SIMULATION AND EXPERIMENTAL VALIDATION OF SYMMETRICAL AND ASSYMETRICAL CASCADED H-BRIDGE MULTILEVEL INVERTERS FOR GRID CONNECTED PV APPLICATION

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ABSTRACT: Advancements in the technology and raise in manufacturing units motivates many users to employ PV systems with utility frequency alternating current that can be coupled to a commercial electrical grid or make use of a local, off-grid electrical network with intelligent controllers to improve the stability of the system. It is a significant module in a PV system. Solar inverters have particular functions adapted for employing with photovoltaic arrays, together with maximum power point tracking and anti-islanding protection. This paper deals with fuzzy controller based DC-DC power converter fed symmetrical five & seven level inverter topologies along with a photo-voltaic system. This type of Hybrid H-Bridge inverter produces greater voltage levels using less number of switching devices. Reducing the number of switches results in reduced switching losses as well as THD. The results were obtained using Matlab/Simulink and these results were validated with the hardware outputs.

KEYWORDS: Cascaded H-bridge (CHB), Photovoltaic (PV), Hybrid H-Bridge inverter, Switching devices, THD, Switching losses.

INTRODUCTION

Fuzzy control is based on fuzzy logic; it is much closer in spirit to human thinking and natural language than traditional logical systems to grid connected PV applications. A PV array consists of numerous photovoltaic modules, offhandedly referred to as solar panels, to renovate solar radiation into usable direct current electricity. A photovoltaic system is useful for so many applications like residential, commercial, or industrial energy supplies usually contains an array of photovoltaic (PV) modules, one or added DC to alternating current power converters, a tracking system that ropes the solar modules, electrical wiring and interconnections, and mounting for other components. With the modules count in the system describes the total power in watts able to being generated by the solar array; however, the inverter eventually directs the amount of AC watts that can be spread for consumption.

A solar inverter or PV inverter renovate the variable direct current output of a solar pv panel into a usefulness frequency alternating current (AC) that can be used by a off-grid, local electrical network or fed into a commercial electrical grid. PV inverters revolve into further and more prevalent within both private and commercial circles. These grid-connected inverters translate the available DC supplied by the PV panels and feed into the utility grid. There are lot of power circuit techniques and control strategies employed in inverters. Unusual design approaches deal with assortment of issues that may be significant depending on the inverter to be used. Normally the H-bridge inverter produces a square wave output, which contains infinite number of odd harmonics and dv/dt stress is also high. Usually PWM inverter can diminish the THD, but switching losses are lofty and also this inverter is limited to low power applications. A moderately new class called multilevel inverters has gained extensive attention. Normal operation of current source and voltage source inverters can be a 2-level inverter since the power switches attached to the positive or the negative DC bus. The AC output could enhance as an estimated sine wave if more than 2 voltage levels were obtained at the inverter output terminals. For this motive multilevel inverters, even though more complex and costly, offer higher performance.

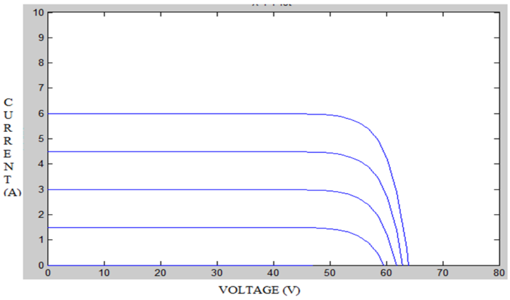

Fig. 1. V-I characteristics PV system

Figure-1 shows the Voltage - current characteristics of PV system. Classical controllers are the majority accepted controllers and extensively used in most power electronic appliances. However many researchers reported effective Fuzzy Logic Controllers (FLC) which is proved to be one of the smart controllers for their appliances. With respect to their unbeaten methodology realization, this kind of methodology put into practice with fuzzy logic controller with feed back by opening of DC/DC converter with a little steady state error and to get better system stability and with high error tolerance.

MULTI-LEVEL INVERTER

Nowadays, for high-voltage and high-power applications multilevel inverters are the most preferable concept due to their characteristics. Desired output voltage is accomplished by appropriate arrangement of multiple low dc voltage sources used at the input side. Output voltage becomes closer to a sinusoidal waveform as the number of dc voltage sources is increased. Good power quality, low switching losses, quasi sine wave form and electromagnetic compatibility due to the low dv/dt transitions are the some advantages of multilevel inverters. So many multilevel inverter topologies are present in the literature but cascaded H-bridge structures, flying capacitor and diode-clamped converter are mostly used by the researchers. All other proposed configurations for multilevel converters are mostly derived from these three fundamental topologies. Amongst three configurations, CHB has got additional concentration in literatures. This paper predominantly focuses on cascaded multilevel converters. CHB is again subdivided into two concepts one is symmetrical and another one is asymmetrical structures. In symmetrical CHB all dc voltage sources are equal, whereas in asymmetrical multilevel inverter consists of dissimilar dc voltage sources. In asymmetrical MLI, the number of produced output voltage levels is high when compared to symmetrical multilevel inverter with the identical number of dc-voltage sources and switches. One of the key challenges in multilevel inverters is to diminish the number of power electronic switches while considering operational conditions.

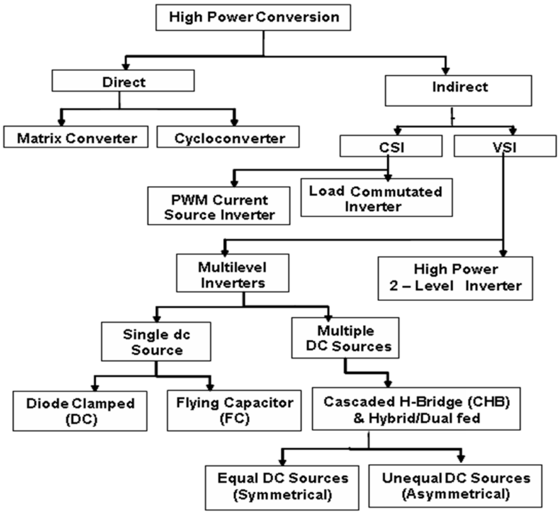

Fig. 2. Classification of High power Converters

Figure: 2 shows the classification of high power converters. Out of all converters Cascaded bridge configuration is more popular. Cascaded bridge configuration is again classified into 2 types 1) Cascaded Half Bridge 2) Cascaded Full Bridge or Cascaded H-Bridge.

Cascaded H-Bridge Five level Inverter

Structure of five-level single-phase cascade H-Bridge inverter is shown in Fig. 2. In conventional structure DC link voltage is shared equally among the DC voltage sources and should be regulated to the equal value at $V_{dc}/2$ if DC voltage across two voltage sources are boosted to V_{dc}. As it is clear, five output voltage levels can be generated based on different switching states.

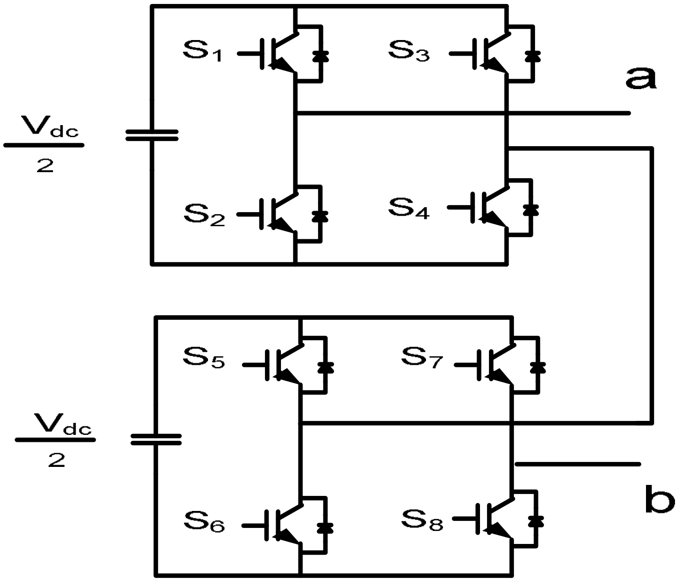

Fig. 3. Cascaded H-Bridge Five level Inverter

Fig. 3 shows the cascaded five level H-Bridge inverter circuit and Table-1 gives the corresponding output voltages for the corresponding switching operation of the power switching devices.

Table 1. Output voltage according to switching ON-OFF condition for symmetrical five level inverter

S1	S2	S3	S4	S5	S6	S7	S8	V_O
1	0	0	1	1	0	0	1	V_{dc}
1	0	0	1	0	1	0	1	$V_{dc}/2$
0	1	0	1	0	1	0	1	0
0	1	1	0	0	1	0	1	$-V_{dc}/2$
0	1	1	0	0	1	1	0	$-V_{dc}$

Cascaded H-Bridge Asymmetrical seven level Inverter

In this seven level CHB a pair of H-Bridges are present. Each H-Bridge consists of a dissimilar voltage sources as $V_{dc}/3$, $2V_{dc}/3$ as shown in Figure.3. $V_1(t)$ and $V_2(t)$ are the corresponding output voltages of two H-Bridges. Hence $V(t) = V_1(t) + V_2(t)$ is the total output voltage. By alternate closing and releasing of different switching configurations we can get different voltage levels.

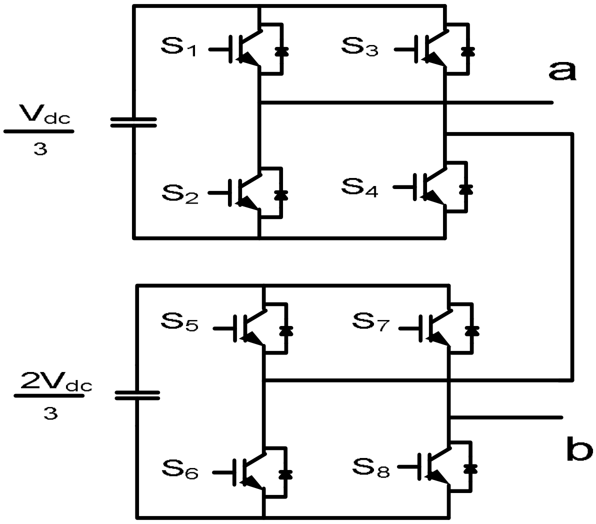

Fig. 4. Cascaded H-bridge Asymmetrical seven level Inverter

Fig. 4 shows the cascaded seven level H-Bridge inverter circuit and Table-II gives the corresponding output voltages for the corresponding switching operation of the power switching devices.

Table 2. Output voltage according to switching ON-OFF condition for asymmetrical seven level inverter

S1	S2	S3	S4	S5	S6	S7	S8	V_o
1	0	0	1	1	0	0	1	V_{dc}
0	1	0	1	1	0	0	1	$2V_{dc}/3$
1	0	0	1	0	1	0	1	$V_{dc}/3$
0	1	0	1	0	1	0	1	0
0	1	1	0	0	1	0	1	$-V_{dc}/3$
0	1	0	1	0	1	1	0	$-2V_{dc}/3$
0	1	1	0	0	1	1	0	$-V_{dc}$

Hardware schematic Diagram

Fig. 5 shows the general schematic diagram of hardware model of multilevel inverter. By proper adjusting the values of two input DC voltages we can obtain the operation for symmetrical five level, asymmetrical seven level inverter topologies as required for the same schematic model.

INTRODUCTION TO FUZZY LOGIC CONTROLLER

In 1965 the first paper was presented in Fuzzy set theory has been extensively used in countless control areas. A simple fuzzy logic control is a completely rule based system with human knowledge. Matlab/Simulink replica is built to study the dynamic performance of single switch based converter which is used for grid applications. L. A. Zadeh is the author of fuzzy logic theory he developed the concepts of fuzzy sets. Since then, a new language was developed to depict the properties of fuzzy in reality, which are very complicated and sometimes even impracticable to be described using conservative concepts.

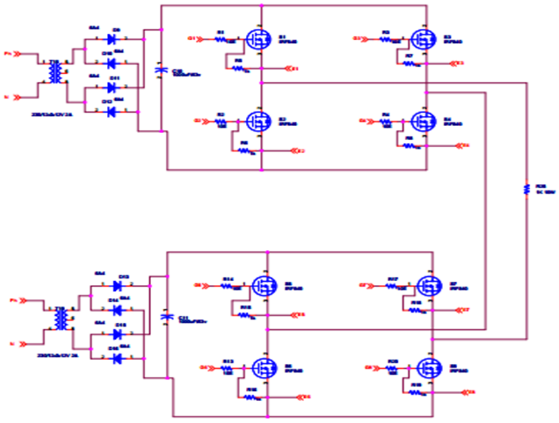

Fig. 5. Schematic Diagram of Hardware model

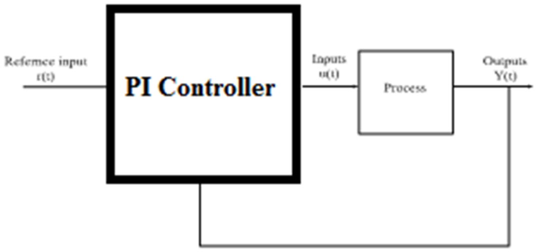

Fig. 6. General Structure of the PI controller on closed-loop system

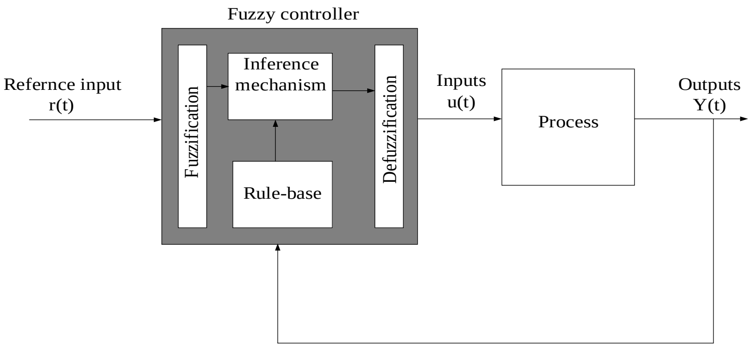

Fig. 7. General Structure of the fuzzy logic controller on closed-loop system

Besides, design of FLC can afford pleasing both minute signal and huge signal vibrant performance at same time, which is not achievable with linear control performance. Thus, fuzzy logic controller has been potential ability to improve the robustness of used converter circuit. The basic scheme of a PI & fuzzy logic controller is shown in Fig.6 as well as Fig. 7. It consists of 4 key components such as: a fuzzification interface, which translates input data into appropriate linguistic values; a knowledge base, which consists of a data base with the obligatory linguistic definitions and the control rules set a decision-making logic which, simulates a human resolution progression, suppose the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which capitulates non fuzzy control action from an incidental fuzzy control action. The fuzzy control systems are depends on professional knowledge that alters the human linguistic concepts into an automatic control strategy without any convoluted mathematical model [10].

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with '*Vdc*' and '*Vdc-ref*' as inputs.

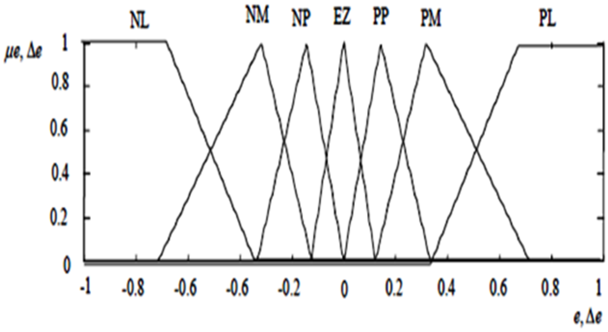

Fig. 8. Membership functions for Input, Change in input, Output.

MATLAB/SIMULINK AND HARDWARE IMPLEMENTATIONS

Case-1: Symmetrical five level inverter

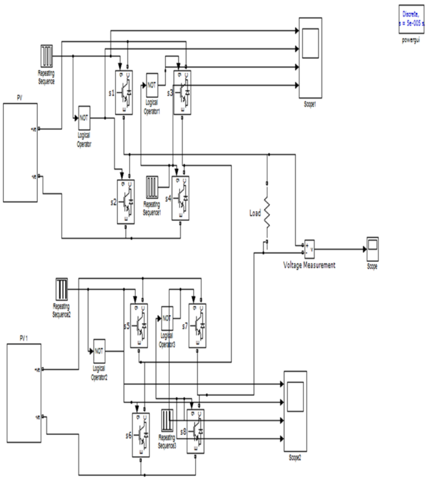

Fig. 9. Matlab/Simulink Power circuit of Cascade Five Level H-Bridge Inverter

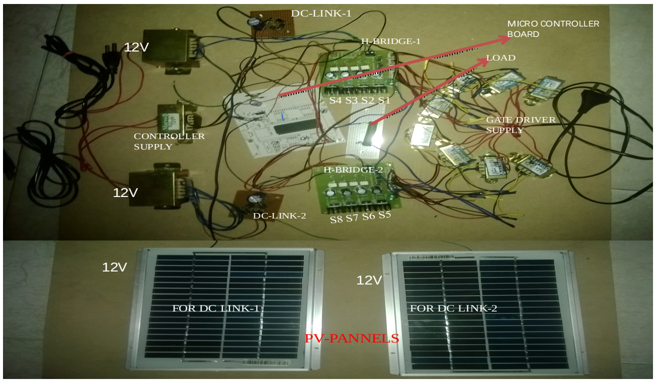

Fig. 10. Hardware Power circuit of Cascade Five Level H-Bridge Inverter

Asymmetrical configuration consists of unequal voltages. Fig. 9 shows Matlab/Simulink Power circuit of Cascade Five Level H-Bridge Inverter and Fig. 10 presents Hardware Power circuit of Cascade Five Level H-Bridge Inverter. Hardware circuit employs 8051 microcontroller to generate required control signals. Hardware circuit shows the two 12V solar panels used as DC link voltage sources. Fig. 11 shows Hardware Switching pulses for Cascade Five Level H-Bridge Inverter and Fig. 12 shows Matlab/Simulink Switching pulses for Cascade Five Level H-Bridge Inverter.

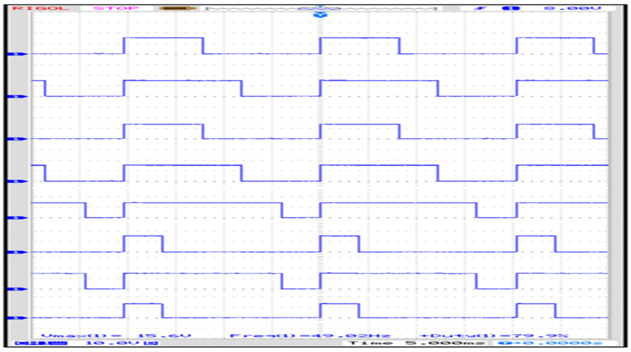

Fig. 11. Hardware Switching pulses for Cascade Five Level H-Bridge Inverter

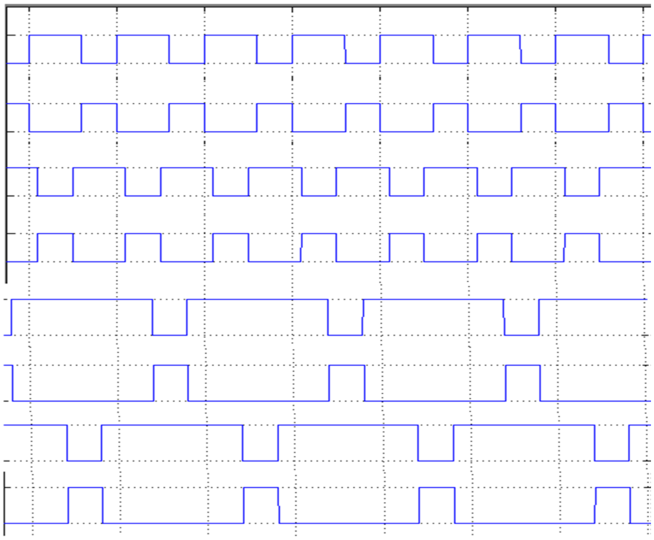

Fig. 12. Matlab/Simulink Switching pulses for Cascade Five Level H-Bridge Inverter

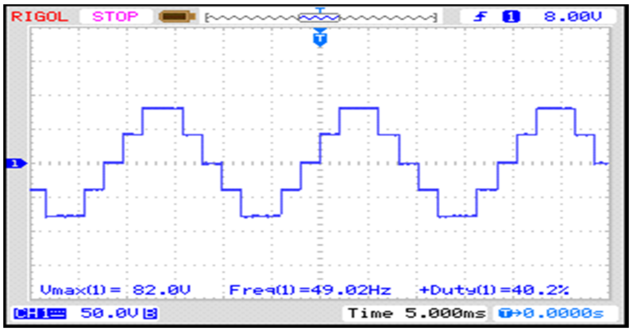

Fig. 13. Hardware output result for Cascade Five Level H-Bridge Inverter

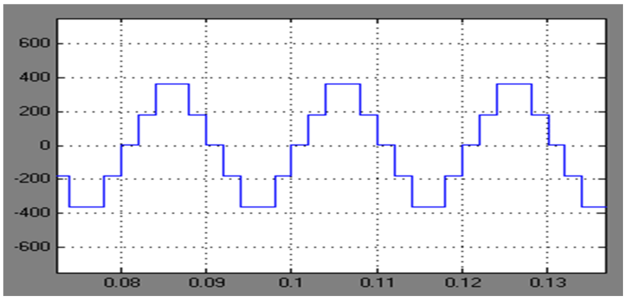

Fig. 14 Matlab/Simulink output result for Cascade Five Level H-Bridge Inverter

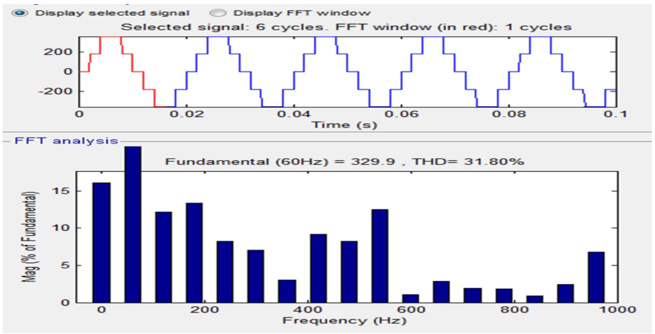

Fig. 15 FFT of Cascade Five Level H-Bridge Inverter

Fig. 13 and Fig. 14 shows the comparison of Hardware and Matlab/Simulink output results for Cascade Five Level H-Bridge Inverter. Also Fig. 15 shows the FFT window for Cascade Five Level H-Bridge Inverter which shows THD as 31.80%.

Case-2: Asymmetrical seven level inverter

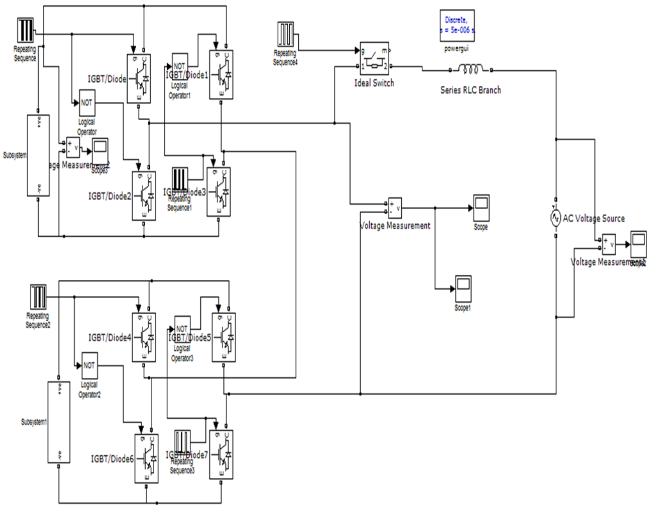

Fig. 16. Matlab/Simulink Power circuit of Cascade seven Level H-Bridge Inverter

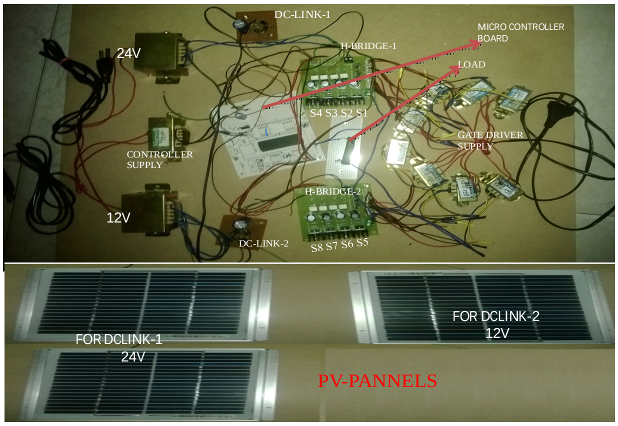

Fig. 17. Hardware Power circuit of Cascade seven Level H-Bridge Inverter

Fig. 16 shows Matlab/Simulink Power circuit of Cascade seven Level H-Bridge Inverter and Fig. 17 gives Hardware Power circuit of Cascade seven Level H-Bridge Inverter. Hardware circuit employs 8051 microcontroller to generate required control signals. Hardware circuit shows the two sets of solar panels 12V and 24V used as DC link voltage sources. To contain 24V, two 12V panels were connected in series. Fig. 18 shows Hardware Switching pulses for Cascade seven Level H-Bridge Inverter and Fig. 19 shows Matlab/Simulink Switching pulses for Cascade seven Level H-Bridge Inverter.

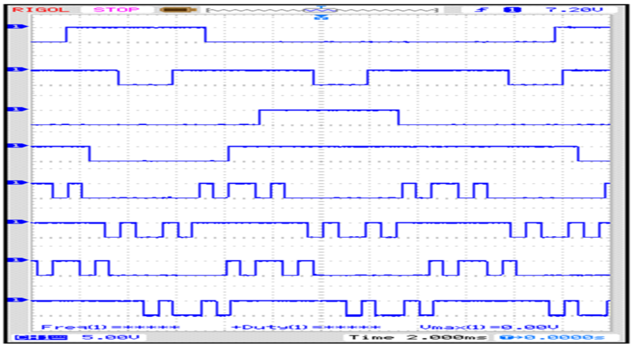

Fig. 18. Hardware Switching pulses for Cascade seven Level H-Bridge Inverter

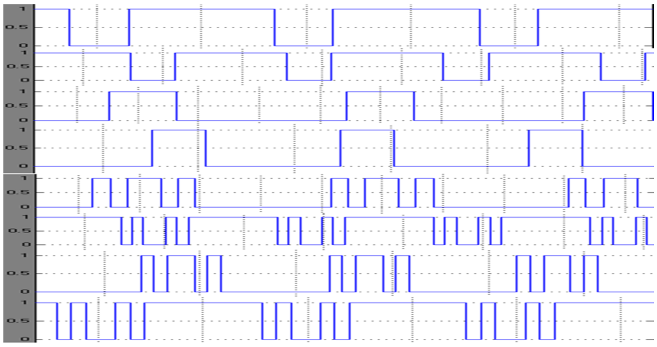

Fig. 19. Matlab/Simulink Switching pulses for Cascade seven Level H-Bridge Inverter

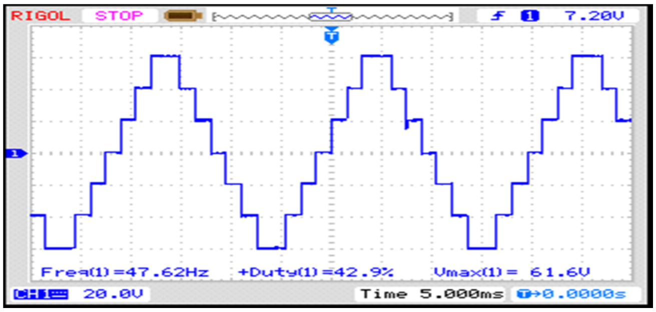

Fig. 20. Hardware and Matlab/Simulink output results for Cascade seven Level H-Bridge Inverter

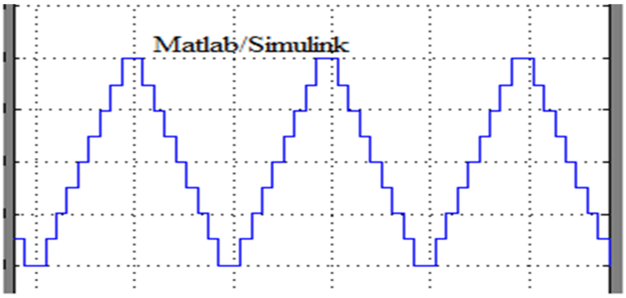

Fig. 21. Hardware and Matlab/Simulink output results for Cascade seven Level H-Bridge Inverter

Fig. and Fig. 21 shows the comparison of Hardware and Matlab/Simulink output results for Cascade seven Level H-Bridge Inverter. Also Fig. 22 shows the FFT window for Cascade Five Level H-Bridge Inverter which shows THD as 18.19%.

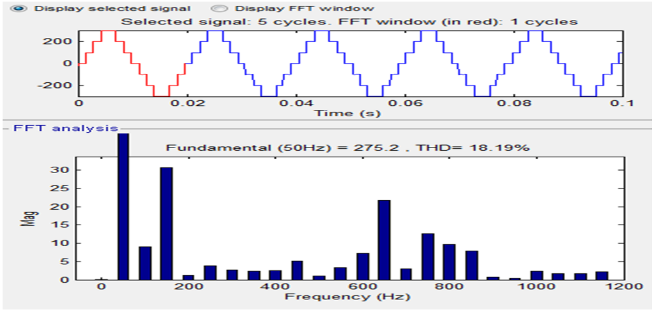

Fig. 22. FFT of Cascade seven Level H-Bridge Inverter

Case-3: Asymmetrical seven level inverter with PI & Fuzzy Based DC-DC Converter

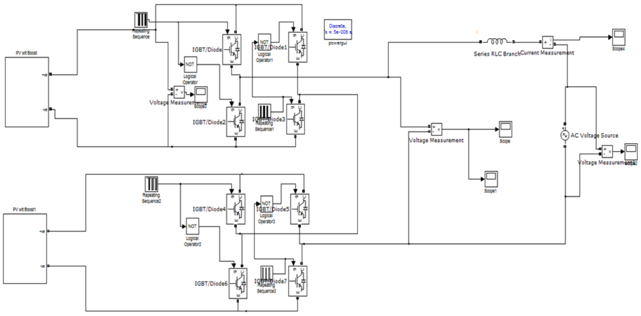

Fig. 23. Matlab/Simulink Power circuit of Cascade seven Level H-Bridge Inverter with Fuzzy Based DC-DC Converter

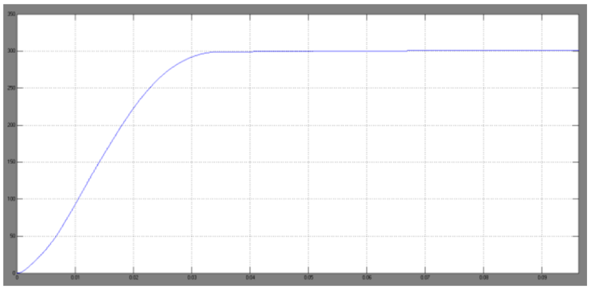

Fig. 24. DC Output Voltage with PI Controller

Fig. 24 shows the DC Output Voltage with PI Controller, due to the classical controller requires 0.03 sec for attaining the steady state, due to this criteria preferred intelligent controllers.

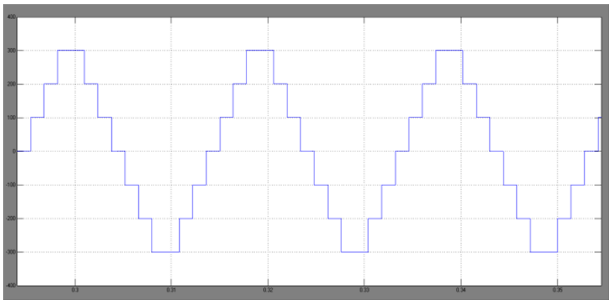

Fig. 25. Seven Level Output Voltage with PI Controller

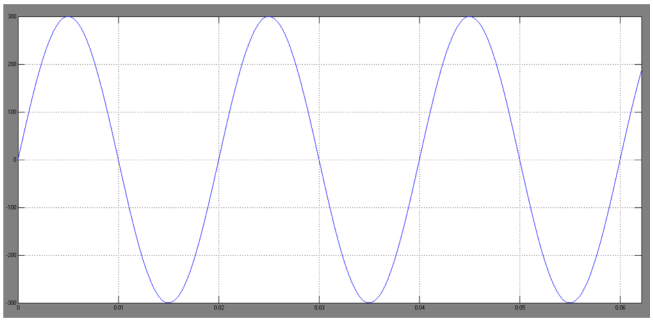

Fig. 26. Grid Voltage with PI Controller

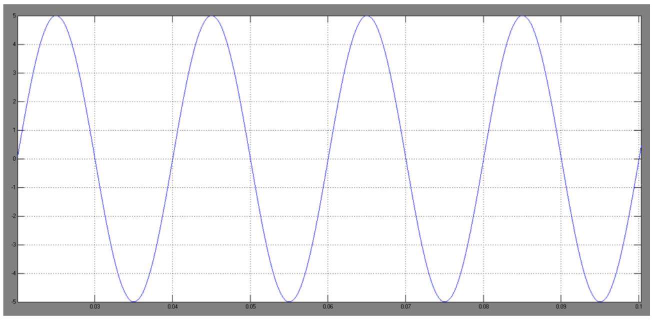

Fig. 27. Grid Current with PI Controller

Fig.25, depicts the Seven Level Output Voltage with PI Controller, Fig.26 depicts the Grid Voltage with PI Controller as well as fig.27 depicts the Grid Current with PI Controller.

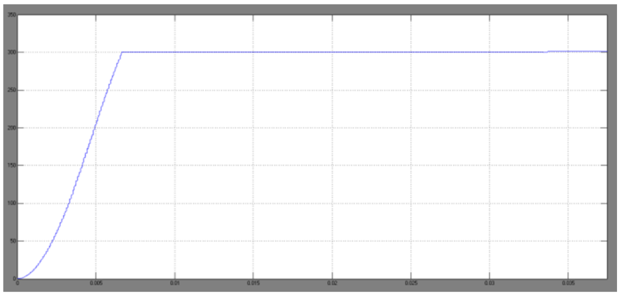

Fig. 28. DC Output Voltage with Fuzzy Controller

Fig. 28 shows the DC Output Voltage with Fuzzy Controller, due to the intelligent controller requires 0.005 sec for attaining the steady state, it have low error components. By using this advanced technology may improve the dynamic stability of the overall grid connected system.

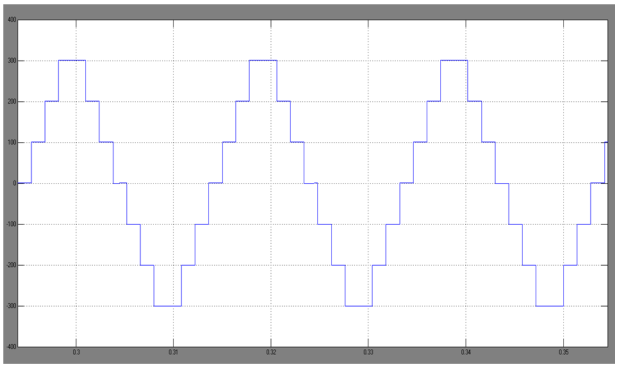

Fig. 29. Seven Level Output Voltage with Fuzzy Controller

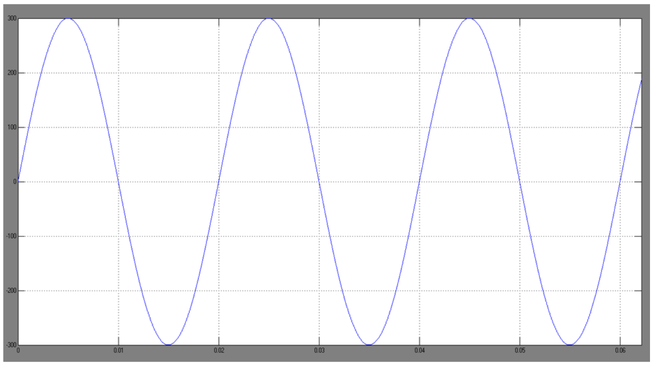

Fig. 30. Grid Voltage with Fuzzy Controller

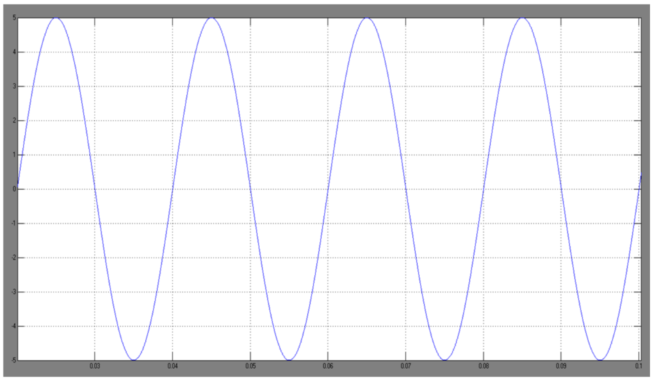

Fig. 31. Grid Current with Fuzzy Controller

Fig.29, depicts the Seven Level Output Voltage with Fuzzy Controller, Fig.30 depicts the Grid Voltage with Fuzzy Controller as well as fig.31 depicts the Grid Current with Fuzzy Controller.

CONCLUSION

A fuzzy controller is implemented in this work to improve the stability of the overall system through DC link voltage with low steady state error. By using multi level inverters the number of output levels can be increased. This multi level inverter concept is used to attain near sinusoidal wave at the output. Here in this paper, the PV output power is assumed as input to the inverter instead of capacitors by employing higher level inverters. The five level symmetrical inverter performance is compared with that of an asymmetrical seven level inverter. The THD reduces as the number of output levels were increased and also increases the system efficiency and performance. Finally the simulation results are validated with hardware results.

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