A New Hybrid Cascaded H- Bridge Inverter for Photovoltaic-Wind Energy System

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***Abstract*— This paper deals with electricity from photovoltaic-wind system for cascaded multilevel inverter. The objective of this paper is to propose a novel multilevel inverter using hybrid Photo Voltaic (PV)/Wind power system in order to simplify the power system and reduce harmonics and the cost effect . This inverter has advantageous of industrial application. The conventional use of converters will increase losses and cost in conventional methods. The proposed nine level multilevel inverter with solar-wind energy using Pulse Width Modulation Technique (PWM) of providing high switching frequency will highly reduce harmonics confirmed by MATLAB as well hardware results.**

Keywords- Pulse Width Modulation (PWM), Multi Level Inverter (MLI), Total Harmonic Distortion (THD), Renewable Energy systems (RES), Photovoltaic (PV), Hybrid MLI(HMLI).

I. Introduction

The term multilevel began with the three-level converter. Consequently, many topologies has been developed for multilevel converters. However, the elementary concept of a multilevel converter to achieve higher power is to use a series of power semiconductor switches with several lower voltage dc sources to perform the power conversion by synthesizing a staircase voltage waveform. Renewable energy voltage sources, batteries and capacitors can be used as the multiple DC voltage sources. The turn ON or OFF of the power switches aggregate these multiple dc sources in order to achieve high voltage at the output of the inverter; but the voltage rating of the power semiconductor switches depends only upon the rating of the dc voltage sources to which they are connected.

A multilevel inverter has several advantages over a conventional two-level converter that uses high switching frequency Pulse Width Modulation (PWM). The attractive features of a multilevel inverter can be briefly summarized as follows. 1) Staircase Waveform Quality: Multilevel inverters not only can generate the output voltages with minimum distortion, and also reduce the dv/dt stresses; therefore Electro Magnetic Compatibility (EMC) problems can be reduced. 2) Common-Mode (CM) Voltage: Multilevel inverters produce smaller Common mode voltage, so that stress in the bearings of a motor get reduced which is connected to the multilevel inverter. Furthermore, CM voltage can be eliminated by using advanced modulation strategies. 3) Input Current: Multilevel inverters can draw input current with low distortion. 4) Switching Frequency: Multilevel inverters can operate at both fundamental switching frequency and high switching frequency PWM [1].

The inverter generates 3^s different voltages (e.g. an inverter with s=2 cells can generate 3^2=9 different voltage levels). In conventional method low level inverter is used and better sinusoidal waveform was not obtained which is the drawback of the conventional system and the harmonics was high. So increasing the levels of inverter to get high resolution, hence the output waveform is mostly sinusoidal waveform [2].

In conventional method, some additional drawbacks like electromagnetic compatibility and common mode voltage problems easily occurs consuming large current cause swing in the voltage due to harmonics which can be easily viewed by our vision . Example: rolling lines in Television using inverters. The cascaded multilevel inverter is prepared by series connection of single phase full bridge inverter [1, 10]. The common function of multilevel inverter is to synthesize a desired voltage from several separate DC sources. Each dc source is connected to a single phase full bridge inverter. Each bridge inverter is potential of generating three different output voltages, $+V_{dc}$, 0 and - V_{dc}.

The output waveform has 9 levels, ± 9, ± 8, ± 7, ± 6, ± 5, ± 4, ± 3, ± 2, ± 1.

II. Modelling of New Hybrid Multilevel Inverter

For the output voltage of each bridge inverter is given by

$$V_{oi} = V_{dc}(S_{1i} - S_{2i}) \qquad (1)$$

and the input DC current is

$$I_{dci} = I_a(S_{1i} - S_{2i}) \qquad (2)$$

Where v_{ij} is the i cell output voltage, and (S_{i1}, S_{i2}) the switching state associated to the i cell. Particular cell i can generate three levels ($+V_i$, 0, $-V_i$). Equation (1) explicitly shows how the output voltage of one cell is defined by one of the four binary combinations of switching state, with "1" and "0" representing the "ON" and "OFF" state of the corresponding switch, respectively [19].

III. Proposed System

The hybrid cascaded H-bridge inverter power circuit is illustrated in Fig. 1. The inverter is composed of two legs, in each one a series connection of two H-bridge inverters fed by independent DC sources that are not equal ($V1 < V2$). In this proposed method of the inverter, has two dc input stages of asymmetric construction module. All the modules are connected as new cascaded with each module having gate triggering switches. The gate triggering power circuit switches may be IGBT, MOSFET or any other power devices, IGBT's are used in this system. At a time power switches from upper and lower leg of corresponding bridge will alternatively act and other two switches are in open condition.

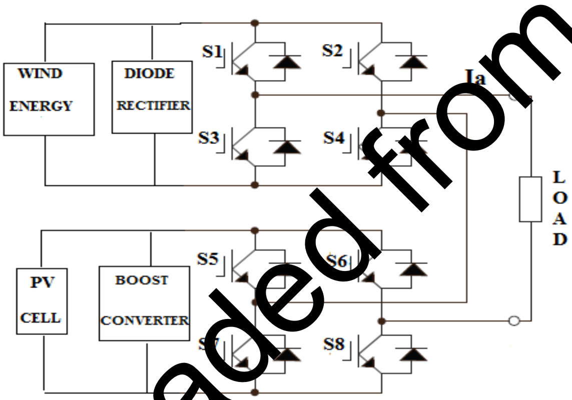


Fig. 1. Proposed System

The use of asymmetric input voltages can reduce, or when properly chosen, eliminate reduced output levels, there by maximize the number of different output levels generated by the H-bridge inverter. Therefore above proposed topology can achieve the same output voltage quality with less number of semiconductor switches. This also reduces volume, costs, and losses and improves reliability. The Maximum Voltage Ratio(MVR) is given as

$$\mathrm{MVR} = \frac{3^{s-1}}{(3^{s-1}/2)} = ¾ \qquad (3)$$

Nine different output levels can be generated using only two cells (8 switches) while four cells (16 switches) are necessary to achieve the same amount of level with symmetric fed inverter. The main advantage of proposed system is IGBT's were used instead of MOSFET switches, flying capacitors reduces which will consequently reduce gate triggering and switching losses.

IV. SWITCHING PATTERN

For first pulse, switches one and four Vdc will act along with action of switches five and six produce one stage level of output waveform and after next duration of pulses switches five and eight act to produce 3Vdc along with action of switches two and four produces -1Vdc gives +2Vdc form next level in the output waveform without any distortion. The next pulses of action from IGBT driver circuit make switches of five and eight in the second bridge of power circuit to produce +3Vdc along with action of switches one and two gives +3Vdc output waveform. After the completion of the third level output waveform the control pulses ready to produce next stage of output waveform by making switches one and four gives Vdc along with action of switches five and eight in the second bridge gives 3Vdc gives fourth stage of level of output waveform with high resolution of high switching frequency reduce harmonics in the output waveform to gives pure supply to load.

Table 1.Active Switching Pattern

S.no	S1	S2	S3	S4	S5	S6	S7	S8	O/P V_{dc}
1	1	0	0	1	0	0	0	0	+1
2	0	1	1	0	1	0	0	1	+2
3	0	0	0	0	1	0	0	1	+3
4	1	0	0	1	1	0	0	1	+4
5	0	0	0	0	0	0	[illegible]	0	0
6	0	1	1	0	0	1	1	0	-4
7	0	0	0	0	0	1	1	0	-3
8	1	0	0	1	0	1	1	0	-2
9	0	1	1	[illegible]	0	0	0	0	-1

This process of action keeps on continuing produces corresponding stage of output level form pure stepped sinusoidal output waveform was produced. This process goes on increasing the level number of outputwaveform to provide harmonic less pure stepped output waveform to load where switching pattern is shown in the Table.1.

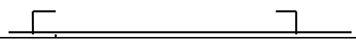
The S number of stages or DC source and the associated number output level can be written as follows:

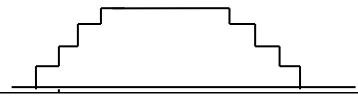
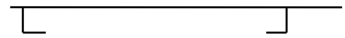
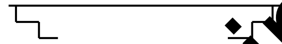
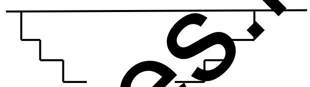
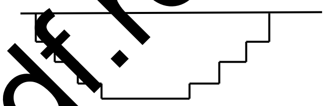
$$N\ level = 3^S \quad (4)$$

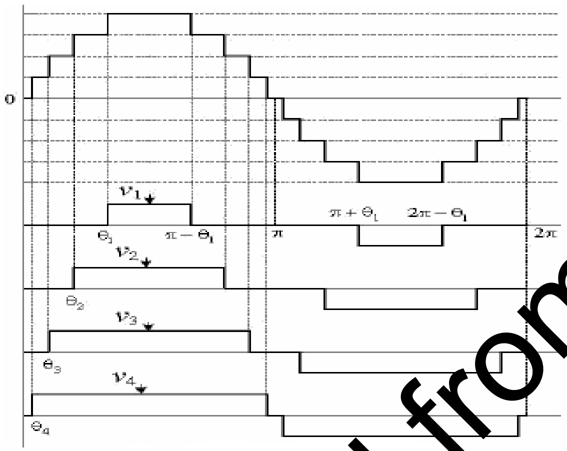
The proposed topology has number of switches used is expressed as,

$$N\ Switches = 4S \quad (5)$$

Table 2. Generation Of Step By Step Output Voltage Waveforms

Stages	Control pulse for reaction of H-bridge					Generation of Waveform of 9-level
	I Bridge 1Vdc	Switching Action	II Bridge 3Vdc	Switching Action	O/P Vdc	
1	+1	1,4	0	5,6	+1	
2	-1	2,3	+3	5,8	+2	
3	0	1,2	+3	5,8	+3	

4	**+1**	**1,4**	**+3**	**5,8**	**+4**	
5	**0**	**3,4**	**0**	**7,8**	**0**	
6	**-1**	**6,7**	**-3**	**6,7**	**-4**	
7	**0**	**5,6**	**-3**	**6,7**	**-3**	
8	**+1**	**1,4**	**-3**	**6,7**	**-2**	
9	**-1**	**6,7**	**0**	**5,6**	**-1**	



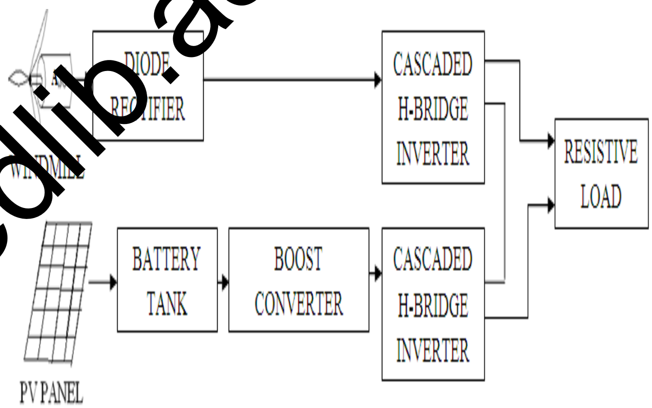


Fig. 3. Block Diagram of Solar-Wind based MLI

Fig. 2. Output Voltage Waveform of 9-Level Cascaded H- Bridge Inverter with Two Separate DC Source

This method is different from conventional inverter method because it has less number of switches for performing the operation. This is simplest block diagram of solar-wind based MLI system in which fallen sunlight will be utilised by the panel and wind energy by turbine in which utilized renewable energy given as source to the multilevel inverter to convert the DC input voltage into AC ouput voltage waveform.

V. SIMULATION WORK

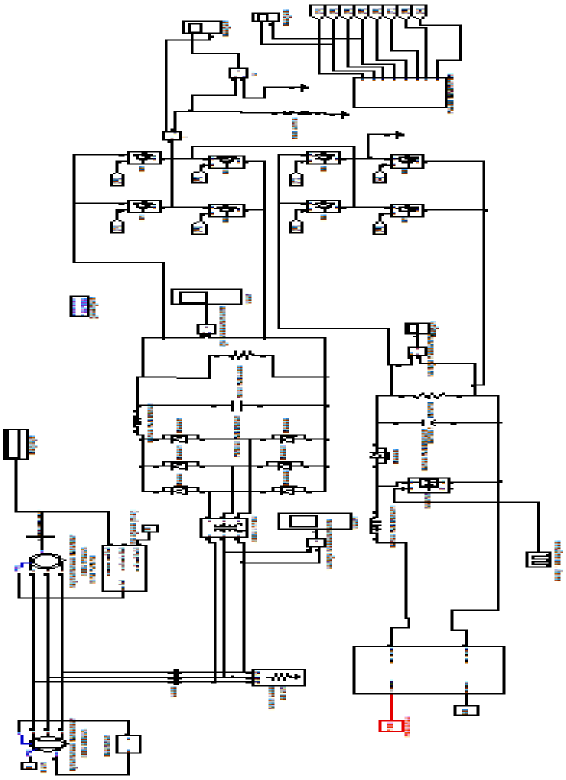


Fig 4. Simulation Diagram

5.1 Design of Solar Cell

Solar cells produce current when sunlight irradiate on them. In this paper the solar cell is simulated for any ambient temperature, sun light intensity and other internal parameters. An equivalent circuit is developed for easy analysis of solar cell [4]. The PV cell is a electrical device, which produces electrical power when exposed to sunlight and they are connected to boost converter. In proposed model the current is considered as constant, and the voltage changes based on the irradiation level. So the equivalent model contains a constant current source. The equivalent model is shown in Fig 5.

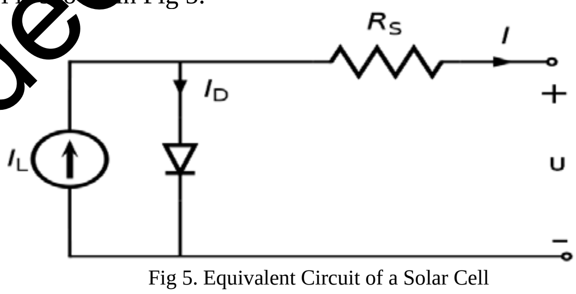


Fig 5. Equivalent Circuit of a Solar Cell

From the equivalent circuit, the current produced by the solar cell is given by,

$$I = I_L - I_D \qquad (6)$$

Where,

I = Output current (Amperes)
I_L = Photo generated current (Amperes)
I_D = Diode current (Amperes)

Light generated current I_L is calculated by

$$I_L = \frac{\phi}{\phi_{ref}}\left[I_{L,ref} + \mu_{I,SC}\left(T_c - T_{c,ref}\right)\right] \qquad (7)$$

where,

ϕ = Irradiance (W/m^2)

ϕ_{ref} = reference irradiance (1000W/m^2)

$I_{L,ref}$ = reference condition of photo current

T_c = PV cell temperature

$T_{c,ref}$ = Reference temperature

$\mu_{I,SC}$ = short circuit current of Temperature coefficient (A/□C)

By the Shockley equation of diode, the current passed through the diode is,

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{nkT/q}\right) - 1\right] \qquad (8)$$

where,

I_0 = Reverse saturation current (Amperes)
n = Diode ideality factor (1 for an ideal diode)
q = Elementary charge
k = Boltzmann's constant
T = Absolute temperature

Saturation Current I_o is given by

$$I_o = I_{o,ref}\left(\frac{T_{c,ref}+273}{T_c+273}\right)^3 \exp\left[\frac{e_{gap}N_s}{q\alpha_{ref}}\left(1-\frac{T_{c,ref}+273}{T_c+273}\right)\right] \qquad (9)$$

where,

$I_{o,ref}$ = The reference condition of saturation current (A)

e_{gap} = band gap of the material (1.17eV for Si)

N_s = number of cells in series of the PV module

q = charge of the electron

5.2. Design of Wind Turbine

A wind turbine is used to convert the linear motion of the wind into rotational energy that can be used to rotate a generator. Wind turbines utilize the power from the wind by means of blades and convert it into rotating mechanical power. These turbines require an average wind speed of about 2.5 m/s to 30 m/s velocity to generate power. The rotor, which converts the wind's energy to kinetic energy of rotation, is a unique and critical part of a wind turbine [5,9]. The rotor is used to control the amount of energy extracted from the wind stream. Turbines cannot operate at wind speeds above 25 m/s because the generators could overheat. In this proposed system single phase Induction Generator (IG) is used to extract power from wind. Single phase IG are not self starting one. A better solution for this problem is connecting an external capacitor, phase difference occurs in between stator inductance and the external capacitor. So by rotating the machine above rated speed, we can run the machine as a generator.

The theoretical available power from the wind is defined by the following equations,

$$P_{Tot} = \frac{1}{2g}\rho A V^3 \qquad (10)$$

g is the conversion factor
ρ is the air density in kg/m3,
s is the surface swept in meter,
υ is the speed of the wind in meter per second

R is the windmill radius in meter,
P is the total power available from wind in watts

VI. CHARACTERISTICS OF PV CELLS

a) Characteristics of PV cell at Constant Temperature

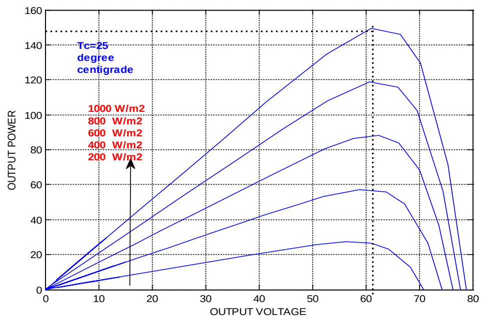


Fig.6. Power and Voltage Waveform at Constant Temperature for PV cells

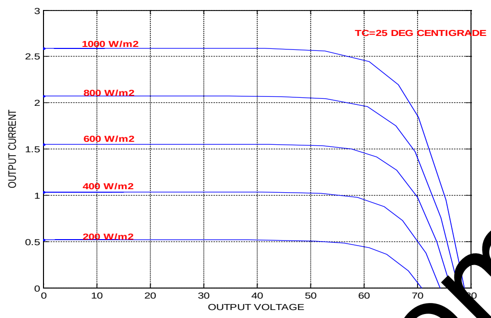


Fig.7. Power and Voltage Waveform at Constant irradiance For PV cell

b) Characteristics of PV Cells for Constant Irradiance

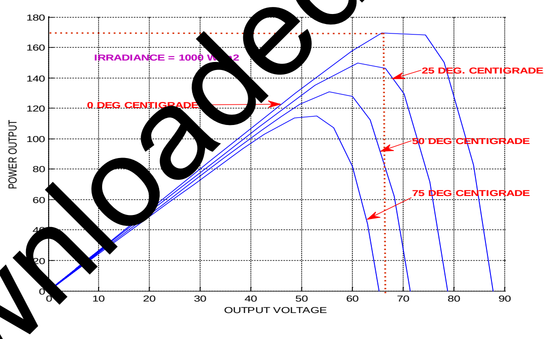


Fig.8. Power and Voltage Waveform at Constant Irradiance For PV cell

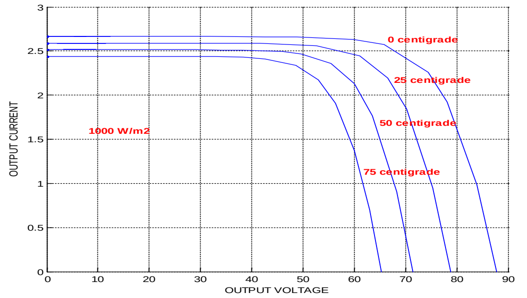


Fig.9. Current and Voltage Waveform at Constant Irradiance
For PV cell

From the above characteristics (Fig.6, Fig.7, Fig.8, Fig.9) curves the power generation continuously varies along with two main factors, which are known as cell temperature and irradiance. In this work module computation PPT technique is used for finding the maximum output at various instant of time.

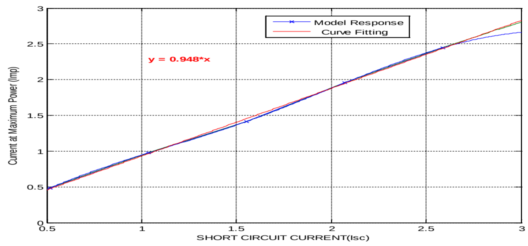


Fig.10. Current based MPPT control

Table 2. Switch Comparison for Nine Level Inverter

Type of MLI	Diode	Capacitor	Switches Required
Diode Clamp	56	8	16
Flying capacitor	-	36	16
Cascaded H-bridge	-	-	16
Proposed	-	-	8

VIII. COMPARISION OF PROPOSED WITH SOLAR-WIND SOURCE AND SEPARATE DC SOURCE

Table 3.Level Description

	Cascaded MLI with Separate DC Source	**Proposed System with solar-wind source**
No of levels S=No of stages S=2	$2^{s+1}-1$ 7 level	3^s 9 level
Input DC Voltage	V dc 1vdc	1Vdc 3Vdc

The efficiency of the proposed system is higher than a conventional inverter for applications where switching losses are high. Reduced numbers of switches were used in the proposed solar-wind based MLI. It is an attractive solution to get large number of levels together with a better efficiency.

IX. SIMULATION RESULT

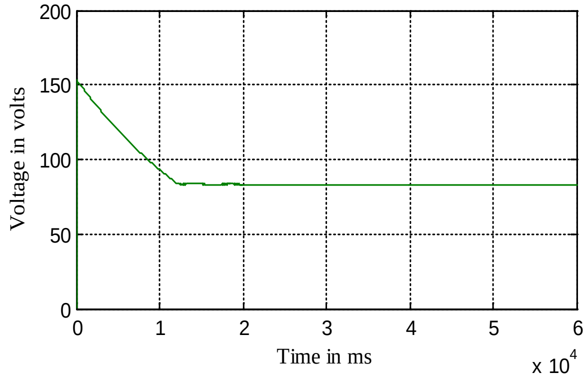


Fig 11. Simulated Voltage Output of Wind Energy System after rectification at 10 m/s

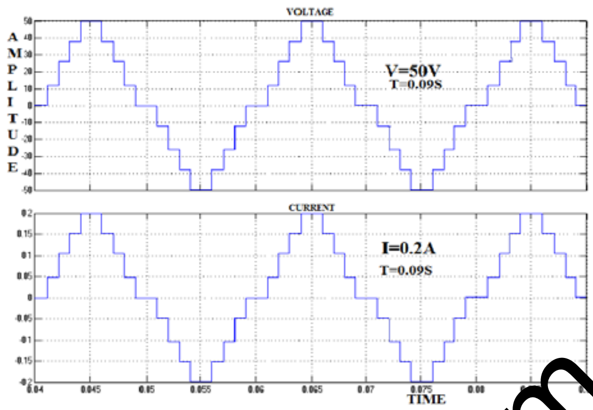


Fig.12. Output Voltage and Current Waveform of MLI

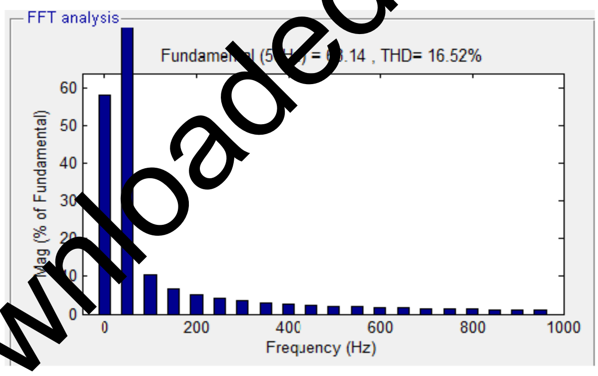


Fig. 13. FFT spectrum Output of Solar-wind based MLI

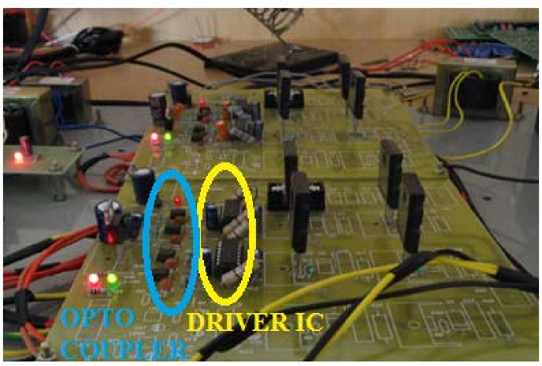
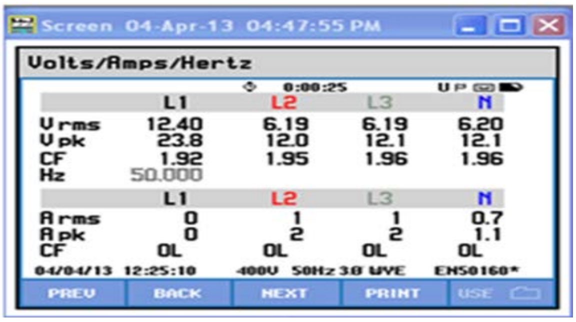
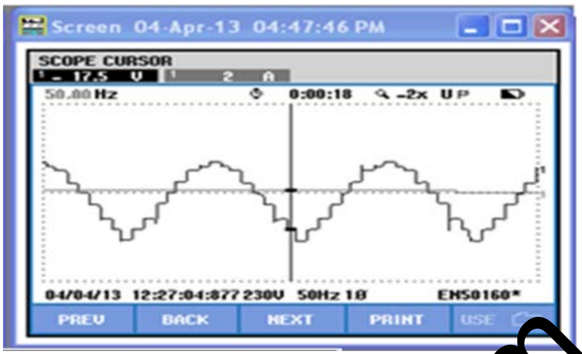


Fig14. Experimental Setup of MLI



(a)



(b)

Fig 15. Power Quality Analyzer Outputs of Hardware

X. RESULT ANALYSIS

It is fact that harmonic components in load current closely affect the performance of the existing inverter. To have best performance harmonic components are tried to be reduced and load current is brought to produce good sinusoidal form. To analyze the harmonic performance of the two techniques for purpose of comparison, several harmonic measures are possible. The (THD) is one of these measures, which evaluates the quantity of harmonic contents in the output waveform and is a popular performance index for power inverters.MLI with solar-wind source results were shown graphically in fig.(6-13) respectively. The experimental results where hardware circuit setup and Fluke meter outputs were shown in fig 14,fig 15.The percentage of harmonics obtained in the proposed system is 16.52%. Harmonic analysis shows that proposed system gives high efficiency.

CONCLUSION

Asymmetrical multilevel inverter hybrid switching topology has been proposed in our work. The most important thing of the proposed system is being convenient for expanding and increasing the number of output levels simply with less number of switches. This method results in the reduction of the number of switches, losses and cost of the converter. If we presented hybrid switching, the multilevel inverter generates near-sinusoidal output voltage and as a result, very has low harmonic content.

The switching losses of the HMLI are less than the conventional inverter. Consequently the system efficiency would be improved by utilizing HMI.In the proposed nine level inverter with solar-wind energy as source is used to get sinusoidal stepped output waveform and also increase the efficiency of the inverter. The nine level inverter has been illustrated in simulation results by using MATLAB. MLI is to obtain high efficiency. The technique is used to improve the level of inverter by reducing harmonics.

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