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A Novel Critical Analysis of Grid Integrated 15-Level Smart Inverter Topologies Using Various Intelligent Controllers

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Abstract : *At present days renewable energy sources are highly utilized for power generation with the accumulation of demanded supply, several concerns related to environment impacts around the globe. These resources are naturally replenished with merely renewable for grid/load connected system like as photo-voltaic, fuel energy, tidal, wind, etc. The grid integrated scheme is interpretation of stand-by strings to co-generation scheme; adjusts the both FC/PV arrangement as a single unit which is recognized highly with power condition systems. The arrangement ranges from an output of 100v to 400v from a supply of 0v to 40v, which is integrated to micro-grid system by using 15-level smart inverter topologies controlled by various intelligent controllers. Mainly, this controllers forecasts the optimal switching states and modulation index for obtaining improved output voltages, better harmonic profile, averts the sudden dips. In this work, the proposed scheme supports perfect sine-voltages which are in phase with current. Finally, a Simulink model is developed to validate the performance of intended 15-level smart inverter topologies with intelligent controllers are explored by using Matlab/Simulink tool, results are conferred.*

Keywords: *Artificial Neuro Fuzzy Inference System, Fuel Cell Stacks, Fuzzy System, Particle Swarm Optimization, PV Cells, PWM Schemes.*

I. Introduction

A co-generation scheme extends the acquired flexibility & splendid scalability for excellent capability of energy management scheme. Owing to safe, clean, eco-friendly specifications attain by the photo-voltaic (PV), fuel cell (FC) PV/FC sources are used imperatively for high stability purposes. The prominent power density is acquired by intermittent creation of PV array & the FC stacks have good dynamic stability, the fast load changes will be implied by using the co-generation system. The proposed system secures simultaneously improvement of transient stability, greater modularity, and quality power at grid. High quality low expensive power generation is most prominent factor for prediction of acute standard of quality life. The necessitated key factor are ameliorate reliability, incredible efficiency, low cost power, refined quality features, interfacing the imperative sustainable availability of energy proposes in [1],[2]. The power conditioning interference is very prominent in grid connected co-power generation scheme due to its conversion of the produced DC power by PV/FC into AC power & fed this AC power into micro-utility grid system [3]-[4]. Since the outcome voltage of photo-voltaic/fuel cell is very low, a DC-DC power interface is preferred in a very low range capacity to integrate the huge outcome voltage, so it can be matched to the DC bus voltage of the inverter structure.

An inductor filter is worn to operate the switching harmonics coming from the inverter, so the measurement of power loss component is proportional to the aggregation of switched harmonics. So as to ameliorate the efficiency of over-all conversion process & the changing of voltages in every switching state & stress of active elements can be reduced by using multi-level inverter [5]-[7]. The power loss originates by the minimization of inductor filter by attenuating the aggregation of switching harmonics. Consequently, the MLI technology has been researched over the few years ago. Improvement of efficiency, harmonic reduction, electro-magnetic interference (EMI) can be attained by higher voltage levels by implementing a advanced multilevel inverter structures. Classical MLI topologies comprises of neutral point clamped type [8]-[10], balancing flying capacitor type [11]-[13], & the series/cascaded H-bridge type [14]-[16]. Neutral point clamped & balanced flying capacitor inverter structures require additional components to acquire the certain voltage levels, it is too difficult to regulation of several capacitors. Diode clamped type & flying capacitor type requires some additional switching components and so difficult to produce the asymmetrical voltages.

Asymmetric voltage technique is more preferable in cascaded H-bridge topology, but it requires more devices for greater the 7-levels. The main affection while utilizing the asymmetric inverter, provides more number of levels, low number of switches by consisting of unequal DC sources, low complex, low space requirement, low cost. Several unique multi-level inverter topologies have been explored in [17].

In this paper, novel low switch smart asymmetric MLI topologies-I & II has been investigated by advanced multi-carrier modulation schemes for micro-grid system via imperative intelligent controllers. The proposed asymmetric inverter topologies generate 15-levels by series/parallel methodology, classical topology requires only 7 switches for generation of 7-levels and proposed topology-I require only 10 switches for generation of 15-level output voltage and proposed topology-II requires only 7 switches for same with optimal/variable switching frequency PWM schemes. The main characteristic of intelligent control objective is constituted as symbolic path of inference system with high proficiency knowledge. For generation of optimal ruler, requires the grid voltage, change in voltage, target voltage are tuned effectively for enhanced stability factor. Several comparative analyses are defined for proposed control schemes over classical schemes in both topologies. Finally, the validation of the classical & proposed inverter topologies-I, II for micro grid system with intelligent controllers is evaluated by using Matlab/Simulink platform & pertaining results are conferred.

II. Formal Inverter Topology

Fig.1 depicts the structure of proposed co-generation system with effective control objective with micro-grid system. The proposed co-generation is comprises of a combination of photo-voltaic array (PV) , fuel cell stacks (FC), are request to become very attracted generation scheme & mostly preferred for micro-grid applications due to their efficiency, reliability, tidiness. Although, several FC technologies are available for use of high range applications, the intended polymer electrolytic membrane fuel cell (PEMFC) has been working as a primary candidate because of acute power density when low operating temperature ranges compared to other FC systems. The co-power generation system is formulated to a micro-grid system via DC-DC converter & a unique 7-level inverter.

The DC/DC power converter converts the low-level voltage to high level that assimilates to a power transformer with a transformation ratio of 2:1. The conversion process of PV/FC outcome power into two self-reliant voltage sources with numerous relationships which are integrated to the inverter, this inverter is comprises of full-bridge converter with a capacitor selected circuit interfaced in a cascaded form. The power semiconductor switches of selection circuit evaluate the charge/discharge of the dual capacitors while dual capacitors are being discharged in series or separately.

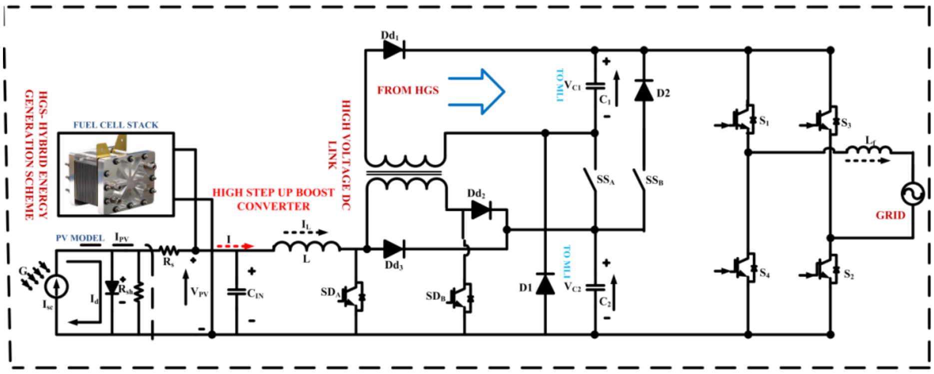

Fig.1 Classical 7-Level Inverter Topology

Table I Switching States for both Positive/Negative Cycle Operations of Proposed 7-Level Inverter Topology

No. of Levels	**SS_A**	**SS_B**	**S_1**	**S_2**	**S_3**	**S_4**
$V_{dc}/3$	1	0	1	1	0	0
$2V_{dc}/3$	0	1	1	1	0	0
V_{dc}	0	0	1	1	0	0
0	0	0	0 or 1	1 or 0	0 or 1	1 or 0
$-V_{dc}/3$	0	0	0	0	1	1
$-2V_{dc}/3$	0	1	0	0	1	1
$-V_{dc}$	1	0	0	0	1	1

Due to several relationships between the voltages of the dual DC capacitors, the final outcome of the selection circuit model conveys the 3-level DC voltage. The full-bridge device converts the 3-level DC voltage into a 7-level AC voltage and that is interfaced with utility voltage with filter inductors. In this process, the proposed co-generation scheme produces a sinusoidal outcome voltages/currents related to grid voltage & is interfaced into a grid/utility system. As can be depicted this novel 7-level inverter requires only 6 active switches. In order to simplify the power conversion circuit which has several advantages such as low complexity, compact integrated device, low switching loss, incredible efficiency, low cost device. But this classical topology has dis-advantage that is nothing but, it is restricted to only 7-levels and for more than 7-levels it was not suited.

III. Proposed Smart Inverter Schemes

3.1 Proposed Topology – I

Based on unique disadvantage in classical topology author proposes a new inverter topologies-I, II, Fig.2 depicts the overall structure of proposed co-generation system with effective control objective for micro grid system via modern asymmetrical 15-level inverter. This co-generation system comprises of a combination of fuel cell (FC) stacks, photo-voltaic (PV) arrays are required for attractive power production attitude due to high reliability incredible efficiency, tidiness. While, stiff power is attained by polymer electrolytic membrane fuel cell (PEMFC) as a primary candidate under low contrasted temperatures.

The PV/FC outcome power is converted into unique self-reliant voltage sources with myriad relationships which are interfaced to the power inverter module via high voltage gain DC-DC converter. This DC link acts as barrier in between these converter modules. The inverter module consists of two different modules; primary is level generation can be formed as a sub-multiple modules. This module consists of two switches per module & holds the DC link voltage with several voltage values like Vdc, 2Vdc, 4Vdc, generates the 7-level DC voltage using 6 switches.

The secondary circuit as a full bridge converter, it converts the 7-level DC voltage into 15 levels AC voltage as a polarity generation concept. In this process, the proposed system generates a sinusoidal outcome of both voltage/currents, these are in-phase with each other & related to grid voltage, then interfaced to utility grid via inductive filters. This converter requires 10 switches for generation of 15-levels, compare to classical inverters it was so better. But author proposes a new converter topology-II, that have reduced switching devices that makes system to be low complex, getting high efficiency, low cost, low THD content, etc.

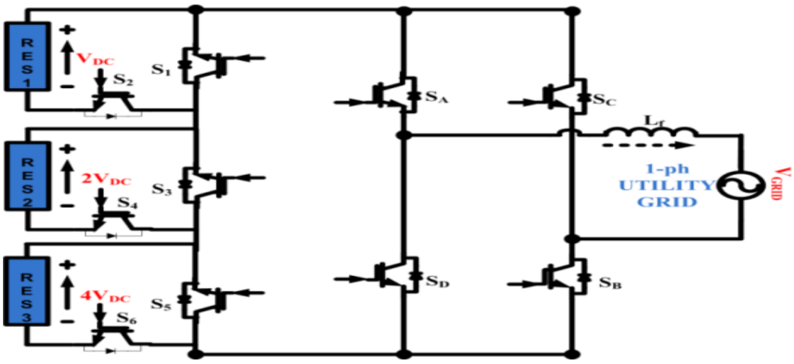

Fig.2 Classical Asymmetrical 15-Level Inverter Topology-I

3.2 Proposed Topology – II

The proposed inverter topology-II consists of coupled inductor turn's ratio, should be magnified by the acquired voltage gain and the secondary winding is series connected with respect to a switched capacitor for enhanced voltage. The Zeta converter is aligned from a M_1 coupled inductor with streamed active switch Sa. The N_1 primary winding of a coupled inductor M_1 is akin to the source inductor of the classical boost regulator, barring the diode D_1 & capacitor C_1. The secondary winding N_2 is append with alternate pair of diode D_2 & capacitor C_2, all these components are series with N_1. The D_3 rectified diode interfaces to its outcome capacitor C_3 & DC bus. The characteristics of the Zeta converter are; 1) coupled inductor's leakage energy is recycled, restraining the voltage spikes at active switch; high boost voltage gain, low stress, greater efficiency, low cost, the active switch isolates the co-generation power during non-working conditions, thus prevents the electric hazards to facilities or human beings.

The classical asymmetrical multilevel inverter topology-I consists of three sources, ten switches, and the voltage sources V_{dc}-100v, $2V_{dc}$-200v, $4V_{dc}$-400v produces the 7-level DC voltage by sub-multi cell module, which is shown in Fig.2. In proposed topology-II comprises of three sources, three balanced diodes, seven switches, the voltage sources are V_{dc}-100v, $2V_{dc}$-200v, $4V_{dc}$-400v generates the 7-level DC voltage by sub-multi cell module, which is shown in Fig.3. The inclusive nature of 15-level outcome voltage is $V(t)=V_{dc}+2V_{dc}+4V_{dc}$ as 7-level DC voltage by the process of level generation. Level generation is the process, which are reify by switching the ON/OFF of S_1, S_2, S_3, S_4, S_5, S_6 switches for topology-I and S_1, S_2, S_3 switches for Topology-II.

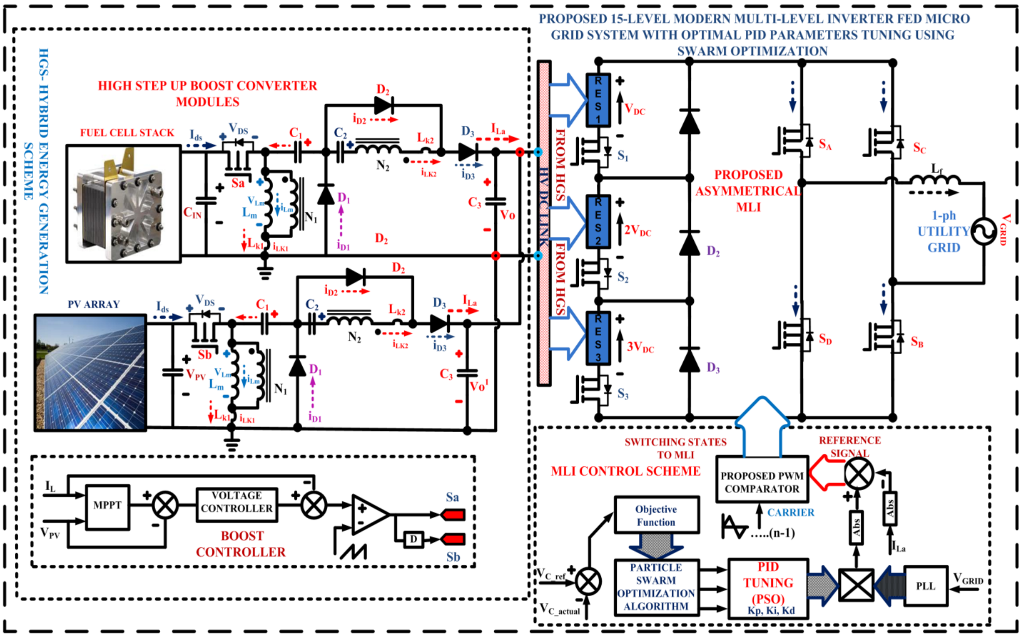

Fig.3 Overall Design of Proposed CO-Generation Scheme with Effective PID-PSO controller for micro-grid system via Reduced Switch Type-Smart Asymmetrical 15-Level Inverter.

Full bridge conversion strategy converts the 7-level DC voltage into AC 15 level voltage by using polarity generation conversion strategy and that is interfaced with utility grid with filter inductors. In this way, proposed system produces a sinusoidal outcome of both voltage/currents, which are in-phase with each other & related to grid voltage. This proposed topology-II requires only 7 switches for generation of 15-levels and is compared to topology-I require 10 switches. So as to simply the conversion structure have many merits such as compact integrated device, low complex design, low switch stress, low cost apparatus, incredible efficiency, called as a smart inverter. The new switching scheme is expressed in Table I, II& III.

The grid voltage is recognized by a voltage detection circuitry send to PLL module so as to produce unified amplitude as a reference signal. The capacitor voltage is recognized, and then compared to actual voltage responds the error & change in error values are passed to intelligent controller. The PLL circuit output and the output are combined to generate a reference signal using multiplier circuitry, while the current of the 15-level inverter is recognized by a current detection circuitry. The reference signals are coming from the referred comparison should be proceed to integrate with proposed PWM generation circuits for production of switching states for 15-level inverter topology according to characteristic table.

IV. Advanced PWM Schemes

Advanced multi-carrier PWM schemes are efficient performance for proposed multilevel inverter topologies, the most encouraged way is getting pure sinusoidal outcome voltage with low harmonic content, low stress, minimized loss component which is compared to classical PWM schemes no need of large size filter. Several Imperative modulation techniques are developed in several applications can be divided as phase/level shifting multi-carrier modulation schemes in [10] based on these modulation schemes author develops a contemporary modulation scheme which have optimal results over classical schemes.

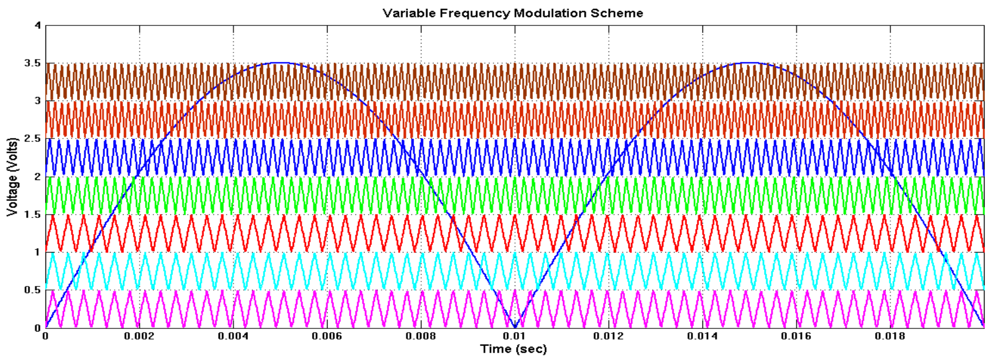

Fig.4 Multi-Carrier Modulation Scheme of Variable Frequency Switching Strategy

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The classical variable switching frequency [11], this technique mainly regards to definite carrier frequency ranges with respect to intended multiplication factor as proposed by authors. The several carrier frequencies are 3050 Hz, 5050 Hz, 7050 Hz are relating to the coming reference signal from intelligent controller as depicted in Fig.4. The intended multi-carrier modulation scheme is merging of both phase-level shifted multi-carrier modulation strategy to trounce the switching action of shifting technique each other & regulates the phase imbalance state. In this technique, all intended carriers have equal frequency and the peak amplitude is un-equal should be disposed vertically. The optimal multi-carrier modulation scheme for 15- level proposed inverter topologies are depicted in Fig.5.

$$MI_a = \frac{V_{ref}}{V_{cr\,(q-1)}} \qquad (1)$$

$$\emptyset_{sh} = \frac{360^{\circ}}{4(n-1)} \qquad (2)$$

For this optimal scheme, (n-1) carriers are needed are defined as essentially disposed vertically by specified measured switching angle. Where V_{ref} constitutes the reference signal from intelligent controller, V_{cr} constitutes the carrier signal, MI_a constitutes the modulation index & $\emptyset_{sh}$ constitutes the disposed phase angle. As, Table II.A & II.B illustrates the switching states for proposed asymmetrical 15 Level multi-level inverter topologies for I&II, production of DC voltage levels & Table III shows the switching pulses for 15 Level MLI for production of polarities, in that “L” specifies the switch is at OFF state & “H” specifies the switch is at ON state.

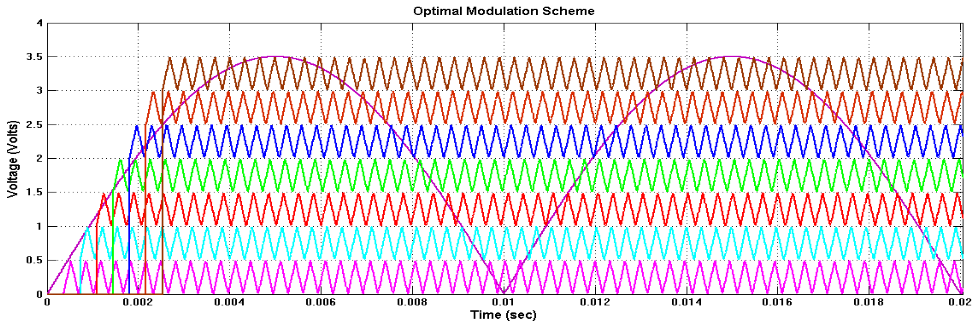

Fig.5 Multi-Carrier Switching Strategy for Optimal Modulation Scheme

Table II. A. Switching Pattern Level Selection Scheme for Proposed Inverter Topology-I

Vo	S_1	S_2	S_3	S_4	S_5	S_6
7Vs	L	H	L	H	L	H
6Vs	H	L	L	H	L	H
5Vs	L	H	H	L	L	H
4Vs	H	L	H	L	L	H
3Vs	L	H	L	H	H	L
2Vs	H	L	L	H	H	L
Vs	L	H	H	L	H	L

Table II. B. Switching Pattern for Level Generation Scheme for Proposed Inverter Topology-II

Vo	S_1	S_2	S_3
7Vs	H	H	H
6Vs	L	H	H
5Vs	H	L	H
4Vs	L	L	H
3Vs	H	H	L
2Vs	L	H	L
Vs	H	L	L

Table III. Switching Pattern Level Generation Scheme for Proposed Inverter Topologies

Vo	S_A	S_B	S_C	S_D
Zero State	L	H	L	H
Positive State	H	H	L	L
Negative State	L	L	H	H

V. Matlab Results

Here simulation is carried out in several cases, in that here simulation is carried out in several configurations, in that 1) Classical 7-Level Inverter Topology Interfacing to Micro-Grid System with CO-

Generation Scheme. 2) Proposed 15-Level Inverter Topology-I Interfacing to Micro-Grid System with CO-Generation Scheme via Intelligent Controllers. 3) Proposed 15-Level Inverter Topology-II Interfacing to Micro-Grid System with CO-Generation Scheme via Intelligent Controllers.

Case 1: Classical 7-Level Inverter Topology Interfacing to Micro-Grid System with CO-Generation Scheme

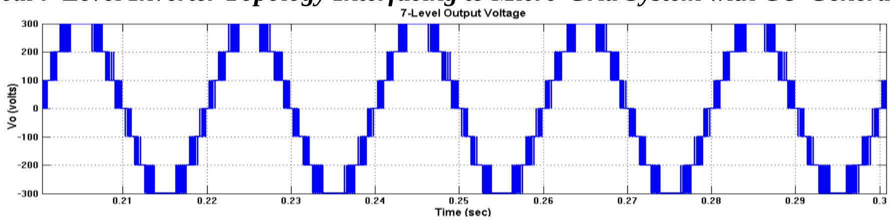

Fig. 6(a) 7-Level Output Voltage

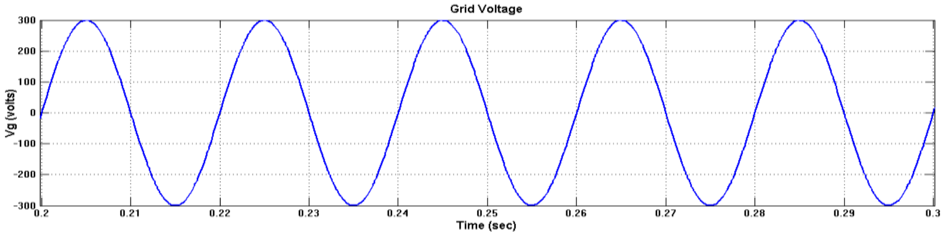

Fig. 6(b) Grid Voltage

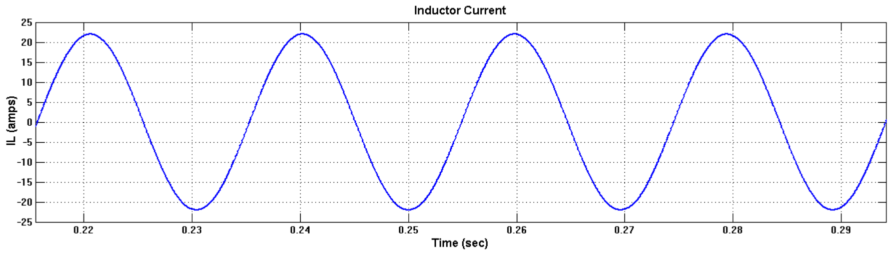

Fig. 6(c) Inductor Current

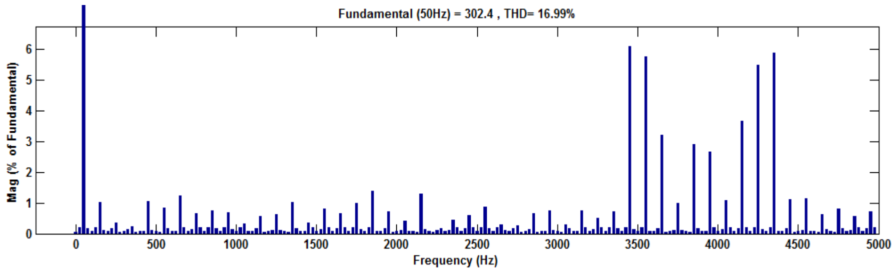

Fig. 6(d) THD of 7-Level Output Voltage

Fig. 6 Simulink Results of Compact Integrated Proposed Asymmetrical 7-Level Inverter using PWM scheme, in that (a) 5-Level output voltage, (b) Grid Voltage, (c) Inductor Current, (d) THD of Output Voltage, attaining 16.99% by without any filter circuit.

Case 2: Proposed 15-Level Inverter Topology-I Interfacing to Micro-Grid System with CO-Generation Scheme via Intelligent Controllers

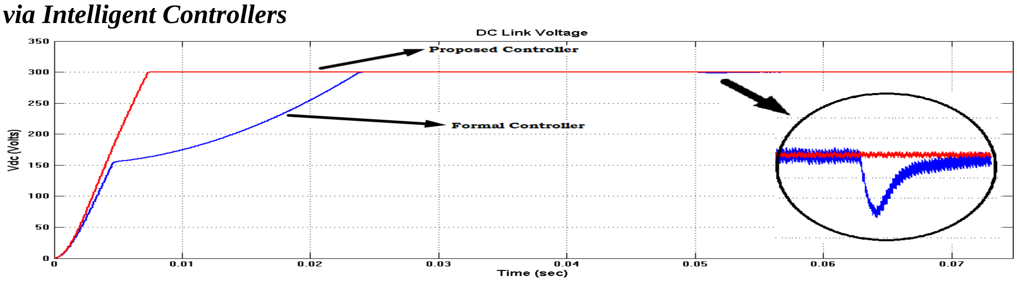

Fig. 7(a) DC Link Voltage

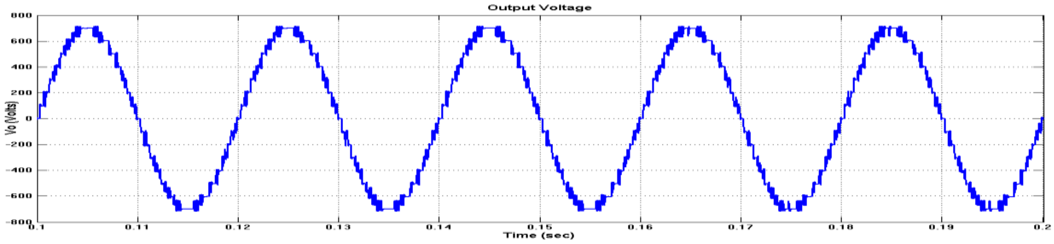

Fig. 7(b) 15-Level Output Voltage

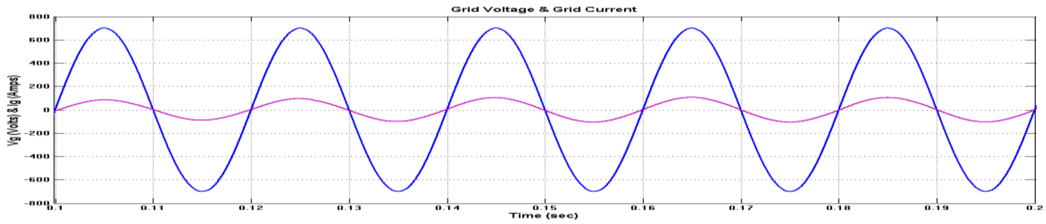

Fig. 7(c) Grid Voltage & Current

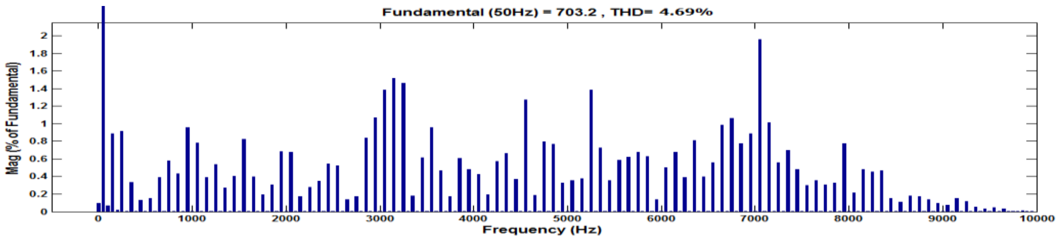

Fig. 7(d) THD of 15-Level Output Voltage

Fig.7 Several Simulations of Proposed 15-Level MLI topology-I for Grid System via Intelligent Controllers

Fig.7 depicts the simulated results of proposed asymmetrical 15-Level multi-level inverter topology-I for grid interfacing System through a intelligent controller and Fig.8 depicts the proposed inverter topology-II for grid system via intelligent controllers, in that in that (a) DC Link Voltage of the proposed controller compared to formal controller, the proposed PSO-PID controller has fast steady state response under step changes in inputs; (b) 15-Level Stair Case Output Voltage; (c) Grid Current & Voltage, both are in pure sinusoidal & in-phase with each other it may specifies the unity power factor; (d) Total Harmonic Distortions (THD) of Proposed 15-Level MLI topology for Grid interfacing system via PSO_PID Controller is 4.69% for topology-I and 2.68% for topology-II. These values are well within IEEE standards without any additional filter circuit. The topology-II is more suitable because of technically perfect & commercial perfect by low switching devices.

Case 3: Proposed 15-Level Inverter Topology-II Interfacing to Micro-Grid System with CO-Generation Scheme via Intelligent Controllers.

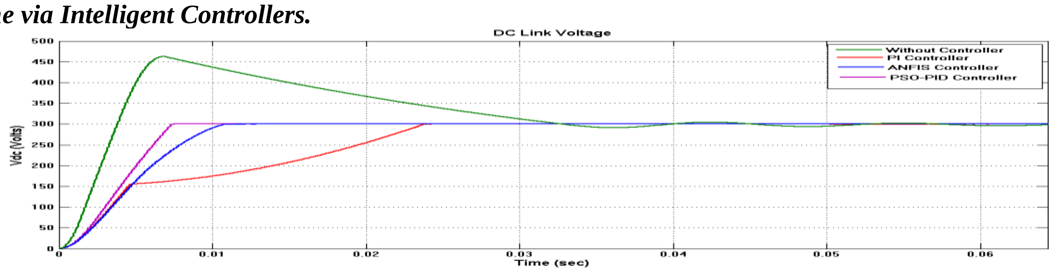

Fig. 8(a) DC Link Voltage

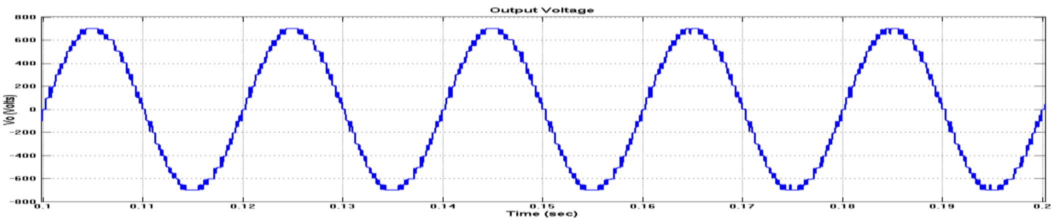

Fig. 8(b) 15-Level Output Voltage

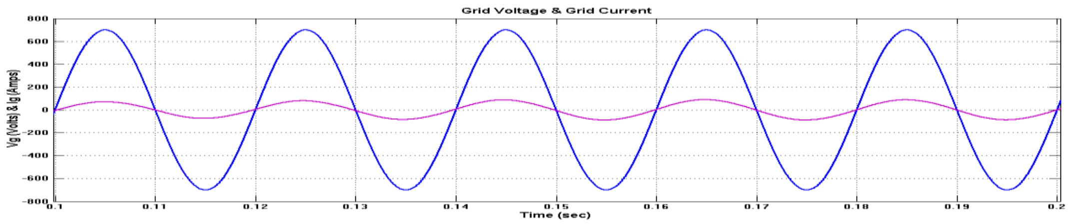

Fig. 8(c) Grid Voltage & Current

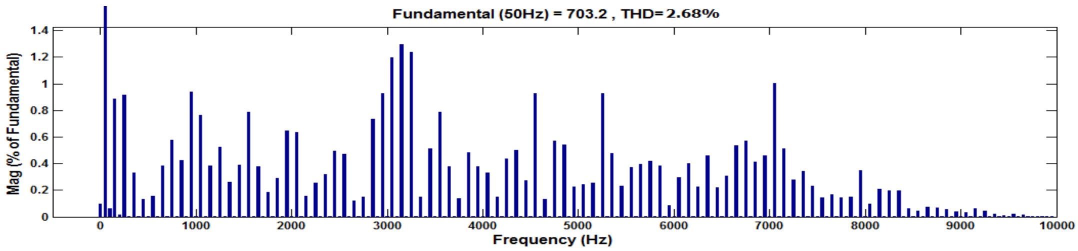

Fig. 8(d) THD of 15-Level Output Voltage

Fig.8 Several Simulations of Proposed 15-Level MLI topology-II for Grid System via Intelligent Controllers

VI. Conclusion

Grid connection results were shown using the proposed asymmetrical inverter modules. The entire PV/FC system structure and its interaction with the grid through PLL and MPPT algorithms were shown by the simulation results. The FFT analysis of proposed inverter topologies are well within the IEEE standards.

Table IV. A FFT Analysis of Output Voltage with Proposed Controller Topology – I over Classical Controllers

Type of Controller	Classical PWM			Proposed Optimal PWM Scheme			Proposed Variable Frequency PWM Scheme		
	PD	POD	APOD	PD	POD	APOD	PD	POD	APOD
PI Controller	7.75%	7.76%	7.76%	7.65%	7.67%	7.67%	7.68%	7.60%	7.71%
Fuzzy Controller	7.22%	7.35%	7.36%	7.39%	7.43%	7.44%	7.29%	7.32%	7.30%
ANFIS Controller	6.65%	6.76%	6.76%	6.85%	6.88%	6.90%	6.28%	6.33%	6.33%
PID-PSO Controller	5.46%	5.56%	5.67%	5.67%	5.70%	5.72%	4.69%	4.70%	4.70%

Table IV. B Comparison of FFT Analysis of Output Voltage of Proposed Topology-II with Several controllers

Type of Controller	Classical Regular PWM			Proposed Variable Frequency PWM Scheme			Proposed Optimal PWM Scheme		
	PD	POD	APOD	PD	POD	APOD	PD	POD	APOD
PI Controller	7.75%	7.76%	7.76%	7.65%	7.67%	7.67%	7.68%	7.60%	7.71%
Fuzzy Controller	5.86%	5.96%	5.95%	4.99%	5.03%	5.03%	6.06%	6.12%	6.12%
ANFIS Controller	4.44%	4.56%	4.57%	3.68%	3.62%	3.62%	4.67%	4.69%	4.73%
PID-PSO Controller	3.09%	3.20%	3.24%	2.80%	2.68%	2.68%	3.33%	3.31%	3.40%

A new scheme is explored for co-generation scheme with several intelligent controllers may include the formation of PV/FC energy via proposed asymmetrical zeta module with advanced PWM schemes. The several unique conclusions are compared from the analysis of proposed smart 15-level inverter with classical topology, it require high switching devices when compared to topology-I and acute space & high cost, low comfort and are low cost, low complex, low switch stress, greater efficiency over topology-II. THD comparison is takes place in Table IV.A & IV.B, in that variable switching frequency modulation technique with PSO-PID controller has better THD % reduction over classical controllers. The outcome simulation results are validated with the proposed-I, II over classical concepts should be more attractive for micro-grid system & attain qualitated power, meticulously manages the co-energy.

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