Performance of PV based Hybrid Multilevel DVR with Wavelet Transform employing SVPWM and SPWM

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Abstract— In this paper the power quality disturbances such as voltage sag, swell is mitigated by using power electronic based device Dynamic Voltage Restorer (DVR) which is of seven level Hybrid Multilevel Inverter composed of Capacitor Clamped and Cascaded H-bridge topology. The PV acts as a source to the Hybrid Multilevel Inverter (DVR) to compensate any voltage disturbances that occur in the system .The PWM pulses to Hybrid MLI are given by Space Vector Pulse Width modulation(SVPWM) and Sinusoidal Pulse Width modulation (SPWM).The power quality events that occur in the system can be easily detected by using Wavelet Transform .Simulations are carried out in MATLAB/SIMULINK software in order to evaluate the performance of Photovoltaic -based DVR in mitigating voltage sag, swell .The Simulation results show that the proposed Multilevel Inverter is very efficient compared to conventional Multilevel Inverter and the study also shows that the Space Vector Pulse Modulation (SVPWM) is more efficient compared to Sinusoidal Pulse Width Modulation(SPWM) in reducing the Total Harmonic Distortions.

Keywords— *DVR, Sag, Swell, Harmonics, Photovoltaic array, Wavelet Transform, SVPWM, SPWM.*

I.INTRODUCTION

In the present day's modern technology, the power quality issues became major concern to both electric utilities and customers. The power quality disturbances such as voltage sag, swell, harmonics, interruption, flickers, transients etc might result in malfunction or damage to the sensitive devices. [1]. There are different custom power devices to mitigate those power quality disturbances such as Distribution Static Synchronous Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), Unified Power Flow Conditioner (UPQC) etc. Among those DVR is the most efficient and cost-effective device. Voltage sags, swells are the more frequently occurring power quality problems. [10]. voltage sag is defined as the momentary decrease in the magnitude of the nominal voltage (i.e. 10% to 90%). Voltage swells are opposite to that of the voltage sag it is defined as momentary increase in the magnitude of the nominal voltage (i.e.110% and above). The main causes for voltage swell are that sudden switching of heavy loads. DVR not only mitigates voltage sag and swell but also does harmonics compensation. The DVR is controlled and designed to perform one or more several functions. The main motive of this proposed paper is mainly focused on the design of the DVR and the control strategies with accuracy and fast operation. The PWM pulses for the DVR is generated through various control schemes such as SVPWM, SPWM. [2]. Wavelet Transform is used to detect the power quality events that taking place.

The paper is structured as follows: In section II operation of DVR is explained. In section III the design of proposed Hybrid Multilevel DVR is explained. In section IV Photo- voltaic fed DVR system model. In section V Wavelet Transform Detection. In section VI SVPWM, SPWM modulation techniques. In section VII represents results of simulations and analysis for different configurations of multilevel DVR and the output results and conclusion in Section VIII.

II.PRINCIPLE OF DVR

DVR is a static var device that has its application in variety of transmission and distribution systems. It is a series compensation device and injects the voltage in series voltage with the source voltage and protecting the sensitive devices from damage. DVR maintains the load voltage balanced by injecting the voltage in abnormal conditions. The operation of DVR is explained through fig.1.

During normal conditions the DVR doesn't inject any voltage but when abnormal conditions are taking place the DVR injects the voltage in series with the source voltage with the help of a booster transformer thus maintaining the load voltage in predetermined level.[3]. The transformer connects to the distribution systems through HV winding. The injecting transformer injects the required magnitude and Angle through suitable control techniques with the source voltage and compensate the unbalanced voltage.

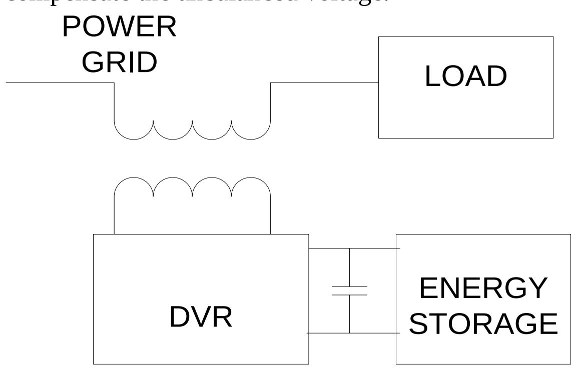

Fig.1. Configuration of DVR in distribution system.

By pass switches, relays, circuit breakers etc. are used to control the DVR. In addition to these the PWM pulses are also to be generated to the inverter and in this paper PI controller with PLL has been used as closed loop control to magnify the required magnitude and angle to inject for maintain the load voltage in predetermined levels.

III.PROPOSED HYBRID MULTILEVEL INVERTER

The proposed Hybrid Multilevel Inverter composes of Capacitor Clamped and Cascaded H-bridge topology. compared to the conventional MLI it has many advantages such as absence of filter, higher output voltage levels etc. The proposed Hybrid MLI is represented in the below fig.2.

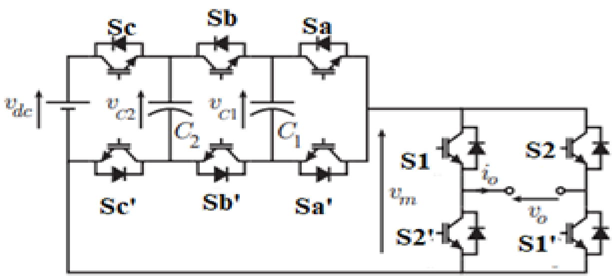

Fig .2. Hybrid Multilevel Inverter.

The converter presented in the fig.2. is composed with mixture of two popular topologies namely, flying capacitor and cascaded H-bridge multicell inverter. This multicell topology allows to double the peak to peak voltage from Vdc to 2Vdc.[4]. The multicell inverters have attractive properties such as for medium and high voltage applications and particularly no need of transformer preserving the output voltage levels. The switches of these multicell inverter are operated in complementary to each other the values for Vm are calculated by using following formula.

Vdc
……
Vm = k/Vdc ; I ≤ k<1
…….
0

In the proposed multicell Inverter the capacitor clamped multilevel inverter gives four level output including zero and the output of this inverter acts as input the cascaded H-bridge hence the output is of seven level. The levels of output obtained in the MCML are V, 2V/3, V/3, 0, -V/3, 2V/3, -V for a DC supply of V volts.

With a proper modulation, the number of levels that this new topology can reach is:

$$L = n\,(2i+1) - 1$$

Where n is the number of cells connected in series and 'i' is the number of FC sub-cells on each cell.

IV.PV BASED DVR SYSTEM

To process electrical current through PV power electronic device converters are used. In this proposed system the DC-DC converter is used. A Buck -Boost converter is used to generate the voltage to higher rate. A simplified model of PV cell is shown in the fig.3.A single diode model with a series resistance is used to generate the voltage based on the equivalent circuit with an ideal current source.

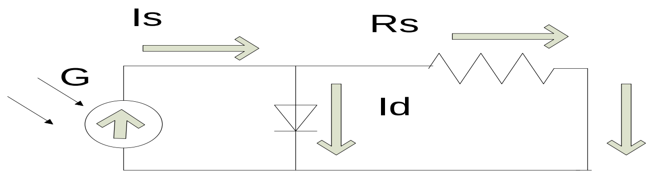

Fig.4.PV cell with single diode and series resistance

The V-I characteristics of solar cell with one diode and series resistance is given by:

$$I = Is\text{-}Io\ [e^{\frac{q(V+IRs)}{mkt}}-1]$$

Where Io is the diode reverse bias saturation current, q is the electron charge, m is the diode ideality factor, k is the Boltzmann's constant, and T is the cell temperature.

In this proposed work Maximum Power Point Tracking (MPPT) technique along with PI controller is used to track the voltage. Fractional open circuit voltage MPPT controller. The working of MPPT controller with PI controller is described in block diagram as shown in fig.5.

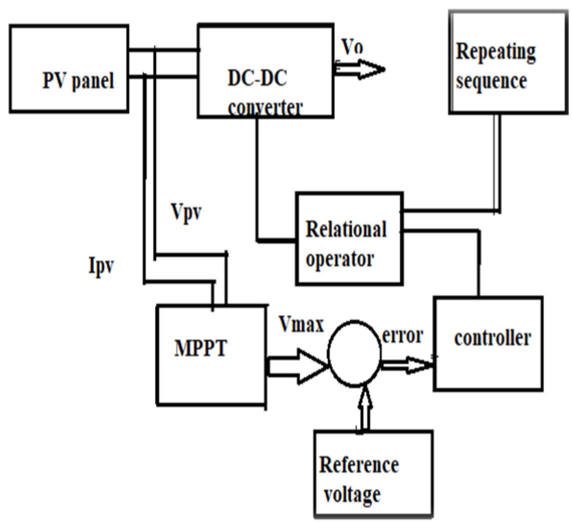

Fig.6.Block diagram of PV array with PI controller.

The open circuit voltage and short circuit current are calculated using relevant formulas from the equivalent circuit. The calculated parameters are tracked by MPPT controller which is designed using fractional open circuit voltage method. Compared to other MPPT techniques the proposed MPPT technique is efficient in terms of cost, time, memory etc. [5].

The MPPT tracked voltage is considered as actual voltage and the reference voltage is given to the PI controller. The controller takes necessary actions and generates an error signal which is given to the DC-DC converter through PWM generator through relational operators the duty ratio and switching frequency are noted and output is generated from converter is fed to the Hybrid Multilevel inverter (DVR).[6].

V.WAVELET TRANSFROM

In this proposed paper the Wavelet Transform is used for detection purpose. The fault identification is done through switch controllers. Wavelet transform is nothing but unlike Fourier transform which analyses a signal but the Fourier transform analyses only in frequency domain but not in time domain. The proposed wavelet transforms analyse the signal both in frequency - time domain.

The wavelet transforms analyse a signal in low frequency and high frequency domain when in low frequency party it has low time resolution and high frequency resolution. Whereas, in high frequency part it has high resolution time and low frequency part.

Compared to other transforms wavelet is chosen for following reasons:

i) Localization of fault both in frequency and time domain.
ii) Fast operation
iii) Each and every fine details of the signal can be separated.

First the input signal has to be decomposed using statistical analysis. It is decomposed by using Low pass and High pass filters. The signal subjected to Wavelet Transform provides two types of coefficients namely, Approximate coefficients (Ca) and Detail coefficients (Cd). There are different types of Wavelets among those Wavelets Daubechies is the most effective Discrete wavelet transform. [7].

The Discrete Wavelet transform is decomposed into detail coefficients (Cd) and approximate coefficients (Ca) is expressed by,

$$Ca(n)= \sum_{k=0}^{n} h(k-2n)Co(k)$$

$$Cd(n)= \sum_{k=0}^{n} g(k-2n)Co(k)$$

Where h(n) is the response of low pass filter and g(n) is the response of high pass filter.

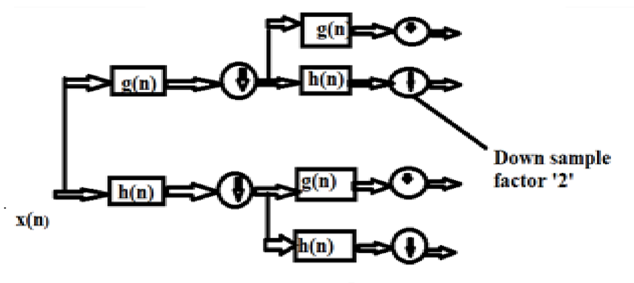

Fig.7.Wavelet Multi resolution Analysis

The wavelet decomposition is done in multiresolution analysis and the decomposition of next level depends on the previous level. The number of approximate and detail coefficients are half of the decomposed signal and hence the coefficients must be up sampled at each level to maintain the number of cycles as constant. [8].

VI.PROPOSED CONTROL STRATEGIES

In this proposed work two PWM techniques are used one is space vector modulation and other is sinusoidal pulse width modulation along with PI controller. By using PI controller, the reference signals are generated and that generated signals gives PWM pulses to the inverter.

A. Space Vector Modulation with PI controller:

The SVPWM technique is the most advanced digital PWM technique compared to the other PWM techniques because of its efficient characteristics. The SVPWM technique is very effective in reducing the Total Harmonic Distortions (THD). The three sinusoidal voltages are taken as reference from the voltage measurement from the source voltage and given to the Phase Locked Loop (PLL) the PLLgenerates or stabilises the input signal in terms of magnitude and angle and the stabilized signal is given to the PI controller the actual signal and the reference signal is compared and the signal generated from the PI controller is given to unit function to generate an error signal and that produces a sinusoidal signal that is used as reference signal to SVPWM generation .[9].

The generated reference signals such as Va, Vb, Vc are given to coordinate transformation (abc reference frame to the stationary dq frame) and treats the three reference sinusoidal voltages at constant amplitude vector rotating at constant frequency .The reference signal is generated through this transformation and is sampled with sample time (Ts).This PWM technique approximates the reference voltage (Vref) in eight switching state vectors (Vo to V7).

$$Va=Vm \sin(wt)$$
$$Vb=Vm \sin (wt-120)$$
$$Vc=Vm \sin (wt+120)$$

The SVPWM considers these three space vectors as a single vector.

$$Vs=3/2Vm[\sin(wt)-j\cos(wt)]$$

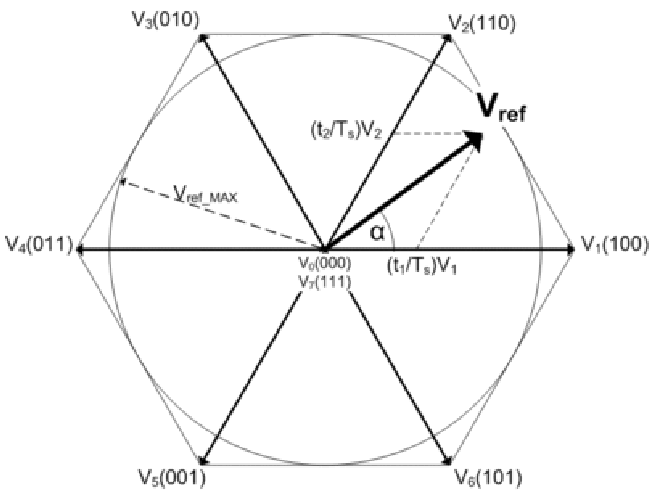

FIG.8. SVPWM switching state vectors

There are eight possible switching vectors in that six are active state vectors and two are non-active state vectors (0,0,0) ,(0,0,1),(0,1,1),(0,1,0),(1,1,0),(1,0,0,),(1,1,1).In order to generate the SVPWM technique first we have to determine the Vd, Vq ,Vref and angle (alpha).Next we have to determine the time duration T1,T2,T0 and in the final step determine the switching times of each transistor.

$$\text{Vref}=\sqrt{Vd^2+Vq^2}$$

Reference voltage is sampled at regular interval 'T'.

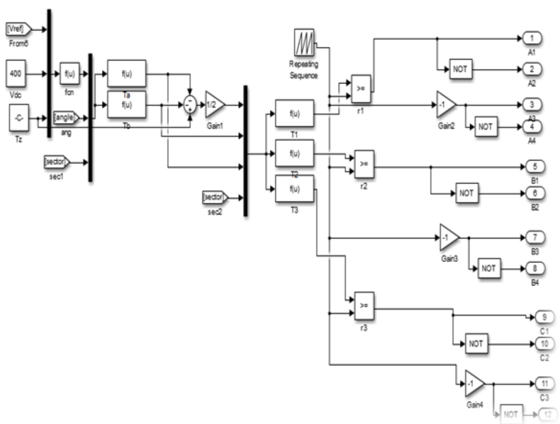

Fig.9. Simulation circuit of SVPWM generation

B. Sinusoidal pulse width modulation with PI controller:

Sinusoidal pulse width modulation is used for Hybrid Multilevel Inverter with a triangular carrier wave and with a reference wave. The only difference between two level SPWM and multilevel SPWM is that the number of carrier waves.

For 'n' level inverter the number of carrier waves required are 'n-1'.

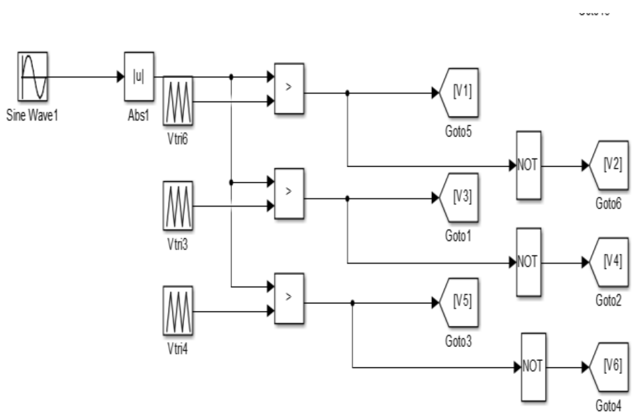

Fig.10. Simulation circuit of SPWM generation for MLI

The phase disposition method is used in which all carrier wave has same phase and angle.

VII.SIMULATION RESULTS

In this proposed Hybrid Multilevel DVR all type of faults such as both symmetrical and non-symmetrical faults are simulated with a nominal voltage of 1 p.u.and PV output power of 3500W and ripple filter inductance of 10mH and capacitance of 20 uF. The injection transformer used is linear transformer of ratio 1:2 and the proportional values of Kp is chosen as 0.9 and given as reference to the PWM generation circuit.

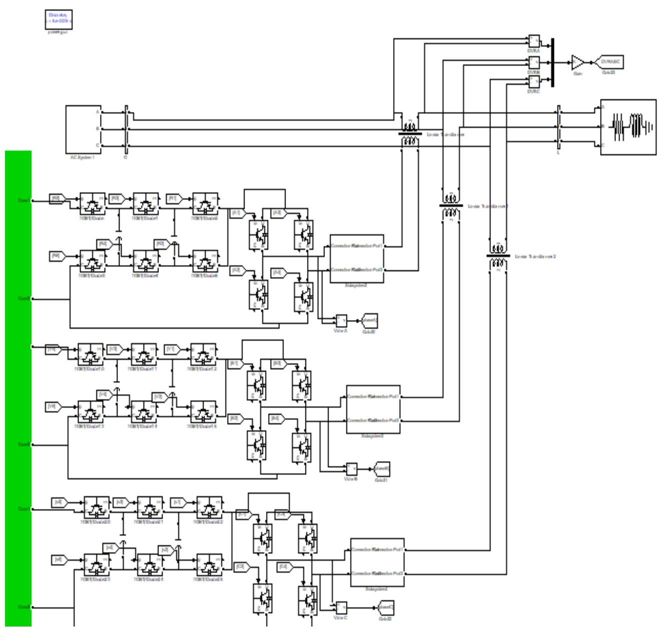

Fig.11. Simulation circuit of PV based DVR

A. Voltage sag in 3- phases (LLLG):

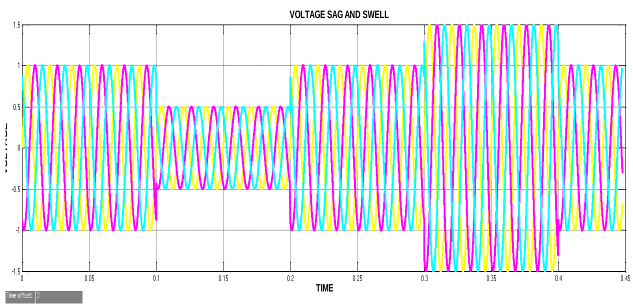

Fig.11. (a). Source voltage (Vs)with sag and swell

From the above fig the sag is created for 3 phases for time 0.1 to 0.2. and swell for 0.3 to 0.4.

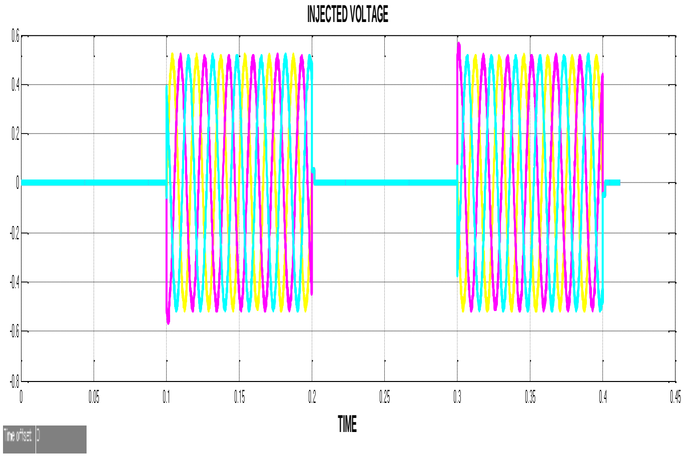

Fig.11. (b). injected voltage (Vc) by DVR

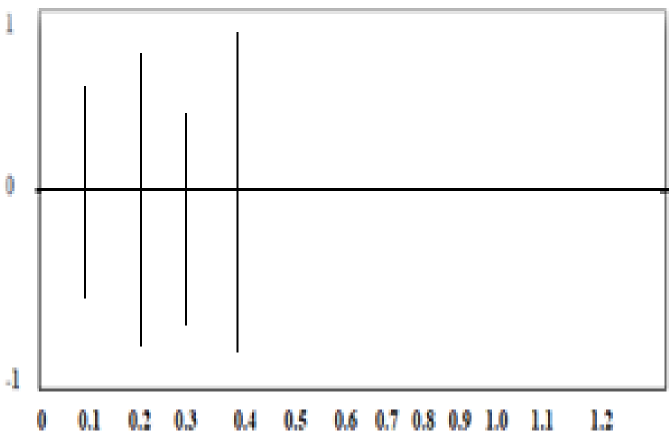

Fig.11. (c). Wavelet coefficients (Cd)by multiresolution analysis.

B. Interruption:

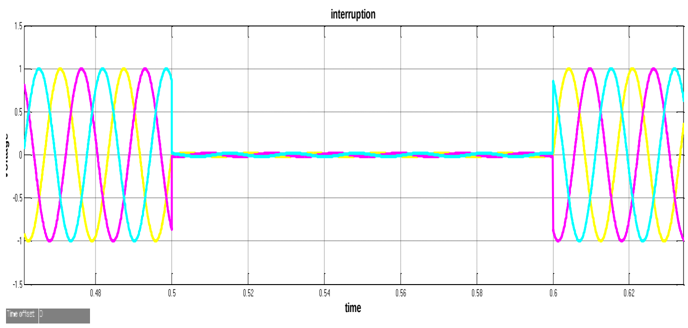

Fig.11. (d). System voltage (Vs) with interruption

From the above fig. the source voltage (Vs)are shown for interruption for time 0.5 to 0.6. The wavelet coefficients (Cd) and injected voltage (Vc).

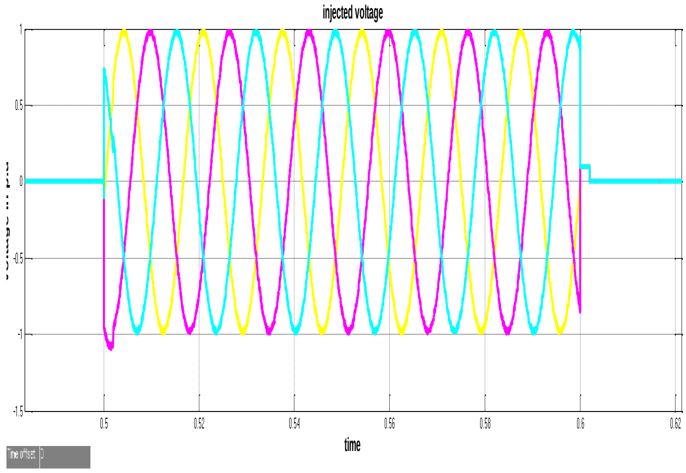

Fig.11. (e). Injected voltage (Vc)

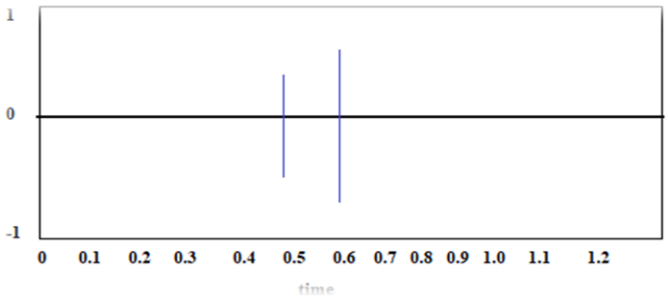

Fig.11. (f). wavelet coefficients (Cd)

C.Voltage sag in 2-phases (LLG):

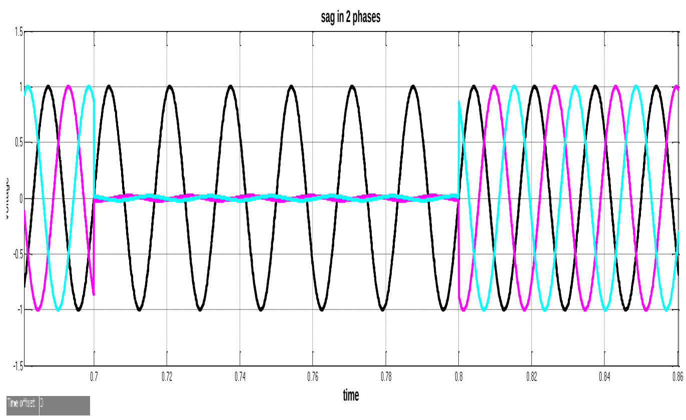

Fig.11. (g). Source voltage (Vs)

From the above fig.the source voltage (Vs) with sag in 2 phases is shown and injected voltage (Vc), Wavelet coefficients (Cd) for time between 0.7 and 0.8.

The sag is injected for 2 phases and injected voltage and wavelet coefficients are presented below

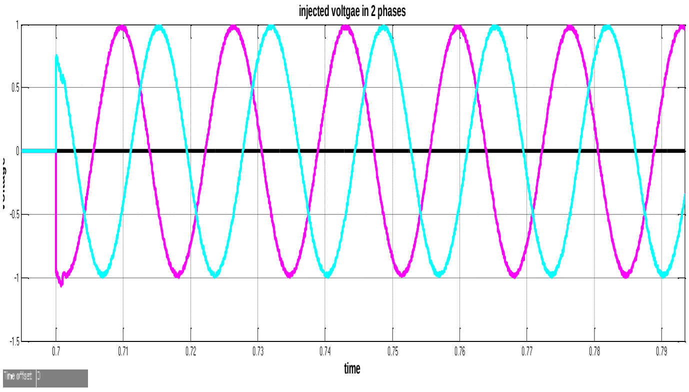

Fig.11.(h). Injected voltage (Vc)

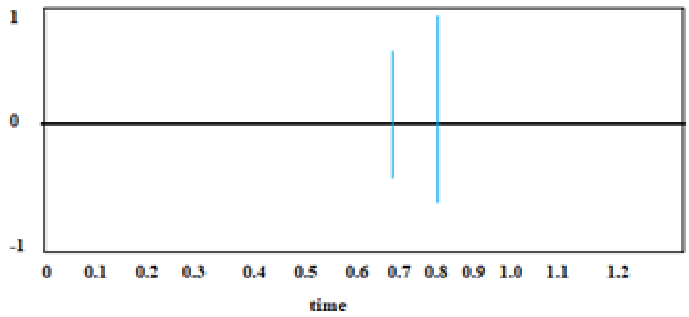

Fig.11. (i). Wavelet coefficients (Cd)

D.Voltage sag in 1-phase (LG):

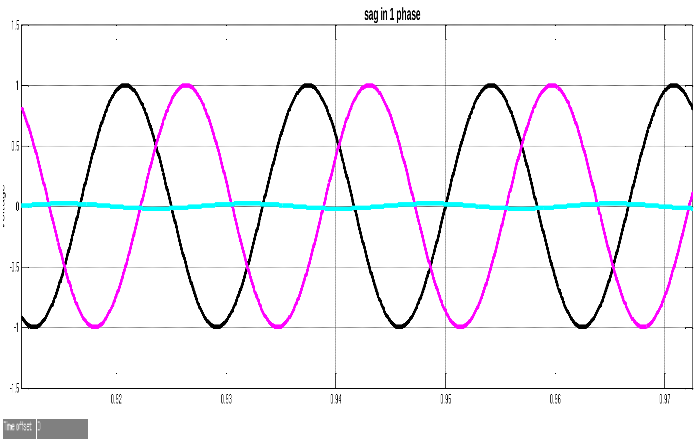

Fig.11. (j). Source voltage (Vs)

From the above fig. the source voltage (Vs) is shown for 1-phase and the injected voltage (Vc), Wavelet coefficients (Cd) for the time between 0.9 to 1.0 is represented

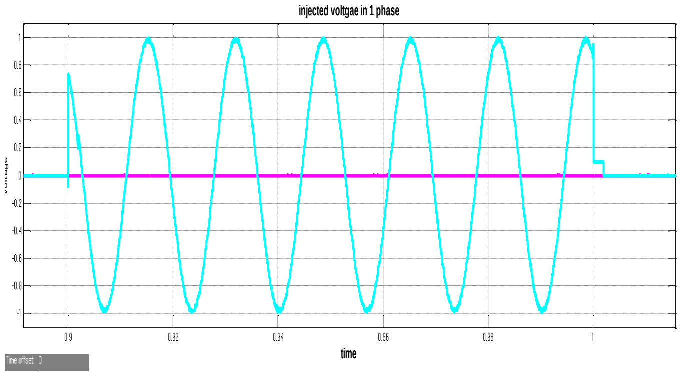

Fig.11. (k). Injected voltage (Vc)

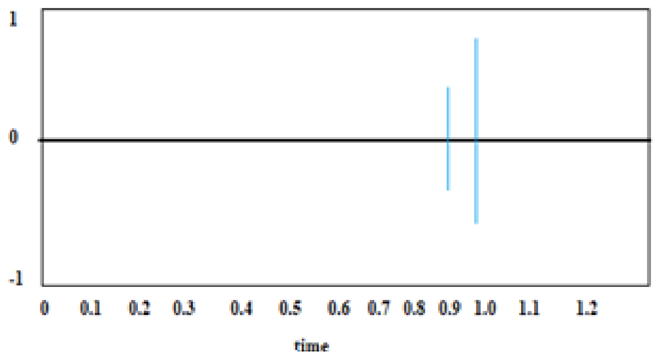

Fig.11. (l). Wavelet coefficients (Cd

E.Solar output Power:

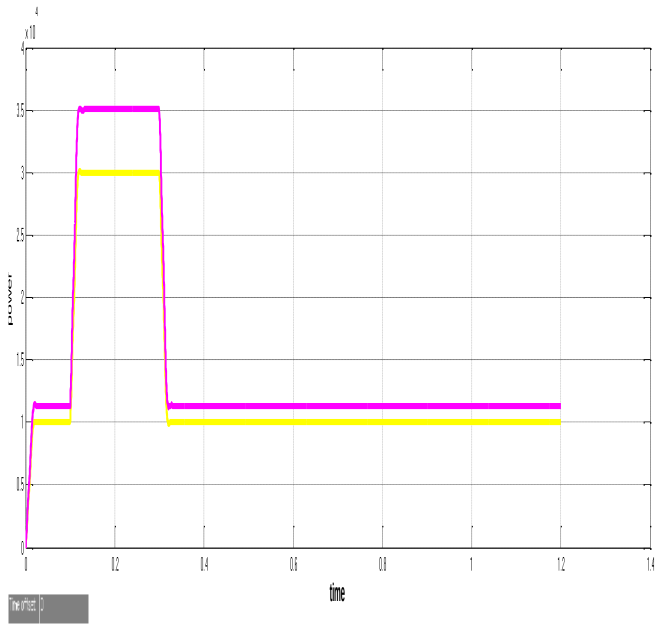

Fig.11. (m). Solar Output Power

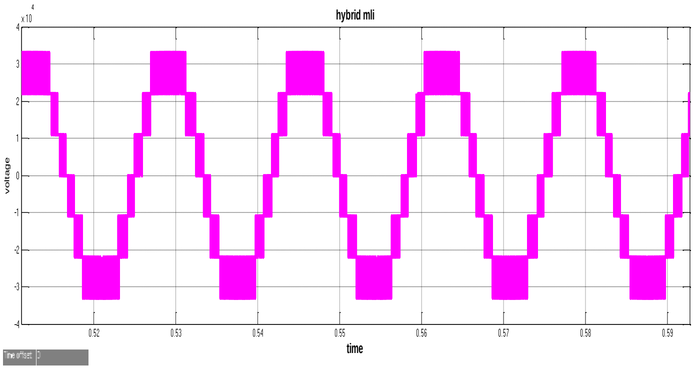

Fig.11.(n).Seven level output of Hybrid MLI

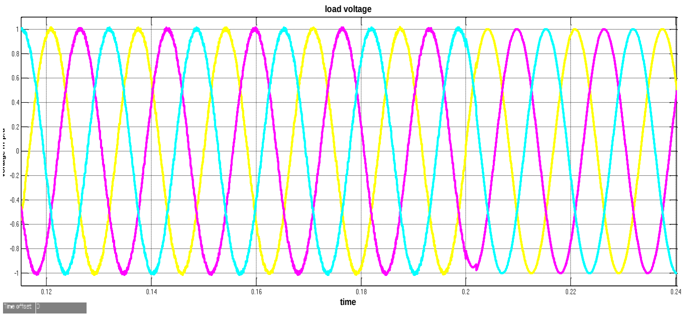

Fig.11. (o). Load Voltage (VL)

Table I : THD comparison table between SVPWM and SPWM

Time	0.1-0.2	0.3-0.4	0.5-0.6	0.7-0.8	0.9-1
Fault	LLLG (sag)	LLLG (swell)	outage	LLG (sag)	LG (sag)
SVPWM % THD	1.33	1.39	1.41	0.50	0.51
SPWM %THD	3.98	4.20	4.24	0.58	0.54

From the above tabular columns, it is clear that the THD % for SVPWM is less than the SPWM technique and is under IEEE standard region.

VIII.CONCLUSION

The performance of DVR is evaluated for both balanced and unbalanced types of faults. The proposed inverter consists of multi cell configuration which has many advantages over traditional multilevel inverters. This inverter employs SVPWM and SPWM modulation strategies and the harmonic distortions are compared when these techniques are adopted. This paper deals with PV based DVR which reduces the drawbacks of self-supported DVR(i.e.) the supply voltages are in phase with each other .The wavelet transform based control algorithm exactly detects the beginning and ending of any power quality event .The comparison table above shows that the % THD in the output voltage with SVPWM is less compared to that of SPWM technique.. The THD content in the output voltage is well within the acceptable limits of IEEE standards. Simulation carried out by using MATLAB/SIMULINK software shows the capabilities of proposed DVR and proves the validity of the proposed topology.

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