ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 11, November 2015

Design of D-STATCOM Inverter with Modular Multilevel Converter using Solar Power System

C.Kadhiravan[1], P.Rajivgandhi[2], J.Baskaran[3]

Assistant Professor, Department of EEE, Adhiparasakthi Engineering College, Melmaruvathur[1, 2]

Professor and Head of EEE department, Adhiparasakthi Engineering College, Melmaruvathur[3]

Abstract: This paper presents the design and implementation of a new distribution static synchronous compensator (D-STATCOM) inverter with the modular multi-level converter (MMC) technology. The D-STATCOM inverter is used to correct the problems related to power quality and to enhance the reactive power compensation by using solar photovoltaic power. A D-STATCOM inverter with modular multi-level converter (MMC) technology is shunt compensation between a source and distribution grid. The phase angle and modulation index are used to regulate active and reactive power flow. Simulations of the D-STATCOM inverter, with 5 levels modular multi-level converter (MMC) technology, have done by using MATLAB/Simulink.

Keywords: Grid connected system, D-STATCOM; Modular Multilevel Converter (MMC); Solar Photovoltaic (PV) Power; Carrier based PWM.

I. INTRODUCTION

Electric power quality is at rated magnitude and frequency it maintains a sinusoidal power distribution in bus voltage. The generality of power utilization has been drawn in reactive loads such as fans, pumps etc. These loads draw lagging power-factor currents and therefore give arise to reactive power burden in the distribution system.

The excessive power flow of reactive power will increases feeder losses and reduces the active power flow in the distribution system which affects the operation of transformers and generators. Reactive power plays a vital role on the security and stability of power system.

Therefore, the reactive power compensation is necessary in the power systems. Here a facts capability device D-STATCOM with inverter (MMC) is used to enhance the reactive power compensation.A D-STATCOM (distribution static synchronous compensator) as shunt compensated devices is used because it has a fast response and provides flexible voltage control.

A D-STATCOM is used for power quality (PQ) improvements such as power factor correction and voltage imbalance. It can regulate the bus voltage by absorbing or generating reactive power from system to the converter and converter to the system at the point of common coupling.

A Modular Multilevel Converter (MMC) with 5-level is used here which has the following advantages:

1) Generate better output waveforms with a lower dv/dt than the standard converter (power quality)

2) Increase the power quality due to great number of levels of the output voltage: in this way, the AC side filter can be reduced, decreasing its costs and losses (low switching losses)

3) Can operate with lower switching frequency than two-level converter, so the electromagnetic emissions they generate are weaker, making less severe to comply with the standards (EMC)

4) Can be directly connected to high voltage source without using transformer; this means a reduction of implementation and costs

A renewable energy system offers several advantages over conventional energy sources. They are clean, pollution free, eco-friendly, no greenhouse gas emissions and health hazards. Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy can be used and also it is one of the most important suppliers of energy especially when other sources in the country have depleted. Solar energy is used here to enhance the reactive power compensation.

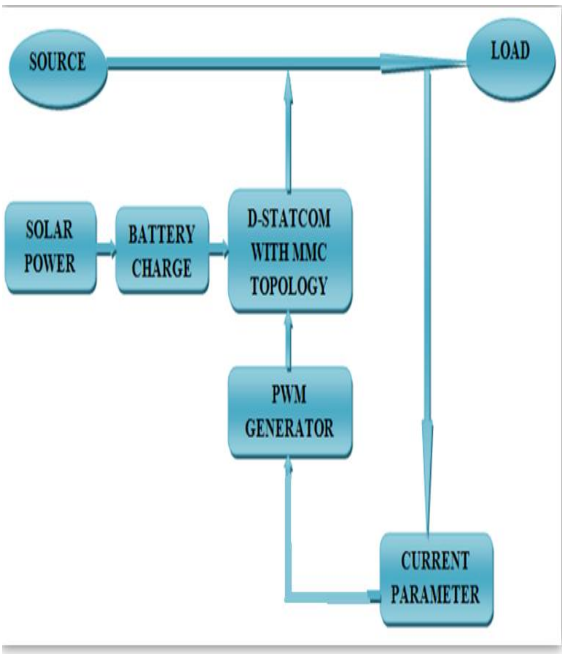

Fig. 1. Block Diagram of Proposed Method

This paper presents the design and implementation of a D-STATCOM inverter for renewable energy systems using modular multi-level converter (MMC) topology. The proposed work is to design and implement a new D-STATCOM inverter by combining the D-STATCOM and inverter (MMC) without any additional cost.

The inverter is placed between the renewable energy source, specifically a solar power, and the distribution grid in order to regulate the active and reactive power required by the grid. This inverter is capable of controlling active and reactive power by controlling its phase angle and modulation index, respectively.

II. MODULAR MULTI-LEVEL CONVERTER (MMC)

A multilevel converter is used to electronic power conversion for high-power applications .It can be applied to utility interface systems and motor drives. These converters offer a low output voltage, THD, high efficiency and power factor. They have a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, high-voltage direct-current (HVDC) transmission, hydro pumped storage, wind energy conversion, and railway traction.

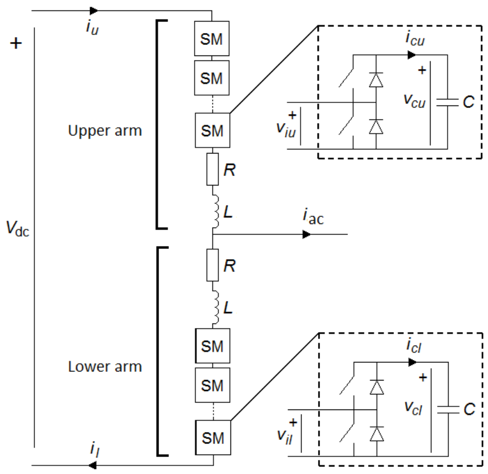

Fig. 2. One phase leg of the modular multilevel converter

Each phase leg consists of two arms, one upper arm and one lower arm, connected in series between the DC terminals. The ac terminal is located at the midpoint between the two arms as shown in Fig. 2. Each arm consists of one arm inductor and N series connected half-bridges with DC capacitors, termed SM's (Sub-Module). [6-12].The number of output voltage levels m in a cascade inverter is defined by,

$$m = 2M+1$$

Where M is the number of separate DC sources required

The multilevel converters require balancing the voltage across the series connected dc bus capacitors. The Capacitors tend to overcharge or completely discharge, at which condition the multilevel converter reverts to a three level converter unless an explicit control is devised to balance the capacitor charge.

The voltage balancing technique must be applied to the capacitor during the operators of the rectifier and inverter. Thus, the real power flow out of the capacitor and the net charge on the capacitor over one cycle remains the same.

The converter is controlled in such a way that the voltages across the sub module capacitors are kept approximately constant. In this way the capacitors act as voltage sources that can be inserted and bypassed in the chain of series connected sub modules. Consequently, each arm can generate an M+1 level voltage waveform. The voltage across each chain of series connected sub modules is referred to as inserted voltage. Ideally, each arm inserts an alternating voltage with a DC offset.

III. WORKING PRINCIPLE OF D-STATCOM

When the STATCOM is applied in distribution system is called DSTACOM (Distribution-STACOM) and its configuration is the same, or with small modifications, oriented to a possible future amplification of its possibilities in the distribution network at low and medium voltage, implementing the function so that we can describe as flicker damping, harmonic filtering and hole and short interruption compensation. Distribution STATCOM (DSTATCOM) exhibits high speed control of reactive power to provide voltage stabilization, flicker suppression, and other types of system control. The DSTATCOM utilizes a design consisting of a GTO- or IGBT-based voltage sourced converter connected to the power system via a multi-stage converter transformer.

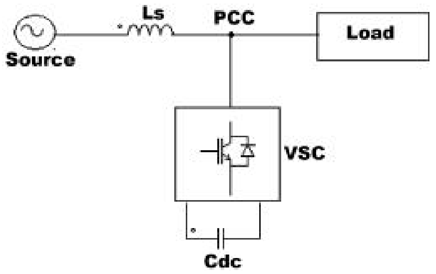

Fig. 3. Block Diagram of D-STATCOM Circuit

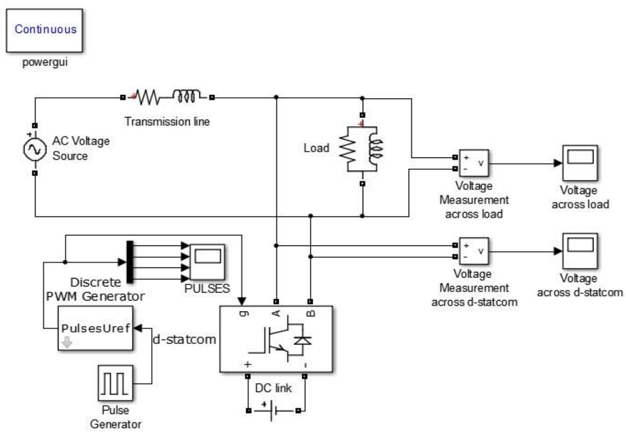

Fig. 4. Simulink Model of D-STATCOM

 DOI 10.17148/IARJSET.2015.21104

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 11, November 2015

The D-STATCOM is a designed with a GTO- or IGBT-based voltage sourced converter connected to the power system via a multi-stage converter transformer. A D-STATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a D-STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.[13-15].

IV. CARRIER BASED PWM GENERATOR

Multi Carrier PWM is an exclusive control strategy for multilevel inverters and has further classifications as discussed below. Several multicarrier techniques have been developed to reduce the distortion of outputs in multilevel inverters based on the classical SPWM with triangular carriers.

The constant switching frequency pulse width modulation technique is most popular and is a very simple switching scheme. For m-level inverter, m-1 carriers with the same frequency fc and the same amplitude Ac are disposed such that the bands they occupy are contiguous.

The reference waveform has peak-to-peak amplitude Am, the frequency fm and it is zero centered in the middle of the carrier set. The reference is continuously compared with each of the carrier signals. If the reference is greater than a carrier signal, then the active device corresponding to that carrier is switched off.

Carrier based PWM methods have more than one carrier that can be triangular waves or saw tooth waves and so on. As far as the particular carrier signals are concerned, there are multiple CFD (Control Freedom Degree) including frequency, amplitude, phase of each carrier and offsets between carriers and as in three phase circuits, the injected zero sequence signal to the reference wave. Therefore multilevel carrier based PWM methods can have multiple CFD. These CFD combinations added with the basic topologies of MLIs will produce many multilevel carrier based PWM strategies.

V. PROPOSED D-STATCOM INVERTER

When the source is connected to a non linear load, the generation of reactive power in the line is increased. In order to enhance the active power and to reduce the reactive power D-STATCOM along with INVERTER is used here. This combination is achieved by introducing an MMC.

Active power required is obtained from solar. And the output is fed into the D-STATCOM inverter. This inverter is designed to control the flow of active and reactive power between the solar and the grid. It is able to provide utilities with distributive control of VAR compensation and power factor (PF) on feeder lines. [15]

To enhance the reactive power control of the proposed inverter; it is equipped with the additional D-STATCOM option. The steady state operation of the D-STATCOM inverter is controlled by adjusting modulation index and phase angle, 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 solar and the grid. It has two modes of operation. They are-

- When active power is gained from the solar power, which is called INVERTER mode
- When no active power is gained from the solar power, which is called D-STATCOM mode.

The active and reactive power flow of the D-STATCOM is as follows:

$$P_S = \frac{m\,E_S\,E_L}{X}\sin\delta$$

$$Q_S = \frac{m\,E_S\,E_L\cos\delta - E_L^{\,2}}{X}$$

Where ES, EL, δ, *m* and X are the voltage of the D-STATCOM, line voltage, power angle, modulation index, and inductance between the inverter and the grid respectively.

VI. SIMULATION RESULT

To maintain the SM capacitor voltages balanced, a carrier-based PWM (CPWM) method is used to control the voltages of the capacitors. For a 5-level MMC inverter, this technique requires four in-phase carriers that are displaced with respect to the zero-axis. The output voltage level is determined by comparing a sinusoidal signal reference with these four carriers.

With a 5-level inverter, at each instant four SMs should be chosen based on their capacitor voltages considering the direction of the current. Depending on the output voltage level, if the current is positive, the SM capacitors are being charged, and therefore a number of SMs with lowest capacitor voltage should be chosen. Likewise, if the current is negative, the SM capacitors are being discharged, and therefore a number of SMs with highest capacitor voltage should be chosen.

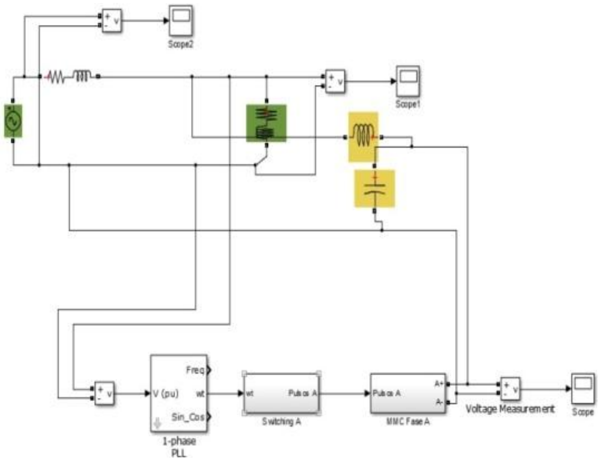

Fig. 5 Overall Simulation Circuit.

Generally, when the output voltage of a SM is equal to zero, it is called off and when the out voltage of a SM is

DOI 10.17148/IARJSET.2015.21104

equal to its capacitor voltage, it is called On. The number of required SMs for each voltage level is as follows: for voltage level 1, in which Vo = - Vdc / 2 , all the four upper SMs should be On and all the lower SMs should be Off. For voltage level 2, in which Vo = - Vdc / 4 , three upper SMs and one lower SM should be On and the other SMs should be Off. For voltage level 3, in which Vo = 0, two upper and two lower SMs should be On and the others should be Off. For voltage level 4, in which Vo = Vdc / 4, one upper SM and three lower SMs should be On and the other SMs should be Off. For voltage level 5, in which Vo = Vdc / 2 , all the upper SMs should be Off and all the four lower SMs should be On. Considering this algorithm, the voltages of the capacitors are maintained balanced and the proper gate signals can be chosen.

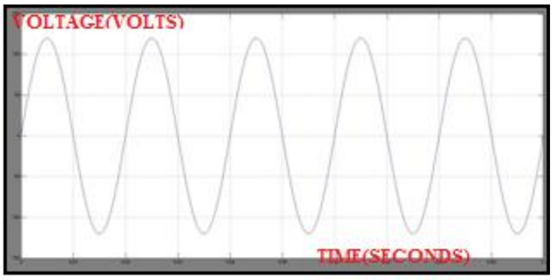

Fig.6. Input voltage

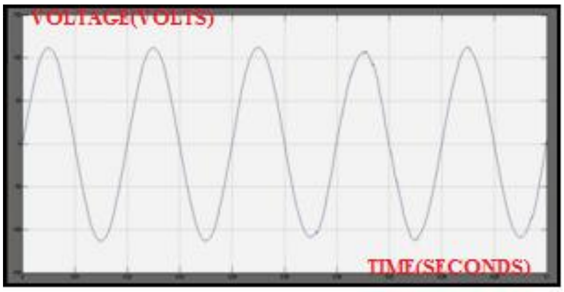

Fig7. Output voltage

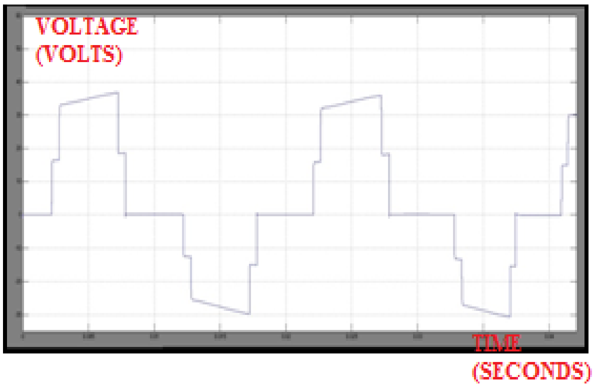

Fig.8.Output of MMC

VII. CONCLUSION

In this paper a proposed concept of design and implementation of a D-STATCOM INVERTER with MMC technology is used to enhance the reactive power compensation. The aim of a paper to combine the two concepts of D-STATCOM and inverter using the most advanced modular multi-level converter topology to make a single unit called D-STATCOM inverter. Here MMC is used as the voltage source converter (VSC) topology to make a D-STATCOM able to regulate reactive and active power and also it would connect solar power and grid. This inverter is a cost-effective inverter and has a capability to regulate active and reactive power flow. The Simulation of the D-STATCOM inverter, with 5 levels modular multi-level converter (MMC) technology, has done by using MATLAB/Simulink.

ACKNOWLEDGEMENT

The authors wish to thank Correspondent, Principal, HOD/Department of EEE, Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu-603319, India for their support and encouragement.

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] Juan Manuel Carrasco, Member, IEEE, Leopoldo Garcia Franquelo, Fellow, IEEE,Jan T. Bialasiewicz, Senior Member, IEEE, Eduardo Galván, Member, IEEE,Ramón C. Portillo Guisado, Student Member, IEEE, Ma. Ángeles Martín Prats, Member, IEEE,José Ignacio León, Student Member, IEEE, and Narciso Moreno-Alfonso, Member, IEEE , “Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey”, IEEE Transactions On Industrial Electronics, Vol. 53, No. 4, August 2006
[3] Soeren Baekhoej Kjaer, Member, IEEE, John K. Pedersen, Senior Member, IEEE, and Frede Blaabjerg, Fellow, IEEE, “A Review of Single-Phase Grid-Connected Inverters for PV Modules”, IEEE Transactions On Industry Applications, Vol. 41, No. 5, September/October 2005
[4] Salvador Alepuz, Member, IEEE, Sergio Busquets-Monge, Student Member, IEEE, Josep Bordonau, Member, IEEE, Javier Gago, David González, Member, IEEE, and Josep Balcells, Member, IEEE, “Interfacing Renewable Energy Sources to the Utility Grid using a three-level Inverter”, IEEE Transactions On Industrial Electronics, Vol. 53, No. 5, October 2006
[5] Gabriele Grandi, Member, IEEE, Claudio Rossi, Member, IEEE, Darko Ostojic, Member, IEEE, and Domenico Casadei, Senior Member, IEEE , “A New Multilevel Conversion Structure for Grid-Connected PV Applications” , IEEE Transactions On Industrial Electronics, Vol. 56, No. 11, November 2009
[6] 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
[7] 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
[8] 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
[9] 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
[10] R. Marquardt and A. Lesnicar, "New concept for high voltage – modular multilevel converter," Power Electronics Specialists Conference, Aachen, Germany, 2004
[11] 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
[12] 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
[13] Alpesh Mahyavanshi, M. A. Mulla, and R. Chudamani, “Reactive Power Compensation by Controlling the DSTATCOM,” International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 11, November 2012
[14] Norman Mariun, Senior Member, IEEE, Hendri Masdi, S.M.Bashi1, Member, IEEE,.,A. Mohamed , Senior Member, IEEE,

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 11, November 2015

Sallehhudin Yusuf, Member, IEEE., " Design of a prototype D-STATCOM using DSP controller for voltage sag mitigation" ,IEEE Conference 2006
[15] C. Tareila, P. Sotoodeh, R. D. Miller., "Design and control of a single phase D-STATCOM inverter for wind application", Power Electronics and Machines in Wind Application PEMWA 2012, Denver, Co, 2012
[16] 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 , vol. 44,no. 4, pp.1239-1248, 2008
[17] 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", *Power Electronics, IEEE Transactions on*, vol. 27, no. 2, pp. 642-651, 2012

BIOGRAPHIES

P.RAJIVGANDHI was born in 1990 in Tamilnadu, India. He received his B.E-EEE degree from Adhiparasakthi college of engineering under the control of Anna University, Chennai in 2012 and M.E-PSE Degree from Arulmigu Meenakshi Amman College Of Engineering under the control of Anna University, Chennai in 2014. Now he is working as a Assistant professor of EEE department in Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India. His research area of interest includes power system, power electronics, FACTS, Distributed power system.

J. BASKARAN was born in 1976 in Tamilnadu, India. He received his B.E degree from Madras University, Chennai in 1997 and M.E Degree from Annamalai University, Chidambaram in 2006 and PhD from Anna University, Chennai in 2010. He has 14 years teaching and 4 years research experience. Now he is working as a professor and Head of EEE department in Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India. His research area of interest includes power electronics, optimization control in power system, FACTS, Distributed power system.

C. KADHIRAVAN was born in 1975 in Tamilnadu, India. He received his B.E degree from Madras University, Chennai in 2001 and M.E Degree from Anna University, Chennai in 2007 and Doing PhD from Anna University, Chennai in 2012 onwards. He has 8 years teaching and 2 years research experience. Now he is working as a Assistant professor of EEE department in Adhiparasakthi Engineering College, Melmaruvathur, Tamilnadu, India. His research area of interest includes power electronics, optimization control in power system, FACTS, Distributed power system.

DOI 10.17148/IARJSET.2015.21104