SINUSOIDAL PULSE WIDTH MODULATION (PWM) AND SPACE VECTOR PULSE WIDTH MODULATION (SVM) TECHNIQUES TO MINIMIZE THE IMPACT OF CCVT TRANSIENT ON PROTECTIVE RELAYS.

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ABSTRACT—*As Power transmission system is exposed to different faults and most of the faults lead to problem of voltage sag in the power system. Similarly in case of heavy loaded transmission lines the voltage level is dropped to a considerable amount. Voltage variation becomes very serious problem when a heavy load is connected or removed in power system; similarly occurrence of fault also contributes a severe problem causing voltage variation. Many methods are used to regulate the voltage at output load end such as tape changer or booster transformers are the most common example for voltage regulation. For reliable electrical system protection relays must be accurate and high speed devices which can discriminate fault and normal system variations. The system voltage is maintained within specific limits and DVR based Model is implemented in MATLAB/Simulink. The results are simulated and the performance characteristics of protection relays are analysis using these switching techniques***.**

Index Terms— FACTS, D-Statcom, DG, PQ.Microgrid.

I. INTRODUCTION

As power transmission system is exposed to different faults and most of the faults lead to problem of voltage sag in the power system. Similarly, in case of heavy loaded transmission lines the voltage level is dropped to a considerable amount. Usually voltage sag caused in power system persist for consider able time which may cause malfunctioning of protection relays under normal operation conditions of power system. So in case of voltage swells the reliability of the protection relays is always on stack which may cause a sever production cost or severe damage of consumer equipment. Voltage variations on transmission lines are compensated with the introduction capacitors or shunt reactors. For reliable electrical system protection relays must be accurate and high speed devices which can discriminate fault and normal system variations. As the reliability of the protection relays is totally dependent on the accuracy of instrument transformers such as current transformer and voltage transformers. Actually current and voltage transformers transmit replica of primary side of power system to secondary side. So to have best result the voltage variations on the primary side of instrument transformers must be controlled. The voltage sags have a severe impact on the performance of the protection relays used in power system. Voltage variation becomes very serious problem when a heavy load is connected or removed in power system [1]; similarly

occurrence of fault also contributes a severe problem causing voltage variation. Many methods are used to regulate the voltage at output load end such as tape changer or booster transformers are the most common example for voltage regulation. Although the tape changer and booster transformers are efficient to maintain the constant voltage at output load but the response for regulation of voltage is not quick. In high and medium voltage power system the active and reactive power flow in transmission lines and transformers is usually controlled by introducing tape changer transformers. A servo stabilizer which is servo motor operated is used for tape changing purpose and voltage regulation is achieved by connecting these regulating transformers. Voltage regulation is also attained by introducing capacitor banks at the load end [2]. Synchronous machines are also used to regulate the voltage by varying their field current. As the servo stabilizer voltage regulators carry the drawback of slow voltage regulation so thyristor switched voltage regulators are used for faster response [3]. Different FACT devices are used for voltage regulation based on electronic circuits in which thyristors are connected to switch as per requirement. These devices are connected in parallel or series for power or voltage compensation in the system. DSTATCOM is shunt compensation while DVR is series compensation device [4] [5]. Basically DVR system is composed of injection transformer; low pass filter voltage sensing system with inverter and voltage control system. An error signal is generated by comparison of control voltage and reference voltage, this error signal is fed to inverter circuit. Different modulation techniques are used in inverter circuit. Sinusoidal Space Width Modulation and Space Vector modulations are used. Similarly, voltage booster transformers or Servo Stabilizers are used to regulate the voltage in power system. Servo Stabilizer is low impedance transformer which regulates the voltage as the voltage stability at the remote end is main concern in smooth running of system. A tape changing circuit is implemented that regulates the voltage thyrister switches are used to for tap changer position switching as per requirement of the voltage level

To overcome the problem of voltage sags different devices are available, Dynamic Voltage Resistor (DVR) is one of these devices. DVR is very effective in this regard. Actually DVR is based on the principal of voltage sags for balanced and unbalanced voltage variation system. The inverter in DVR circuit plays a key role in restoration of voltage sag.

In this paper two inverter is based on switching schemes are used for this purpose, Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width modulation (SVPWM) are two most effective switching techniques that can be implemented for DVR inverter switching. SPWM and SVPWM are implemented in MATLAB/Simulink. The results are simulated and the performance characteristics of protection relays are analysis using these switching techniques. The rest of the paper presents the following sections: Section-II

describes Dynamic Voltage Restorer infrastructure; Section-III about voltage sag problems and protection relays; Section-IV presents test system Model Section-VI presents analysis & results and Section-V concludes the paper.

II. DYNAMIC VOLTAGE RESTORER

An abrupt change in voltage supply causes damage to power equipment and is a major reason for unwanted delay of production. To maintain or regulate the voltage supply due to voltage swells or sags problem Dynamic Voltage Restore can be used. DVR has wide varieties of applications; mostly it is used in manufacturing industries such as plant utilities [6].DVR is composed of different electronic components and performs voltage injection in the power system. The key role of DVR is to provide constant RMS voltage and protect the sensitive load. The distortions and disturbances in power system are compensated by injection of voltage in system through DVR [7]. To attain excellent power quality which means the voltage must be sinusoidal with constant system frequency such as 50 or 60 Hz DVR is used to provide voltage compensation at distribution as well as transmission level. DVR is installed on the electrical power feeder which has tendency of voltage sag problem due to nature of load installed on it and this feeder is declared as critical feeder. DVR ensure the voltage compensation of this feeder having unbalanced phase supply and active power is provided by DC storage. Faults and disturbances that may occur in system can be effectively eliminated by DVR but circuit breaker must be close and main source should be connected at time of these disturbances. Many techniques has been proposed for compensation of voltage supply but most effective method is to compensate on bases of symmetrical components such as positive and negative sequence components. Basically method for supply compensation by utilizing positive and negative sequence component is economical method. As a step-up transformer with high impedance is mentioned in simple schematic diagram of DVR so the zero components cannot be passed through this system.

A.Main Component of DVR

a. DVR main circuit

DVR main circuit is composed of three phase inverter, comparator and series connected transformer. The proposed configuration of DVR main circuit is shown in figure 1. The main circuit sensed the disturbances in the circuit this is sensed by voltage transformer connected in series of inverter. The dq0 transformation is utilized to convert this signal and comparator conversion signal with reference signal. The comparator output signal triggered the three phase inverter which is actually error signal generated after comparison with reference voltage. Three phase inverter output signal is fed to set-up transformer for the compensation of distorted voltage in main circuit. As the output of three phase inverter has harmonics so these harmonic must be suppressed through filtration. For this purpose LC filter is used which filter the harmonics and this filtered signal is input to booster transformer.

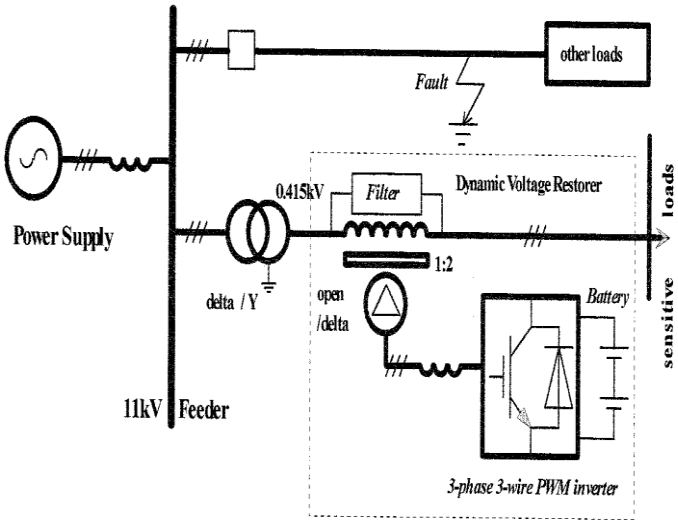

Figure-1 Schematic DVR main circuit

b. DVR control algorithm

As DVR is controlled base system so the controller is main component of DVR device [8]. DVR controller controls the DVR by its output which is error signal after the detection of voltage variation such as voltage swell and sag in power system. The controller compared the voltage signal in case of disturbances with reference voltage and an error signal is generated which is used to generate the pulses for triggering operation of three phase inverter. These trigger pulse are generated by some switching technique. This DVR controller selects the operation mode of DVR system it interchanges the inverter to rectifying mod when there is no disturbance and DC storage unit is connected to it. Simple control blocks are shown in figure 2.

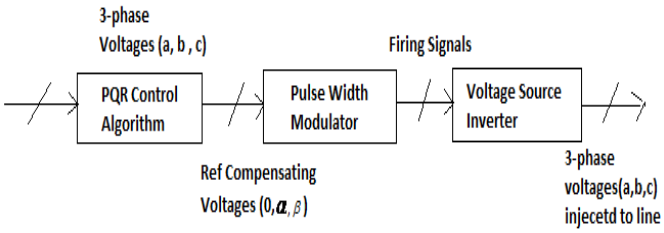

Figure-2 Control flow of DVR controller

c. Voltage Source inverter

The switching is performed by VSI device, this switching device is used for conversion of DC into Ac power. It also provides an interconnection for storage source and switching devices [9]. The controller output provides the desired parameters to generate the sinusoidal signal for compensation of transient or temporary distortion in the voltage. The VSI has capacity to generate the required signal of specific magnitude, phase and frequency. Basically VSI in DVR system performs magnitude and phase restoration of main

supply signal. The rated specification of VSI is selected on the bases of set-up transformer due to this set-up transformer the VSI has high current and low voltage ratings.VSI can be designed by different electronics circuit but most simple and common is VSI multilevel three phase converter. DC capacitors are used to absorb these harmonic contents at each stage. VSI based on PWM is expressed in figure-3

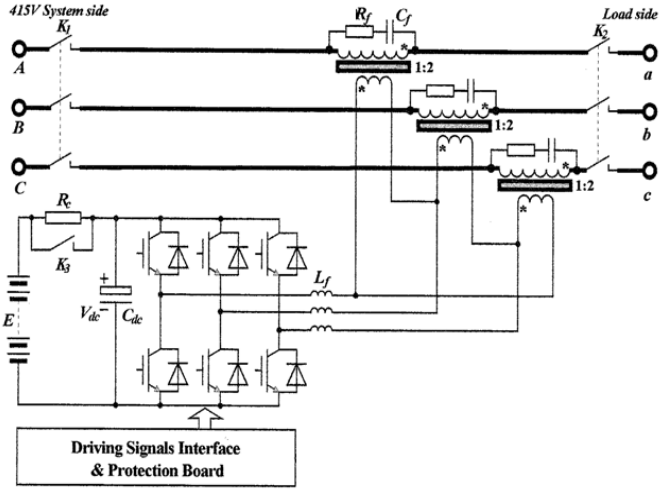

Figure-3 Three phase VSI.

d. Switching Devices

As DVR is based on switching so switching elements has vital importance in DVR circuit. Many semiconductor devices are available for this purpose some of these are given as

- Metal Oxide Semiconductor Field Effect Transistors (MOSFET).
- Insulated Gate Bipolar Transistors (IGBT).
- Gate Turn- Off thyristors (GTO).
- Integrated Gate Commutated Thyristors (IGCT).

These switching devices are used as per circuit requirement each device has its own advantages and disadvantages. IGBTs are commonly used for switching purpose in modern electronic circuits, IGBTs are switching elements and create harmonics at the output which can be eliminated using harmonic filter.

e. Harmonic Filter

As already discussed the Voltage source inverter contains harmonic contents, VSI is based on switching devices and during operation of these switching devices ripples are generated as the operation of these devices is based on high frequency. VSI produced output with ripples having small magnitude and high frequency. Although ripples are small in magnitude as these ripples are 2% of nominal voltage signal but these ripple contents must be filtered out. Harmonic filters are used for this purpose in DVR circuit these filter are connected at input and output sides of booster transformers. As most of the harmonic contents are generated by inverter therefore harmonic filter must be placed at the output of this voltage inverter before booster transformer. Filter is placed closed to source which is low voltage and high current side of transformer this filter also provides blocking for the harmonic contents to enter in booster transformer winding. These harmonic filters are basically combination of inductor and capacitor elements. These inductor and capacitor create phase shift in signal therefore voltage will be drooped during compensation.

f. Storage Batteries

Voltage source inverter (VSI) generates a signal to inject voltage in the system during system voltage variation such as swell or sag. This energy is provided by energy link to VSI. During occurrence of disturbances the energy storage link provides active power at load end through VSI. So as for purpose of DVR is concerned the storage unit is the most important module of VSI. The energy storage link has vital importance as the duration of sag/swell compensation is directly affected by this energy storage unit.

g. Series Connected Transformer

A transformer is connected in series known as injection transformer or booster transformer having low resistance winding. This transformer is used for various purposes as

- Isolation is provided by booster transformer between load and DVR.
- Coupling noise and transient energy consumption is minimized by injected transformer.
- Main circuit is connected with DVR through injection transformer.

Injected transformer is fed by output of voltage source inverter.

III. VOLTAGE VARIATION PROBLEM AND PROTECTION RELAY

Voltage variation becomes very serious problem when a heavy load is connected or removed in power system; similarly occurrence of fault also contributes a severe problem causing voltage variation. Many methods are used to regulate the voltage at output load end such as tape changer or booster transformers are the most common example for voltage regulation. Although the tape changer and booster transformers are efficient to maintain the constant voltage at output load but the response for regulation of voltage is not quick. For reliable electrical system protection relays must be accurate and high speed devices which can discriminate fault and normal system variations. As the reliability of the protection relays is totally dependent on the accuracy of instrument transformers such as current transformer and voltage transformers. Actually current and voltage transformers transmit replica of primary side of power system to secondary side. So to have best result the voltage variations on the primary side of instrument transformers must be controlled. The voltage sags have a severe impact on the performance of the protection relays used in power system. In power system protection relays are used to protect the power equipment in case of fault. A fault is detected and located by protection relays and a trip signal is sent to the concerned circuit breaker so that the faulty system can be isolated from healthy system. These relays detect fault based on changes in its input electrical quantities such as voltage and current. The power system require high integrity in case of protection relays these relays must no operate in normal condition or for healthy power system and it must be operated in abnormal conditions. The reliable protection system is essential to avoid

unnecessary outage of power system. In order to ensure this reliability the protection zones are created and the relay is configured in such a way that it must be operated only for faulty section of power system. The input for sensing the condition of power system is current and voltage those are usually fed to relays by voltage transformers (VTs) and current transformers (CTs) respectively. As the voltage and current transformers transform the exact replica of primary side condition on secondary side so any variation on primary side of these transformer has direct impact on secondary side where protection relays are connected. Therefore, for the voltage variation such as Sag or swell problem these protection relays are also affected and these relay can be mal operated. The DVR is implemented to overcome this voltage sag or swell problem so its impact must be analyzed on these protection relays.

IV. SYSTEM MODEL

In power industry power quality is main concern as variation in voltage can cause heating or damage of power equipment and unnecessary tripping of healthy system. Dynamic Voltage Restorer is used to overcome the voltage sag of swell problem, Basically DVR system is based on injection transformer, low pass filter voltage sensing system with inverter and voltage control system. An error voltage is calculated and fed to inverter for maintain voltage as required. Higher level harmonics present in output is eliminated by low pass filter in DVR. Voltage inversion schemes Sinusoidal Pulse Width Modulation (SPWM) is implemented and its impact is analyzed on the protection relays. Both the schemes are implemented in MATLAB Simulation their impact on protection relay is analysis and harmonic contents and response time is calculated.

Sinusoidal PMW and SVM techniques are simulated for DVR. Simulation is performed in MATLAB and results of both techniques are analyzed for DVR. The desired model is simulated with following methodology.

1. MATLAB simulink is used to simulate the power system. Power system with three phase input voltage, set of setup transformer a set down transformer and transmission line with RLC load is simulated.
2. Load voltage is measured using voltage measurement and this measured voltage is fed to control system.
3. Control system is used to convert phase sequence from abc to dq0. Control system is based on principle of park transformation.
4. After that, inverse Park's transformation is simulated for dq0 to abc transformation.
5. PMW generator is simulated to generate output.
6. Power inverter block is used which is connected with output of PMW generator output.
7. A simple inductor and capacitor is used to form LC filter, inverter one end is connected to filter block and other end is connected to DC link.
8. The injection or booster transformer is used before LC filter to inject voltages for sensitive load.
9. Over current and differential relays are simulated.

The basic idea of voltage source inverter is the conversion of DC to AC by using different switching techniques. PWM and SVM are used for switching of inverter switching devices such as IGBTs, IGBTs turn on and turn off on principle of these techniques.

A. Test Model

The power network with the 11 KV feeder is implement and Sinusoidal pulse with modulation (SPWM) is simulated in MATLAB/Simulink as shown in figure 4.

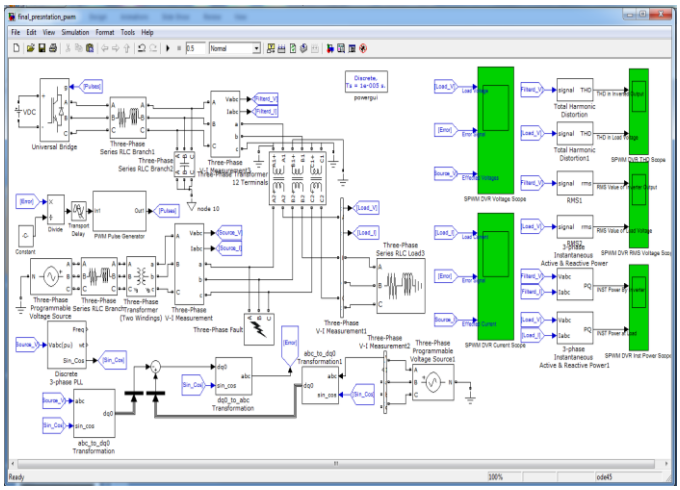

Figure 4 Matlab/Simulink based System Model.

Two control schemes for DVR are implemented in Matlab/simulink and system voltage variations are simulated to analyze the system performance. The impact of voltage variation is also analyzed on protection relays.

V. ANALYSIS AND RESULTS

This section covers the simulation results for the power quality issues associated with the transient voltage overshoot and harmonics. Sag and swell are result of amplitude disturbance in supply voltage. The abnormal condition is simulated by creating 25% sag and 80% increase in voltage for this simulation.

a. DVR with PWM control algorithm

The fault near Red phase the grid is system is simulated 0.5 sec to 0.1 sec it is shown in figure-4 that DVR is provides voltage compensation and system voltage is maintained.

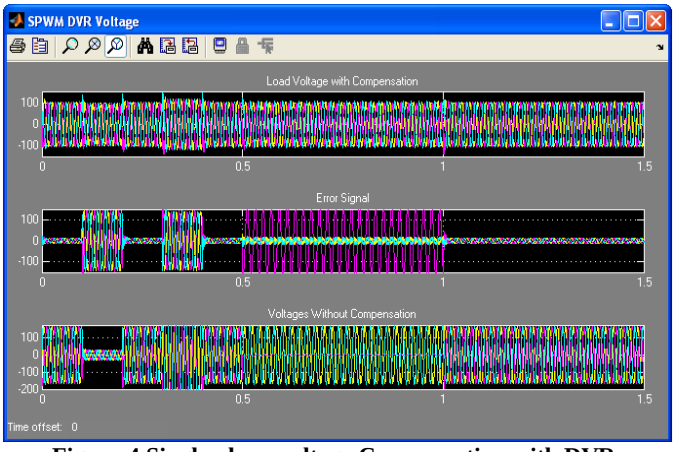

Figure-4 Single phase voltage Compensation with DVR

Now three phase fault near the grid system is simulated and the figure-5 shows the voltage compensation with DVR.

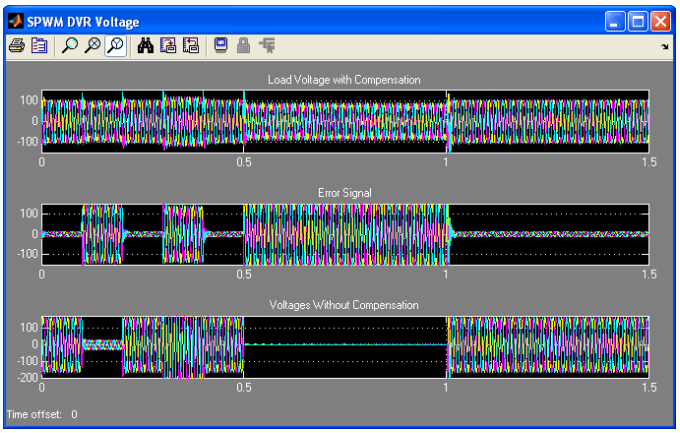

Figure-5 Three phase voltage compensation with DVR

As during fault the current increases until the faulty section is disconnected from the system.

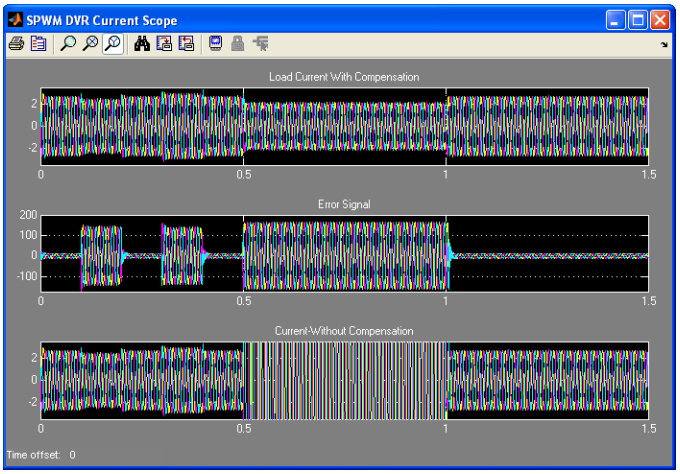

Figure-6 Load Current Compensation with DVR

Now sag and swell are formed by disturbing the voltage supply phase angle. S-PWM model with DVR is simulated with same parameters.

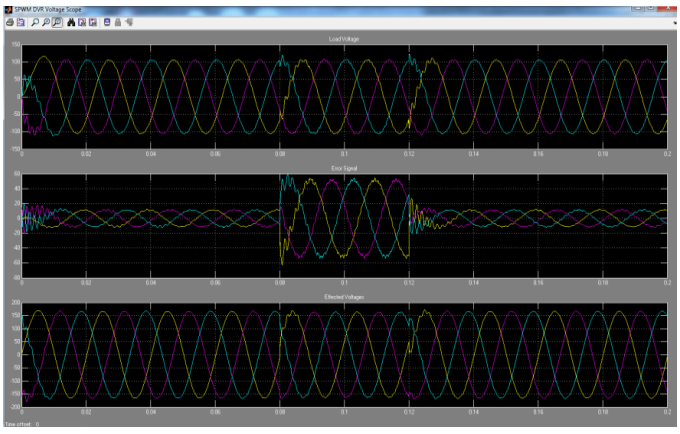

Figure-7 Phase disturbance in Supply Voltage and compensation for sag / swell

b. Simulation Results with SVM

Sag and swell are result of amplitude disturbance in supply voltage. The abnormal condition is simulated by creating 25% sag and 80% increase in voltage for this simulation.

Similarly the three phase fault is simulated and the voltage compensation is performed with DVR as shown in figure.7 and figure-**8.**

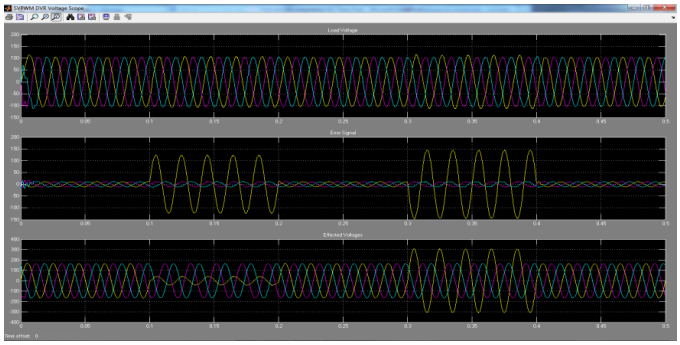

Figure-7 Single phase voltage Compensation with DVR

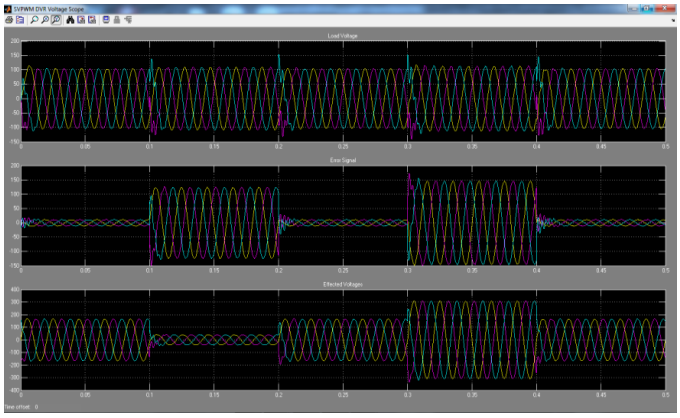

Figure-8 Three phase voltage compensation.

Similarly, harmonic are presents in the system voltage as shown in figyre-9

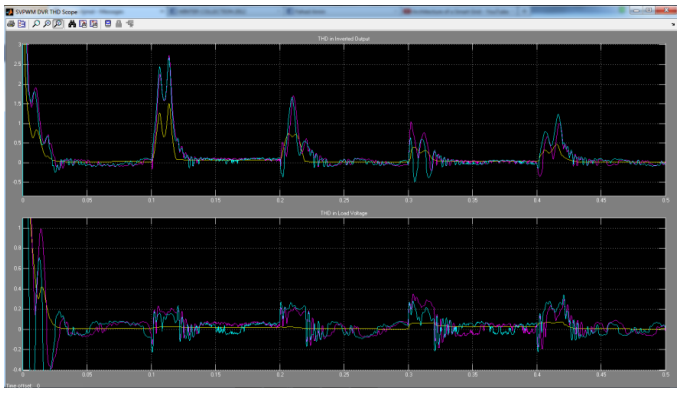

Figure-9 Harmonic distortion during disturbance.

Harmonic distortion can be eliminated by using SVM control scheme in DVR as shown in figure.10.

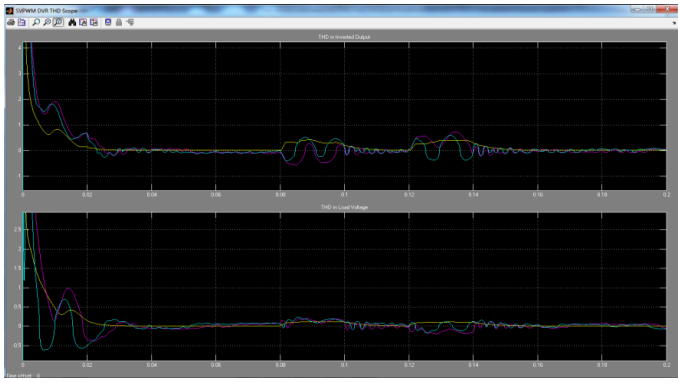

Figure-10 Harmonic distortion compensation with phase disturbances.

c. Impact on Protection Relay

The differential relay is the primary protection for transformer it was simulated with following setting parameters as in table-1.

Table 1 Setting parameters

Current Value	Primary side=2.9 A Secondary current=5 A
HV side Current	1.5A
LV Side Current	5 A

The harmonic contents have the direct impact on performance of protection relay the tripping time of relay depends on harmonic contents as shown in table-2

Table 2 Relay behavior on different Frequencies

Frequency (Hz)	Tripping Time (ms)
50	900
100	1100
150	No operation
200	No operation

The impact of voltage sag/swell is also studied and simulation is performed for it, as the harmonic contents effects the sensitivity of protection relay so by reducing the harmonic distortion the sensitivity of protection relay can be achieved. The space vector modulation technique reduces the harmonic distortion which improves the sensitivity of protection relay.

VI. CONCLUSION

The proposed scheme is to eliminate the sag or swell problem in voltage. It is observed that it provides voltage regulation and the unbalance disturbances are compensated. The sag swell in produces harmonics in system and these harmonic contents affect the performance of protection relay. The harmonic compensation is provided with proposed scheme which also improve the sensitivity of protection relay. These results shows that harmonic contents are absent during voltage sag and swell.

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