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A DYNAMIC VOLTAGE RESTORER (DVR) BASED MITIGATION SCHEME FOR VOLTAGE SAG AND SWELL

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Abstract— Power Quality is the measure, analysis and improvement of bus voltage, usually a load bus voltage to be sinusoidal at rated voltage and frequency, while power quality at the transmission and distribution level refers to the voltage staying within plus (or) minus 5 percent. The voltage sag and swell are the major issues of power quality, it will create severe problems for industrial customers and much attention is needed for its compensation. One of the most popular method of voltage sag and swell mitigation are employing by a Dynamic Voltage Restorer (DVR) added to the power system network. The DVR is fast and flexible equipment that provide efficient solutions to the mitigation of voltage sag and swell problems. It initializes power electronic control devices that enable three phase controllable voltage sources, whose voltage vector (magnitude and phase angle) changes when the source voltage changes during voltage sag and swell event, and it restore the load voltage to its normal valve. The DVR is designed for protecting the whole plant with load and it can restore the load voltage within few cycles. This project work proposes a simulation study of voltage sag and swells mitigation by using DVR, and it is carried by using MATLAB/SIMULINK software package and PLC PROGRAMMING. The simulation results show that the proposed method is able to provide desirable power quality with the presence of disturbances.

*Index terms—Dynamic Voltage Restorer (DVR), Filter, Injection/Booster Transformer, Point of Common Coupling (PCC), and Voltage Source Converte*r.

1 .INTRODUCTION

Power quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .The advent and wide spread of high power semiconductor switches at utilization, distribution and transmission lines have non sinusoidal currents. The electronic type load causes voltage distortions, harmonics and distortion. Power quality problems can cause system equipment malfunction, computer data loss and memory mal function of the sensitive equipment such as computer, controllers, and protection and relaying equipment. Voltage sag and swell are most wide spread power quality issue affecting distribution systems, especially industries, voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute. Voltage swell, on the other hand, is defined as a swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min, typical magnitudes are between 1.1 and 1.8 up. Swell magnitude is also is also described by its remaining voltage, in this case, always greater than 1.0. The causes for the voltage swells are switching off a large inductive load or energizing a large capacitor bank is a typical system event that causes swells.

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Power quality in the distribution system can be improved by using a custom power electronic device DVR for voltage disturbances such as voltage sags, swells, harmonics, and unbalanced voltage. The function of the DVR is a protection device to protect the precision manufacturing process and sophisticate sensitive electronic equipment's from the voltage fluctuation and power outages. The DVR has been developed by Westinghouse for advance distribution and also to maintain power quality. The DVR is able to inject a set of three single-phase voltages of inappropriate magnitude and duration in series with the supply voltage in synchronism through injection transformer to restore the power quality.

This paper introduces Dynamic Voltage Restorer and its operating principle. Then, a simple control based on dqo method is used to compensate voltage sags/swell. At the end, MATLAB/SIMULINK model based simulated results were presented to validate the effectiveness of the proposed control method of DVR to maintain the power quality. The PLC programming was also done along with it for the additional operational function of the controller in the system in order to maintain power quality.

2. DYNAMIC VOLTAGE RESTORER

The basic functions of the DVR are the detection of voltage sag/swell occurred in the power line and injection of balance voltage through injection transformer so as to maintain the desired load voltage. This can be achieved either by absorbing or injecting the active and reactive power. It basically consists of, Battery energy storage, Voltage Source Inverter, Passive Filter, Injection/ Booster Transformer as shown in Fig 1.

1) DC Energy Storage:

This circuit charges the energy source after sag compensation and maintains dc link voltage at the nominal dc link voltage. Various devices such as flywheels, lead acid batteries, super conducting magnetic energy storage and super capacitors can be used as energy storage devices. The DC energy storage device will act both during voltage sag and swell.

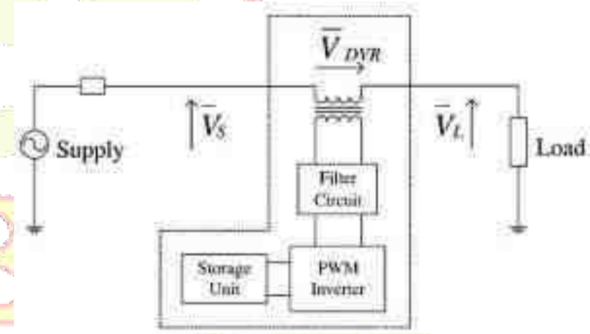

Fig 1. Circuit diagram of DVR

2) Voltage Source Inverter (VSI):

It converters the DC Voltage supplied by the energy storage device to a sinusoidal voltage at any required frequency, magnitude and phase angle. There are four types of switching devices, Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Gate Turn off thyristor (GTO), Insulated Gate Bipolar Transistor (IGBT) and Integrated Gate Commutated Thyristor (IGCT).Each type has its own benefits and drawbacks.

3) Passive Filter:

It consists of an Inductor and a capacitor .It eliminates the higher order harmonic component during DC to AC conversion in Voltage Source Inverter which will distort the compensated output voltage. These Filters can be placed either load side or inverter side.

4) Injection /Booster Transformer:

The primary of the injection transformer is connected in series with the distribution line and the secondary of the injection transformer is connected to the DVR power circuit. The main functions of

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Injection /Booster Transformer are the increasing the voltage supplied by the filtered Voltage Source Inverter (VSI) to a desired level and isolation of the DVR circuit from distribution network.

2.1. EQUIVALENT CIRCUIT

The equivalent circuit of the Dynamic Voltage Restorer (DVR) was given below as follows in the Fig.2.The Fig 2 shows the Thevenin equivalent circuit of the DVR. During Voltage sag/ swell, the DVR injects a series voltage V DVR through the injection transformer so as to maintain the desired load Voltage VL .The series voltage injected by the DVR (VDVR) can be obtained as,

$$VDVR=VL + ZTH\ IL-VTH \text{...... (1)}$$

Where,

V_L ➔ desired load voltage

Z_{TH} ➔ Thevenin equivalent impedance

I_L ➔ Load current

V_{TH} ➔ system voltage during fault.

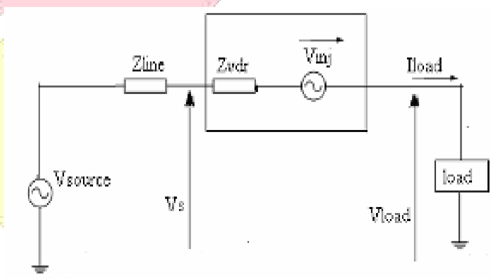

Fig 2. Equivalent Circuit of DVR

The load current is given by,

$$I_L= [P_L+jQ_L]/ V \text{...... (2)}$$

The Load power factor angle θ is given by,

$$\theta= \tan -1 (Q_L/ P_L) \text{...... (3)}$$

The complex power injected by DVR can be written as

$$S_{DVR}= V_{DVR} *I_L \text{...... (4)}$$

From the above equation, it is clear that when the injected voltage VDVR is in quadrature with IL, DVR requires only reactive power and the DVR itself generate the reactive power. Other phase relationship between V DVR and I L requires active power injection which must be provided by the energy storage of the DVR system.

2.2. OPERATING MODES OF DVR

The operating modes of the DVR were given by three following modes as follows:

- Protection Mode
- Standby Mode
- Injection/Boost Mode

a) Protection Mode:

If the over current on the load side exceeds a permissible limit due to short circuit on the load or large inrush current, the DVR will be isolated from the systems by using the bypass switches and supplying another path for current.

b) Standby Mode:

In the standby mode the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation and the full load current wills pass-through the primary.

c) Injection/Boost Mode:

In the Injection/Boost mode the DVR is injecting a compensating voltage through the booster transformer due to the detection of a disturbance in the supply voltage for both voltage sag and swell.

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3. EXISTING SYSTEM

The power quality was maintained generally by using two techniques.1) line conditioning and 2) load conditioning. In the line conditioning the power quality was maintained in the transmission line side and also the power quality was maintained in the load side by using the load conditioning and these conditionings were done by using various techniques. The existing system for the Dynamic Voltage Restorer (DVR) is to remove the faulty part in the power system, when there is fault occurred in the transmission line then the dynamic voltage restorer will act and isolate the faulty part in the power system without disturbing the other systems. So that the fault can be rectified by the technicians and the fault will be removed.

4. PROPOSED METHOD

The proposed method by using the DVR to maintain the power quality was given by the block diagram given below in Fig 3 and Fig 4. The first block represents the overall system,

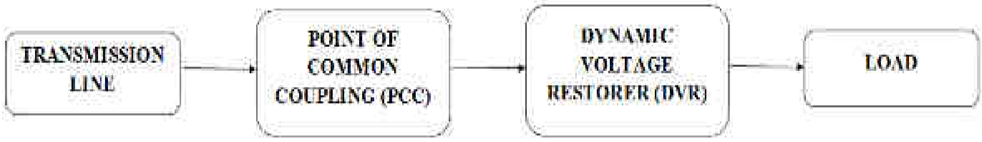

Fig 3. Block Diagram of Overall System

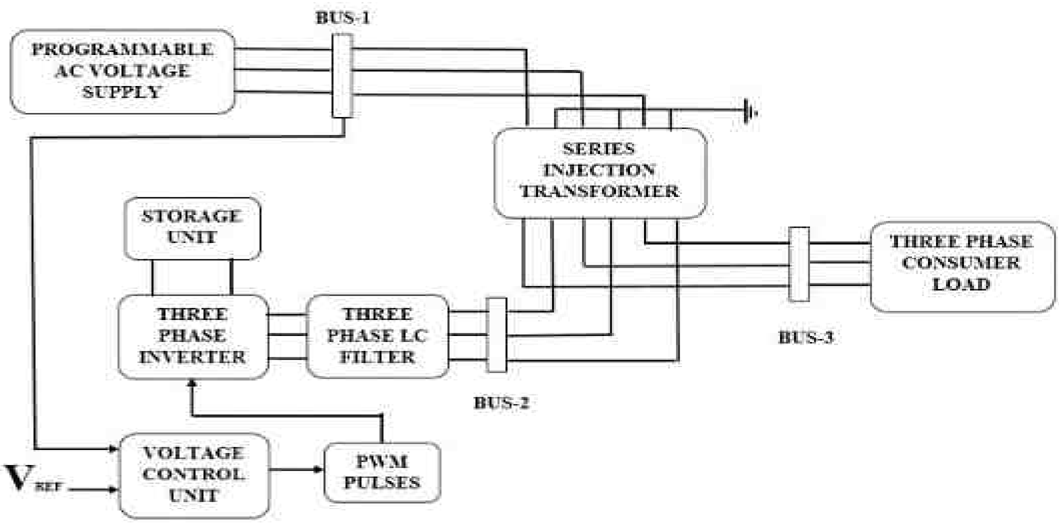

Fig 4. Block Diagram of DVR operation

The DVR was introduced between the Point of Common Coupling (PCC) and load, so that the power quality was maintained at the PCC. The voltage sag and the swell Mitigated at that point. The operation of the DVR was explained clearly from the above block diagram Fig 4.Generally the voltage and the current was measured in the transmission line with the help of VI measuring unit, and allows the signal to the control unit. The control unit measures the actual signal and the reference signal and if any variation is present in the controller the signal was sent to the driver circuit and the driver circuit will decide whether the operation required is inverter or rectifier and the operation will occur based on that problem occurred in the power system. The schematic diagram of the DVR was given in the Fig 5.

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4.1. CONTROL STRATEGY:

A DVR must be able to react very fast on different kinds of voltage sag and swell. The amplitude of the load-side voltage must be restored and for most loads large phase jumps must be avoided.

Especially, the correct compensation of single-phase voltage sag/swell is a major issue. Since DVR uses ESD and DC-link, it will be discharged during the compensation. Hence, the voltage of DC-link will be constantly decreasing during operation mode. Therefore, the modulation index must be kept constant and adapted during the fault. There are two basic control strategies, namely amplitude compensation and amplitude and phase angle compensation adopted for VSC control. To avoid a loss of power supply, the amplitude of the load voltage has to be restored by the DVR.

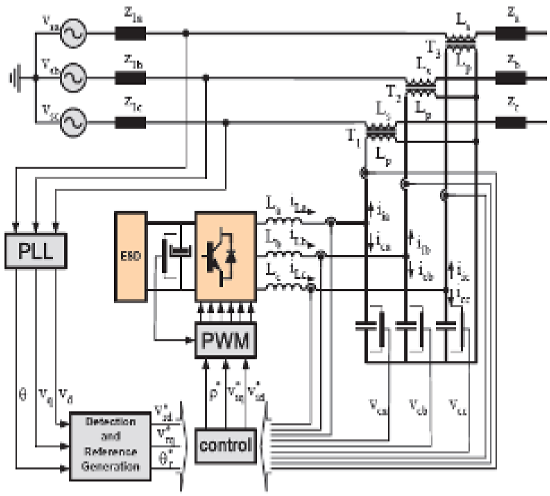
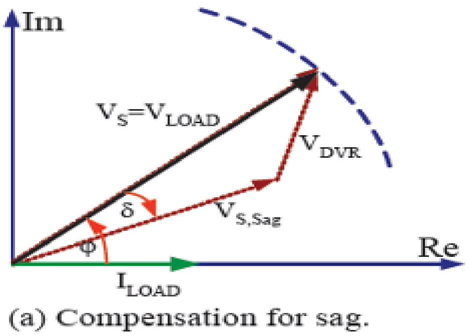


Fig 5.Schematic diagram of DVR



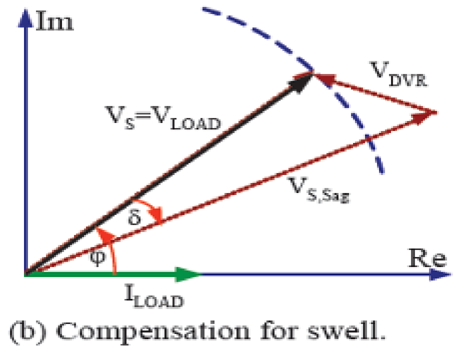


Fig 6. Over compensation for Sag Fig 7. DVR Compensation for Swell

4.1.2. CONTROL ALGORITHM:

The basic functions of a controller in a DVR are the detection of voltage sag/swell events in the system; computation of the correcting voltage, generation of trigger pulses to the sinusoidal PWM based DC-AC inverter, correction of any anomalies in the series voltage injection and termination of the trigger pulses when the event has passed. The controller may also be used to shift the DC-AC inverter into rectifier mode to charge the capacitors in the DC energy link in the absence of voltage sags/swells.

The dqo transformation or Park's transformation is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities are expressed as the instantaneous space vectors. Firstly convert the voltage from a-b-c reference frame to d-q-o reference. For simplicity zero phase sequence components is ignored in the system. Figure 8 illustrates a flow chart of the feed forward dqo transformation for voltage sags/swells detection. The detection is

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carried out in each of the three phases. The control scheme for the proposed system is based on the comparison of a voltage reference and the measured terminal voltage (Va,Vb,Vc).

The voltage sags is detected when the supply drops below 90% of the reference value whereas voltage swells is detected when supply voltage increases up to 25% of the reference value. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The commutation pattern is generated by means of the sinusoidal pulse width modulation technique (SPWM); voltages are controlled through the modulation.

The block diagram of the phase locked loop (PLL) is illustrated in Figure 8. The PLL circuit is used to generate a unit sinusoidal wave in phase with mains voltage, equation 5 defines the transformation from three phase system a, b, c to dqo stationary frame. In this transformation, phase A is aligned to the d-axis that is in quadrature with the q-axis. The theta (θ) is defined by the angle between phases A to the d-axis.

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad \ldots\ldots. (5)$$

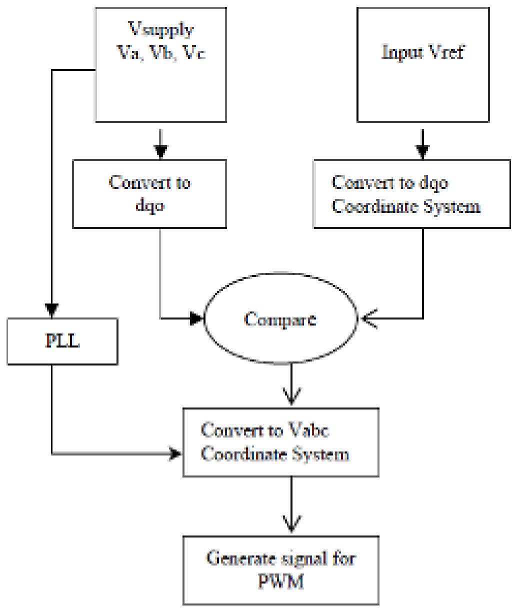


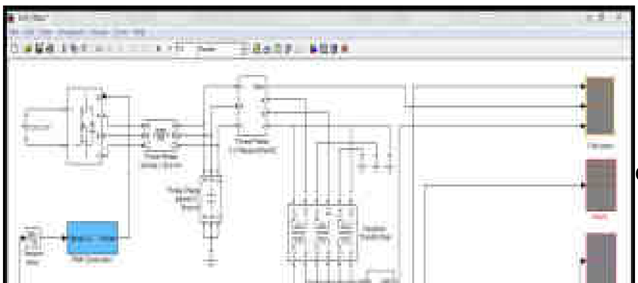
Fig 8. Flow chart of feed forward control for DVR based on dqo transformation

Thus the control algorithm for the Dynamic Voltage Restorer (DVR) was explained with the flow chart using the Phase Lock Loop (PLL).

5. SIMULATION RESULTS AND DISCUSSION

5.1. MATLAB/SIMULINK SIMULATION:

A detailed system as shown in Figure 8 has been modeled by MATLAB/SIMULINK to study the efficiency of suggested control strategy which was given below as follows, and the events which will happen during the voltage sag and the voltage swell was given below as follows technique .



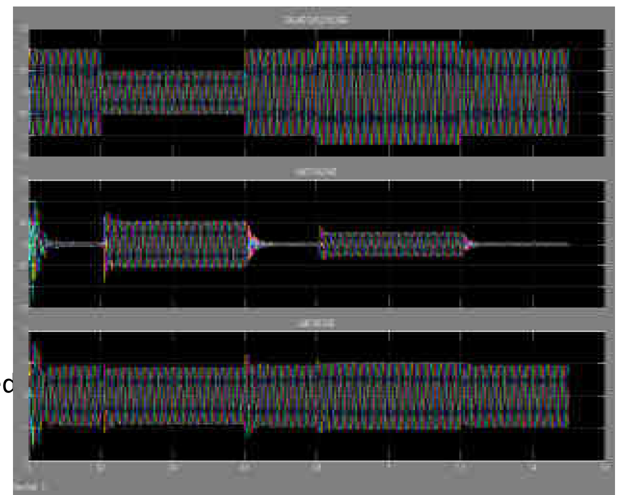


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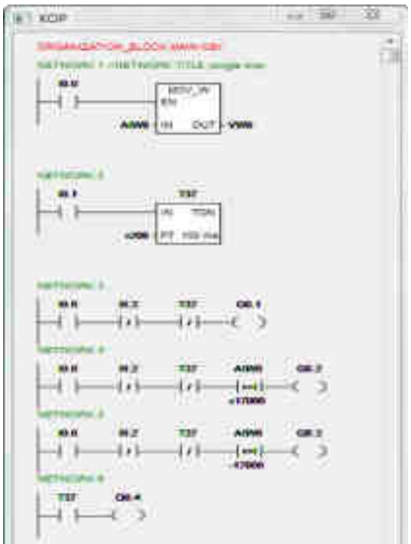
Fig 9. MATLAB simulation

Fig10. Three-phase voltages sag and swell: (a)-Source Voltage, (b)-Injected voltage, (c)-Load voltage

5.2. PLC PROGRAMMING:

1. Platform : Siemens Programming
2. Tool : Micro win 32 Step 7
3. Type : Modular PLC S7-200
4. Description :

The controller operation of the Dynamic Voltage Restorer (DVR) during the voltage sag and voltage swell event was explained with the help of the Programmable Logic Controller (PLC) S7-200. The general concept of the PLC S7-200 and the simulation operation was explained below. The program which is required to done the operation in the controller was given in the Fig 11. In this software the controller operation was clearly explained by using the Micro win 32 step 7 software and the overall working of the controller was given below and the controller successfully function for both the voltage sag and voltage swell the operation of the software and the output was given below by the screen-shot in the Fig 12 as shown.



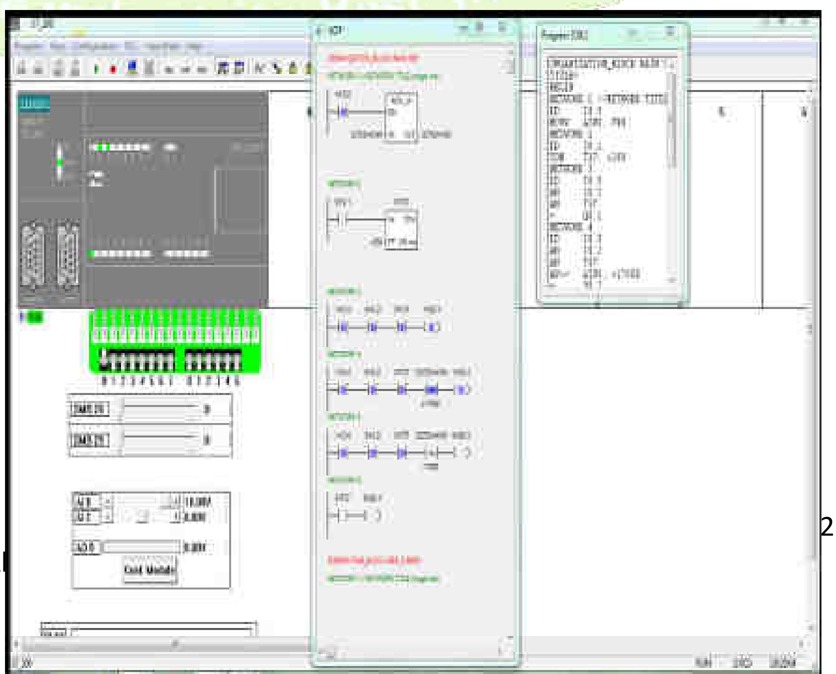


Fig 11. PLC Programming in Ladder Logic

Fig 12. PLC Operation in Controller

6. CONCLUSION

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. A control system based on dqo technique which is implemented between source side of the DVR and its reference for sags/swell correction has been presented. The simulation shows that the DVR performance is satisfactory in mitigating voltage sags/swells. By using DVR the harmonic compensation, fault current limitation, and the transient stability was maintained. From simulation results also show that the DVR compensates the sags/swells quickly and provides excellent voltage regulation. The DVR handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component to the supply voltage to keep the load voltage balanced and constant at the nominal value.

The simulation of PLC was also implemented for the controller operation, so that in industries we can maintain the power quality by modifying their own PLC by adding additional program which implemented in this project, so that the cost can be minimized and also the power quality can be maintained. The future work will be done by implementing this method into real-time to maintain power quality with the help of Dynamic Voltage Restorer (DVR) for a short period of time. Further this can be advanced in future by introducing the microcontroller for the complete automation operation.

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