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PI Controlled Multi-Level Inverter Based Dvr with Multi-Carrier SPWM for Power Quality Improvement

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Abstract: Quality of the power is to be ensured for the error free and effective functioning of electrical equipments, particularly sensitive loads, which may malfunction and/or may be damaged when the power quality deteriorates, resulting financial blow on the consumer. Quality of the power is exacerbated by voltage swells and voltage sags which are introduced in the power lines by load fluctuations. Shunt active filters, STATCOM, UPFC and Dynamic Voltage Restorer (DVR) are some of the mitigation strategies to address this power quality issue. Out of the above, DVR is cost effective with faster response and therefore, a 27 level cascaded H-bridge inverter based Dynamic Voltage Restorer (DVR) is proposed in this work to assure the quality of the power delivered. Modulation technique preferred is alternate phase opposition disposition (APOD) multi carrier sinusoidal pulse width modulation in view of its superiority over its counterpart's viz. phase disposition (PD) and phase opposition disposition (POD). MATLAB-Simulink is used to simulate the proposed system and simulation results show that the performance of the proposed technique is satisfactory. A single phase experimental prototype based on PIC16F86 is developed to evaluate the simulation results and the experimental results match with those of the simulation with reasonable accuracy.

Key words: Multi level Inverter (MLI) · Multi Carrier Sinusoidal Pulse width Modulation (MCSPWM) · Alternate phase opposition disposition (APOD)

INTRODUCTION

In general, the worthiness of the electrical power, to yield reasonable and satisfactory output from consumer devices, is defined as Power Quality. Continuity of service, voltage magnitude, supply frequency and wave shape are the major factors that decide the quality of the power delivered to the load. Non-compliance of specifications, grounding, bonding and internally generated power disturbances are the major sources for power quality deteriorations. This problem may be regarded as issues within a facility as opposed to the utility i.e. the transfer of the disturbances within the load to the supply. Reduced life time and efficiency of the equipments, increased installation and running expenditures, abrupt failure of equipments are some of the major consequences of the supply of low quality power and need to be addressed [1,2].

Out of the major reasons for the deteriorated power quality, voltage magnitude factor is predominant. The two types of magnitude problems are *voltage swell*and*voltage sag,* respectively the abrupt raise or fall in the supply voltage from its nominal value for a short period and are due to the switching on and off of heavy loads. One of the major consequences of this problem is the increase in reactive power in the system which unnecessarily loads the supply. Injection of high frequency components is another major issue, due to which the network experiences more stress and operates at reduced efficiency level. In a three phase network, a sudden fluctuation in one of the phase's results in imbalance in the network increases the neutral current and builds-up neural to earth voltage, a highly dangerous phenomenon. In addition to the above all other loads connected to the network are subjected to stress and flickers [3, 4].

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The custom power quality improvement proposed so far by several researchers may be classified in to two viz. Network reconfiguration type and Compensating type. The three strategies under first type are static transfer switch, static current limiter and static circuit breaker. In all these techniques, in the event of a fault, the circuit inductance and/or capacitance are modified for fast current limiting and current breaking. Dynamic voltage restorer (DVR), DSTATCOM and Unified power quality controller (UPQC) are the three techniques available under second category. Unlike the first type, the circuit parameters are intact in the second type and mainly used for active filtering, load balancing, power factor improvement and voltage regulation. It is observed that DVR is more economical, has better response time than its counterparts, maintains constant voltage across the load in the event of sags or swells, uses real power only and hence, chosen in this work [4, 5].

Overview of DVR: DVR is basically a high speed power electronic controlled device and belongs to static series compensator type. The block diagram of a typical DVR is shown in Fig. 1 and as shown, the major components of a DVR are Voltage Source Inverter (VSI), injection transformer and control circuitry. DVR continuously monitors the line voltage and whenever the line voltage deviates significantly from its rated value, DVR injects the compensatory voltage through injection transformer in such a manner that the injected quantity in phase with the line quantity to bring the line voltage back to its original value. In-phase compensation, pre-sag compensation and energy optimization compensation are the three commonly used compensation strategies. In-phase compensation strategy is preferred in this work in view of its simplicity and ease of control. The pharos diagram of the in-phase compensation method is depicted in Fig. 2. [6-9].

VSI is the major section of the DVR in which the DC voltage is converted into AC voltage of required magnitude and phase, which will in turn be injected into the line for compensation through injection transformer. Hence, it is required to minimize the harmonics in the injected voltage in order to alleviate the effects of harmonics on the other equipments connected in the network. Multi-level inverter (MLI) is one of the best choices for the above process. A series of power semiconductor switch blocks constitute a high power multilevel inverter, with each block energized by independent low voltage DC source and the voltage levels of the source may be same or different, depending of the choice of application. MLIs are suitable for high power and medium voltage applications and the power conversion from DC to AC is realized by synthesizing a staircase voltage waveform. In addition, the flexibility of replacing the conventional DC sources by renewable energy sources enhances the choice of MLI [10, 11].

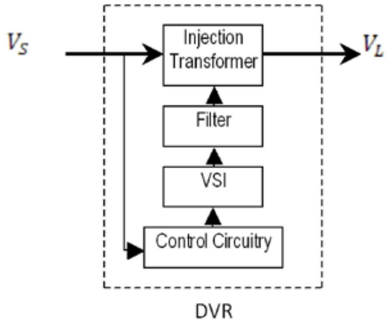

Fig. 1: Block Diagram of DVR

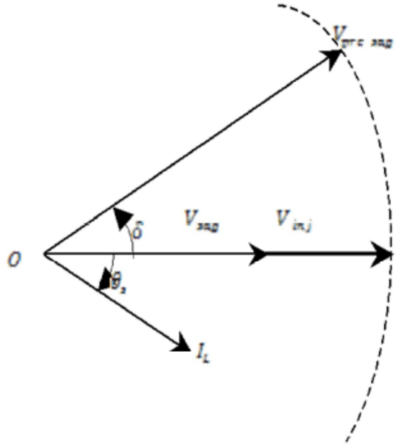

Fig. 2: In-phase compensation - Phasor diagram

Electro-magnetic compatibility issues are less with MLI as the voltage distortion and *dv/dt* stress in the output are reduced.The common mode characteristic of MLI reduces the stress on bearings in electric drive systems. It is also estimated that MLI draws current from the supply with low distortion and can operate at both fundamental and high switching frequencies. The structures in which MLIs are realized are diode clamped, cascaded H-bridge and flying capacitors. The second structure is selected in this work as it is well suited for battery based applications. For a H-bridge MLI the number of levels m' in the output voltage is given by $2S + 1$where `S' is the number of DC sources of MLI and

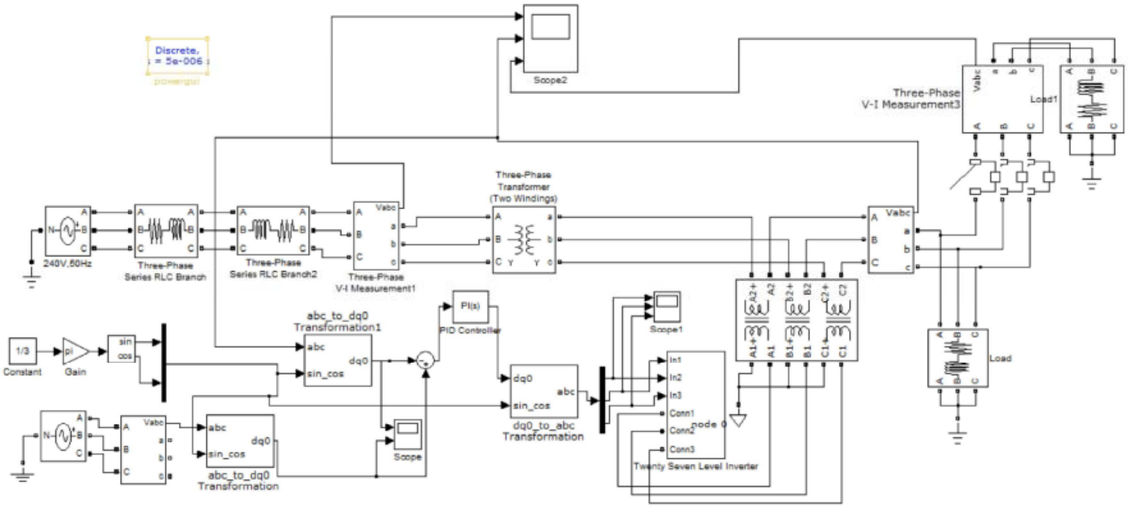

Fig. 3: Simulation Block Diagram of DVR

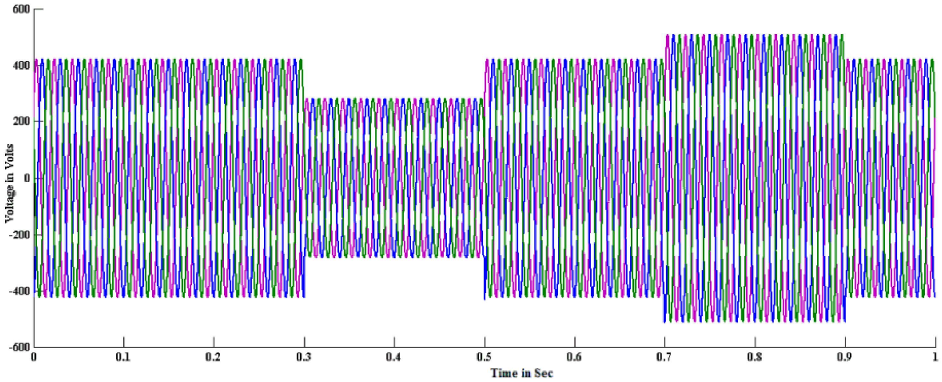

Fig. 4: Supply voltage with 30% sag and 20% swell

the requirement of that many number of separate DC sources limit the application of H-bridge MLI, particularly for systems with multiple separate DC sources [10-14].

The modulation technique chosen for a MLI determines its performance as it decides the amount of switching losses, harmonic content etc. The technique selected in this work is alternate phase opposition disposition (APOD), vertical carrier distribution fundamental frequency with multi carrier sinusoidal pulse width modulation technique (MCSPWM). For an ‘*n*’ level MLI, ‚*n* -1´ carrier waves are required and in the selected technique they are arranged in vertical manner with a phase difference of 180° between any two adjacent carrier waveforms [10-17].

Simulation of DVR: A three phase distribution system has been chosen to evaluate the performance of the proposed 27 level H-bridge MLI based DVR.

Table 1: Specifications Adopted For The Simulation of DVR

S.No.	Description	Parameters	Value
1	Voltage Source	Line Voltage	415 V
2	Filter	Filter Inductance	38mH
		Filter Capacitance	20μF
3	Injection Transformer	Power	7.5 KVA
		Voltage Rating	415/ 415 V
4	Load	Load Resistance	20 Ω
		Load Inductance	10mH
5	PI Controller	Proportional Gain (Kp)	5
		Integral Gain(Ki)	0.1
6	Carrier Signal	Triangular Wave	$V_P = 1$ V 20Hz

The parameters of the desired system are listed in Table 1 and MATLAB-Simulink is used to simulate both system and DVR. The schematic of the simulated system is given in Fig 3. The performance of the DVR is estimated by inducing a 30% sag and a 20% swell back-to-back, both lasting for 0,2 seconds, with reasonable delay between them, as shown in Fig. 8.

The three phase load voltage and the corresponding reference voltage are compared after converting them in to d-q-0 frame from a-b-c frame using Park's transformation. The output of the comparator is fed to PI controller and the controlled error signal in d-q-0 frame is converted back to a-b-c frame using inverse Park's transformation, which acts as modulating signal for MLI. The frequency of the carrier signal is 20 KHz. With modulating signal and carrier signal, MLI generates the required compensating voltage and injects the same into load through injection transformer, to alleviate the swell/sag[18].

RESULTS AND DISCUSSIONS

As induced, the voltage sag is observed between 0.3 second and 0.5 second and the amplitude during that period is 290 Volts and that of the swell is 500 Volts between 0.7 second to 0.9 second. Hence, the error voltages in each phase are respectively -125 Volts and +85 Volts. The error voltages for one of the phases is shown in Figure 5. To mitigate these issues, the proposed controller injects the voltage, which is the negate of the error in the same phase as shown in Fig. 8. It is may also be noticed that the injected voltages for sag and swell are 180 out of phase, which conveys that for ith bridge, pair will be selected during sag and the pair will be selected during swell.

Fig. 9 shows the load voltage with DVR and it may be observed that there is no impact of either sag or swell present in the line voltage, as they are compensated by the voltage injected by DVR. Table 2 shows the load voltage, power factor and total harmonic distortion (THD) of the system with DVR. The THD with DVR is given in Fig 10 and it is noticed that THD is improved to 3.4% from 6.3%. In addition the results show that there is a substantial improvement in load power factor also. Power factor with DVR is estimated as 0.93 where as it is 0.85 without DVR.

Table 2: THD Analysis for inverter modulation techniques

System	RMS load Voltage	Load PF	% THD
DVR with APOD using PI Controller	382	0.85	6.3
DVR with APOD using Fuzzy logic Controller	412	0.93	3.4

Hardware Description: To evaluate the functioning of the proposed DVR, a single phase, 24W, 12Volts AC system is designed and fabricated. The hardware set upis given in Fig. 11. The functionality of the low power, low voltage single phase transmission system may be extended for a high power three phase transmission system. DVR, the associated switching algorithms and PI controller algorithms are realized using PIC Micro-controller16F887. The switches are realized using MOSFET IRF840, whose specifications are V_{DS}=500V, I_D = 8A, power dissipation of 50W and V_{GS} = ± 20V gate voltage... The 12V transmission system is realized with a 230V/15V-12V-9V, 2A transformer. The rated voltage is set to 12V and the sag and swell are introduced manually by switching the transformer to 9V and 15V respectively.

The PIC micro controller 16F887 controls the entire operation of the circuit. The rectified DC voltage is maintained at 5V by the regulator and it is used to turn ON the controller. The input supply load should be maintained at 12V but whenever sag voltage is detected PIC responds to it and compensates the Sag voltage (9 V) by triggering the inverter accordingly. Similar inverter operation, in case of Swell voltage (15V) condition also.

The Hardware implementation is done by using DVR comprising of 6 V batteries, Converter, Inverter and a series injection transformer. However, the resistive load has to be supplied with 12 V initially. The PIC microcontroller is programmed in such a way that when sag voltage of 9 V is detected then it enforces DVR operation in order to compensate it. Similar in case of swell voltage of 15 V. The PIC microcontroller operates the converter through the driver circuit to get the required

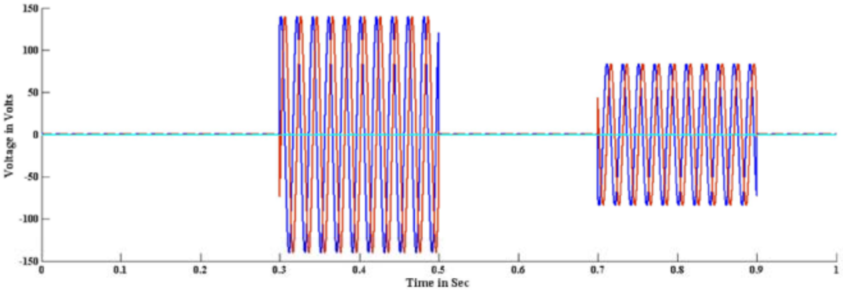

Fig. 5: Error signal from comparator

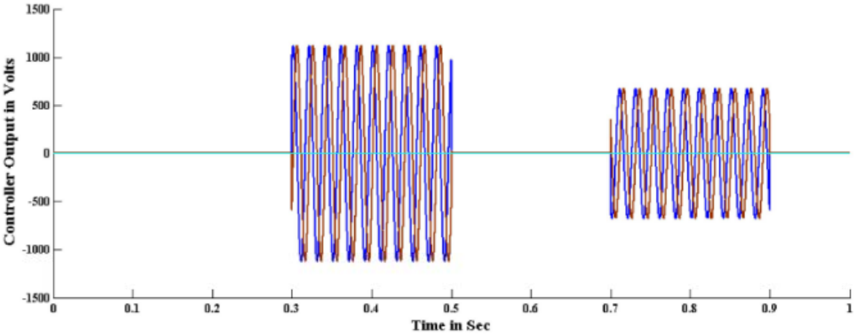

Fig. 6: Fuzzy Logic controller output

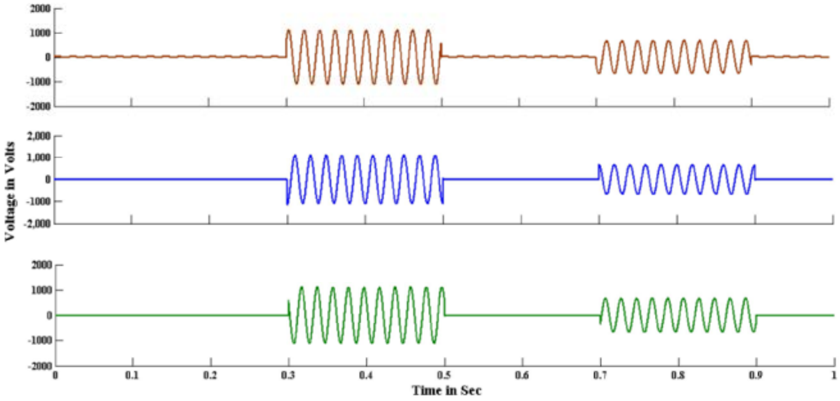

Fig. 7: Modulating signal for MC SPWM generation

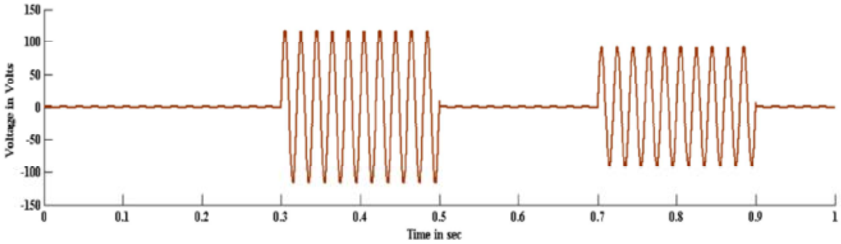

Fig. 8: Compensating voltage injected by DVR (V_{DVR})

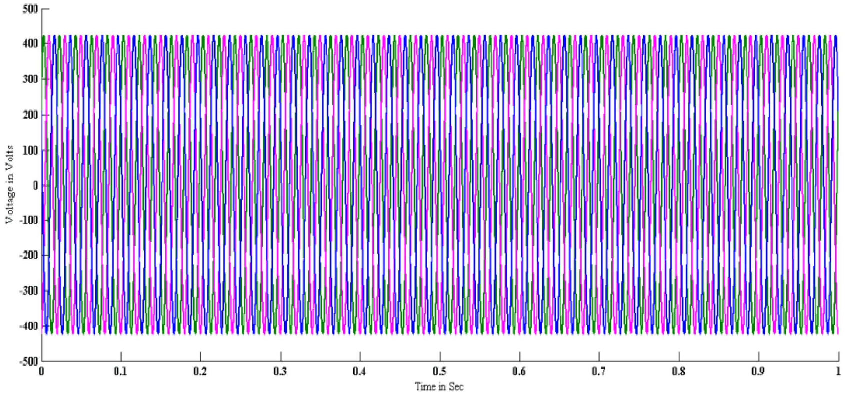

Fig. 9: Compensated load voltage

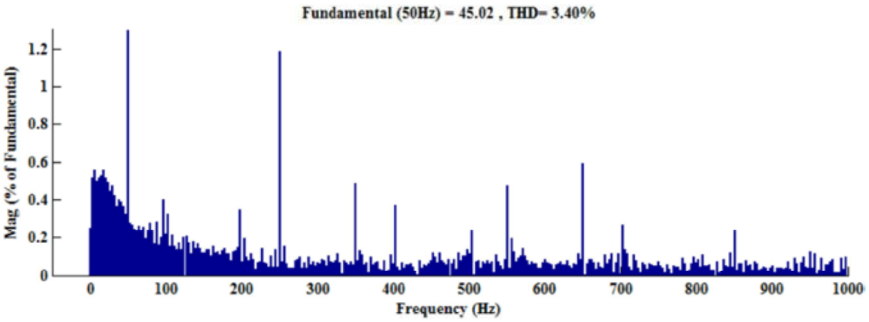

Fig. 10: % THD of load voltage for DVR with Alternate Phase Opposition Disposition PWM

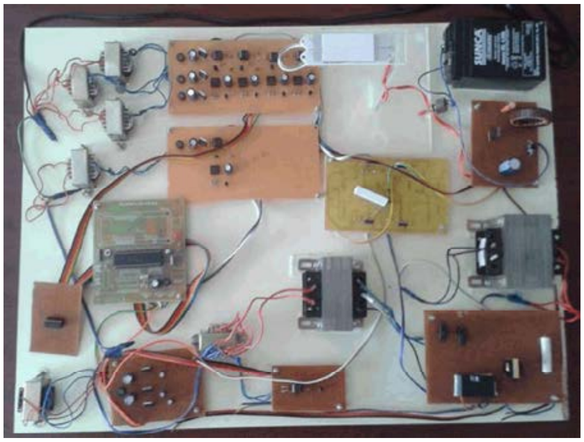

Fig. 11: Hardware setup for single phase DVR

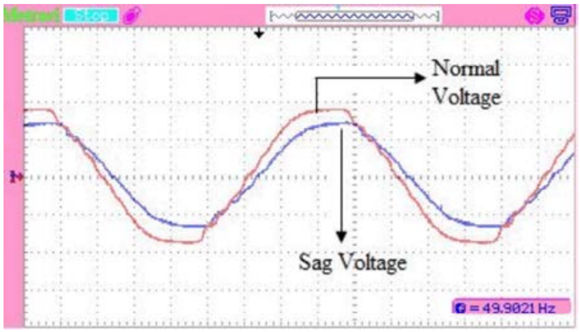

Fig. 12: Supply Voltage with 25% Sag

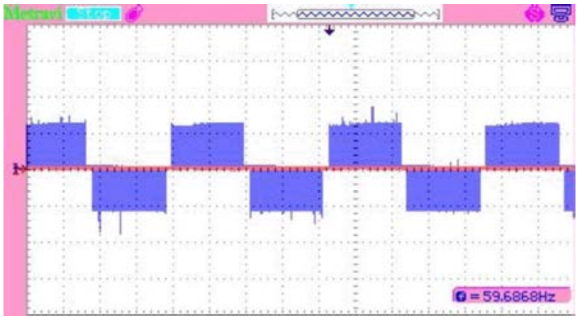

Fig. 13: DVRVoltage Injected

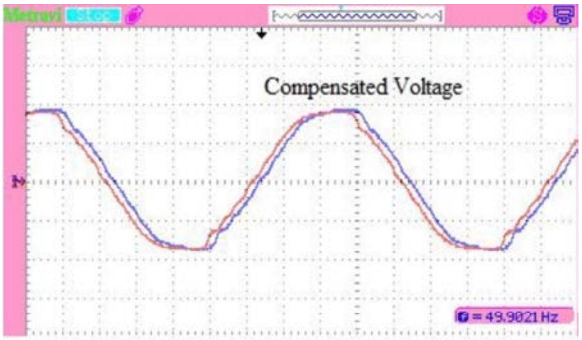

Fig. 14: Compensated Load Voltage

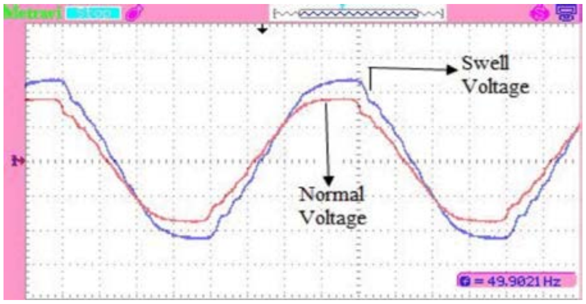

Fig. 15: Supply Voltage with 25% Swell

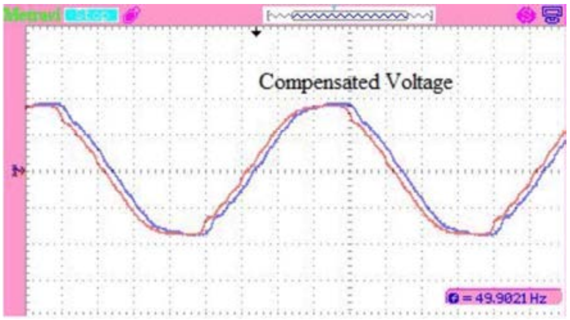

Fig. 16: Compensated Load Voltage

Compensating voltage which is to be fed to the inverter based on the sag/swell condition. Likewise, Inverter also get triggered by the driver circuit so that compensation of voltage sag/swell can be achieved. PV Panel Charges the 6 V battery and that battery supplies the boost converter. Sag/Swell Voltage is created by a tap changing transformer. 230 V/9-12-15 V.

The results of hardware set up is shown Fig. 12 to Fig. 16 with 25% voltage sag and swell and respective voltage injected by DVR.

CONCLUSION

In this paper, a PI controlled CMCI based DVR is proposed in mitigating voltage sag and swell and its performance is analyzed using MATLAB/Simulink as well as single phase hardware set up. The PI controller is suggested to improve the performance of the DVR during the sag and swell and it is observed that during sag and swell the compensating voltage is injected exactly in phase and magnitude. The simulation results show appreciable improvement vin the quality of the power delivered. The hardware results also support the simulation output for power quality improvement. In this work proposed DVR is controlled by PIC microcontroller and in future it may be evaluated with other controllers like DSP and ARM 7 etc.

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