Single Phase 13-Level D-STATCOM Inverter with Distributed System

R. Kamalakannan, N. Ravi Kumar

Abstract—The global energy consumption is increasing persistently and need for distributed power generation through renewable energy is essential. To meet the power requirements for consumers without any voltage fluctuations and losses, modeling and design of multilevel inverter with Flexible AC Transmission System (FACTS) capability is presented. The presented inverter is provided with 13-level cascaded H-bridge topology of Insulated Gate Bipolar Transistor (IGBTs) connected along with inbuilt Distributed Static Synchronous Compensators (DSTATCOM). The DSTATCOM device provides control of power factor stability at local feeder lines and the inverter eliminates Total Harmonic Distortion (THD). The 13-level inverter utilizes 52 switches of each H-bridge is fed with single DC sources separately and the Pulse Width Modulation (PWM) technique is used for switching IGBTs. The control strategy implemented for inverter transmits active power to grid as well as it maintains power factor to be stable with achievement of steady state power transmission. Significant outcome of this project is improvement of output voltage quality with steady state power transmission with low THD. Simulation of inverter with DSTATCOM is performed using MATLAB/Simulink environment. The scaled prototype model of proposed inverter is built and its results were validated with simulated results.

Keywords—FACTS devices, distributed-Static synchronous compensators, DSTATCOM, total harmonics elimination, modular multilevel converter.

I. INTRODUCTION

THE power electronics in distributed systems have improved greatly in recent years where these devices usually convert the non-conventional form of energy into suitable energy for power grids in terms of voltage and frequency. The generation of energy from renewable energy sources is to provide power to consumers and achieve transmission control flexibility in power systems. In general wind power generation for consumers causes several troubles like PF issues and harmonics. In order to decrease power losses and voltage fluctuations, high power factor is desirable. The steady state power transmission over the grid line is achieved through FACTS devices.

In power transmission, the reactive elements can create voltage fluctuations and harmonic noise, therefore reactive power compensation is done to improve voltage regulation. Traditional PF issue compensation is capacitor bank utilization with inverter MMC to meet the requirement of single phase system [1], [2]; this is very expensive. The regular Static synchronous compensators (STATCOM) for single phase wind applications are placed on the exterior to regulate PF of grid; and increase the cost of the system significantly [3]. The proposed inverter with FACTS capability is cost effective and compatible with IEEE standards. Inverter deployed with D-STATCOM to regulate the reactive power and fixes PF at a target [3]. Proposed inverter can regulate active and reactive power beside MMC is used to meet requirements of single phase high voltage DC system (HVDC) [5]; PWM utilized for voltage balancing strategy to control power flow and net DC burst under balanced and unbalanced conditions [6]. Multilevel PWM inverters for high power applications designed for total harmonic elimination for grid integrated renewable energy sources in order to improve power supply, reliability and quality [7]. The integration of an energy storage system, such as battery energy storage, into a FACTS device can provide much needed flexibility for power flow problems [8]. In power electronic equipments interconnections use bus bars inductance in which switching losses and electromagnetic interference increase inside the inverters are produced [9], [10].

The above literature survey has the drawbacks of increase in size of power system, high cost of STATCOM and its use of separate capacitor banks to mitigate to PF issues [1], occupies additional space and increase in size of the system. The proposed inverter design make use of small DSTATCOM devices and 13 level inverter which provides power factor stability, THD elimination achieving voltage regulation.

II. INVERTER TOPOLOGY

The different inverter topologies are Diode clamped inverter, Capacitor clamped inverter, Cascaded multi-cell inverters. The cascaded H-bridge provides improved output voltage quality, smaller filter size, lower THD and reduced number of switches. The proposed single phase multilevel inverter is deployed with the series connection of H-Bridge topology with separate DC sources. The AC production from the cascade multilevel inverter is the sum of the character converter output [4]. The number of Output phase voltage level is defined by, n=2N+1 where N is the number of DC sources. The electrical energy ratio given to the inverter module is n0: n: n3: 2n3: 10n, (n=3) and 123 output voltage levels are obtained. The planned system presents superior output voltage levels with reduced number of switches. The layout of H-Bridge inverter is shown in Fig. 1. This resourceful cascaded multilevel inverter is urbanized to decrease the total choral deformation in power application. PWM technique is implemented to generate the staircase waveform. The output voltage level is increased with reduced

R. Kamalakannan and N. Ravi kumar are with the Department of Electrical and Electronics Engineering, S.A. Engineering college, Chennai, India (e-mail: kannan.r.kamalakannan28@gmail.com, ravikumar21.rmk@gmail.com).

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:8, 2016

number of switches. Therefore it can decrease the fitting area and the charge. The Inverter with D-STATCOM is placed between grid and turbine to regulate PF and distributed power transfer [1]. Modern WEI with FACTS capability meets the target requirements of compensation in PF issues; also it is cost effective and compatible with IEEE standards. The proposed control strategy utilized acts as inverter and DSTATCOM when enough wind power is produced where as when there is less wind generation DSTATCOM option is preferred. The active power (P) is controlled with power angle δ; the angle between voltage of inverter and grid which provides net transfer of real power from turbine [3]. The reactive power (Q) is regulated by modulation index m; reactive power that returns to source and 90° out of phase.

The block diagram of proposed system shown in Fig. 2 provides the input source from wind turbine side is connected to dc link of inverter as distributed energy source through a rectifier and MPPT from which a boost converter is provided in order to boost up the DC voltage from wind turbine. DC voltage obtained is provided to inverter for conversion of direct current from source to alternating current for distribution system. PWM triggering is provided by control unit with microcontroller where the pulses are fed to IGBT used in H-Bridge cascaded multilevel inverter module with compensators to eliminate THD. At the grid side, inverter output AC is fed into series connected second order filter to a distribution transformer. The reactive and active power calculation is done with
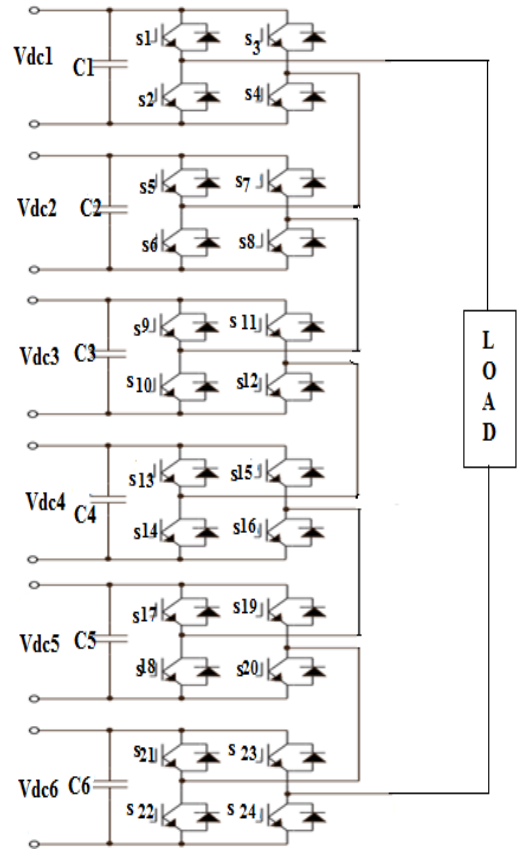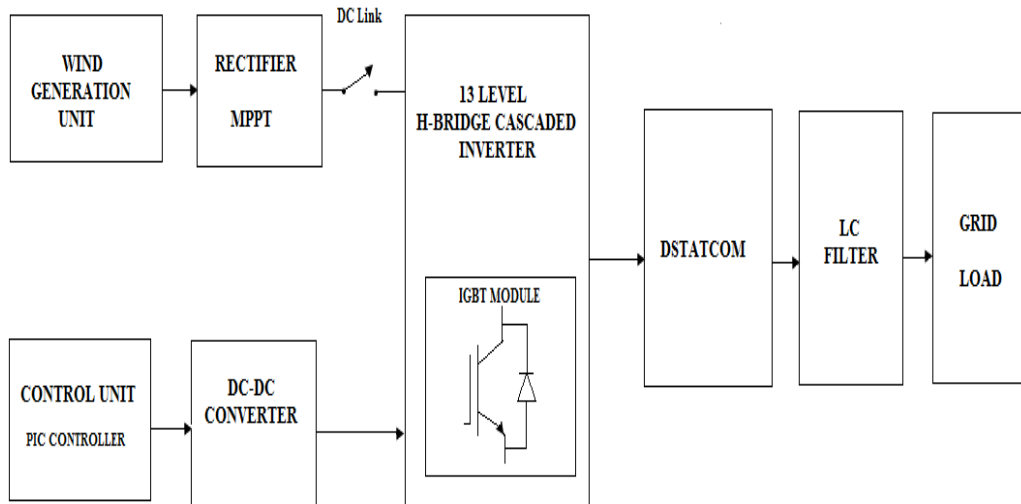

Fig. 1 13-Level Cascaded H-Bridge Inverter

Fig. 2 Block diagram

$$S^2 = P^2 + Q^2 \qquad (1)$$

where, S is the apparent power (VA) with volt ampere reactive, Q is the reactive power and P is active power from wind turbine which provides net transfer of real power to inverter module. Each phase arm must be provided with current control to limit the false currents. The output voltage of each modules of inverter can be calculated by

$$V_{dc} = V_{upperarm} + V_{lowerarm} \qquad (2)$$

where, V_{dc} represents Dc output voltage; the upper and lower arm indicates number of voltage levels. Voltages of upper and lower arm of the sine wave produced are:

$$V_{upperarm} = \sum_{i=0}^{n-1} (S_{ui} V_{ci}) + V11 \qquad (3)$$

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:8, 2016

$$Vlowerarm = \sum_{i=0}^{n-1} (SliVci) + V11 \qquad (4)$$

From (3) and (4) the S_{ui} represents the status of ith sub module in upper arm and S_{li} the status of ith sub module in upper arm. The corresponding capacitor voltage is given by $v_{ci.}$

$$V_{out} = \frac{V_{DC}}{2} V_{upperarm} = \frac{V_{DC}}{2} V_{lowerarm} \qquad (5)$$

For the single phase inverter dc and ac voltage outputs v_{out} of H-bridge multilevel inverter topology refer (5). The active and reactive power between inverter and distributed grid with its modulation index m is provided with

$$P_s = -\frac{m\,E_s\,E_L}{X} Sin\,\delta \qquad (6)$$

$$Q_s = -\frac{m\,E_s\,E_L\,Cos\,\delta X\,E_L^2}{X} \qquad (7)$$

Active and reactive power flow between the DSTATCOM device and power lines are represented as:

$$P_s = -\frac{E_s\,E_L}{X} Sin\,\delta \qquad (8)$$

$$Q_s = -\frac{E_s\,E_L\,Cos\,\delta X\,E_L^2}{X} \qquad (9)$$
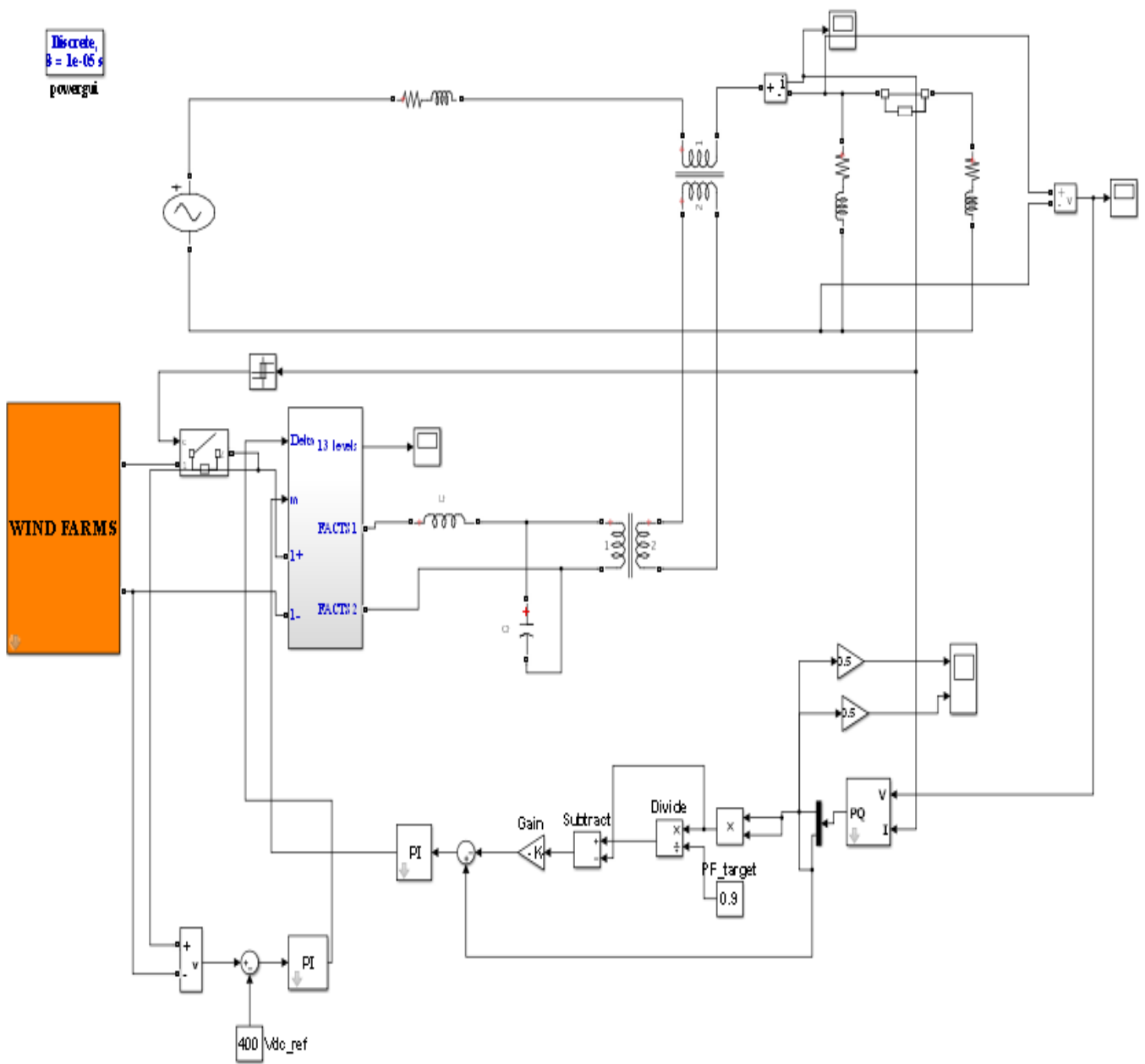
Fig. 3 Simulink model for inverter, DSTATCOM and FACTS circuit

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:8, 2016

The target active power and reactive power is calculated from (10) and (11):

$$P_G = \left(\sqrt{P_G^2 + Q_T^2} \right) \times PF_T \tag{10}$$

$$Q_T = \sqrt{\left(\frac{P_G}{PF_T} \right)^2 - P_G^2} \tag{11}$$

x represents the inductance between DSTATCOM, E_L is RMS line voltage and E_S is RMS DSTATCOMs voltage. PF_T is the target PF utility. The elimination of THD is done with the ratio of the sum of powers of all harmonic components (V_2, V_3, V_4, … V_n) to the power of voltage fundamental frequency (V_1). That can be measured by (12):

$$THD = \sqrt{\frac{V_2^2 + V_3^2 + \dots + V_n^2}{V_1}} \tag{12}$$

Refer (10) and (11); the target reactive power is determined and compared with actual value of reactive power to grid. The function of control logic is to keep the capacitor's voltage constant to maintain PF. Proposed MLI is analyzed with carrier SPWM signal is compared with reference sinusoidal signal with the help of feedback.

III. SIMULATION AND PRACTICAL RESULTS

The design of H-Bridge cascaded multilevel inverter and implementation of DSTATCOM within the inverter module is carried out using MATLAB/Simulink Fig. 3 shows the complete design of multilevel inverter with DSTATCOM in built.

The initial condition for voltage regulation is maintained with respect to load in case of additional load current change accordingly. The sudden change in voltage is undesirable for additional load hence it has to be maintained at required voltage level of 240 V. The target power factor calculation as mentioned in (10), (11) is performed using T_{PF} of 0.90 and V_{ref} as reference voltage from grid.

If additional load is added to the grid, the current increases and voltage decreases; hence, to avoid changes in line voltage, DSTATCOM and inverter circuit are provided. The power requirement is met according to changes in load; THD is considerably reduced. When the simulation started, it provides enough compensation to reach the target PF to maintain it constant for 240 V for the period of 0 to 0.5 seconds time period. The addition of load is set to maintain between 0.5 and 1 seconds time period, again it is maintained constant since the load is removed from the grid. The set-point for dc link voltage of the inverter is 2000 V and the RMS value of the output ac voltage is 600 V.
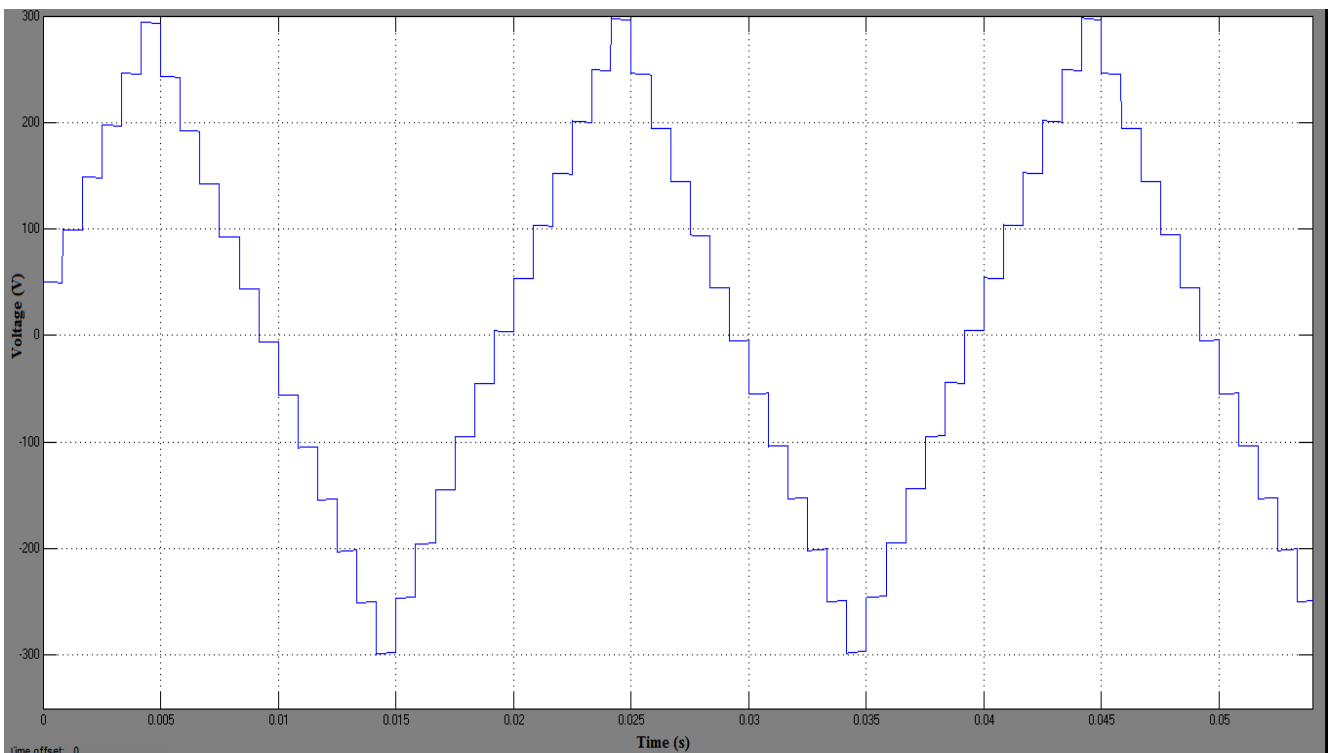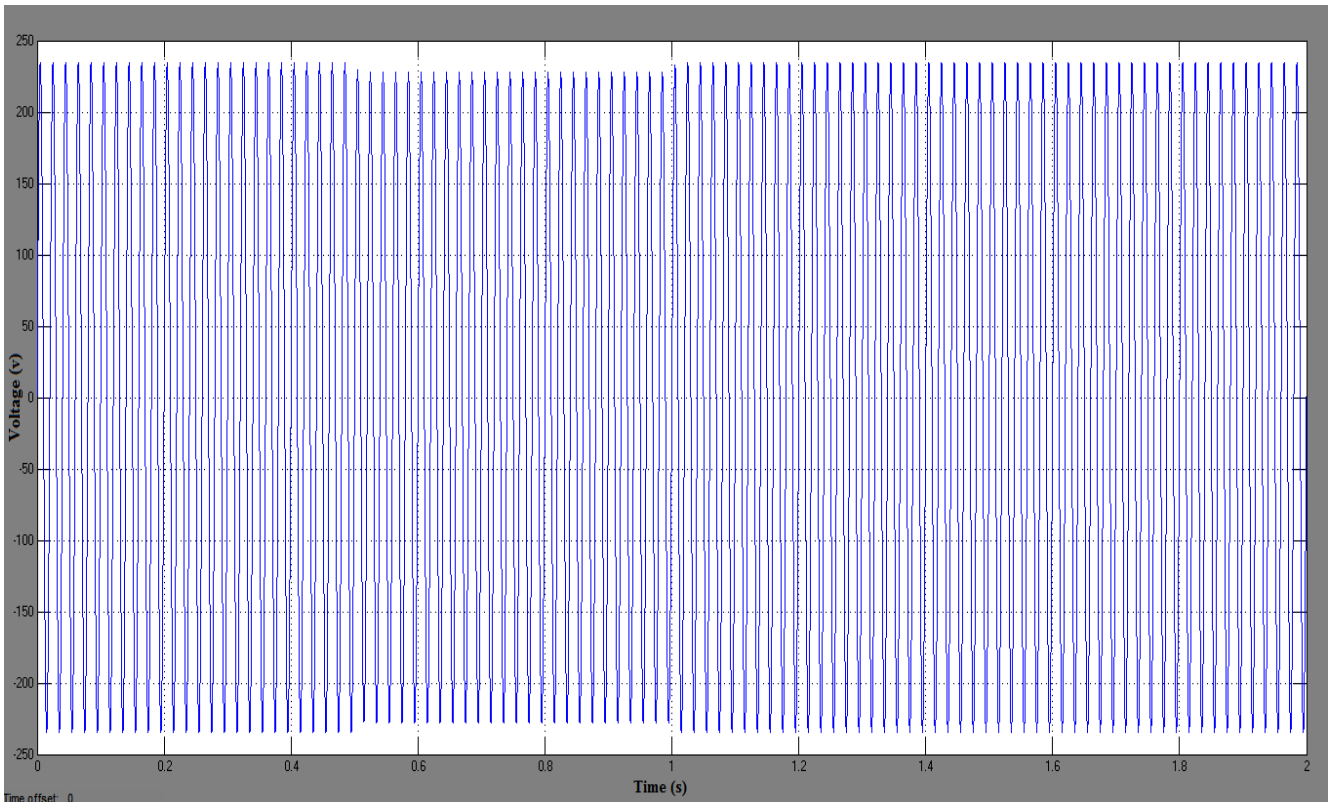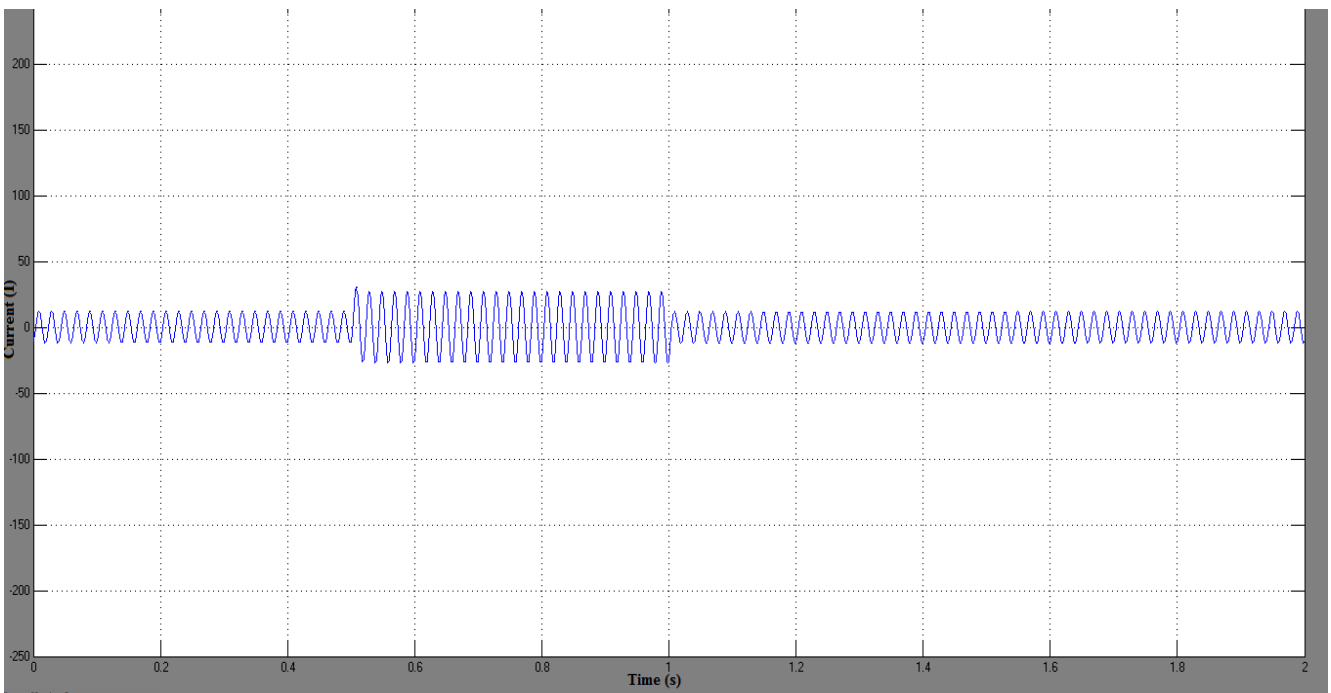

Fig. 4 Output of inverter

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:8, 2016

Fig. 5 Grid Voltage

Fig. 6 Grid current

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
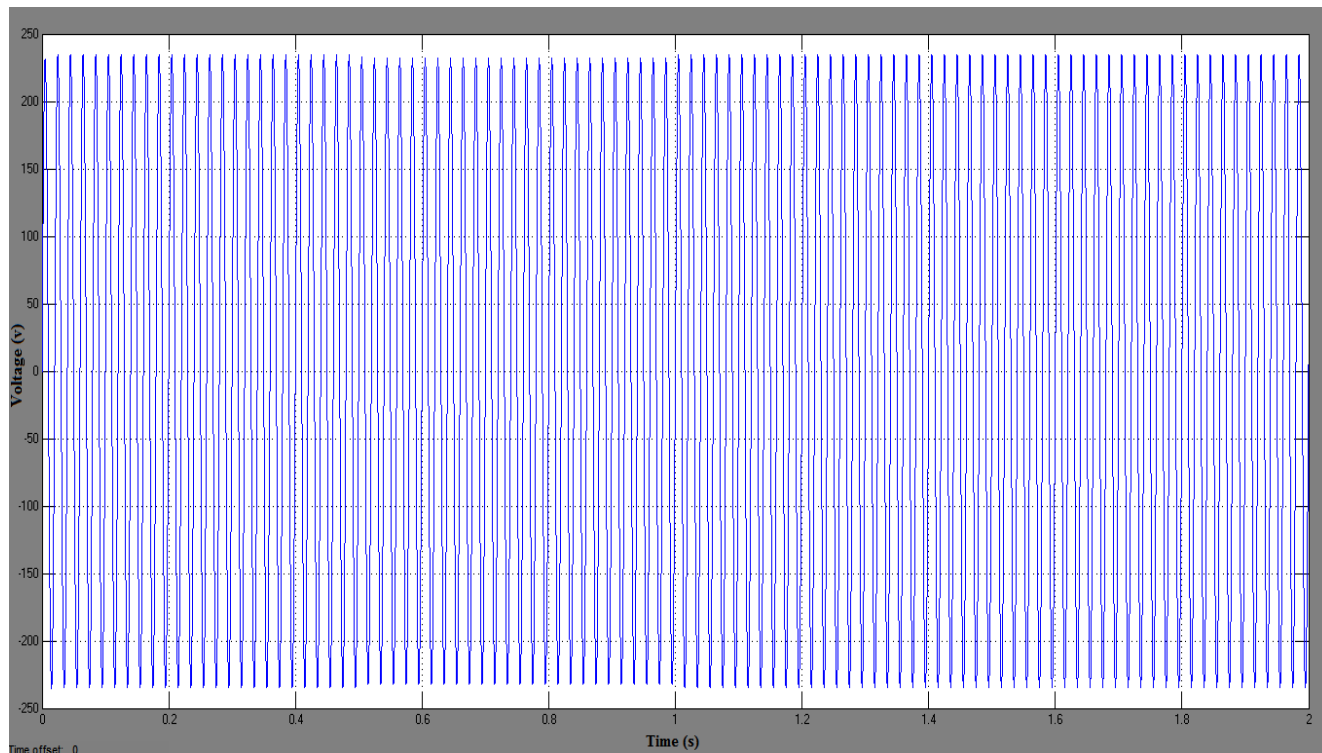Vol:10, No:8, 2016

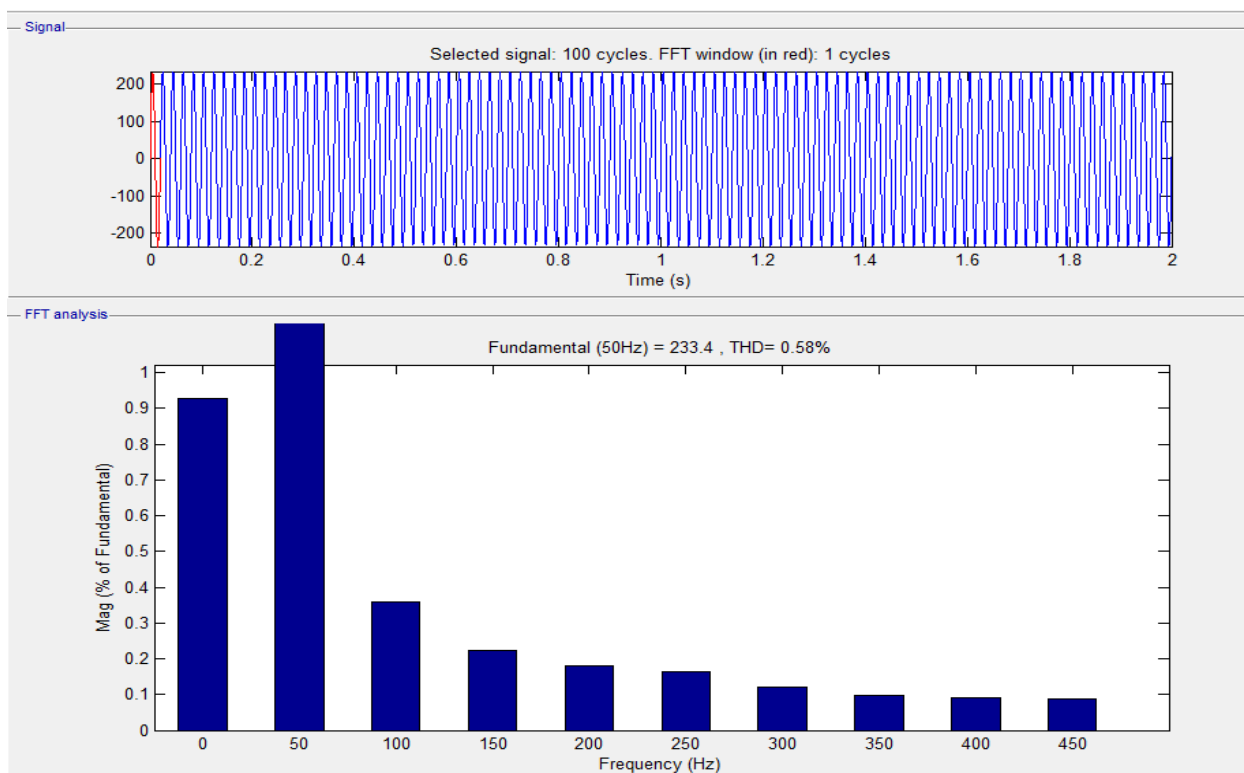Fig. 7 Voltage across grid with DSTATCOM

Fig. 8 THD elimination with DSTATCOM

The output wave form for 13-level inverter is given in Fig. 4 with 13 level step signals. The addition of more load component to grid than essential load components causes variation in voltage. This results in voltage fluctuations.

The resultant graph of current and voltage waveforms across grid without the DSTATCOM is given in Figs. 5 and 6 respectively where voltage fluctuation occurs with additional load across grid. This sudden change in line voltage is not

World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:10, No:8, 2016

desirable; hence, DSTATCOM is implemented within the inverter.

TABLE I
SIMULATION PARAMETERS

PARAMETER	SYMBOL	VALUE/UNIT
Transformer primary voltage	V_p	12000 V
Transformer secondary voltage	V_s	600 V
Line resistance	R_{Line}	15 Mh
Line inductance	L_{Line}	1 Ohm
Filter inductance	L_{Filter}	5 mH
Switching Frequency	F	2kHz
Load active power	P	50 kW
Load reactive power	Q	34.8 Kvar
DC Link voltage	V_{dc}	2000 V
Target Power Factor	T_{PF}	0.90

The voltage regulation across load is represented in Fig. 7. The elimination of THD is achieved only 1.8% till 1.5% with respect to power factor. The presented system with simulation results in Fig. 8 gives a clear view that the THD elimination is achieved up to 0.58% with DSTATCOM shown in Fig. 8 at the switching frequency of 2 kHz. To analyse power factor, FFT analysis is utilized.

The scaled prototype model for 13-level cascaded H-Bridge inverter is built using IGBTs and the control pulse of PWM is given to inverter using PIC μc 16F877a. The experimental setup is shown in Fig. 9 with inbuilt DSTATCOM.
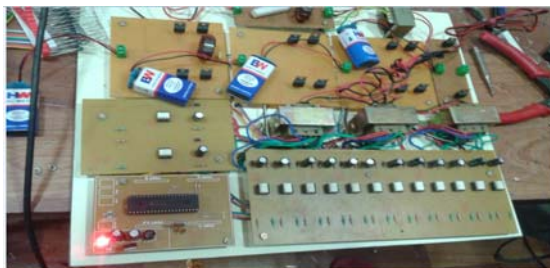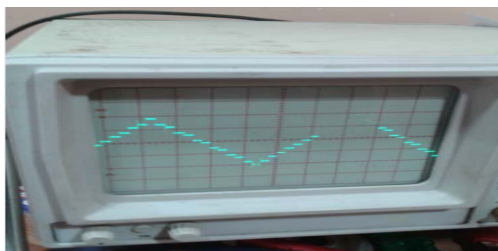

Fig. 9 Experimental setup

Fig. 10 Output waveform of 13-level inverter

The output waveform for 13 levels of the inverter is verified using Cathode Ray Oscilloscope (CRO) which is presented in Fig. 10 where THD elimination is about 0.82% PF is maintained stable in spite of additional load.

Voltage regulation across the transmission line is verified using choke connected as load and its voltage is measured using multimeter readings. PF compensation is about 0.82% is achieved in comparison with simulation results where voltage

regulation at transmission side and across the distribution system is maintained stable to provide power to consumers.

IV. CONCLUSION

The presented system demonstrates the application of new multilevel inverter with FACTS in a single unit without any additional cost. The DSTATCOM inverter replaces the need of external STATCOM device to regulate the PF of the grid. The existing traditional WEI does not provide size compensation along with low cost and less effective PF maintenance inadequacy; hence, the presented strategies of inverter amid FACTS and DSTATCOM facility overwhelm the limitations of existing system. Despite of severe changes in wind speed this proposed system can deliver constant power to grid with low cost and provide voltage regulation across the distribution system.

REFERENCES

[1] Colin Tareila, Pedram Sotoodeh and Ruth Douglas Miller, "Design and control of a Single- phase D-STATCOM Inverter for Wind Applications", IEEE Proceedings of Power Electronics and Drive Systems, pp. 1–5, July 2012.
[2] Juan Manuel Carrasco, Leopoldo Garcia Franquelo, Jan T. Bialasiewicz, Eduardo Galván, Ramón C. Portillo Guisado, Ma. Ángeles Martín Prats, and Narciso Moreno-Alfonso, "Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey" IEEE Transactions on Industrial Electronics, Vol. 53, No. 4, pp. 1002–1016, August 2006.
[3] Kenichiro Sano and Masahiro Takasaki, "A Transformerless D-STATCOM based on a multi voltage cascade converter requiring no DC sources," IEEE Transactions on Power Electronics, Vol. 27, No. 6, pp. 2783–2795, June 2012.
[4] Pedram Sotoodeh and Ruth Douglas Miller, "Design and implementation of 11-level inverter with FACTS capability for distributed energy systems" in Proceedings of IEEE Power Energy Society, Vol 2, No. 6, pp. 87–96, March 2014.
[5] Rodriguez, J. S. Lai, and F. Z. Peng, "Multilevel inverters: Survey of topologies, controls, and applications," IEEE Transactions on Industrial Applications, Vol. 49, No. 4, pp. 724–738, August 2002.
[6] Saeedifard. M and R. Iravani, "Dynamic performance of a modular multilevel back-to-back HVDC system," IEEE Transactions on Power Delivery, Vol. 25, No. 4, pp. 2093–2912, October 2010.
[7] Wei Jie, Guo Yuan and Gu Shuhua, "Economic Assessment of Large Grid- connected Wind Farms-Avoided Cost Method", IEEE Transactions on Power Electronics Systems, Vol 4, No 1, pp. 1341-1344, March 1999.
[8] Xiangjun Li, Dong Hui, and Xiaokang Lai, "Battery Energy Station (BESS) – based Smoothing Control of Photovoltic (PV) and Wind power Generation Fluctuations", IEEE Transactions on Sustainable Energy, Vol. 4, No. 2, pp. 464 – 473, April 2013.
[9] Yang. Z, C. Shen, L. Zhzng, M.L. Crow, and S. Atcitty, "Integration of STATCOM and battery energy storage", in Proceedings of IEEE Transactions on Power Systems, Vol. 16, No. 2, pp. 254–260, May 2001.
[10] Yi Rong and Zhong Yulin, "Modeling Of Bus bars In High Power Neutral Point Clamped Three-Level Inverters," IEEE Transactions on Power Electronics Systems, Vol. 13, No. 1, pp. 91-97, February 2008.