-STATCOM inverter for small- to mid-sized (10-20kW) wind installations is presented and shows a new way in which distributed renewable sources can be used to provide control and support in distribution systems. The proposed single-phase DSTATCOM inverter using MMC topology can actively regulate the reactive power on individual feeder lines while providing the variable output power of the renewable energy source. The aim is to provide utilities with distributive control of VAR compensation and power factor correction on feeder lines. The proposed D-STATCOM inverter performs in two modes: 1) inverter mode, in which there is a variable active power from the wind turbine, 2) D-STATCOM mode, in which the DC link is open circuit and no active power is gained from the renewable energy source.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

REFERENCES

[1] J.T. Bialasiewicz, "Renewable energy systems with photovoltaic power generators: Operation and Modeling", Ind. Electronics, IEEE Trans. on, vol. 55, pp. 2752-2758, 2008

[2] AWEA, "AWEA U.S. wind industry annual market report year ending 2010," American Wind Energy Association, Washington DC, 2011

[3] SEIA, "U.S. solar market insight, 2010 year end review executive summary," Solar Energy Industries Association, Washington DC, 2011

[4] J. Rodriguez, J. S. Lai and F. Z. Peng, "Multilevel inverters: Survey of topologies, controls, and applications," Industry Applications, IEEE Transactions on, vol. 49, no. 4, pp. 724-738, 2002

[5] F. Z. Peng, J. S. Lai, J. W. McKeever, J. VanCoevering, "A multilevel voltage-source inverter with separate DC sources for static vargeneration," Industry Applications, IEEE Transactions on, vol. 32, no. 5, pp. 1130-1138, 1996

[6] L. M. Tolbert, F. Z. Peng, "Multilevel converters as a utility interface for renewable energy systems," in Proceedings of 2000 IEEE Power Engineering Society Summer Meeting, pp. 1271-1274, 2000

[7] Kouro, S., Malinowski, M., Gopakumar, K., Pou, J., Franquelo, L.G., Bin Wu, Rodriguez, J., Pérez, M.A., Leon, J.I., "Recent advances and industrial applications of multilevel converters", IEEE Electronics, IEEE Transaction on, vol. 57 , no.: 8, pp. 2553 – 2580, 2010

[8] C. Tareila, P. Sotoodeh, R. D. Miller., "Design and control of a singlephase D-STATCOM inverter for wind application", Power Electronics and Machines in Wind Application PEMWA 2012, Denver, Co, 2012

[9] M. Davies, M. Dommaschk, J. Dorn, J. Lang, D. Retzmann, and D. Soerangr, "HVDC PLUS nasic and principle of operation," Siemens AG Energy Sector, Erlandgen, Germany,2009

[10] B. Gemmell, Siemens USA, J. Dorn, D. Retzmann, D. Soerangr, Siemens Germany, "Prospects of multilevel VSC technologies for power transmission," in Proc. IEEE Transmission and Distribution Conference and Exposition, pp. 1-16, 2008

[11] R. Marquardt and A. Lesnicar, "New concept for high voltage – modular multilevel converter," Power Electronics Specialists Conference, Aachen, Germany, 2004

[12] A. Lesnicar and R. Marquardt, "An innovative modular multilevel converter topology suitable for a wide power range," IEEE Power Tech Conference Proceedings, Bologna, Italy, 2003

[13] M. Saeedifard, R. Iravani, "Dynamic performance of a modular multilevel back-to-back HVDC system", Power Delivery, IEEE Trans. On,.vol. 25, no. 4, pp. 2093-2912, 2010

[14] J. Kim, S. Sul, P. Enjeti., " A carrier-based PWM method with optimal switching sequence for a multilevel four-leg voltage-source inverter" , Industry Applications, IEEE Transactions on, v.ol. 44, no. 4, pp.1239- 1248, 2008

[15] J. Pou, J. Zaragoza, S. Ceballos, M. Saeedifard, D. Boroyevich, "A carrier-based PWM strategy with zero- sequence voltage injection for a three-level neutral-point-clamped converter", IEEE Tansactions on, v.ol. 27, n.o. 2, pp. 642-651, 2012.