Design of modified Seven Level Power Converter with reduced switches for Renewable Solar Power Generation System

[1] J.Karthikeyan, [2] A.LiyasBasha, [3] N.Vinothini

[1]*PG Scholar, Department of Electrical and Electronics Engineering, AVS Engineering College, Salem, Tamilnadu*

[2]*PG Assistant Professor Department of Electrical and Electronics Engineering, Annai mathammal Sheela Engg college, namakkal*

[3]*PG Scholar, Department of Electrical and Electronics Engineering, AVS Engineering College, Salem, Tamilnadu*

Abstract

In Renewable systems, a inverter is main devices which are used for power conversion. Usually multi-level inverters are adopted for this purpose. This project deals with a Seven-Level inverter topology that follows this trend. A review of the state of the art of the Seven-Level topology and a solar power stabilization are the proposed solution of this project. The proposed inverter architecture is based on the full-bridge topology with two additional power switches and two diodes which is connected to the midpoint of the dc link. The T noraditional converter has less number of switching devices to reduce the loss and cost. Since the two added levels are obtained by the discharge of the two capacitors of the dc link, the balancing of the midpoint voltage is obtained with a specific (Plz specify which type) pulse width modulation (PWM) strategy. Simulation and experimental results has shown the effectiveness of the solution.

Keywords- Dual active clamp converter, Series resonance technology, Zero Voltage Switching, Zero Current Switching and Voltage Stress.

I. INTRODUCTION

The DC-DC converter with high power density, high efficiency and reduced voltage stress is needed for the applications such as plasma display panels, photo voltaic solar systems and fuel cells. For high power density and small size the switching frequency will be increased which affects turn on and turn off losses. These losses will limit the operation at high frequencies. By resonant converters the losses can be minimized in comparative with PWM converters, the resonant converters suffer with large component voltage stress due to peak current and voltages. This problem is addressed with combination of PWM converters with soft switching characteristics of resonant converters.

Phase shifted zero voltage switching full bridge converter is the best among the PWM converters with soft switching characteristics because it allows the switches to operate at zero voltage switching (ZVS) by utilising the leakage inductance

of transformer. The voltage stress and complexity will increase with full bridge converter so active clamp circuit with asymmetrical PWM controller to obtain ZVS for the switches.

The block diagram of Dual active clamped converter is shown in the Fig. 1. It consists of a DC source, inverter with active clamp technique, high frequency transformer, diode bridge rectifier, filter, pulse generator and load. A transformer is used to step up the voltage ratings along with the inverter and rectifier in a DC-DC converter.
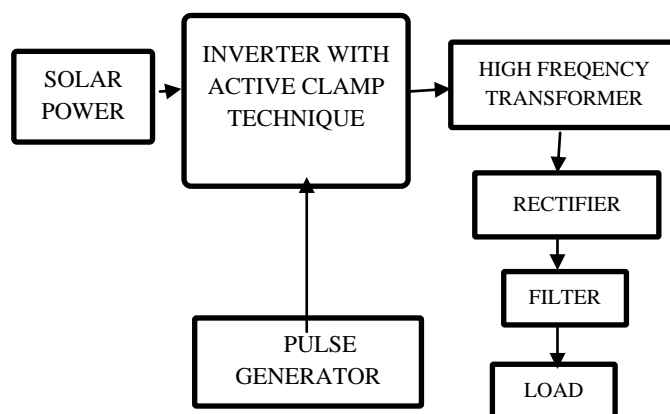

Fig. 1 Block Diagram of Dual Active Clamped DC-DC Converter

A. Solar Power

Solar electric system converts the sunlight into direct current. The movement of electrons from upper layer to the lower layer through the element is electrical current. The output voltage of the panel depends on the number of cells connected in series. The output wattage is dependent on the efficiency of the cells and the size or area of each cell in the panel.The fundamental of the PV panel is cell. The material that is present is a kind of semi conducting material The PV cell comprises of both P and N type of semiconductor. When both this P and N type are bought together and a junction is formed and the charges can flow in between them. When several cells are bought together they form the panel. These panels can be placed in series or parallel this forms the photovoltaic array. The number of series or

parallel connections depends on the application for which this is being utilised. There are different types of the photovoltaic panel and they are classified based on the structure of the silicon and they are classified as,

1. Crystalline.
2. Polycrystalline.
3. Amorphous.

The output current is a function of solar radiation, temperature, wind speed and coefficient that are particularly the cell technology. The source current is represented as IPh the diode and series resistance D, RS respectively. The series resistant represents resistance inside each cell and between the cells. The total current is termed as the difference between photocurrent and the diode current.

$$I = I_{ph} - I_p \tag{1}$$

$$I = I_{ph} - I_O \left(\frac{\exp(V + IR_S)}{mKT_c} - 1 \right) \tag{2}$$

Where,
M Idealizing factor
K Boltzmann's gas constant
T_c The absolute temperature of the cell
E Electronic charge
V Voltage imposed across the cell
I0 The dark saturation current

$$V = V_O - IR_S \tag{3}$$

Where,
V and I is the output voltage and current.
RS is the series resistance.

The characteristics of the solar cell are given by short circuit current, open circuit voltage, maximum power point and maximum efficiency. The performance of the module is determined by exposing it at known conditions.
Nominal conditions of solar cell:
Irradiation =800 w/m2
Ambient temperature =20ºC
Wind speed = 1m/s
Standard condition of solar cell:
Irradiation =1000w/m2
Cell temperature =25ºC

Since solar energy being the alternative source of energy now a days solar has many advantage with them and few are discussed their structure is static, modular, the operation of the system is quiet, they have high power density per unit weight, modular structure so plant economy is not a function of size and less maintenance is required so these advantage make them very powerful.

B. High Frequency Transformer

A transformer is a static device that transfers electrical energy from one circuit to another circuit through inductively coupled inductors and transformer coils. The physical size is dependent on the power to be transferred as well as the operating frequency. The higher the frequency smaller will be physical size. Frequencies are usually between 20 and 100 kHz. Ferrite is mainly used as the core material.

C. Filter

A PI filter is used in the system to obtain the output signal to be reduced in noise and to avoid the undesired frequencies. The utilization of the two different types of filters, the capacitance filter and the inductance filter allows the PI filter to operate more efficiently. It provides control for the circuit that requires a reduced ripples and noise free input signal. These types of filters are more commonly used in transformer circuits because they are able to filter one kind of signal from another.

D. Driver

Driver is an electrical circuit which is used to control another circuit or other components. They are usually used to regulate current flowing through a circuit or control the other factors such as prevent high voltages or rapidly changing voltages from damaging components or distorting other components.
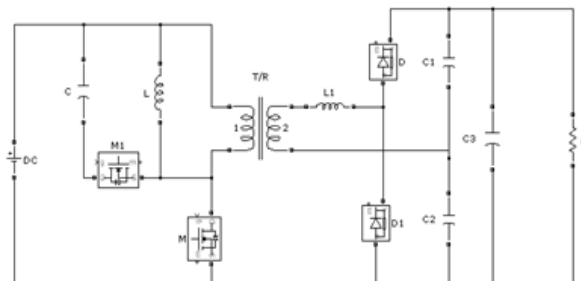
II. SERIES RESONANCE CONVERTER

Fig. 2 Conventional Series Resonance DC-DC Converter Circuit

The series-resonant circuit consists of two resonant capacitors C1, C2 and two output diodes D1, D2.The voltages vd1 and vd2 across the output diodes are clamped to the output voltage Vo.

The transformer utilization of series resonant converter is much better than that of the forward converter and the fly back converter. When the main switch S1 is turned on, the resonant secondary current is generated by a one series-resonant network composed of the leakage inductance Llk and the resonant capacitors C1, C2 flows through the output diode D1.

Series resonance circuit provide the zero current turnoff of the diodes by utilising the leakage inductance of transformer and the output diodes. The main disadvantage of the resonance converter is that the ZVS operation of the switches is not possible and the main switch and auxiliary switch will operate under hard switching. So, the dual active clamped converter is proposed to overcome the above problem.

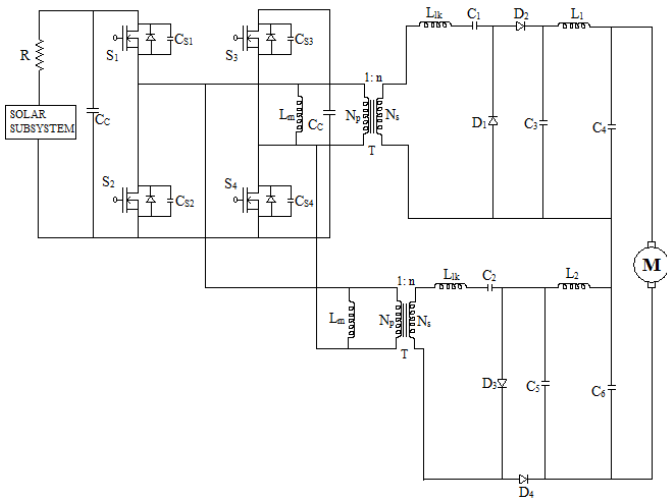## III. DUAL ACTIVE CLAMPED CONVERTER

Fig. 3 Proposed Dual Active Clamped DC-DC Converter

The proposed converter has main switches S_1 and S_4, the active clamping circuit consists of switches S_3, S_2 and clamp capacitor C_c. the parallel connected transformers have magnetising inductors L_{m1}, L_{m2} and leakage inductors L_{lk1}, L_{lk2} and the turns ratio are of $N_p : N_s$. The proposed converter has two voltage doubler rectifier circuits C_{r1}, D_{o1}, D_{o2}, C_{o1} and C_{r2}, D_{o3}, D_{o4}, C_{o2}. The DC motor is connected to voltage doubler circuit through a pi filter.

The switches S_1, S_2, S_3 and S_4 have its own parasitic capacitance and diode. The switches will operate at constant switching frequency of 20 kHz. The output voltage is the summation of both capacitors voltages.

$$V_0 = V_{c1} + V_{c2}$$
(4)
Where,
V_0 is the output voltage
V_{c1} is the voltage across capacitor
V_{c2} is the voltage across capacitor

The active clamp circuit provides Zero Voltage turn on of Switches (ZVS) by utilising the magnetising inductor and parasitic capacitor. When the voltage across the switch is higher than the input voltage the parasitic capacitance plays the role of clamping by charging and discharging to the input

voltage. When the current across the switch is negative then the free wheeling diode will conduct and safe guard the switch. This operation is called as clamping.

Series resonance is formed by utilising the energy stored in leakage inductor and resonant capacitor which makes the output diodes to be turned off at zero current condition. The series resonance circuit provides ZCS operation and reduce the voltage stress of each output diodes to half.

IV. ANALYSIS AND OPERATION OF DUAL ACTIVE CLAMPED CONVERTER

The proposed converter has six different modes of operation. The analysis and design concept for the turn on ZVS operation of switches and turn off ZCS operation of output diodes are clearly explained in this section.

The operation will be continued with a assumption that the primary current is negative and secondary current is zero.

Mode1: Before turn on the main switches the auxiliary switches have to be turned off. The negative primary current i_p discharges the capacitances Cs1, Cs4 of the main switches and charges the capacitances Cs2, Cs3 of the auxiliary switches.

Mode 2: The capacitor will reach to steady state after certain time. At that time the voltage across the main switches becomes zero. Now the switches are turned on because the voltage across the switches is zero, so as to achieve the ZVS operation. In this interval input power at primary side is transferred to the secondary side of transformer and the difference between the primary current i_p and magnetising current i_m is secondary current.

Mode 3: The secondary current i_s will start resonance by the leakage inductance and the resonance capacitors. The diodes D_{o1} and D_{o4} are turned on. The magnetising current increases linearly.

$$i_s = (C_1 + C_2) \frac{dv_{c1}}{dt}$$
(5)
Where,
i_s is the secondary current
C_1 is the capacitance of transformer1
C_2 is the capacitance of transformer2.

Mode 4: when the primary current and the magnetizing current are equal then at that instant the secondary current is zero. The primary current i_p terminates the first resonance and increases linearly. At this instant the switches S1, S4 are turned off and the diodes will get turned off when the current across

them is zero, so in this mode ZCS operation is obtained.

Mode 5: The primary current i_p charges the capacitors of main switches S1, S4 and discharges the capacitors of auxiliary switches S2 and S3. After certain time the voltage across the auxiliary switches is zero. At that time the switches S2 and S3 are turned on because ZVS operation of the auxiliary switches can be achieved.

Mode 6: After turning on the auxiliary switches, secondary current will flow through the diodes Do2 and D03 and magnetising current decreases linearly but in negative direction. In this mode input power is transferred to the output side. The resonance will be formed with leakage inductor and capacitor.

$$i_s = -(C_1 + C_2)\frac{dv_{c2}}{dt}$$
(6)

Mode 7: when the magnetising current i_m and primary current i_p is equal then the secondary current will be zero. The primary current changes its direction and it terminates the second series resonance. The diodes Do2 and Do3 will get turned off at zero current condition with which ZCS operation of the diodes will be achieved. The zero current turn off of diodes will remove the problem of reverse recovery.

V. DESIGN CONSIDERATIONS

A. Transformer Design
$E_1 = 4.44 \times N_1 \times \varphi \times f$
(7)
$50 = 4.44$
$N_p = 28$ turns.

$E_2 = 4.44 \times N_2 \times \varphi \times f$ (8)
$350 = 4.44$
$N_s = 98$ turns.
Where,
E_1 is the input voltage of transformer
E_2 is the output voltage of transformer
N_p is the primary turns
N_s is the secondary turns
f is the switching frequency
φ is the flux of transformer

Output voltage Vo = 350v
The turns ratio n = N_s /N_p (9)
           = 3.5
Input voltage V_d = 50v

$$V_o = \frac{nV_d}{1-D}$$ (10)
Duty cycle, D = 0.5

Table 1 Transformer Parameters

Parameters	Values
Nominal input voltage	50v
Nominal output voltage	350v
Magnetizing inductance	500H
Number of turns in primary	28 turns
Number of turns in secondary	98 turns

B. Resonant Circuit Design
The resonant circuit is designed by using the resonant frequency, which can be written as,

$$F_r = \frac{1}{2\pi\sqrt{LC}}$$
(11)

Let, $C_s = 6\mu F$
     $F_r = 20kHz$
$$L = \frac{1}{(2\pi)^2 f^2 C^2}$$
(12)
$L = 10.55\mu H$.

Table 2 Resonant Circuit Parameters

Resonant filter parameters	Values
Series capacitance C_s	$6\mu F$
Series inductance1 L_{s1}	$10.55\mu H$

C. Design Parameters of π Filter

$$C_1 = C_2 = \frac{1}{4\sqrt{2}L_r R_1}$$
(13)
        = 9.4μF
Where
C_1 & C_2 is the filter capacitances
r is the ripple factor
R_1 is the resistor
L is the filter inductance.

Table 3 Π Filter Parameters

Π filter parameters	Values
Filter capacitances C_1& C_2	9.4μF
filter inductance	4.45μH
Ripple content	0.02

D. Simulation Circuit Parameters

Table 4 Values for Simulation Setup

Simulation setup parameters	Ratings
Nominal input voltage	50 V
Output voltage	350 V
Switching frequency	20 KHz
Transformer turns ratio	28:98
Duty cycle	0.5

VI. OUTPUT WAVEFORMS AND RESULTS

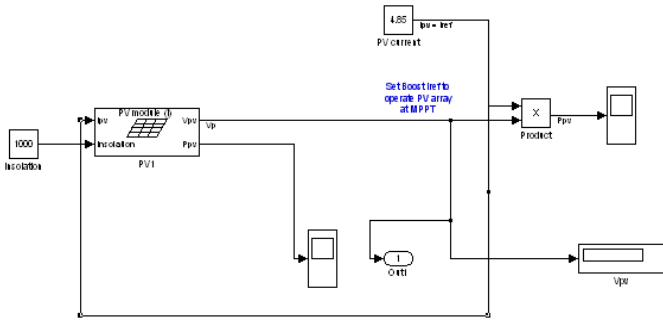The simulation circuit of solar PV panel which can generate a voltage of 50v.

Fig. 4 Simulation Circuit of Solar PV Panel

The input to the dual active clamp converter is obtained from the simulation of solar sub circuit. By choosing the short circuit current and the open circuit voltage we will get the desired output from the PV array.
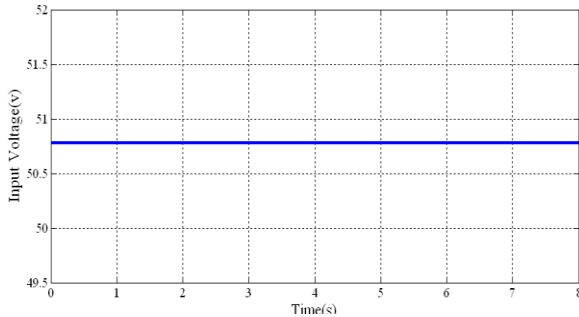

Fig. 5 Input Voltage Waveform

The ripple free DC voltage is given to the dual active clamp converter.

A. Switching Sequence

The waveform shown in fig.6 is the triggering pulses of the switches of the dual active clamped converter. According to the requirement of the output voltage the switching sequence will change with change in duty cycle. An asymmetrical PWM technique has used which will give a different phase delay for the switches S_1, S_4 and S_2, S_3
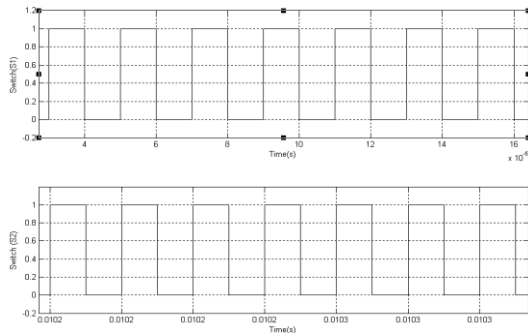

Fig. 6 Switching Sequence of the Switches

The switching sequence with a phase delay of 0^0 is applied to the switches S_1, S_4. The switching sequence with a phase delay of 30^0 is applied to the switches S_2, S_3.

B. Soft Switching Sequence

The fig. 7 below explains the soft switching operation of main switches S_1, S_4. The main switches will be turned on at zero voltage.
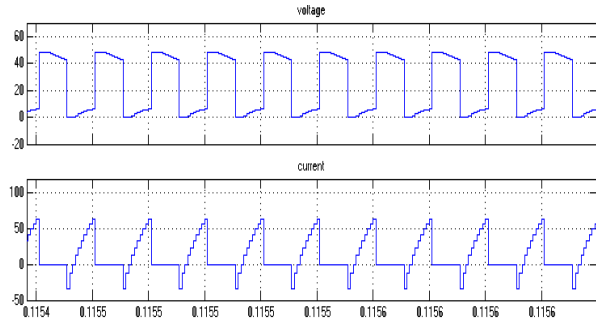

Fig. 7 Turn on at Zero Voltage

The fig. 7 clearly explains the soft switching operation of diodes and it shows that the diodes are turned off at zero current condition.
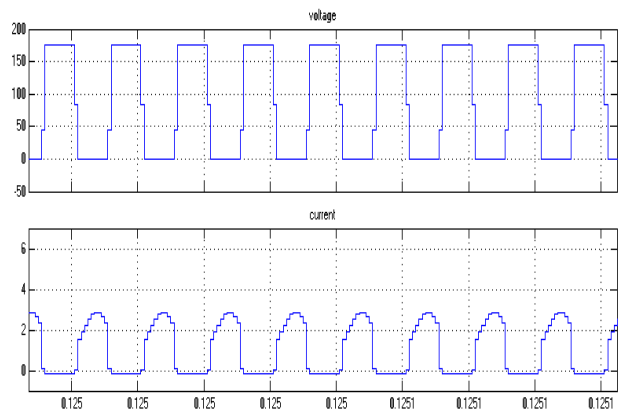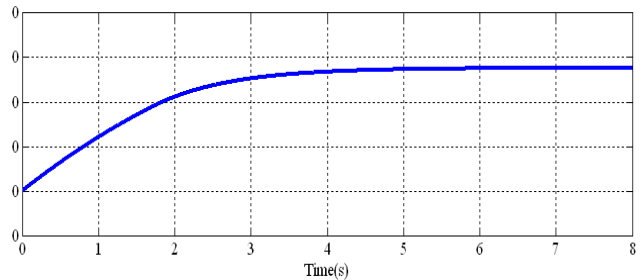

Fig. 8 Turn off at Zero Current

C. Speed and Torque of a DC motor

The output of the dual active clamped converter is applied on the DC motor. Ripple free speed and the pulsation less torque is obtained.
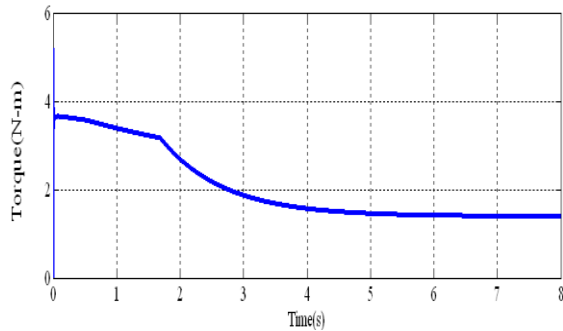
Fig. 9 Speed and Torque Characteristics of DC Motor

The above speed, torque characteristics clearly explains that the smooth operation of DC motor is possible by using pi filter in the output sides and the diodes are turned off at zero current. In the beginning the motor is under transient condition and after short time it will reach steady state operation.

VII.CONCLUSION

A dual active clamped step up DC-DC converter is proposed in this paper. The voltage stress of the semiconductor switches can be reduced by using the active clamp technique. Dual series resonant circuit will perform the soft switching operation. The voltage stress of the output diodes are clamped to the output voltage. The proposed DC-DC converter achieves an efficiency of 90% at 350w output power. Operation principle, analysis, circuit design and efficiency have been presented. The proposed converter has low switching loss and high efficiency.

REFERENCES

[1] H. Mao, J. Abu-Qahouq, S. Lou, and I. Batarseh, "Zero-voltage switching half bridge DC-DC converter with modified PWM control method" IEEE Trans. Power electron., vol. 19, no.4, pp.947-958, Jul. 2004.

[2] R.Huber and M. M. Jovanic, "Forward-fly back converter with current doubler rectifier: Analysis, Design and evaluation Results," IEEE Trans. Power electron., vol. 14, no.1, pp.184-192, Jan. 1999.

[3] C.-M. Wang, "Novel zero voltage transition PWM DC-DC converters," IEEE Trans. Power electron., vol. 53, no.1, pp.254-262, Feb. 2006.

[4] R.-J. Wai, C.-Y. Lin, R.-Y. Duan and Y.-R. Chang, "High-efficiency DC-DC converter with high voltage gain and reduced voltage stress," IEEE Trans. Power electron., vol. 54, no.1, pp.354-364, Feb. 2007.

[5] B.-R. Lin and C.-H. Tseng, "Analysis of parallel connected asymmetrical soft switching converter," IEEE Trans. Power electron., vol. 54, no.3, pp.1642-1653, Jun. 2007.

[6] G.-B. Koo, G.-W. Moon and M.-J. Youn, "Analysis and design of phase shift full bridge converterwith series connected two transformer," IEEE Trans. Power electron., vol. 19, no.2, pp.411-419, Mar. 2004.

[7] R.Redl, N.O. Sokal, and L. Balogh, "A novel soft switching full bridge dc/dc converter: Analysis, Design and evaluation Results," IEEE Trans. Power electron., vol. 6, no.3, pp.408-418, Jul. 1991.

[8] Z. Ling, R. Guo, J. Li, and A. Q. Huang, "A high efficiency PV module integrated DC/DC converter for PV energy harvest in FREEDM system," IEEE Trans. Power electron., vol. 26, no.4, pp.1146-1153, Apr. 2011.