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PERFORMANCE ENHANCEMENT OF HYBRID POWER GENERATION SYSTEM USING MULTILEVEL BOOST CONVERTER FED ASYMMETRICAL MULTILEVEL INVERTER

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This paper proposes a photovoltaic (PV)-fuel cell (FC) hybrid system with multilevel boost converter (MLBC) fed asymmetrical cascaded H-Bridge multilevel inverter (ACHBMLI) to supply quality and reliable power. Hybridization of PV source with FC can tackle the issue of irregular power obtained from photovoltaic system. MLBC is used in proposed system because the voltage gain obtained using traditional boost converter is very limited. It is not possible to obtain high gain using boost converter without much stress on the switches. Reasonable high gain may be obtained by the use of multiplier circuit with boost converter. Switched capacitor circuit can act as a multiplier circuit and can be combined with boost converters in order to increase the gain. The dc voltage obtained from MLBC can be converted into ac voltage using ACHBMLI. Phase disposition PWM is used to generate the pulses for the inverter. The aim of this paper is to design a hybrid system with effective voltage control and less harmonic distortion in the output voltage by using fractional order PI controller(FO-PI) .The output voltage is maintained at 229.9V which is very close to the reference value (230V) and voltage harmonics are reduced from 26.51% to 18.66%,current harmonics are reduced from 3.10% to 2.54% by providing closed loop. MATLAB /SIMULINK is used for simulating the proposed circuit

Keywords: Asymmetrical Multilevel inverter, Fuel cell, Fractional order controller, Multilevel boost converter, Photovoltaic cell

1. Introduction

The energy utilization in the world increases day by day in response to current situation of power utilization, world is gradually thinking towards alternate or non-conventional energy resources. Among various energy sources PV energy is mostly utilized in low power applications. Photovoltaic generators have many advantages, for example being pollution free, not exhaustible, no rotating parts and so forth. But due to intermittent weather conditions the PV power generation system experiences large variations in its output power which may leads to operational issues at the power station, such as large frequency

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variations. This issue can be overcome by coordinating the photovoltaic plant with other sources known as diesel, fuel cell (FC) etc. But hybridizing of PV system with fuel cell is most effective due to various alluring highlights such as modular production, fast load-response and good efficiency of fuel cell .The necessity and advantages of combing PV and FC as an hybrid system is explained in [1]. Hence the mix of photovoltaic-fuel cell (PV-FC) system might have the capacity to tackle the present issue of irregular power obtained from photovoltaic system [2].The modeling of fuel cell is discussed in[3]. The hybrid system can act as a standalone power system and well suited for remote and rural areas where grid connection is not technically feasible.

The prime challenge in getting solar energy is that the power generated from the PV source is a variable one. It is hypothetically realized that wind speed, moistness, temperature, irradiance and so on affects the output of PV. Many researchers suggested that P&O MPPT is very efficient and simple among various MPPT techniques to extract the maximum power from PV[4]. The hybrid system explained in [5-6] used conventional DC-DC boost converter to step up the voltage. But in order to achieve higher output voltage without operating the switch at extreme duty ratios MLBC are used in the proposed system instead of conventional boost converters. The detailed explanation about MLBC is given in [7]. MLBC has many advantages compared to conventional boost converter such as low switching frequency, low voltage stress, high efficiency etc. Also, many researchers used two level inverter in hybrid power generating system (HPGS) to convert DC power in to AC power. Due to this the filter requirements are increased to reduce the harmonics in the output of the inverter. So in the proposed system seven level ACHBMLI is used to reduce the harmonics at the output. ACHBMLI produces sinusoidal ac waveform with fewer harmonics by a smaller number of switches [9]. Phase disposition technique implemented to generate the pulses for the switches in the inverter [10]. This paper also proposed a closed loop operation for the ACHBMLI using fractional order –PI controller to achieve voltage control at the output of the inverter with reduced distortions under variable loading.[11]. FOPI controller being robust in nature provides extra degree of freedom for tuning.

The main contributions of this paper are as given as follows:

- The quality and reliable power is supplied to the consumers by hybridizing the PV with FC
- Conventional boost converter and two-level inverters in Hybrid power generating systems are replaced with MLBC and ACHBMLI.
- Fractional order PI controller is used at the output to provide constant voltage with less overshoot and fewer harmonic.

Subsequent sections in this paper describes about the system representation, Multi-level boost converter, Seven level Asymmetrical CHBMLI, Modulation techniques, Voltage controller, Fractional order controllers followed by simulation results, conclusions and references.

2. System representation

The block diagram of proposed PV-FC hybrid power generation system is shown in Fig.1.The power sources are connected to multilevel boost converters instead of normal boost converter to expand the working range of yield voltage. PV system consists of P&O MPPT controller to extract maximum power. The DC power obtained form MLBC is converted into AC power by using 7 level asymmetrical CHBMLI instead of normal two-level inverter in order to decrease the harmonic content, furthermore closed loop is provided with FO-PI controller to keep the load voltage constant.

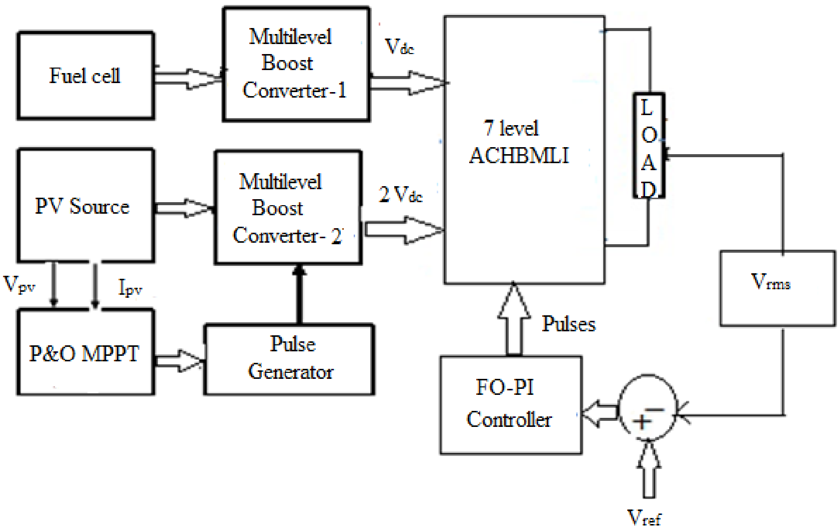

Fig 1. Block diagram of proposed PV-FC system with MLBC and ACHB multilevel inverter

3. Multilevel boost converter

The combination of boost converter and switched capacitor is called dc-dc Multi level boost converter. It has *2N-1* capacitors and *2N-1* diodes, one Inductor and one driven switch to provide different levels of yield voltages for an N level MLBC. The circuit of 2 level boost converter is given in Fig 2. It is based on the principle of multilevel converters and is suggested to be used in applications known as PV or Fuel cell systems with multilevel inverters where various voltage level are required with unidirectional current and self-balancing.

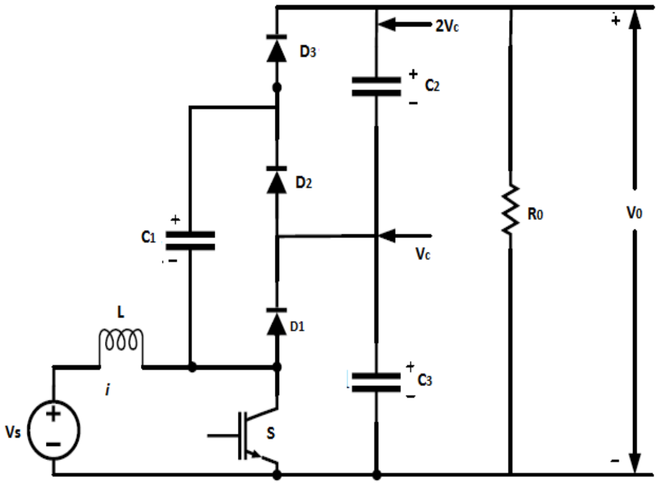

Fig 2 Circuit of multi-level boost converter

3.1. Design of MBC

The yield voltage of the normal boost converter is

$$V_0 = \frac{Vs}{1-d} \tag{1}$$

But for the MLBC the yield voltage (*V_0*) to produce n level with a duty cycle *d* and input voltage (*Vs*)is given

$$V_0 = \frac{N \times Vs}{1-d} \tag{2}$$

The value of capacitor and inductor to reduce ripples at output of MLBC is given by Eq.(3) &Eq.(4).Detailed explanation is given in[12]

$$C_1=C_2=C_3=d\times \frac{Vo}{\Delta V_{in} \times F_s \times R_o} \tag{3}$$

$$L_{min}= \frac{5\times(R_o(1-d)^2)dT_s}{n^2} \tag{4}$$

Where R_o is load resistance, T_s is switching period=$1/F_s$.

4. Seven level Asymmetrical CHBMLI

Asymmetrical CHBMLI comprises DC voltage sources having unequal magnitudes to obtain more levels in the output. To generate 7 levels it requires two H-bridges which are connected in cascade and are excited by V_{dc} and $2V_{dc}$ respectively[13]. To generate 7 levels, it needs two H-brides each having 4 switches. In the present system V_{dc} obtained from output of MLBC-1 connected to Fuel cell and $2V_{dc}$ obtained from output of MLBC-2 connected to PV system.MOSFET is used as switching device.

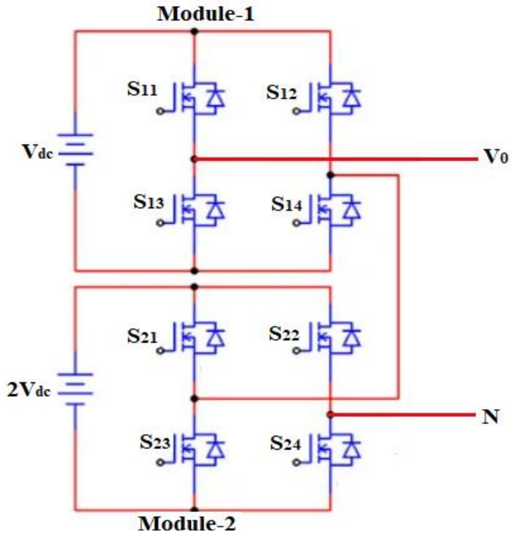

Fig 3. Seven level ACHB multi-level inverter

5. Modulation technique

To generate pulses to the switches of multi-level inverter there are many Modulation techniques available and the various techniques are listed in Fig 4.In this proposed system bipolar level shifted multi carrier PWM techniques is used for analysis. With this strategy absolutely *(n-1)* number of carrier signals and one modulating signal can be utilized to create *'n'* levels in the yield of inverter. The carrier signals in PD-PWM are in phase. The frequency (f_c) and amplitude (V_c) of carrier signals are same.

The expressions for frequency index (m_f) and modulation index (m_a) *are* given by the following expressions [14]

$$m_f = \frac{f_c}{f_m} \tag{5}$$

$$m_a = \frac{2V_m}{(n-1)V_c} \tag{6}$$

Where V_c and V_m represents magnitude of carrier signal and magnitude of modulating signal and n is the number of levels. Fig.5 shows carrier and reference signal arrangement of PD-PWM technique considered to generate pulses.

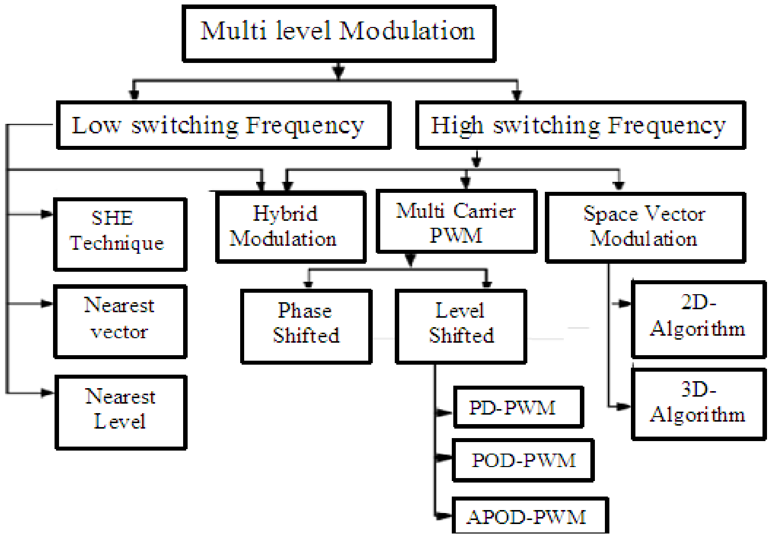

Fig 4. Multi-level inverter modulation techniques

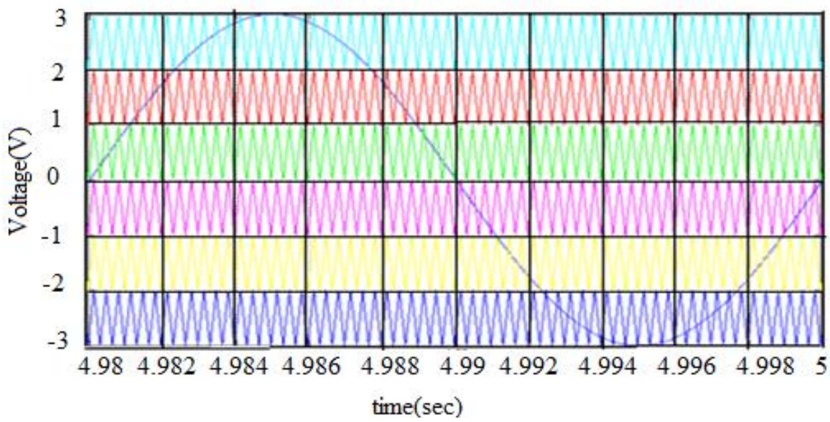

Fig 5. Carrier signal arrangement of PD-PWM

6. Voltage controller

The closed loop is needed when degraded performance of system is observed due to sudden changes in load [15]. Fig 6 shows the block diagram of voltage and frequency control system used in the present study. FO-PI controller is introduced to operate the inverter in closed loop. Here the RMS value of the inverter yield voltage and required voltage (V_{ref}) are compared and the error is fed to the controller. The modulating signal is multiplied with controller output and the resultant is compared with carrier signals to produce pulses for the inverter switches. This strategy helps to keep the yield voltage at a steady value.

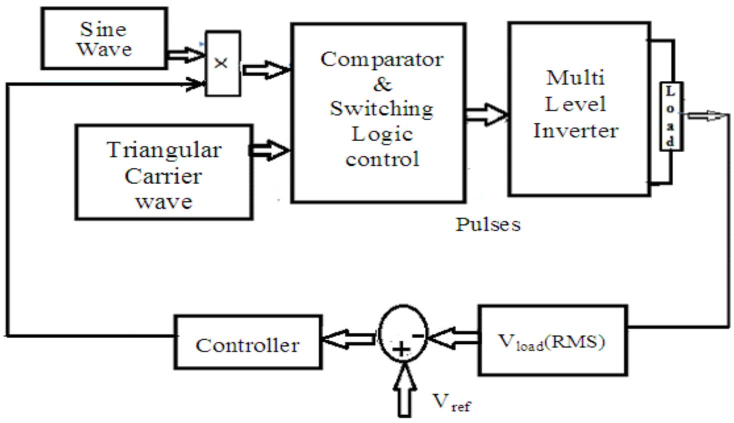

Fig 6. Voltage control strategy

7. Fractional order controller

The most widely recognized type of a FO-PID controller is the $PI^{\lambda}D^{\mu}$ controller with a differentiator and integrator of order μ and λ respectively. Here μ and λ can be any real number [16]. The FO-PID controller transfer function is given by [17]

$$G_C(S) = \frac{U(S)}{E(S)} = K_P + K_I \frac{1}{s^{\lambda}} + K_D s^{\mu}, (\lambda, \mu > 0) \tag{7}$$

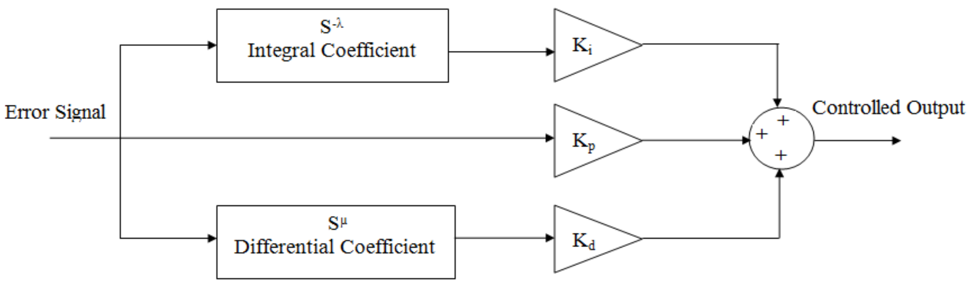

Fig 7. Fractional order PID controller

The FO PID controller has five parameters for tuning, i.e. two more than the ordinary PID controllers, and it is the principle behind the prevalence of FOPID over PID [18].

The transfer function of small signal model of seven level inverter [19] to design the parameters of controller is given in Eq. (8).

$$G_v(S)=\frac{V(S)}{U(S)}=\frac{(1+CR_dS)\sum_{k=1}^{2}V_{dck}}{s^2(LC+\frac{LCR_d}{R})+S(CR_d+\frac{L}{R})+1} \tag{8}$$

After substituting the values in the given above equation then the open loop transfer function obtained is given below

$$G_v(S)=\frac{V(S)}{U(S)}=\frac{360}{2\times10^{-8}s^2+8\times10^{-5}s+1} \tag{9}$$

FOMCON tool box is used to calculate and optimize the parameters of FO controller [20]. This tool provide for identifying the process by the models(FOPDT,IPDT,FOIPDT) and calculating gains of IO-PID controller using Ziegler-Nichols tuning strategy. The parameters of PI are initially set to

$$K_p = K_i = 50,\ \lambda = 1.$$

Initially to design integer order PI controller the exponents are fixed. The following integer order PI parameters K_p = 0.01, K_i =0.1, are set by optimization with above mentioned settings. Later the gains are fixed, and exponents are set to λ = 0.5 and by enabling strict option the process is then continued. As a result, the exponents are found that λ = 0.7.

The closed loop transfer function is given by

$$G_v(S)=\frac{V(S)}{U(S)}=\frac{0.03s^{1.05}+0.5s^{0.6}+0.5}{2\times10^{-8}s^{2.6}+8\times10^{-5}s^{1.6}+0.03s^{1.0}+1.5s^{0.6}+0.5} \tag{10}$$

8. Simulation results

MATLAB/Simulink is used in order to investigate the performance of proposed PV-FC system with multi-level boost converter and seven level asymmetrical multilevel inverter under two different conditions such as open loop and closed loop.

Table.1

PV system simulation parameters

Parameter	Value
Open circuit voltage	25V
Short circuit current	3.87A
Temperature	298K
Irradiance	1000 W/m^2

Table.2

Simulation parameters of ACHBMLI

Parameter	Value
Modulating signal frequency	50 Hz
Carrier wave frequency	2 KHz
Input to H-Bridge- 1	from Fuel cell
Input to H-Bridge- 2	from PV cell
Filter parameters	L=4.25mH & C=5 microF
Load	R=50 Ω ,L=100mH RL-Load

Fig 8 & Fig 9 shows output of photovoltaic and fuel cell. Fig 10 and Fig 11 shows the output of multilevel boost converters which are fed to inverter. Here the output voltages are very high compared to conventional boost converters. Fig 12 shows the output of seven level ACHMLI.

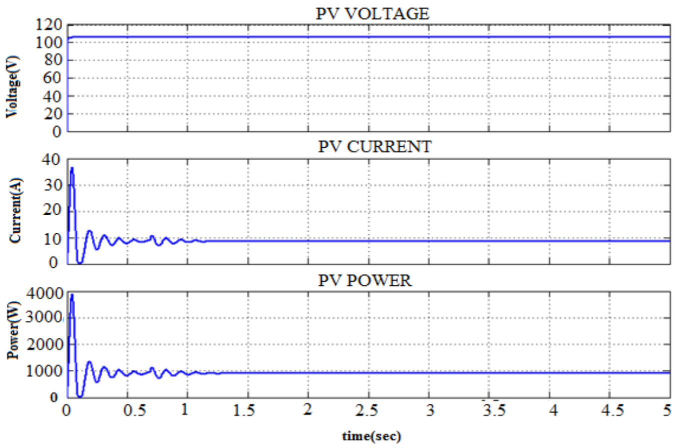

Fig 8. Output of PV with RL-Load

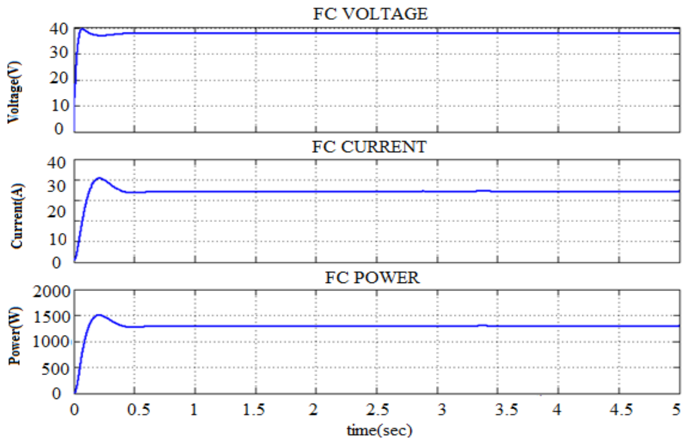

Fig 9. Output of FC with RL-Load

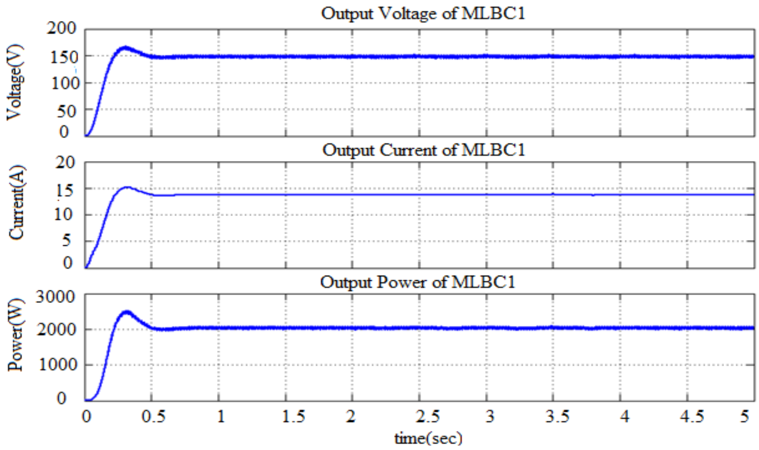

Fig 10. Output of MLBC-1

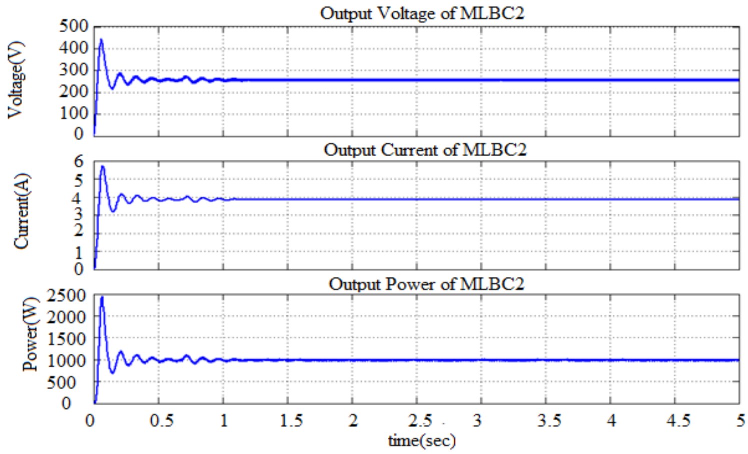

Fig 11. Output of MLBC-2

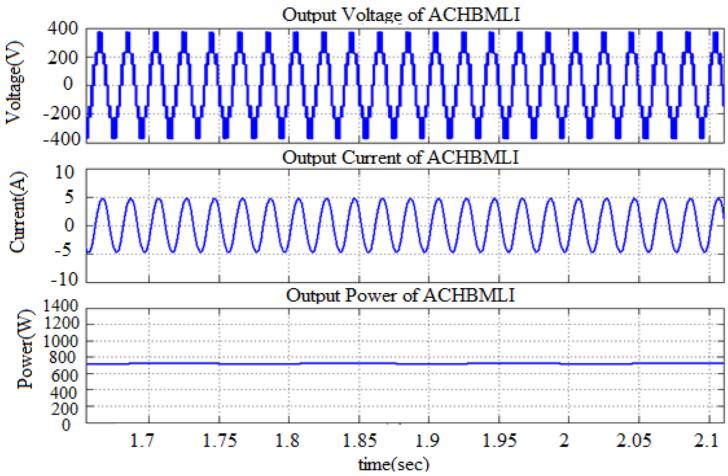

Fig 12. Output of 7-level ACHBMLI

Fig. 13 and Fig. 14 shows output voltage of inverter with closed loop PI and FO-PI controller respectively. From these results it is found that by using FO-PI controller the response is much better and the overshoot is much reduced and settles much faster with very less steady state error.

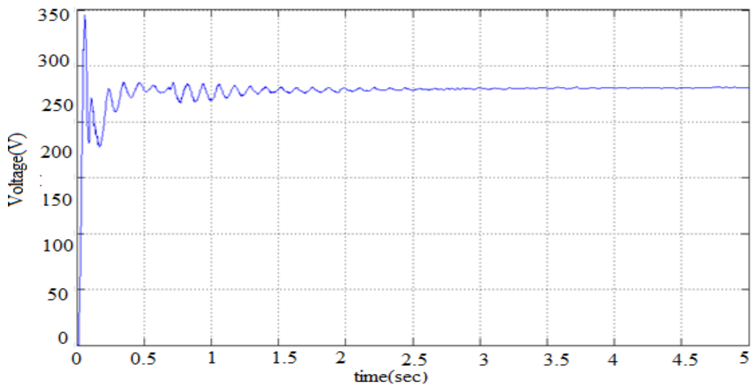

Fig 13.Output voltage of ACHBMLI with PI controller

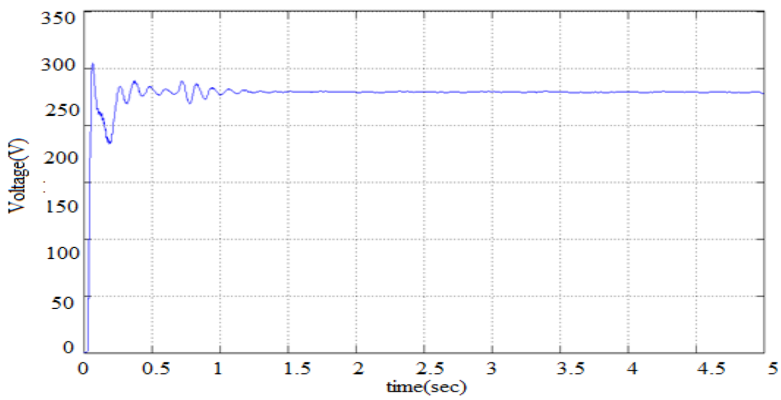

Fig 14.Output voltage of ACHBMLI with FO- PI controller

Fig 15 and Fig 16 shows the total harmonic distortion of output voltage of inverter under closed loop PI and FO-PI controller respectively. From these it is observed that the THD are much reduced by using FO-PI controller

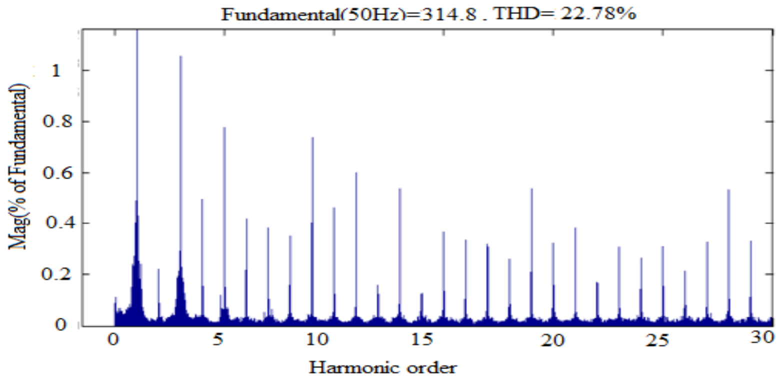

Fig 15.Voltage THD of ACHBMLI with PI controller

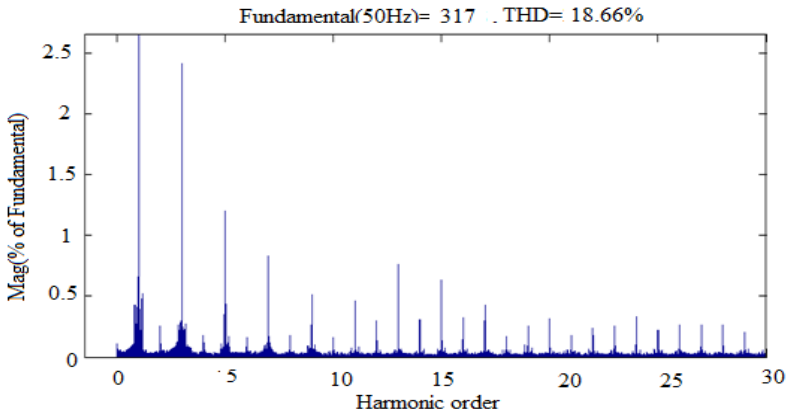

Fig 16. Voltage THD of ACHBMLI with FO-PI controller

Fig 17 and Fig 18 shows the total harmonic distortion of output current of inverter with closed loop PI and FO-PI controller respectively. From these it is observed that THD are much reduced by using FO-PI controller.

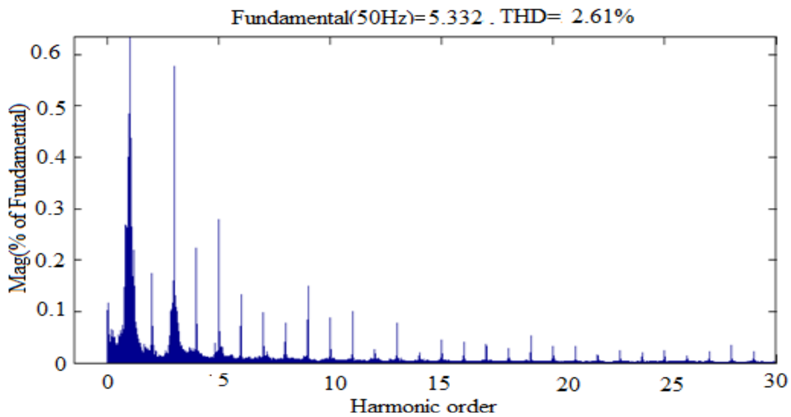

Fig 17. Current THD of ACHBMLI with PI Controller

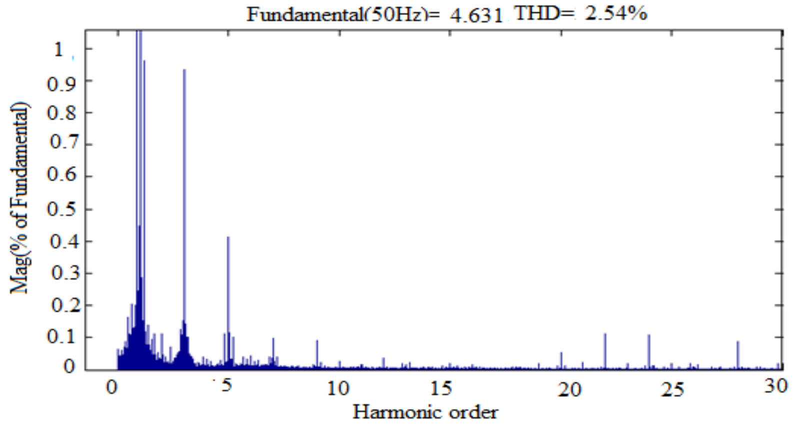

Fig 18. Current THD of ACHBMLI with FO-PI controller

Both PI and FO-PI controller based asymmetrical CHBMLI using multi carrier bipolar level shifted technique such as Phase disposition technique is simulated in MATLAB/Simulink. The r.m.s value of load voltage for open loop and closed loop with PI and FO-PI controller is shown in Table.3 and Table.4 shows the variation of voltage and current THD with different modulation and frequency index. From this we can observe that the best values obtained at 2000Hz and m_a=1 under open loop. In open loop the load voltage is less and also harmonics are more. By using FO-PI controller the voltage is very close to the reference value i.e.230V. So the steady state error is very less by using FO-PI compared to conventional PI.

Table 3

Comparison of output voltage

Load	RMS Value Of Output Voltage		
	Open loop	PI-Controller	FO-PI Controller
RL-Load	209.5V	227.85V	229.9 V

Table 4

Comparison of output voltage

f_C(Hz)	m_a	PD-PWM	
		Voltage THD	Current THD
1000	0.8	28.13	4.15
	1	27.31	3.33
	1.2	27.12	4.85
2000	0.8	27.52	3.25
	1	26.51	3.10
	1.2	24.23	4.92
3000	0.8	27.50	3.22
	1	26.7	3.12
	1.2	24.01	5.01

Table 5

Comparison of Voltage THD

Load	Voltage THD		
	Open loop	PI-Controller	FO-PI controller
RL-Load	26.51 %	22.78%	18.66%

Table 6

Comparison of Current THD.

Load	Current THD		
	Open loop	PI-Controller	FO-PI Controller
RL-Load	3.10 %	2.61 %	2.54 %

From Table 5 & Table 6 it can be inferred that THD of voltage and current is lesser by providing closed loop control with FO-PI controller compared to PI controller. So, results and analysis shows that, it is better to use MLBC and ACHBMLI with closed loop FO-PI controller in hybrid PV-FC system to supply quality power.

9. Conclusions

A hybrid PV-FC power generation system with multi-level boost converter and Asymmetrical CHBMLI is proposed to supply constant voltage and quality of power to the consumer. Higher step up voltage can be achieved using multilevel boost converters without the use of extreme duty ratios. Asymmetrical CHBMLI produces more levels in the output voltage with fewer switches, and hence the total harmonic distortion is less compared to conventional inverters. A closed loop control scheme is proposed for the inverter using FOPI controller. It can be concluded from the simulation results that output voltage is maintained constant with less overshoot by using FO-PI controller. Also, the THD of voltage and current is less by using FO-PI controller compared to PI-Controller and open loop. Hence FO-PI controller enhances the system control performance compared to conventional PI controller. By increasing the levels or by using the filters we can reduce the THD of output voltage and output current.

R E F E R E N C E S

[1] *Rai,Neerparaj,and Bijay Rai*,“ Control of fuzzy logic based PV-battery hybrid system for stand-alone applications”, Journal of Electrical Systems and Information Technology ,**vol.5**,no.2,2018, pp.135-143.

[2] *Mostafazadeh, Asgar, Tohid Kargar Tasooji, Metehan Sahin, and Omer Usta*, “Voltage control of PV-FC-battery-wind turbine for stand-alone hybrid system based on fuzzy logic controller”, 2017 10th International Conference on Electrical and Electronics Engineering (ELECO), pp.170-174, 2018.

[3] *Nehrir, Mohammad Hashem, and Caisheng Wang*, “Modeling and control of fuel cells: distributed generation applications”, **Vol. 41**. John Wiley & Sons, 2009.

[4] *Ali, Ali Nasr Allah, Mohamed H. Saied, Mohamed Z. Mostafa, and Talaat M. Abdel-Moneim*, “A survey of maximum PPT techniques of PV systems”,In Energytech, 2012 IEEE,pp. 1-17, 2012.

[5] *Naik, Anant, R. Y. Udaykumar, and VinayakKole*, "Power Management of a Hybrid PEMFC-PV and ultra-capacitor for Stand-alone and Grid Connected Applications", Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference, pp. 1-5, 2012.

[6] *Jayalakshmi, N. S., Pramod Bhat Nempu, and R. Shivarudraswamy*, "Control and power management of stand-alone PV-FC-UC hybrid system", J. Electr. Eng, 25 pp.45-60,2012

[7] *Rosas-Caro, Julio C., Juan M. Ramírez, and Pedro Martín García-Vite,* "Novel DC-DC multilevel boost converter, Power electronics specialists conference", 2008. PESC 2008. IEEE, pp.2146-2151, 2008

[8] *Ahmed, M. Sundar Manoharan and J. Park*, "An Efficient Single-Sourced Asymmetrical Cascaded Multilevel Inverter With Reduced Leakage Current Suitable for Single-Stage PV Systems", *IEEE Transactions on Energy Conversion*, **vol.34**, no.1, March 2019, pp.211-220.

[9] *Rodriguez, Jose, Jih-Sheng Lai, and Fang Zheng Peng*, "Multilevel inverters: a survey of topologies, controls", and applications. IEEE Transactions on industrial electronics, **vol.49**, no. 4,2002, pp. 724-738.

[10] *P. Sochor and H. Akagi*, "The theoretical and experimental comparison between phase-shifted PWM and level-shifted PWM in a modular multilevel SDBC inverter for utility-scale photovoltaic applications", IEEE Trans. Ind. Appl., **vol. 53**, no.5, Sept.-Oct. 2017, pp. 4695-4707

[11] *Sierociuk, Dominik, and Michal Macias*, "Comparison of variable fractional order PID controller for different types of variable order derivatives",Carpathian Control Conference(ICCC), 201314thInternational,pp.334-339.IEEE,2013.

[12] *Mayo-Maldonado, Jonathan C., Julio C. Rosas-Caro, Rubén Salas-Cabrera, Aarón González-Rodriguez, Omar F. Ruíz-Martínez, Rafael Castillo-Gutiérrez, Jesus R. Castillo-Ibarra, and Hermenegildo Cisneros-Villegas*."State space modeling and control of the dc-dc multilevel boost converter." In 2010 20th International Conference on Electronics Communications and Computers (CONIELECOMP), pp.232-236,2010

[13] *Tiago DaviCuriBusarello, André Luiz de Sousa Marcondes Reuter, Adriano Péres, M. Godoy Simões*, Understanding the Staircase Modulation Strategy and its Application in Asymmetric Cascaded H-Bridge Multilevel Inverter, Industry Applications Society Annual Meeting (IAS) 2018 IEEE, pp. 1-8, 2018

[14] *Colak, Ilhami.,ErsanKabalci., and RamazanBayindir*, "Review of multilevel voltage source inverter topologies and control schemes". Energy Conversion and Management, **Vol.52**, no.2,2012. pp. 1114-1128

[15] *Atithi B.Patel, Hiren H. Patel*, "Control of Asymmetric cascaded H-Bridge multilevel inverter", International Journal Of Current Engineering and Scientific Research, **vol.2**, no.7, 2015,pp. 44-49.

[16] *Aleksei, T., Eduard, P., & Juri, B*, "A flexible MATLAB tool for optimal fractional-order PID controller design subject to specifications". In IEEE Proceedings of the 31st Chinese Control Conference, pp.4698-4703, july 2012.

[17] *D M Kumar, H K Mudaliar, M Cirrincione, U Mehta, M Pucci*, "Design of a fractional order PI(FOPI) for the speed control of a high performance electrical drive with an induction motor,In 21st international conference on electrical machines and systems (ICEMS), pp. 653-658,. IEEE, 2018.

[18] *Birs, C. Muresan, I. Nascu and C. Ionescu,* "A Survey of Recent Advances in Fractional Order Control for Time Delay Systems", *IEEE Access*, **vol. 7**,2019, pp.30951-30965.

[19] *Busarello, Tiago Davi Curi, et al,* "Simplified small-signal model for output voltage control of asymmetric cascaded H-bridge multilevel inverter", IEEE Transactions on Power Electronics, **vol.33**, no.4,2017, pp.3509-3519.

[20] *Tepljakov, Aleksei, Eduard Petlenkov, and Juri Belikov*, "FOMCOM: a MATLAB toolbox for fractional-order system identification and control", International Journal of Microelectronics and Computer Science, **vol.2**, no.2, pp. 51-62.