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An Enhanced Voltage Sag Compensation Scheme for Dynamic Voltage Restorer

Ms. Ruchita Rathod, Mr. Ankur Chaudhri

Student,M.E.(electrical),Semester 4, Assistant Professor, Electrical Engineering

Merchant Engineering college, Basna,
Mahesana, Gujarat

***Abstract*— Voltage sags can be symmetrical or unsymmetrical depending on the causes of the sag. At the present time, one of the most common procedures for mitigating voltage sags is by the use of dynamic voltage restorers (DVRs). By definition, a DVR is a controlled voltage source inserted between the network and a sensitive load through a booster transformer injecting voltage into the network in order to correct any disturbance affecting a sensitive load voltage. This paper present the Improving Voltage quality of Sensitive Load From voltage sags using dynamic Voltage Restorer. DVR is mean of series compensation to mitigating the effect of voltage sag meanwhile the H Bridge Power converter topology has also become a work horse topology in high power application. This paper present the detailed design of a close loop regulator to maintain the load voltage in acceptable levels in a DVR. Using Transformer Coupled H-Bridge converter. This paper present System Operation and controller design approaches, computer Simulation & single phase Dynamic Voltage Restorer Hardware Implementation.**

Key Words: Dynamic voltage restorers. Faults. Power conditioners, Power quality, Unbalanced conditions, Voltage source Inverter, SMPS, Micro-controller.

I. INTRODUCTION

Recently, much attention has been focused on the power quality domain in power system networks. Power quality measures the fitness of electric power transmitted from the utilities to the different consumers in the case of the conventional centralized generation or in some cases from the consumers to the utilities in the case of distributed generation. Voltage distortion that may occur due to power system harmonics and voltage sags is widely recognized as the most severe issue affecting power quality, because it affects both the utility company and consumers alike. Nonlinear loads create voltage and current harmonics which may have detrimental effects on consumers' equipment.
IEEE Standard 1159-1995 defines voltage sags as a root mean-square (rms) variation with a magnitude between 10% and 90% of nominal voltage and duration typically ranging from a few milliseconds to sixty seconds.

Voltage Sag takes place at nearby feeders with a detrimental feeder subjected to one of the causes of voltage sag. Short circuits due to faults in the power system structure, lightning strokes, high starting currents of induction motors, and inrush currents are the common causes of voltage sags. Voltage sags can be symmetrical or unsymmetrical depending on the causes of the sag. If the individual phase voltages are equal and the phase relationship is 120 degrees, the sag is symmetrical. Otherwise, the sag is unsymmetrical. A three-phase short-circuit fault can produce symmetrical sags. Single line-to-ground, phase-to-phase, or two phase-to-ground faults due to lightning, animals, accidents, and other causes, as well as energizing of large transformers, can cause unsymmetrical sags.

A power conditioner is a device proposed to enhance the quality of the power that is delivered to a sensitive electrical load. In addition, it can be defined as a device that acts on delivery of a voltage of the appropriate level and characteristics to facilitate the effective utilization of critical loads. At the present time, one of the power conditioners most commonly used to mitigate voltage sags is the dynamic voltage restorer (DVR). By definition, a DVR is a controlled voltage source inserted between the network and a sensitive load through a transformer injecting voltage into the network in order to correct any disturbance affecting the sensitive load voltage. More functions can be included with the DVR such as reactive power compensation, harmonics mitigation, and fault current limitations. DVRs' controllers have an important effect on the system dynamic response, stability and steady-state accuracy.

In the literature, there are many types of controllers that can be used in the DVR compensation practice, such as feedback and feed-forward, double-vector, proportional and integral (PI), fuzzy and adaptive PI-fuzzy controllers, which are widely used in low-voltage small capacity DVR applications. Recently, a novel software phase-locked loop (SPLL) is proposed by combining the advantages of leasterror- squares (LES) filters and the instantaneous symmetrical components method, which has a fast phase-lock tracking ability and guarantees no data fluctuation of the sag detection algorithm under non-sinusoidal conditions . Additionally, a new strategy with the positive and the negative sequence extractions (PNSE) from the fundamental and the higher distorted harmonic orders is proposed, which improves the dynamic response of the DVR with an accurate steady-state compensation. Despite the valuable development added by such novel algorithms, they are mainly dedicated to high/ medium-voltage applications which need large capacity dynamic voltage restorers with enhanced capability controllers, especially for the utilities that have complex nontypical industrial consumers and may considerably suffer from parameters uncertainty and/or wide range of operation circumstances, such as the grids integrated with large-scale wind and/or solar Power Resources.

This study proposes a new configuration of Dynamic Voltage Restorer (DVR) with fuzzy logic based feedback controller capable of compensating for power quality problems associated with voltage sags/swells and maintaining a prescribed level of supply voltage at the induction motor load terminals. The simulation of the proposed DVR is accomplished using MATLAB/SIMULINK sim power systems toolbox. The performance of the proposed DVR for different supply disturbances is tested under various operating conditions. The simulation results have shown that the proposed DVR is capable of mitigating both balanced and unbalanced voltage sags/swells with acceptable efficiency and reliability.

II. Dynamic voltage restorer

A dynamic voltage restorer is a solid-state power electronic switching device which is connected in series to the load voltage bus in order to inject a dynamically controlled voltage. This voltage can remove any detrimental effects of a bus fault on a sensitive load voltage. Fig. 1 shows a schematic diagram of a typical DVR structure which is used for voltage recovery. It consists of the following units:
(i) Energy storage unit: This is DC storage energy with a proper capacity which supplies the DVR during compensation by the required real power. It can be simply a capacitor or a battery. Recently, super capacitors, fly wheels, and super magnet conductors are emerging as energy storage devices with a fast response. Unfortunately, difficult maintenance and the high cost of these facilities compared with conventional facilities have been noted in the power quality markets, delaying their widespread deployment in a broad sense.

(ii) Injection transformer: The DVR transfers the voltage which is required for the compensation from the voltage source converter to the distribution network through the injection transformer. The high voltage side is normally connected in series with the distribution network while its low voltage side is connected to the power circuit of the DVR.

(iii) Voltage source converter (VSC): This is a power electronic configuration which is used to generate a sinusoidal voltage with the required magnitude, phase, and frequency. Its dc input is the energy storage unit.

(iv) LC passive filter: A simple output filter composed of passive elements such as a resistance R, inductance L, and a capacitance C. It is used to reduce the undesired harmonic components of the waveform generated by the converter to their permissible limit. Its output is asinusoidal waveform with low total harmonic distortion.

(v) Bypass switch: This is used to isolate the DVR from the system in case of high currents.

(vi) Control unit: This is used to detect the presence of voltage sags in the system. In other words, it is considered as a monitor of the load-bus voltage. If a sag voltage is sensed, the controller will be initiated in order to inject the missing voltage after determination of its magnitude and phase.

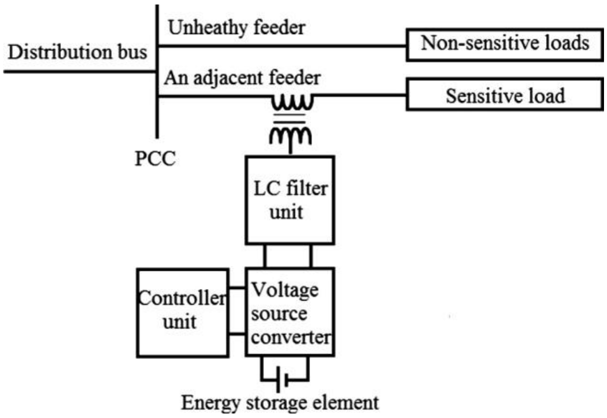


Fig. 1 Schematic diagram of a typical DVR structure.

The DVR has two main modes of operation, which are as follows:
Standby mode: This is the monitoring action of the load-bus voltage. No voltage is injected and the transformer low-voltage side is shorted through the converter.

Injection mode: The DVR in this mode injects the required voltage to the system to correct the sag.. Consequentially, one can say that the DVR is a series connected device between the source and a sensitive load that injects a dynamically controlled voltage and protects voltage sensitive equipment from sags. On the other hand, uninterruptible power supplies (UPSs), static voltage compensators (SVCs), distributed static compensators (DSTATCOMs), and super-magnetic energy storage (SMES) are other approaches that can handle the case. Unfortunately, large size, difficult maintenance, and the higher cost of these facilities compared with the DVR facility have been noted in the markets. Thus, the simplest and cheapest device for voltage sag correction is the DVR.

Voltage sag calculation

Fig. 2a shows a simplified equivalent circuit of a Thevenin source system represented by voltage source VS and source reactance XS. It is feeding two equal loads represented by Z1 and Z2 through two feeders F1 and F2, where Z represents the load impedance and XF the magnitude of feeder reactance.

IS is the supply current. In normal operation, the pre-sag voltage at the point of common coupling (VPre-sag) and the supply current are given as follows:

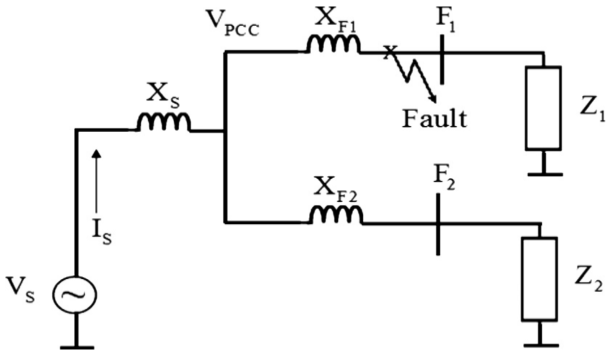


Fig. 2a Simplified equivalent circuit for voltage sag calculation

$$\mathrm{VPresag} = \mathrm{VS} - \mathrm{IS\,XS}. \tag{1}$$

$$\mathrm{Is} = \mathrm{I1} + \mathrm{I2} = \frac{\mathrm{V\ pre\ sag}}{\mathrm{Z1+XF1}} + \frac{\mathrm{V\ presag}}{\mathrm{Z2+XF2}} \tag{2}$$

When a fault occurs on F1 (the unhealthy feeder), a high current will flow through it as well as the supply current.
During such a case, the supply current IS,fault and the voltage at the point of common coupling during sag (VSag) will be given as follows:

$$Vsag = Vs - Is, faultXs \tag{3}$$

$$\mathrm{Is\ fault} = \frac{\mathrm{Vsag}}{\mathrm{Xf1}} + \frac{\mathrm{Vsag}}{\mathrm{Z2+Xf2}} \tag{4}$$

Accordingly, the voltage across the adjacent feeder F2 will be reduced due to the excessive voltage drop that will appear across the source reactance XS. This voltage drop will be defined as voltage sag. Hence, a DVR represented by a controlled voltage source VDVR will be inserted between the point of common coupling and the sensitive load Z2 as shown in Fig. 2b.

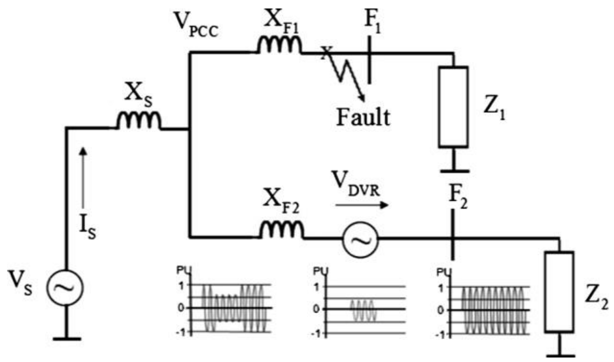


Fig. 2b Simplified equivalent circuit for the DVR voltage injection.

Operation Modes of DVR

The operation of Dynamic Voltage Restorer (DVR) can be categorized into three modes namely protection mode, standby mode and injection mode. In protection mode of operation DVR is protected from the over current in the load side due to short circuit on the load or large inrush currents. Bypass switches are used to separate the DVR from the system in protection mode.

Generally DVR operates in standby mode in normal steady state conditions. In this mode of operation, the DVR may either be bypassed or inject small voltage to compensate the voltage drop on transformer reactance or losses. DVR is generally bypassed because the small voltage drops do not disturb the load requirements if the distribution circuit is not too weak. DVR enters the injection mode of operation as soon as an abnormality is detected in load side voltage. DVR injects a three phase compensating voltage with each of the three phases having independently controlled magnitude and phase to meet the requirements on that particular phase. The DVR should ensure the unchanged load voltage with minimum energy dissipation for injection due to the high cost of capacitors.

Control Methods for DVR

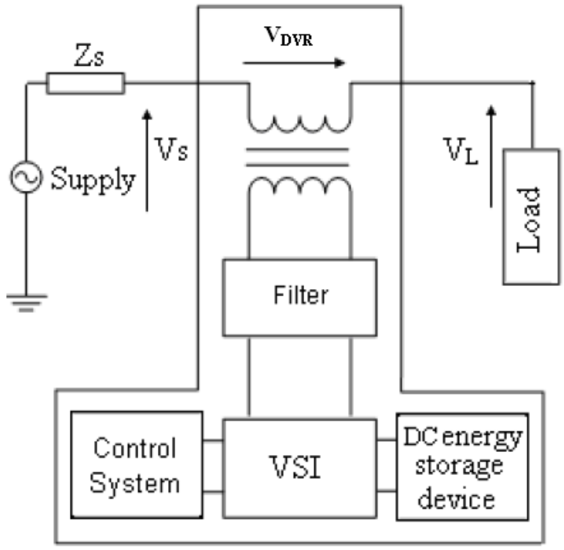
DVR Control strategies fall mainly in one of the two categories namely linear control methods and Non-linear control methods.

Linear control methods can be employed with the feedback, the feed-foreword and the combined feed controllers. Non-Linear control methods comprising the Artificial Neural Networks (ANN), the Fuzzy Logic (FL) and the Space Vector (SV) controller Although

feedback controllers are popular, they require load and source tracking, whereas feed-foreword controllers are much simpler yet open-looped, there is no feedback from the load voltage or current.
The proposed DVR utilizes capacitors as the energy storage units fed through the supply mains via the rectifier. The compensation strategy is chosen to be the in phase compensation method due to its simplicity of implementation and induction motor no being sensitive to phase angle jumps. And the control of the proposed DVR is based on a fuzzy logic based feedback controller.

III. MATERIALS AND METHODS

This study proposes a fuzzy logic controlled DVR with in-phase compensation strategy for voltage sag/swell compensation for industrial induction motor loads. Since the in-phase compensation strategy is simpler and efficient, the operation of the proposed DVR is simpler and its response time is also faster. Fig shows the block diagram of the proposed controller for the DVR.



DVR

Detection of Sag and Swell Events

Sag/Swell detection includes determination of the instants when a sag/swell event starts and ends, magnitude of the variation and the phase angle jumps. Several approaches for detection of sag/swell events available are Classical Fourier Transform method, Wavelet analysis, use of RMS values, use of peak values, the transformation of the three phase voltages to a two dimensional frame (dq frame) and therefore to one phasor.

In this study, the proposed DVR uses the traditional Fourier Transform method to detect the voltage sag/swell events. The Fourier transform based sag/swell detector associated with the proposed DVR can track the magnitude and the phase angle of the fundamental frequency component of the supply voltage simultaneously in order to make sure that the injected sine wave will be in-phase with the remaining sine wave during the sag/swell events, to have a constructive vector addition of the DVR and the supply voltages. Since the compensation strategy used in the proposed DVR is in-phase method, computation of the compensating voltage magnitude is done using a comparator with one input as the variable load voltage and the other being the reference voltage for each of the three phases independently. The output of the comparator determines the magnitude of the voltage required to be injected by the DVR and is called the error signal which is the input to the fuzzy logic based feedback controller used for controlling the output voltage of the inverter the control of the modulation index for each of the three phases of the inverter independently.

Compensating Voltage Generation

The inverter circuit in DVR is responsible for generation of the compensating voltage. Hence the control of the inverter will directly affect the performance of the DVR. The inverter used in the proposed DVR is a three phase six pulse inverter. The thyristors used in the inverter circuit are chosen to be Insulated Gate Bipolar Transistors (IGBT) for their fast response and robust operation. The inverter uses Sinusoidal Pulse Width Modulation (SPWM) for controlling the modulation index hence controlling the output voltage of the inverter.

In SPWM, a sinusoidal reference signal of supply frequency (i.e.50 Hz) is compared with a high frequency triangular carrier waveform (i.e. 1080 Hz for this study). When the sinusoidal reference signal is greater than the triangular carrier wave, a batch of three IGBT switches out of the six are turned on and the counter switches are turned off and when the reference sinusoidal signal is smaller than the triangular carrier waveform in magnitude then the second batch of three IGBT switches are turned on and the first batch of switches are turned off. The magnitude of the sinusoidal reference signal determines the modulation index of the PWM signal generator which is dependent upon the error signal. The magnitude of the sinusoidal reference signal is controlled by the fuzzy logic based feedback controller which adjusts the magnitude according to the error magnitude and hence control the modulation index. The proposed DVR utilizes large capacitor banks for storing dc energy. Supply line voltage is rectified and used to charge the capacitor banks. DC voltage from alternative supply sources can also be utilized with the proposed configuration of DVR.

Fuzzy Logic Controller

Fuzzy logic theory is considered as a mathematical approach combining multi-valued logic, probability theory, and artificial intelligence to replicate the human approach in reaching the solution of a specific problem by using approximate reasoning to relate different data sets and to make decisions. The performance of Fuzzy Logic Controllers is well documented in the field of control theory since it provides robustness to dynamic system parameter variations as well as improved transient and steady state performances.

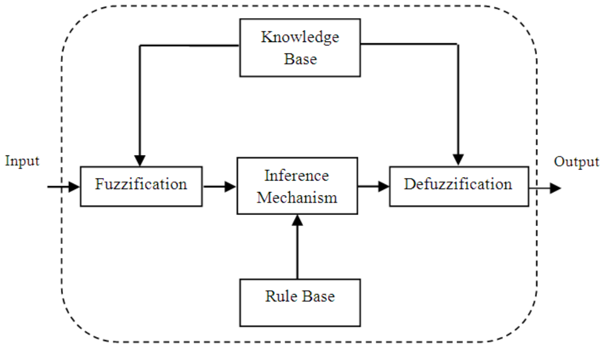


Fig 2: Schematic representation of Fuzzy Logic Controller

In this study, a fuzzy logic based feedback controller is employed for controlling the voltage injection of the proposed Dynamic Voltage Restorer (DVR). Fuzzy logic controller is preferred over the conventional PI and PID controller because of its robustness to system parameter variations during operation and its simplicity of implementation. Since the proposed DVR uses energy storage system consisting of capacitors charged directly from the supply lines through rectifier and the output of the inverter depends upon the energy stored in the dc link capacitors. But as the amount of energy stored varies with the voltage sag/swell events, the conventional PI and PID controllers are susceptible to these parameter variations of the energy storage system; hence the control of voltage injection becomes difficult. The proposed FLC scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

The fuzzy logic based control scheme (Fig) can be divided into four main functional blocks namely Knowledge base, Fuzzification, Inference mechanism and Defuzzification. The knowledge base is composed of data base and rule base. Data base consists of input and output membership functions and provides information for appropriate fuzzification and defuzzification operations. The rule-base consists of a set of linguistic rules relating the fuzzified input variables to the desired control actions. Fuzzification converts a crisp input signals, error (e), and change in error (ce) into fuzzified signals that can be identified by level of memberships in the fuzzy sets.

The inference mechanism uses the collection of linguistic rules to convert the input conditions to fuzzified output. Finally, the defuzzification converts the fuzzified outputs to crisp control signals using the output membership function, which in the system acts as the changes in the control input (u).

IV. MODELING AND SIMULATION

The performance of the proposed fuzzy logic based DVR is evaluated by using MATLAB/SIMULINK program as a simulation platform. The DVR is connected in series between a three phase programmable (controllable) voltage source with 400V line to line RMS voltage, 50 Hz and a load of active power p = 10 KW and reactive power Q = 1 KVAR (with installation of power factor correction capacitors). The Simulink model of the proposed DVR is shown in Fig 15.

RESULTS AND DISCUSSIONS

Results are obtained by simulating the proposed DVR system in MATLAB/SIMULINK software. The minimum operation time of the DVR is 1 cycle or 20 milliseconds. Several power quality phenomena associated with voltage sag and swell have been simulated and the results are arranged in the following sequence for all cases: (a) the supply voltage (VSupply), (b) the DVR voltage (VDVR) and (c) the load voltage (VLoad).

Simulation Results

A three phase balanced voltage sag is simulated by reducing the line to line voltage on each phase to 60% of the normal value for a duration of 0.3 seconds from t=0.4 sec till t=0.7 sec as shown in Fig The simulation duration was 1 second.

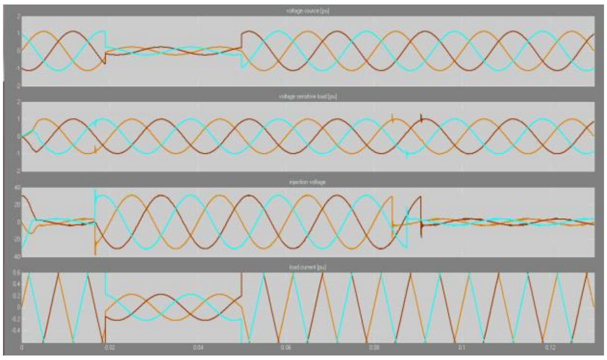


Fig 3: Results Voltage Sag and injected voltage

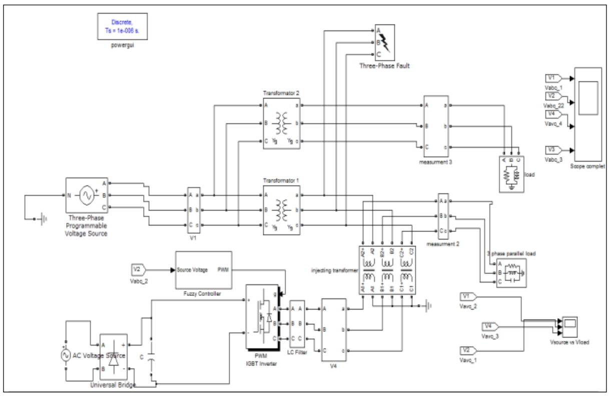
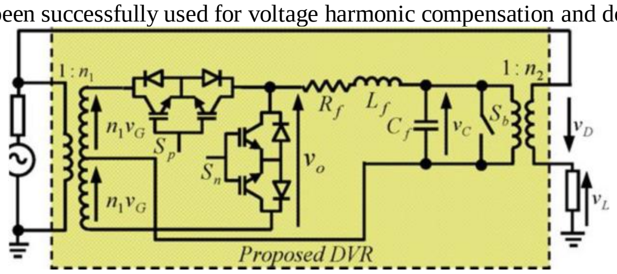


Fig 4: simulink model

Hardware Implementation Of Single Phase Dynamic Voltage Restorer

In the DVRs that employ ac/dc/ac conversion, it is required to use a large capacitor in the dc link to smooth the dc link voltage. Hereafter these topologies are called conventional DVRs. A considerable amount of technical works has been done on the conventional DVRs concerning both hardware circuit topology, control strategy and voltage disturbances detection methods. The topologies of DVRs vary from both viewpoints of how to connect to the system and the used inverter topology in the DVR structure.

The DVRs can operate in both low voltage and medium voltage distribution systems Application of multilevel inverters in the conventional DVRs has been presented as a solution to handle high voltage and high power by the DVRs. Beside the voltage sag and swell compensation, the DVR has been successfully used for voltage harmonic compensation and downstream fault current limitation.



Proposed topology for single-phase DVR

In this paper, a new ac/ac converter based single-phase DVR is proposed to compensate voltage sag/swell and harmonics and limit downstream fault currents with a simple topology. Although, the proposed topology is singlephase, it can be extended to any n-phase (such as three-phase) system. The proposed topology can be used for higher voltage levels with lower voltage rating switches which do not require the forced commutation circuits (as high voltage thyristors). Therefore, the proposed topology does not have the problems associated with the forced commutation circuits. Moreover, the low voltage switches (such as insulated MOSFET have negligible turn on and turn off delay time in comparison with the high voltage switches such as thyristors and gate turn off thyristors (GTO). As a result, the quality of the output waveform is higher. Unlike MOSFET, thyristors and GTOs usually cannot operate with high frequency which is necessary for many of applications.

Protection Schemes

Different protection schemes are incorporated in DVR for its safety and rendering reliable services to the operator in case of fault. Due to overload, the load current exceeds its rated value. A bypass scheme is incorporated in DVR. During bypass operation, the secondary of the injection transformer is shorted through anti-parallel SCR pair.

During this mode transformer works in zero voltage injection mode. Control logic is implemented which turns on the SCRs in case load current exceeds its safe limit. limit. The upper limit of load current selected for bypass operation is 125% of its rated load current. However for this range of overload current, DVR bypass operation takes place after a duration of 10 s. The time duration after which bypass operation takes place, goes on decreasing with increase in value of load current above its rated value. In case of short circuit fault on load side, a large current flows through the secondary of injection transformer. The corresponding current on the primary side may damage the power electronic switches (IGBTs, MOSFETs etc.)of inverter. To avoid this, fuse is connected in series with output to stop the flow of large current. During starting of the DVR, dc-link capacitor is completely discharged. Due to high value of capacitor, a large magnitude of current can flow through the shunt converter at starting of DVR. To limit this initial current, a resistor is connected in series with shunt converter at starting of DVR called precharging resistor Rs. As dc-link voltage become equal to the peak of ac voltage, Rs is bypassed with help of a relay connected in parallel with Rs. The DVR compensates the voltage in the range 185-265 V (rms). If the voltage to be compensated exceeds this limit, the DVR is turned off. To turn off DVR, the pulses supplied by the DSP to the converters are stopped and load is supplied by the bypass SCRs.

Plug and Play Operation of DVR

As soon as DVR, is plugged in load circuit at starting, the following steps are adopted for its reliable and fault free operation. At starting the MOSFETs of both the converters are kept off and bypass DRIVER are kept on. Charging of dc link capacitor takes place through pre-charging resistance. As capacitor voltage reaches to peak value of ac voltage, pre charging resistor is bypassed through the relay. At the same instant, soft start operation to build dc link voltage up to 200 V is initiated. Voltage and current controller determine the switching sequence of the shunt converter. As soon as dc link capacitor reaches at 200 V, the switching pulses to the load side converter are released. The DVR is connected to the circuit and bypass DRIVER are turned off.

STEPS:

Step 1: Start the program.
Step 2: Initialize the Port C and Port B of microcontroller.
Step 3: Initialize LCD connected to Port D.
Step 4: Clear the LCD display.
Step 5: Display the “WELCOME”.
Step 6: Check whether voltage sag problem occurred or not
Step 7: If “yes”, go to next Step, otherwise go to Step 11.
Step 8: Microcontroller passes signals to Relay,
Comparator and activates DVR Circuit
Step 9: Repeat Step 3 and Step 4.
Step 10: Display “VOLTAGE SAG OCCURS” and
“VOLTAGE TO BE ADDED “
Step 11: Check whether the voltage is in Normal condition or not.
Step 12: If “yes”, go to next step, otherwise go to Step
14.
Step 13: Repeat Step 3 & Step 4 and display “NORMAL STATE”.
Step 14: Check whether the voltage is above the Normal level.
Step 15: If “yes”, go to next Step, otherwise go to Step 6.
Step 16: Repeat Step 3 & Step 4 and display “LOAD REMOVED”.

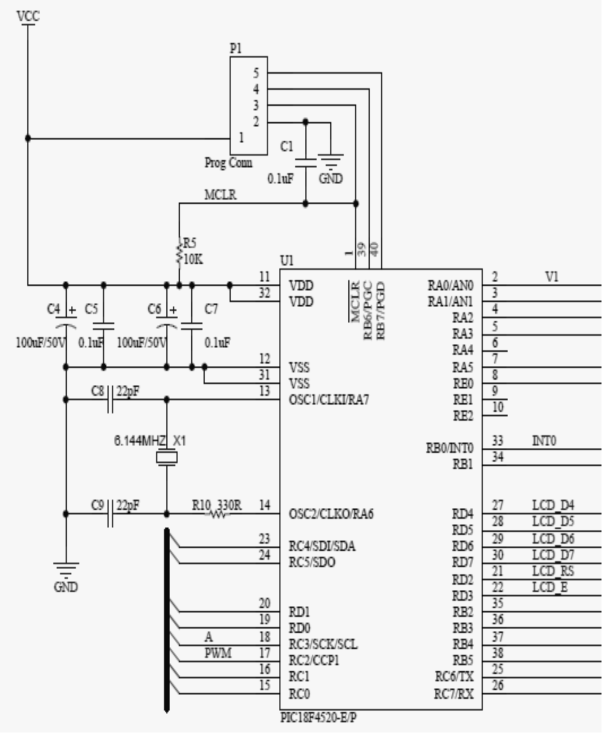


Fig: 5 Controller circuit

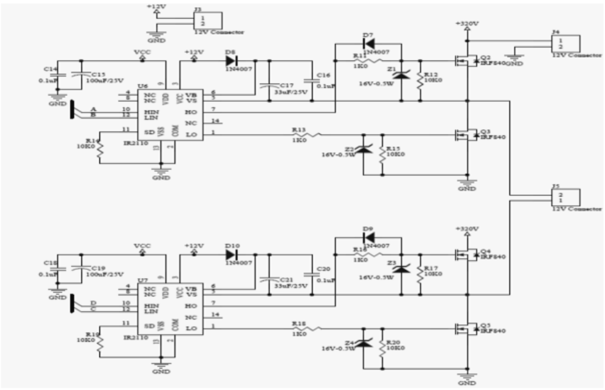


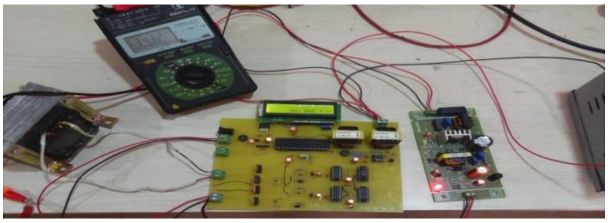
Fig: 6 Full bridge Inverter Connection with Driver

Circuit Description:

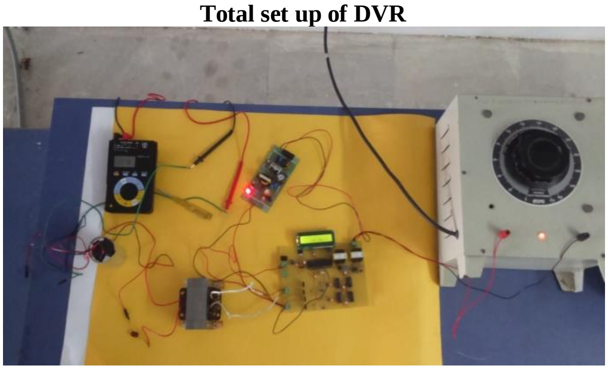
The charge less device control using cell phone is designed using ring counts. The ring is connected by using ring detector circuit. The IC 4017 based ring detector circuit gives sequence pulses to capacitor charger based comparator circuit. Where capacitor provide input values for each comparator. For each ring any one of the comparator is selector and capacitor starts to charge. The 1K and 10K based voltage divider circuit provide reference values for each comparator.

In our demo version we choose rings 3, 5 and 7 for operating the electrical device. After making required ring the corresponding RC network charger and produce pulses to next stages. In microcontroller, toggle operation is carried on.

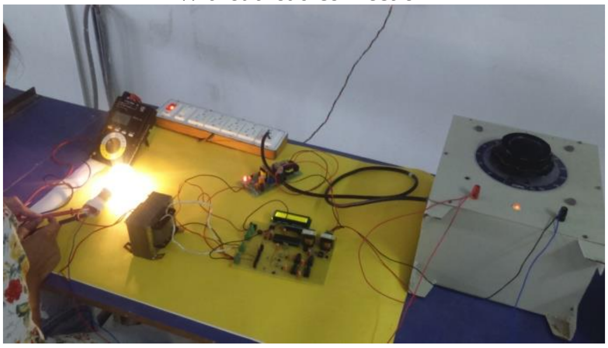
RESULTS AND OUTPUTS



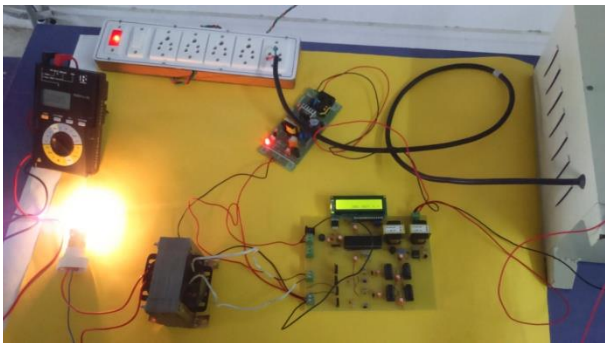
Total set up of DVR



Without load connection



With 15 w load



With 25 w load

V. CONCLUSION

In this project, the hardware implementation of a DVR has been presented. The hardware results showed clearly the performance of the DVR in mitigating voltage sag as well as swell. The DVR handles the situation without any difficulties and injection or absorption the appropriate voltage component to correct rapidly any changes in the supply voltage thereby keeping the load voltage balanced and constant at the nominal value. In this study, the DVR has shown the ability to compensate for voltage sag. this has been proved through hardware implementation. The efficiency and effectiveness on voltage sag compensation showed by the DVR makes it an interesting power quality device compared to other custom power devices. It is planned to implementation of DSP based for the Dynamic Voltage Restorer in future work.

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