International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 07, July 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Mathematical Modeling of High DC-DC Augment Converter Based Solar/Wind/Battery Hybrid System with a Single Phase Fifteen Level Inverter

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ABSTRACT

The main problem today is the shortage of energy, which is mainly due to population, economy growth and environmental pollution caused by use of non renewable energy sources. These problems can be avoided by employing renewable energy sources to meet ultra clean energy demand. Among the non conventional energy resources, solar & wind energy sources are most preferred by the public due to abundant, ultra clean energy and ease of accessibility. This paper describes high DC-DC augment converter to produce high gain for low voltage solar and wind renewable energy systems. Bi-directional boost and buck converter based storage system has been designed to give continuous supply to load while in the case of PV cell or wind energy is absent. DC output voltage of combined solar PV, wind and battery is converted to AC voltage by a single phase an asymmetric cascaded full bridgeless fifteen level inverter. The usage of single phase cascaded fifteen level inverter eliminates the full bridge inverter module by proper sequence of dc input sources. Similarly it reduces switching losses and total harmonics distortion by using minimum number of switches. In this proposed paper has mathematical modeling of all sub systems of hybrid energy system. *Keywords: Photovoltaic System, Wind Energy System, High DC-DC Augment Converter, Bi-directional Buck and Boost Converter, Cascaded Fifteen Level Inverter*

I. INTRODUCTION

In recent day's power generation from renewable energy resources are profiting more attraction, because of its reliable, plentiful and high potentially be very cheap. Renewable energy generates only minute levels of carbon emission because of no need of the exploration, mining and drilling process for to power generation. Solar and wind energy are most promising power generation tool for meet ultra clean energy demand [1].

The output of PV panel is not giving continuous constant output voltage due to consequences variations of environment condition (temperature and irradiation of solar panel). MPPT techniques are implemented to get constant maximum power from PV array, in which matching point between PV module and high boost converter. Different type of MPPT algorithms are there for tracking maximum power from PV systems. Using of high DC-DC augment converter, the peak voltage is extracted from PV panel by implementation of MPPT algorithm. By use of PI controller match MPP voltage, this voltage control the duty cycle of high DC-DC boost converter to get maximum constant voltage from PV cell.

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ISSN (O) 2319 - 8354
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Wind energy is the fastest growing and most hopeful renewable energy source. In this paper, low RPM permanent magnet brushless generator is used to operate at the speed range below 25 RPM. Suitably developed low speed PMSG directly coupled with multi-blade vertical axis wind turbine. Therefore the wind power system can be simplified by eliminating the gear box and by using low speed generator. The rotor of VAWT rotates at the same speed as the rotor of the turbine. The hypothesis in this work is that the typical generator-gear solution in the wind power plant can be replaced by a low rpm Permanent Magnet Synchronous Generator with reduced cost. However It has the power quality issues because of the output voltage incessantly varied due to variation of incoming wind speed. Using of Controller and wind sensor to protect the wind power system and produces constant output voltage.

The proposed wind and solar hybrid system, the renewable energy can be extracted from low wind prone areas. A low rpm Permanent Magnet Brushless Generator is connected as a generating portion for VAWT suitably designed to operate at low wind speed regions. When the sun raises the density of air gets reduced and the power in air also gets reduced where we can use solar power. Therefore Vertical Axis Wind Turbine and Solar PV Panels can complement each other to give better results. Basic requirement for the above system is the Low RPM generator which should run at a speed less than 100 rpm.

For high power application, the augment DC-DC converter boost the low level input voltage range (12V- 100V) to 450V. Bi-directional boost and buck converter based storage system has been designed to give constant supply to load while in the case of wind energy or PV cell is not working properly.

The multilevel inverter works a major interfacing role in between DC input to AC load. Multilevel inverters are classified in to three types. These are (a) Flying capacitor multilevel inverter (b) Diode clamped multilevel inverter (c) Cascaded H-bridge multilevel inverter. For high voltage application, the flying capacitor multilevel inverter needs more storage capacitors. They are high cost and total circuit is complex. Similarly diode clamped multilevel inverter requires more clamping diodes for high power applications. In this case control of real power flow is complex. So theses two types of multilevel inverters have some disadvantages. The cascaded H bridge multilevel inverter generates stepped AC voltage by proper sequence of DC input source. It requires number of full bridge inverter but no need to require capacitors and diodes for high power applications. The main drawback of cascaded multilevel inverter is use of number of switches is high due to presents of full bridge inverter.

This paper proposes high dc-dc augment converter based solar/wind/battery hybrid system with a single phase an asymmetric cascaded full bridgeless fifteen level inverter. An asymmetrical cascaded fifteen level inverter is produces required stepped output voltage by proper arrangement of DC input source and proper sequence of switches by without uses of full bridge inverter. It has some advantages. They are less THD, low distortion, less EMI effect, less dv/dt across all switch and its can operate at wide range of switching frequencies from standard frequencies.

II. PROPOSED HYBRID SYSTEM

The proposed block diagram consists of PV panel, wind turbine, storage system, augment dc-dc converter, bidirectional dc-dc boost converter and multilevel inverter is shown in fig 1. PV panel consists of no of modules and wind turbine consists of permanent magnet brushless generator for to generation of power to meet energy

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

demand. Fig.2 shows that sub block diagram of complete end-end model of wind turbine. In which consists of blade models, permanent magnet generator and rectifier. Output voltage of PV, wind and battery is given to fifteen levels cascaded inverter through DC-DC augment converter. MPPT algorithm is used in PV array for to get maximum power to tackle energy demand. The switching pulse is generated from MPPT algorithm, which is given to high augment boost converter. Switching pulse generated from MPPT algorithm is depends on energy demand. DC voltage is converted in to pure stepped AC voltage by cascaded multilevel inverter is given to load.

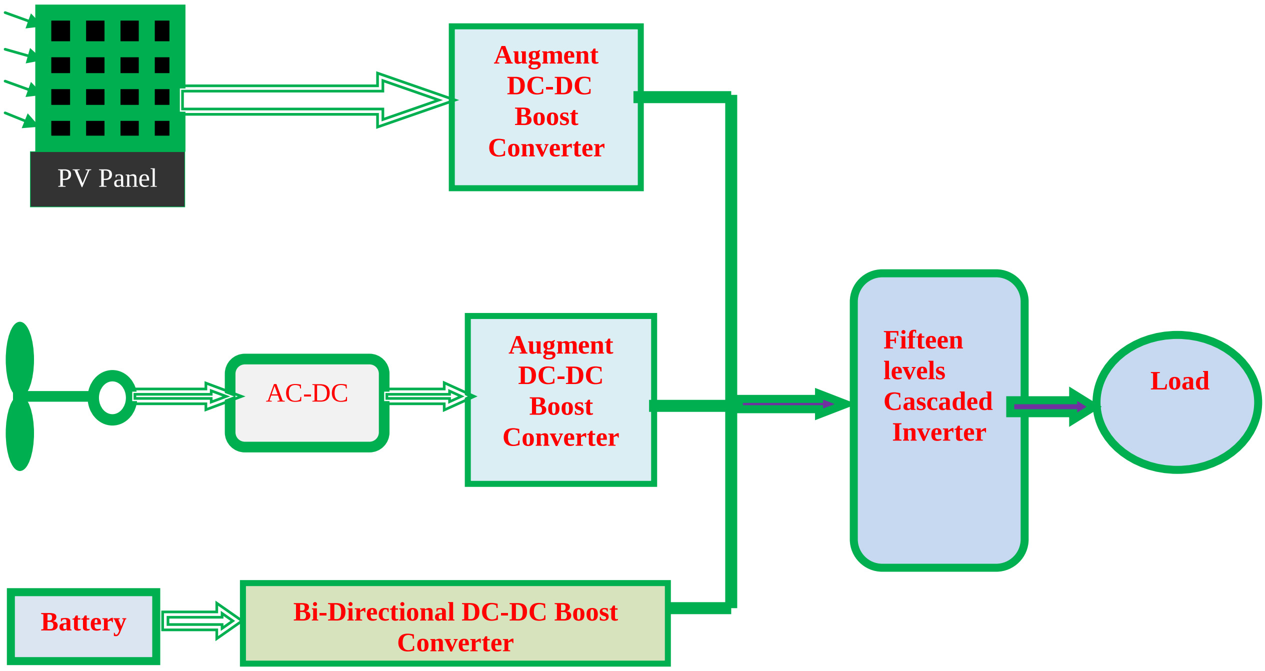

Fig.1 Block Diagram of Proposed Hybrid Energy System

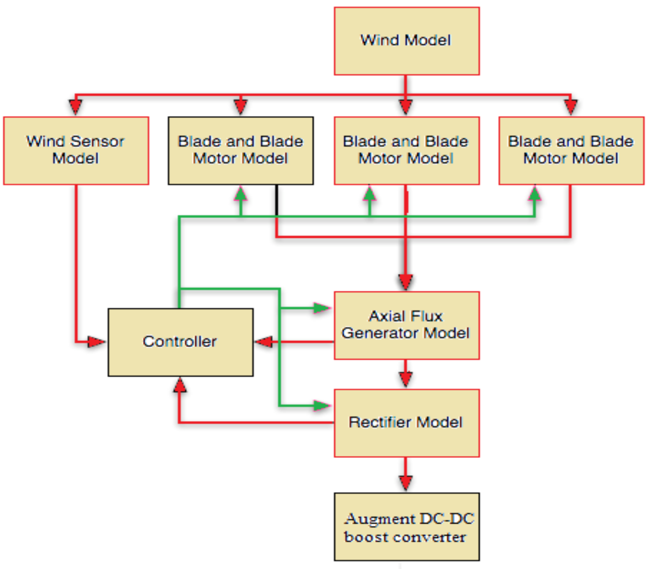

Fig.2 Sub Block Diagram of Vertical Axis Wind Turbine

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III. MODELLING OF HYBRID ENERGY SYSTEM

This session has mathematical model of solar, wind energy resources and power electronics converters for the purpose of buck, boost and conversion in the proposed hybrid renewable energy system.

A. PV System Modelling

Solar cell is modeled by use of a current source, parallel diode, shunt resistance and series resistance. The maximum power point tracking is operated, which is depends on variation of sunlight and load.

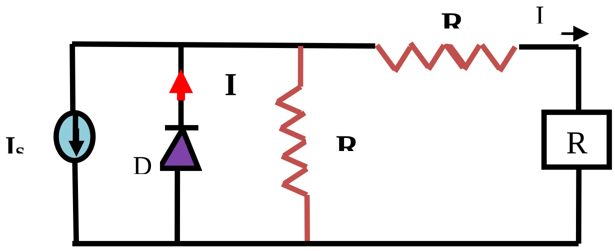

Fig. 3 Equivalent Circuit of a Photovoltaic Cell

Solar cell circuit consists of a current –source supplying current I_{sc}, R_{sh} and R_s are the internal shunt and series resistance respectively. I_J is the current at the p-n junction. Ish is the current through the shunt resistance. I is the current passing through a load of resistance R_L and having a voltage drop of V across it. Based on this circuit, the load current (I), at fixed values of the temperature, radiation and the related voltage (V) by the expression.

$$I = I_{SC} - I_O\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \quad (1)$$

I_0 represents the current that flows from the p side to the n side in the dark under the condition of an open circuit, I=0 and V=VOC. I_0 = Dark current (A), e = Charge of an electron=1.602×10-19 J/V,

k- Boltzmann constant= 1.381×10-23 J/K, T=absolute temperature (K)

I_{SC}= short circuit current (A).

$$0 = I_{SC} - I_0\left[\exp\left(\frac{eV_{OC}}{kT}\right) - 1\right] \quad (2)$$

$$V_{OC} = \frac{kT}{e}\ln\left(\frac{I_{SC}}{I_0 + I}\right) \quad (3)$$

The power from the photovoltaic cell is given by

$$P = VI \quad (4)$$

$$P = \left[I_{SC} - I_O\left\{\exp\left(\frac{eV}{kT}\right) - 1\right\}\right]V \quad (5)$$

In order to find the location of the maximum power, differentiate the equation (A.5) with respect to V and equal it to zero.

$$\left(1 + \frac{eV_m}{kT}\right)\exp\left(\frac{eV_m}{kT}\right) = 1 + \frac{I_{SC}}{I_O} \quad (6)$$

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ISSN (O) 2319 - 8354
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Where V_m= voltage at which the power is maximum. Equation (6) is an implicit equation for V_m and the value of V_m has to be found out by trial-and error. The load current I_m corresponding to maximum power can be determined by (6) in (3).

$$I_m = \frac{\frac{eV_m}{kT}}{1 + \frac{eV_m}{kT}} \left(I_{SC} + I_O \right) \tag{7}$$

$$P_m = \left(\frac{\frac{eV^2{}_M}{kT}}{1 + \frac{eV_m}{kT}} \right) \left(I_{SC} + I_O \right) \tag{8}$$

Power generated by PV is depends on changing atmospheric conditions. The maximum conversion efficiency of a solar cell is given by the ratio of maximum useful power to the incident solar radiation.

$$\text{Maximum Efficiency} = \frac{I_m V_m}{I_T A} = \frac{FF(I_{SC})V_{OC}}{I_T A} \tag{9}$$

Here I_T-incident solar flux, A- Area of the cell. For an efficiency solar cell have high value of open circuit voltage, short circuit current and fill factor.

B. Wind Turbine Modelling

This section consists of mathematical modeling of wind energy system. In which the rated capacity P_R generated at the rated wind velocity v_R. Here ϕ_v is the probability per wind velocity interval, in that the wind velocity will be in the interval v to (v+dv). E is the energy produced by the wind turbine in the period T. E_v is the energy extracted per interval of wind velocity, when wind velocity v.

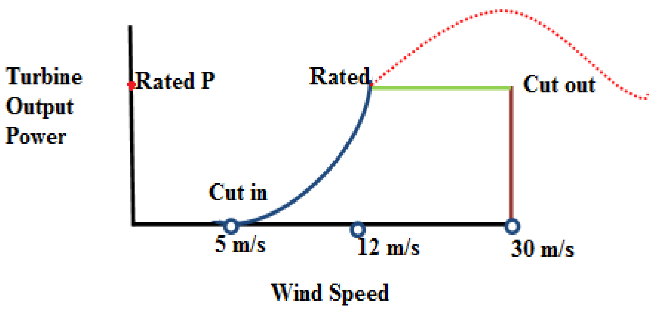

Fig.4 Wind Turbine Operating Region and Power Performance

Standard characteristics for while blade pitch control

Actual operating characteristics of stall regulation machine

$$E = \int_{V=0}^{\infty} E_v dv = \int_{v=0}^{\infty} (\phi_v T) P_{T,v} dv = \int_{v=0}^{\infty} A_1 \left[\frac{1}{2} \rho v_0^{\ 3} C_P (\phi v T) \right] dv \tag{10}$$

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

A_1 is the swept area of the wind turbine and v is the ambient wind velocity. The average power extracted, if the air density is considered constant is

$$\frac{E}{T} = \overline{P_T} = \frac{\rho A_1}{2} \int_{v=0}^{\infty} \phi_v v^3 C_P dv \qquad (11)$$

The capacity factor is the annual average power generated as a proportion of the turbine rated power. The wind capacity factor is

$$\left(\frac{\rho A_1}{2}\right) \int_{v=0}^{\infty} \left[\frac{(\phi v v^3 C_P dv)}{\left(\left(\frac{C_P \rho A_1}{2}\right) v^3{}_R\right)} \right] \qquad (12)$$

This summation cannot be evaluated until the dependence of C_P
On the upstream wind velocity $v=v_0$ is established.
v_0 less than cut in velocity v_{ci}

$$E_v = 0 \text{ for } v_0 < v_{ci} \qquad (13)$$

V_0 greater than rated velocity v_R, but less than cut-out v_{co}

$$E_v = \phi_{v \geq v_R} P_R T \qquad (14)$$

V_0 greater than cut-out speed v_{c0}

$$E_v = 0 \text{ for } v_0 > v_{c0} \qquad (15)$$

V between v_{ci} and v_R

The turbine power output P_T increases with v in a way that depends on the operating conditions and type of machine.

$$P_T \approx a v_0{}^3 b P_R \qquad (16)$$

a and b are constants.
At cut-in speed, $P_T=0$

$$v_{Ci}^3 = \frac{bP_R}{a} \qquad (17)$$

At rated power $P_T=P_R$

$$v_R^3 = (1+b) P_R / a \qquad (18)$$

$$\left(\frac{v_{Ci}}{v_R}\right)^3 = \frac{b}{(1+b)} \qquad (19)$$

a and b can be determined interms cutin speed(V_{ci}), rated speed(V_R) and rated power (P_R)..

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C. Augment Dc-Dc Boost Converter

The augment dc-dc boost converter uses V_{in} dc input voltage, Main switch, Coupled inductor N_P and N_S, Clamp diode D_1, Clamp capacitor C_1, Two capacitors C_2 and C_3 and Two diode D_O and Output capacitor C_O. Coupled inductor includes magnetizing inductor L_M leakage inductor L_K and an ideal transformer.

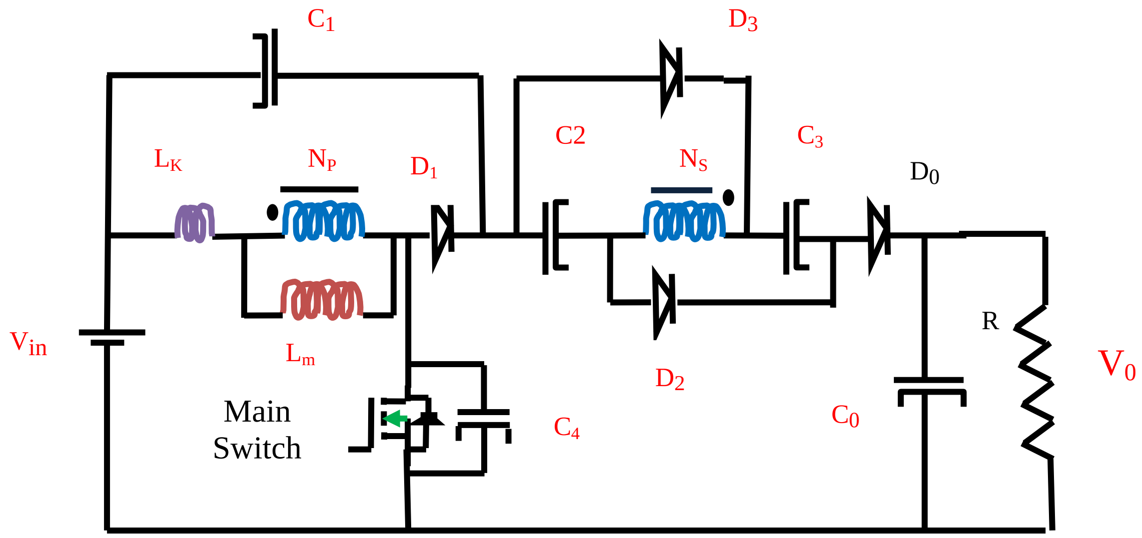

Fig.5 Augment DC-DC Boost Converter

For analysis of the circuit, the following conditions are assumed. Capacitors C_1, C_2, C_3, C_4 and C_0 are large sufficient. Thus V_{C1},V_{C2},V_{C3}, V_{C4} and V_0 are considered as constants in one switching period, Power devices are ideal, but the parasitic capacitor of the power switch is considered and The coupling co-efficient of the coupled inductor K is equal to Lm / (L_m+L_k), and the turn ratio of the coupled inductor n is equal N_s/N_p.

The augment dc-dc converter operating in continuous condition mode (CCM) and discontinuous conduction mode (DCM) is analyzed.

D. Continuous conduction mode

Voltage gain is

$$M_{CCM} = \frac{V_0}{V_{in}} = \frac{1+nk}{1-D} + \frac{D}{1-D}\left(\frac{(K-1)+n(1+K)}{2}\right) \quad (20)$$

Voltage gain for ideal transformer k=1

$$M_{CCM} = \frac{1+n+nD}{1-D} \quad (21)$$

$$D_{C1} = \frac{2(1-D)}{n+1} \quad (22)$$

D_{C1} is the energy released duty cycle.

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E. Discontinuous conduction mode

$$M_{DCM} = \frac{V_0}{V_{in}} = \frac{1+n}{2} + \sqrt{\left(\frac{(1+n)^2}{4} + \frac{D^2}{2\tau L_m}\right)} \tag{23}$$

Table 1 Parameters of Augment DC-DC Converter

Input dc voltage (V_{in})	12V-100V
Output dc voltage(V_0)	450V
Maximum output power	200W
Switching Frequency	50HZ

F. Bi-Directional DC-DC Boost Converter

Bidirectional dc-dc converter is shown in figure 6. DC link voltage is maintained as constant by bi-directional dc-dc converter. S1 and S2 switches are kept on, when it is charging and it works as boost converter. When discharging conditions, S3 is kept on.

The converter consists of a coupled inductor with same winding turns in the primary and secondary sides. In boost mode, the secondary and primary windings of the coupled inductor are operated in parallel charge and series discharge to obtain high step-up voltage gain. In step-down mode, the primary and secondary windings of the coupled inductor are operated in series charge and parallel discharge to achieve step-down voltage gain. Thus, the converter has higher step-up and step-down voltage gains than the conventional bi-directional dc-dc boost buck converter. The average value of the switch current in the bi-directional converter is less than the conventional bi-directional boost buck converter.

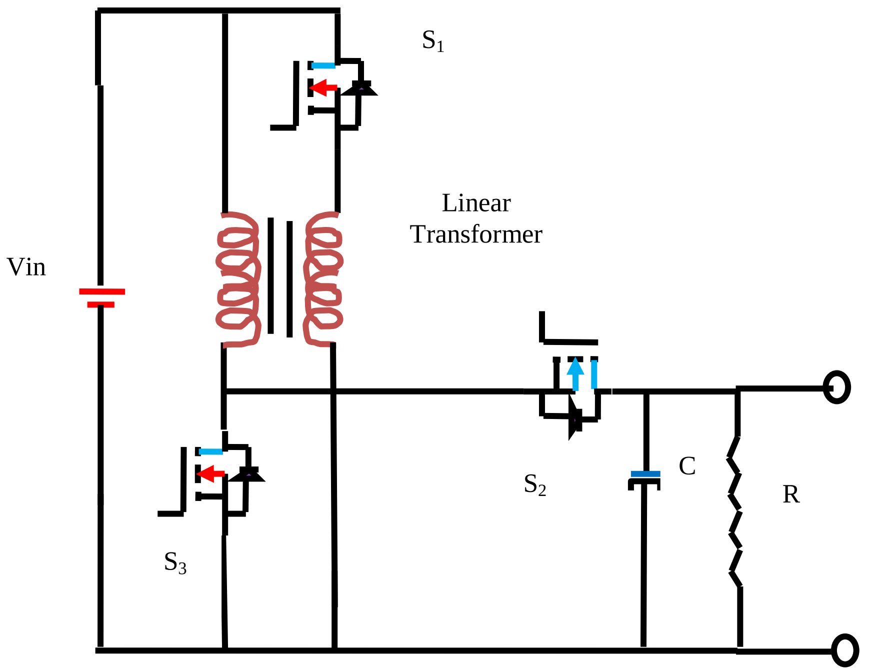

Fig.6 Circuit Diagram of Bi-directional Buck and Boost converter

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ISSN (O) 2319 - 8354
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G. Fifteen Level Inverter

A new cascaded multilevel inverter is modeled without using of full bridge inverter modules. In proposed system eliminates the full bridge inverter by arranging the input dc sources in a proper sequence. This type of inverter no needs to require any additional Diodes and Capacitors.

The input voltage arrangement of the proposed multilevel inverter for the second voltage pattern is shown in Fig. 7. In this pattern, voltage (V_4) is alone connected in the reverse direction. Hence it should be considered as a negative voltage. For the 15 level output, with 10V step the peak to peak at voltage is varied from +420V to -420V. So the voltage magnitudes are taken as V_1=60V, V_2=120V, V_3=240V, V_4=480V.

The switching state of the proposed 15 level inverter is given in Table 2. It provides the working states for each step.

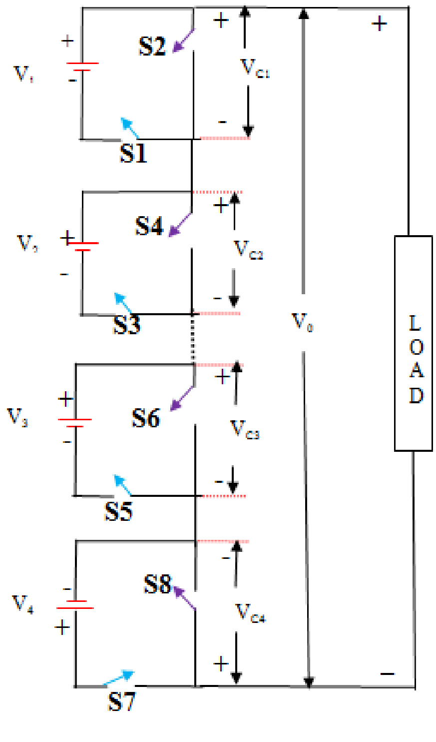

Figure 7 Structure of the Proposed 15 Level Inverter

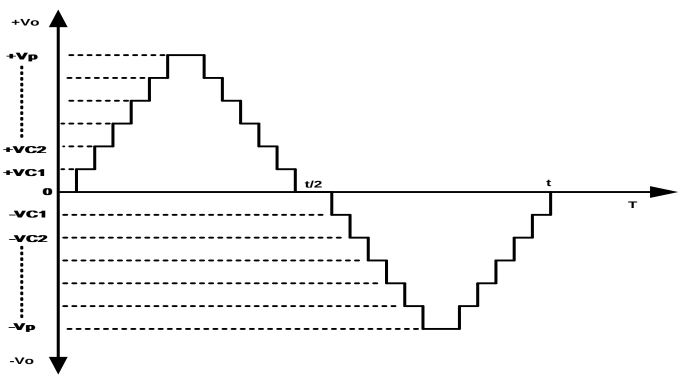

Figure 8 Generalized Output Voltage of Multilevel Inverter

Table 2 Switching States of the Proposed 15 Level Inverter

V_o	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
60	1	0	0	1	0	1	0	1
120	0	1	1	0	0	1	0	1
180	1	0	1	0	0	1	0	1
240	0	1	0	1	1	0	0	1
300	1	0	0	1	1	0	0	1
360	0	1	1	0	1	0	0	1
420	1	0	1	0	1	0	0	1
-420	1	0	0	1	0	1	1	0
-360	0	1	1	0	0	1	1	0
-300	1	0	1	0	0	1	1	0
-240	0	1	0	1	1	0	1	0
-180	1	0	0	1	1	0	1	0
-120	0	1	1	0	1	0	1	0
-60	1	0	1	0	1	0	1	0

IV.CONCLUSION

This paper has been described high DC-DC augment converter based solar/ wind/ battery hybrid energy system with single phase an asymmetric cascaded full bridgeless fifteen level inverter under stand-alone mode. In the stand-alone mode the performance of the system is evaluated for low rpm permanent Generator for VAWT as well as PV panel. Bi-directional boost and buck based Battery system is used to maintain the balance between the source and load. Single phase an asymmetric cascaded full bridgeless fifteen level inverter has been implemented for reduce switching losses and total harmonics distortion in output side. The performance of the developed system is evaluated in mathematical platform. This project will support to harness renewable energy and will play a role in securing a sustainable and de-carbonized financial system with safety.

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