

1.1 OVERVIEW:

Power system is made up of three components which are very commonly known as Generation, Transmission and Distribution. These three when collectively combined is termed as Power system. A power system can't be reliable until it generate sufficient amount of power to meet consumer demand, and transmission system must be capable of transmit bulk power without losing stability and overloading and distribution system should deliver the power from the above two stages to each consumer. Distribution system basically indicates the end of the system and is directly concerned with consumer application. So we may say that power quality greatly depends on distribution side. So we see that power quality is customer-driven issue, and the reliability of a power system hang mainly with distribution network. It became essential, particularly with the presentation of adulterate device. Whose execution is very responsive to the peculiarity of power supply, we may say that Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality. On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, we would suspect that the power quality is poor. As a general statement, any deviation from normal of a voltage source (either DC or AC) can be classified as a power quality issue. Power quality issues can be very high-speed events such as voltage impulses / transients, high frequency noise, wave shape faults, voltage swells and sags and total power loss. Each type of electrical equipment will be affected differently by power quality issues. By analyzing the electrical power and evaluating the equipment or load, we can determine if a power quality problem exists. Power attribute dilemma is a happening exhibited as a nonstandard current, voltage and frequency which result in collapse of equipments. About 90% of the electrical distribution network failure because of customer interruption. We know power is the rate of energy delivered and it is the product of voltage and current in proportionality. Power quality mainly concern with quality of voltage, so to maintain power quality within a permissible limit there are certain standards as for example the power system

typically designed to operate at frequency 50-60 Hz and a particular magnitude of voltage, if there is any deviation take place in magnitude of voltage and frequency that may lead to illness of power quality. Power superiority issues may be categorized as short duration, long duration, and continuous categories. These categories in detail will be discussed on the next chapter. We have discussed various causes which leads to power quality dilemma, but generally it is found that 90% of power quality arises within the site. And the most general reason behind this includes not proper grounding and bonding problems, code violations and internally generated power disturbances. Other internal issues include powering different equipment from the same power source. Let's take an example of a laser printer and a personal computer. Most of us would not think twice about plugging the laser printer into the same power strip that runs the PC. We are more concerned about the software and communication compatibility than the power capability; however, some laser printers can generate neutral-ground voltage swells and line-neutral voltage sags every minute or so. The long term effect to the PC may be power supply failure. We have to be careful in how technology is installed and wired. The scenario which is going on today is mostly dependent upon electronic based such as PLC & SCADA system which Utilizes most of electronic equipment & drives. The electronics devices used in the system are the great cause of distortion which are the byproduct of power quality issues such as Voltage sag, harmonic Distortion, & others issues. In all the time of fault monitoring system it is found the voltage sag is the most severe issue present in the electrical distribution system & mostly arise in the system due to frequent use of electronic devices in industrial & residential end users. The measure support of load on the common coupling point is the voltage for providing reactive power in the system. The best ever solution of to eliminate the reactive power from the distribution system is to establishment of capacitor bank on the distribution transformer in the parallel connection & seen everywhere in practical. These capacitor banks are either mechanical switching characteristics or automatic operated unit. The mechanical switching perform its operation by a scheduled method which is programmed on the signal coming from the most universal supervisory control system & well known as SCADA. This SCADA system has tendency to whether operate on scheduled operating time or not switching mode except of the scheduled time

The power quality of electrical system is found to be improved initially by FACTS devices which later described in 3 others ways & well known as Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (SATCOM), & unified power flow controller (UPFC). The new technology also has been included in FACTS devices & is known as Inter line power flow controller (IPFC). All above given technology are used for the power quality improvement for the transmission system which is not a major issue in present condition of electrical system, but the most severe problem of improvement is faced by power engineer & researchers are in the sector of distribution & need power quality improvement mostly. The FACTS devices again used in the distribution side but it required a very few & powerful changes in the circuitry for the betterment of quality of system. These new circuitry represent a CUSTOM FACTS devices & used frequently in distribution side towards the improvement in power attribute. These custom Facts devices are known in electrical society as Active Filter, Distribution static synchronous compensator dynamic voltage restorer & unified power quality conditioner. In power system word power quality has a valuable mean we can't separate one another. Any affects in power quality may easily observed by customers – commercial, industrial and even by residential, although residential customer do not suffer most financial loss in case of lack of power quality. This paper work shows the various factor which lead to illness of power quality and their mitigation technique. .

1.2-Literature survey:-

Above we have discuss about brief introduction of power quality, factor which become obstruct to have better quality, later I have also mentioned the whole factor which disturb us to have better power attributes, their mitigation etc. there are various presentations and research work has been taken out for the enhancement of power quality. To have better reliability and efficient power quality initially FACTS devices were introduced in the system. The power quality of electrical system is found to be improved initially by FACTS devices which later described in 3 others ways & well known as Static Synchronous Series Compensator (SSSC), Static Synchronous Compensator (SATCOM), & unified power flow controller (UPFC). Later on after certain modification on above said FACT'S devices new circuitry were designed. These

new circuitry represent a CUSTOM FACTS devices & used frequently in distribution side towards the improvement in power attribute. These custom Facts devices are known in electrical society as Active Filter, Distribution static synchronous compensator dynamic voltage restorer & unified power quality conditioner. These devices found to be most effective in own way, some of the FACTS devices were being used for mitigation purpose of harmonics; some were used to overcome the sag and swell. But from the collection of work which has been carried out for the purpose of power quality betterment, it was found the problems which are now a day's mainly occur on power system is because of end side users. And as a result it is found that reliability of the network greatly depends upon the consumer side. There are various papers which show the work with different CPD'S to have better power quality. What we see from the literature survey that today's most severe problem which become obstruct to have better power quality is voltage sag. So here the main concentration of my work is to overcome the one of the most severe problem "sag" in power system. For the mitigation of voltage sag and as a result of having betterment in power quality here DVR is taken out.

1.3-Scope of work:-

The objective of thesis has been already discussed in above summarized lesson & our task is to minimize the voltage disturbance in the system by involvement of various compensating devices which are extremely diversified, in later on it is found that there is a lot of scope come in mind to examine the component of compensating devices for different load on the distribution system. As the distribution system analyses the end of power system & connected to consumer premises. Thus the reliability of power supply majorly depends upon distribution system. The consumer requirement is increases rapidly that means reliability on system is also increased. Research shows that about 90% of failure in electrical distribution field arises due to consumer interruption. This whole topic forces us to increase the reliability of power system on the distribution end. In this thesis my main aspect is going through collecting various factors which are responsible for Power quality distortion & how to minimize them. The term which is most affective for the mitigation in voltage sag is overcome greatly by use of DVR or *DYNAMIC VOLTAGE RESTORER*. The DVR has great sense of analyzing Power quality

performance. For power quality betterment in power system different fault condition are considered with different load.

1.4:-Summary of paper work:-

Chapter-1:- It deals with the introduction part of the title chosen and also it shows whatever work has been carried out yet, and scope of work.

Chapter-2:- Gives the detail description about power attributes, factor which causes power quality dilemma and their categorization.

Chapter-3:- presents the custom power devices, their use and benefit with the CCPD'S devices.

Chapter-4:-Discussion about DVR, its working, configuration and application.

Chapter-5:- it shows simulink model of realized DVR system in different way.

Chapter-6:- presents the conclusion, result and also shows the future work of the DVR.

2.1-Introduction

The word power quality may be defined as “analysis, measurement and improvement of bus voltage” to maintain that voltage at specified potential quantity & amplitude of current Or Frequency. Power quality may be illustrated as “it is a provision of system plan and voltage for the electric utility consumer that they can hold electrical energy from the power system network without any disturbance or interference”

The IEEE standard dictionary for electrical and electronics, defines power quality as a concept of grounding and powering sensitive electronic equipment in a manner which is suitable for the operation of that equipment. In power system word power quality has a valuable mean we can't separate one another.

The term power quality determines the fitness/healthiness of electrical power to the different type of consumer and their devices. We may say that the quality of power is nothing but the proper synchronization of voltage, frequency and phase, it means the proper contribution of these voltages, frequency, and phase allows the system to work properly without any significant loss of performance or life. Any affects in power quality may easily observed by customers – commercial, industrial and even by residential, although residential customer do not suffer most financial loss in case of lack of power quality.

2.2 POWER QUALITY- The Burning issue

Power quality is one of the most burning issues of the present scenario. The power attributes is directly concern and have direct impact on we consumers, utilities, and electrical equipment manufacturers. Resent scenario of modernization and automation of industry involves with the rapid increasing rate of use of computers, microprocessor and power electronic systems. The power electronic system involves largely on the behavior of power attributes dilemma, as we know that the power electronics devices lead to cause of generation of harmonics. The impact of power quality dilemma may be easily felt to us customers- industrial, commercial and even by residential one. So far we have discussed about power quality and came to know that, the ultimate reason for which we are too much interested in power quality is nothing but economic

value. The power quality may give direct economic impact on industrial customer, in the industries where semi-conductor material is being manufactured; the economic impact which is associated with equipment sensitivity is momentary voltage sag. Besides the financial impact on both utilities and industrial customer, there are various costs which are not easy to describe associated with power quality. Residential consumer generally do not suffer economically as a result of problem in power quality, but they have right to demand quality of power when they perceive that utility is providing poor services. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

2.3 Problems correlated with power quality:-

2.3.1-Transient:-

The word transient in power system network is often used to demonstrate the nature of the system which is undesirable and momentary in nature. Transient may be categorized in two ways which are:

- a) Impulsive transient and
- b) Oscillatory transient,

Both of the term shows the voltage and current transient wave shape.

a) Impulsive transient:-

An impulsive transient is a phenomenon which occurs when a sudden, non-power frequency change in the steady-state condition of current, voltage, or both which is unidirectional in polarity (either positive or negative)

b) Oscillatory transient:-

An oscillatory transient is a phenomenon which occurs when a sudden, non-power frequency change in the steady-state condition of voltage, current, or both which includes both positive and negative polarity values.

2.3.2 Long-duration voltage variations:-

Long-duration variations are the variation which sustain when RMS (root mean square) deviation at power frequency longer than one minute. It may be either under voltage or over voltage. Whatever the up & down come in system voltage are not the consequences of system faults but these are all belongs to load changes in system & frequent switching operation in industrial sector which are the major cause of load variation .The term which represent over voltage in system is due to increase in RMS AC voltage merely more than 110% at the generation frequency say in India 50 Hz. Which sustain for larger than 1 min, generally it is the outcome of load switching.

As for example energizing a capacitor bank or switching off of a large load.

An under voltage is the decrease in the RMS AC voltage which is less than 90 % at the power frequency which last for a duration longer than one minute, under voltage is the result of switching action which are just opposite to the switching action that cause over voltage.

2.4 Short-Duration voltage variation:-

Such variation are caused by fault condition like there is a loose connection in power wiring or large load energization which require very high starting current, depending on system condition and location of fault, fault may lead to either temporary voltage rises (swells), voltage drops (sags), or may cause complete loss of voltage (interruptions).

2.4.1 Interruptions:-

Interruption can be the cause of equipment failures, power system faults and control malfunction. It occurs only when load current or supply voltage decreases to less than 0.1 pu for a time period not exceeding one minute.

2.4.2 Sags (dips)

The term sag refers to decrease in RMS value of voltage or current in between 0.1 pu and 0.9 pu at the generation frequency for duration between 0.5 cycle to 1 min. voltage sag in the electrical power system is usually a presentation of short duration voltage

decrease. This voltage sag is not a significant result of faults only but also come in picture due to heavy load synchronization & extraction of high current due to starting of heavy motors.

2.4.3 swell (rise):-

Overtoltage condition in power system or Swell is defined as changes in the RMS voltage & Current from 1.1 pu to 1.8 pu at the generated frequency which lie between time duration of .5 cycle to 1 min .Swells are generally concern with system fault condition, but it rarely occur, means it is not as common as sag.

2.5 Waveform Distortion:-

Steady-state changes from the sinusoidal waveform of power frequency are termed as waveform distortion, there are five category of waveform distortion which is as follows:-

- a) DC offset
- b) Harmonics
- c) Notching
- d) Noise
- e) Inter-harmonics

2.5.1 DC offset:-

The term DC offset may be defined as the availability of direct current or direct voltage in ac system. It occurs due to asymmetry or geomagnetic disturbance of electronic power converter.

2.5.2 Harmonics:-

The definition of harmonic states that it is sinusoidal voltage or current which have frequency multiple of fundamental frequency at which the electrical system is proved to generate the power in distribution area.

2.5.3 Notching:-

When the system current attribute is transformed from one phase to another a disturbance in system periodic voltage takes place which is the general consequent of operation of power electronics devices & termed in electrical system as “Notching”.

2.5.4 Hissing sound or Noise:-

The sound which is in nature of hissing or say electrical noise is the result of unwanted electrical signal interaction with broadband spectral content below having frequency of 200 Khz. These are produced by arcing equipment control circuit, various solid state devices or power electronics devices etc

2.5.5 Inter-harmonics:-

The electrical attribute of having neither frequency which neither represents the harmonic characteristics in system nor the fundamental frequency characteristics for which system has to be operating are known as either non-harmonic or inter-harmonic.

2.6 Voltage fluctuation and voltage flicker:-

Voltage oscillation or fluctuation is a series of non predicted voltage change in the system or systematic changes of voltage packets which quantifying value is ranges between .9 pu to 1.1 pu while the voltage flickering is the effect of voltage fluctuation which normally can be seen on the fluctuation on lamps which can easily perceived by humans eye.

2.7 Power frequency variation:-

Power frequency variation is the deviation of the fundamental frequency from its specified normal value (50-60 Hz). It is directly concern with rotational speed of generator supplying the system. As the dynamic balance between load and generation changes there is a slight variation in frequency take place.

2.8 Category and characteristics of power system electromagnetic phenomena:-

S. no	Category	Spectral content	Duration	Voltage magnitude
1.0	Transient			
1.1	Impulsive			
1.1.1	Nanosecond	5-ns rise	<50ns	
1.1.2	Microsecond	1- μ s rise	50 ns-1 ms	
1.1.3	Millisecond	0.1-ms rise	> 1 ms	
1.2	Oscillatory			
1.2.1	Low frequency	< 5 khz	0.3-50 ms	0-4 pu
1.2.2	Medium frequency	5-500khz	20 μ s	0-8 pu
1.2.3	High frequency	0.5-5 Mhz	5 μ s	0-4 pu
2.0	Short duration variation			
2.1	Instantaneous			
2.1.1	Interruption		0.5-30 cycles	< 0.1 pu
2.1.2	Sag (dip)		0.5-30 cycles	0.1-0.9 pu
2.1.3	Swell		0.5-30 cycles	1.1-1.8 pu
2.2	Momentary			
2.2.1	Interruption		30 cycles-3s	<0.1 pu

2.2.2	Sag (dip)		30 cycles-3s	0.1-0.9 pu
2.2.3	Swell		30 cycles-3s	1.1-1.4 pu
2.3	Temporary			
2.3.1	Interruption		3s- 1 min	<0.1 pu
2.3.2	Sag (dip)		3s- 1 min	0.1-0.9 pu
2.3.3	Swell		3s- 1 min	1.1-1.2 pu
3.0	Long duration variation			
3.1	Interruption		>1 min	0.0 pu
3.2	Undervoltages		>1 min	0.8-0.9 pu
3.3	Over voltages		>1 min	1.1-1.2 pu
4.0	Voltage unbalance		Stedy-state	0.5-2%
5.0	Waveform distortion			
5.1	DC offset		Steady-state	0-0.1%
5.2	Harmonic	0-100 th harmonics	Steady-state	0-20%
5.3	Inter harmonic	0-6 Khz	Steady-state	0-2%
5.4	Notching		Steady-state	
5.5	Noise	Broadband	Steady-state	0-1%
6.0	Voltage fluctuation	<25 Hz	intermittent	0.1-7%
7.0	Power frequency variation		<10 s	

2.9 Way to solve power quality problem:-

There are two different ways for the improvement of power quality namely load conditioning and line conditioning with both approaches we can mitigate power quality problem, the There solution for power quality may be achieved either from th consumer end or the various utility side. The very first approach of solution is called load conditioning which is more liable for the equipment sensitivity requirement for the power disturbances and also give great flexibility for operating in large voltage oscillation. One more way is to establish the line conditioning which minimizes the power system instability. The compensating devices used in low voltage or medium voltage distribution system are come in application by use of series or parallel connection with the distribution system. There are two type of compensating devices are available in the system from the manner of connection one is series active power filter for voltage source control & shunt active filter in order to eliminate load current harmonics. These both scheme are very much helpful for the power quality improvement with voltage source PWM converters with pulsating source component which sustain reactive component preferably like capacitor.

2.9.1-Thyristor based static switches:-

In the sense of voltage support need the static switching technology is more comfortably used in distribution sector. The vibrant response time is about 1 cycle, & for this static switch can be used more affectively for the alternatively power line, capacitor filter Battery storage system to correct voltage flicker sags or interruption quickly. This all can be used in alternate power line application

2.9.2-Energy Storage Systems:

The energy storage system is broadly used as a protective system to protect responsive fabrication equipment from shutdown which is mainly outcome of either of voltage sag or interruptions. The above said storage system is nothing but a direct current (DC) storage system and they may be categorized as Batteries, UPS, super conducting magnet energy storage (SMES), and even that may be the fly wheels that accelerate the DC generators etcetera. The outcome of these devices is directly applied across the inverter

circuit for the emergency backup by fast acting electronic devices like IGBT and GTO. Whenever fault condition such as voltage sag or interruption in power occurs a sufficient energy is provided by inverter to minimize the effect of fault energy. For the mitigation of voltage sag and swell the application of custom power devices (CPDs) is most effective as compare to other method. The word custom power employs the application of power electronic devices in distribution system. As FACTS devices is helpful for power transfer capabilities improvement and stability limit, in the same very way custom power makes it sure for customer to get pre-specified reliability and quality of power supply. This pre-specified quality may include a combination of specification such as, Very low changes in the load voltage, lower order of harmonic distortion in load voltage, unbalance in phase co-ordination of lower value, the time span & amount of overvoltage & under voltage within pre-defined limit acceptance in voltage fluctuation, & least factor quality of load without having effect of terminal voltage. There are numerous type of custom power device such as Battery energy storage system (BESS), Surge arrester (SA), Dynamic voltage restorer (DVR), Active power filters (APF), Distribution static synchronous compensator (DSTATCOM) , Distribution series capacitors (DCR), Super conducting magnetic energy system (SMES), Solid state transfer switches (SSTS), Static electronic tap changers (SETC), Solid state fault current limiter (SSFCL), Static Var compensator (SVC), Uninterruptible power supply (UPS), Thyristor Switched capacitor (TSC), and Unified power quality conditioner (UPQC).

3.1-Introduction:-

Through custom power devices, we consign to power electronic static controller applied for power quality betterment on distribution network rated 1 through 38 KV. This main enlist in the usage of power quality devices (PQDs) arises from the sensitivity of consumer demands and assurance. Lack of power quality may lead to customer dissatisfaction and costly downtime. Custom power devices has been installed by many power providers for mitigate power peculiarity problem. There are mainly three particular major power quality devices (PQDs) which are being used now a days is an advanced static VAR compensator, a high speed transfer switch and a Dynamic voltage restorer (DVR).

For the purpose of power quality improvement and reliability of the system initially FACT devices like Static synchronous series compensator (SSSC), Static synchronous compensator (STATCOM), Unified power flow controller (UPFC), and Interline power flow controller (IPFC) is being widely used in the system. These FACT devices are used in system at transmission level. But now a day our more concentration is on distribution side for power quality enhancement, for this these FACT devices is modified and called as “custom power devices”. The term Custom power pertain value-added power offered by electric utilities to their customer. The value addition involves use of efficient power electronic controller to distribution system which is connected with end user of various order in magnitude preferably given as commercial consumer & industrial consumer. There are many type of custom power devices available for the enhancement of power quality in which widely used given as Active power filter (APF),), Dynamic voltage restorer (DVR), Unified power quality conditioner (UPQC) and Distribution static synchronous compensator (DSTATCOM), Etcetera. These are the devices which are normally connected to the distribution network. N.G. Hingorani has a great achievement in power quality improvement as he was first person who introduced FACTS controller for the betterment of power quality. Later on these devices are known as Custom power devices (CPD). Furthermore these are categorized as in 3 types & based on VSC

1. Series connected Dynamic voltage restorer (DVR)
2. Shunt connected Distribution STATCOM (DSTATCOM)
3. Combined series and shunt, unified power quality conditioner (UPQC).

The operating principle of Dynamic voltage restorer (DVR) is identical with SSSC while UPFC is identical with UPQC. Although these are identical but still there is some differences between them from the point of improving power attribute. The biggest over difference found in between them is the injection of harmonic current & voltage in system by load. DVR has tendency to neutralizing the harmonic component in the system from the non linear load with adding more quality such as providing better voltage regulation & balance between receiving & sending end voltage. UPQC is a collectively defined as combination of DSTATCOM and DVR where DSTATCOM is taken in operation for eliminating harmonic content, adding with injection of reactive power in the system to raise the power factor & regulate the load bus, voltage and to raise power factor.

3.2-Configuration:-

The custom power devices can be categorized on the basis depending upon number of phases & various different terminologies. Generally voltage source inverters of bridge structure are used for improvement of custom power devices used in power quality enhancement. These all technologies are given in manner of shunt (DSTATCOM), series (DVR), or combination of both (UPQC).

3.2.1- Converter based classification:-

Because of self supporting dc-voltage bus with a large DC capacitor generally VSI is used for the development of compensating type custom power devices. The use of CSI is less accounted and such topology find application in evolution of active filter, UPQC and DSTATCOM. The VSI topology is familiar because it can be extended to multi level, multi step and chain converter to raise the performance with lower switching frequency and enhance power handling capacity. This topology can exchange a considerable amount of real power with energy storage devices in place of DC capacitor.

3.2.2- Supply system based classification:-

This arrangement of compensating devices is established on the Distribution side or end user side either of single phase (two wires) or three phase (3 wire or four wire) system. On the distribution board various load are connected which are in nature of linear & non linear type connected to single phase supply system. In three phase system ASDs are assume as more sensitive for the non linear characteristics & inject harmonic in 3-phase system. Some of single phase load of non linear characteristics are also get connected in 3 phase 4 wire system like commercial lighting, computers and so on. Hence, compensating devices may also be divided accordingly as two-wire, three wire, and four-wire types.

3.2.3-Topology based classification:-

Topology-wise custom power devices may also be sub divided into series(DVR), Shunt (DSTATCOM), & hybrid connection of both series & shunt (UPQC). When a DVR is get connected with line give proper voltage regulation & DSTATCOM is get connected with the line for power factor improvement perform the elimination in current distortion & provide proper load balancing.

1. DSTATCOM:-

DSTATCOM is given as sort of *CPDs* which is used to eliminate the harmonic from the source current and also balance them in order to provide reactive power compensation and to gain power factor or govern the load bus voltage.

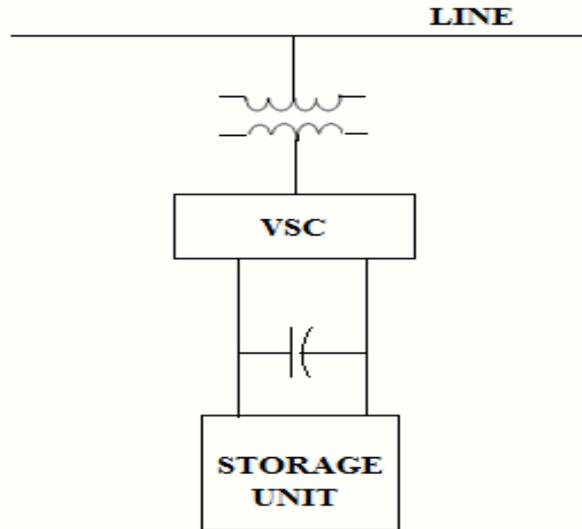


Fig-3.1 Distribution shunt connected STATCOM

2. DVR (Dynamic Voltage restorer):-

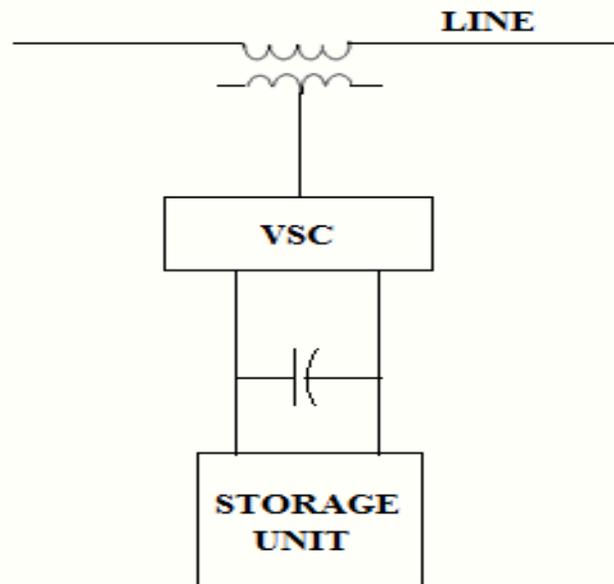


Fig 3.2 Series connected Dynamic Voltage Restorer

The Dynamic Voltage Restorer (DVR), also quoted as the Series Voltage Booster (SVB) or the Static Series Compensator (SSSC), it is a device which utilizes solid state (or static) power electronic elements, and is connected in the series to the utility primary distribution circuit. The DVR provides three phase controllable voltage, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag condition. A DVR is given as custom power devices whose function is to isolate the harmonic content & behave like an obstacle for harmonic current in the source voltage towards the load, also resulting balance the system voltage and accumulate voltage regulation.

3. UPQC (Unified Power Quality Conditioner):-

A UPQC also comes into the category of custom power devices (CPDs) which combines the operation of Dynamic Voltage Restorer (DVR) and DSTATCOM together.

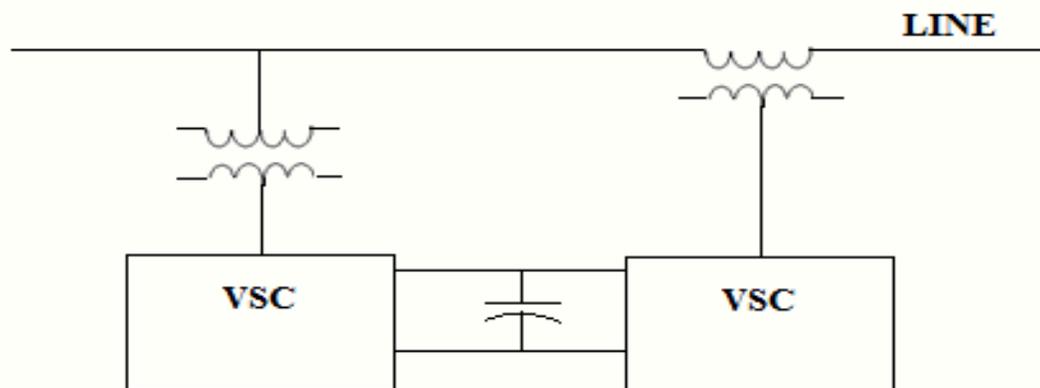


Fig 3.3 unified Power Quality Conditioner

3.3-Need of custom power devices:-

In power system word power quality has a valuable mean we can't separate one another. Any affects in power quality may easily observed by customers – commercial, industrial and even by residential, although residential customer do not suffer most financial loss in case of lack of power quality. Mainly the reliability of power system depends on distribution network. It became essential, particularly with the presentation of adulterate

device. Whose execution is very responsive to the peculiarity of power supply. Power attribute dilemma is a happening exhibited as a nonstandard current, voltage and frequency which result in collapse of equipments. About 90% of the electrical distribution network failure because of customer interruption. If there is any deviation take place in magnitude of voltage and frequency that may lead to illness of power quality. Various problems which generally occur in power system is sudden rise or dip in voltage magnitude, fluctuation and flickering etc. To overcome such dilemma we prefer to locate custom power devices in the network. In general we may observe that the power system especially we may say the distribution network have numerous non-linear loads, which finally affects our system most. And as a result of having such non-linear load at the distribution side the purity waveform fails to achieve. To consider all the above said points the design of custom power and their location is being experienced which is somewhere found to be very grateful for all types of customer. To solve one of the most severe problem which is voltage sag a custom power device is designed which is termed as Dynamic voltage restorer (DVR). And it is found to be very efficient and effective custom power devices, and it is generally located at distribution network. It is most familiar CPD'S because its appeal makes the fast response during disturbances, lower in cost and smaller in size.

3.4- Benefits with the application custom power devices:-

The custom power devices like DSTATCOM, UPFQ and DVR etcetera are used to increase the reliability of the distribution system by accumulating voltage support at critical buses in the system (with series connected controllers) and control power flow in critical lines (with shunt connected controllers) like DSTATCOM. The two, Voltage and power flow are governed by the combined series and shunt controller which is referred as UPQC. When the system is subjected to the disturbances power electronic control is quite rapid and this enables regulation, both under steady state and dynamic condition in comparison to the other controller. The several main advantages of custom power devices are as following:-

- a. The dilemma of starting voltage dip in case of industrial load like induction motor can be overcome by these devices.

- b. They contribute to superior system operation by improving voltage profile and attenuate power losses.
- c. Through these devices dilemma of voltage fluctuation especially dynamic over voltages can be conquer.
- d. The steady-state or small signal stability region can be promoted by providing auxiliary stabilizing controllers to depress low frequency oscillations.
- e. The transient stability limit is enhanced thereby enhancing Dynamic security of the system and decreasing the incidence of Blackouts originated by cascading outages.
- f. The power flow in critical lines may be made better as the operating margin can be attenuated by fast controllability.
- g. The power carrying capacity of lines may be enhanced to values up to the thermal limits prescribed by current carrying capacity of the conductor.

4.1- Introduction:-

The Dynamic Voltage Restorer (DVR), also quoted as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), it is a device which utilizes solid state (or static) power electronic elements, and is connected in the series to the utility primary distribution circuit. The DVR provides three phase controllable voltage, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag condition. A DVR is a custom power device which can act as a harmonic isolator to obstruct the harmonics in the source voltage attaining the load, in addition to balancing the voltages and accumulate voltage regulation. Among the problem which affects power attribute like (Sags, Swells, and Harmonics etc.). Voltage sag is the most severe disturbance which greatly affects the system. The concept of CPD is recommended to conquer such dilemma.

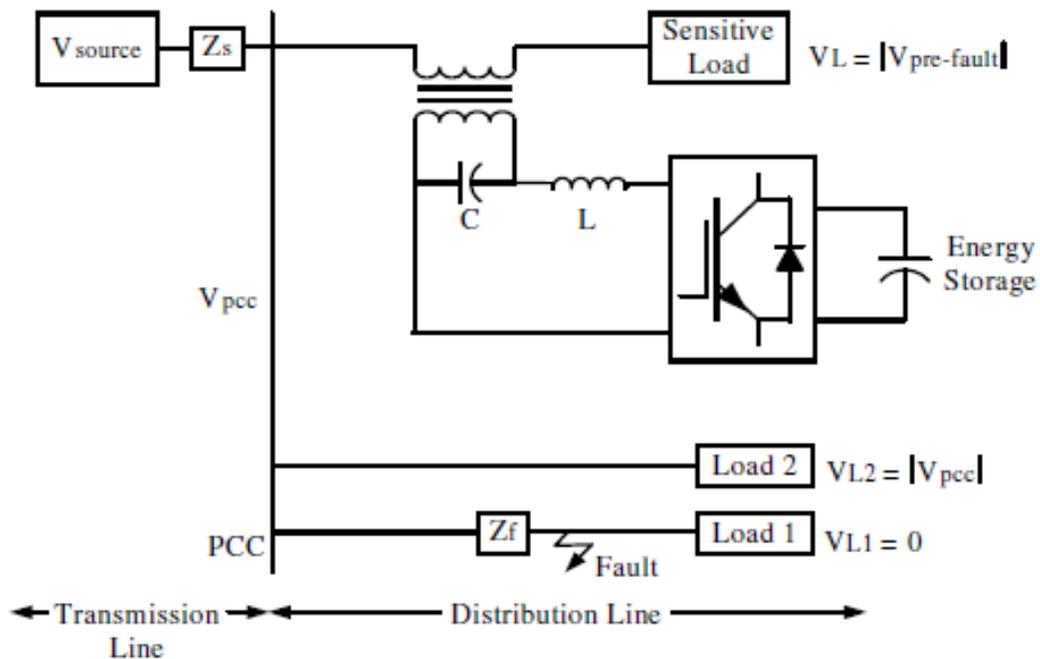


Fig 4.1-Role and Location of the DVR

In the CPDs technology DVR is major concerned of power quality improvement & considered as the most effective & advance custom devices. The custom devices are

mostly located on the distribution level at the point of common coupling (PCC). Apart from voltage sag & swells compensation DVR also find importance in reduction of transient in voltage, harmonic content & line voltage as well as limitation in fault current.

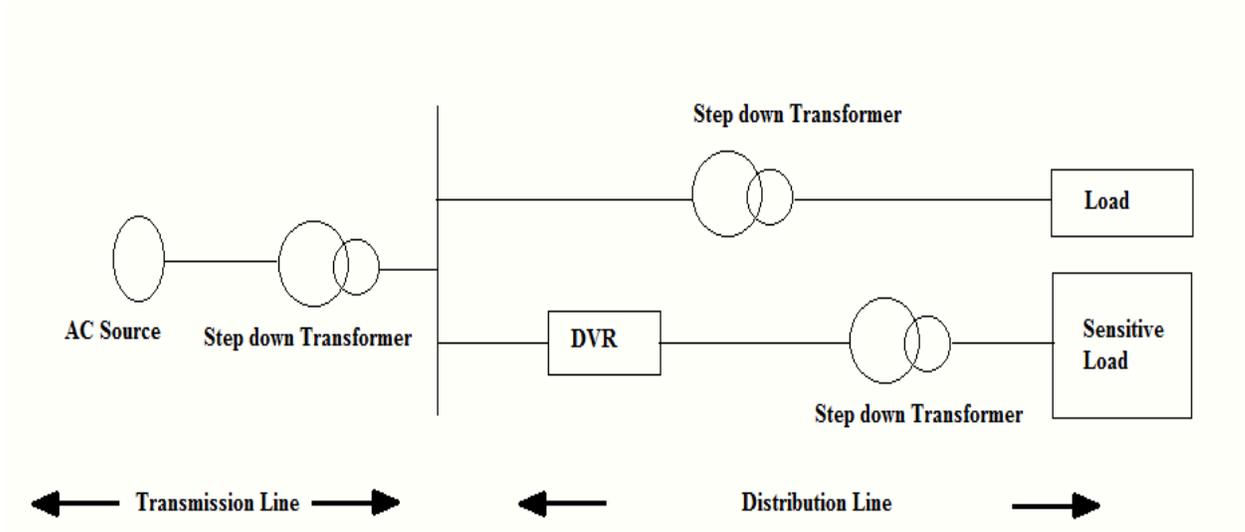


Fig 4.2- location of DVR

4.2-Principle of operation of DVR:-

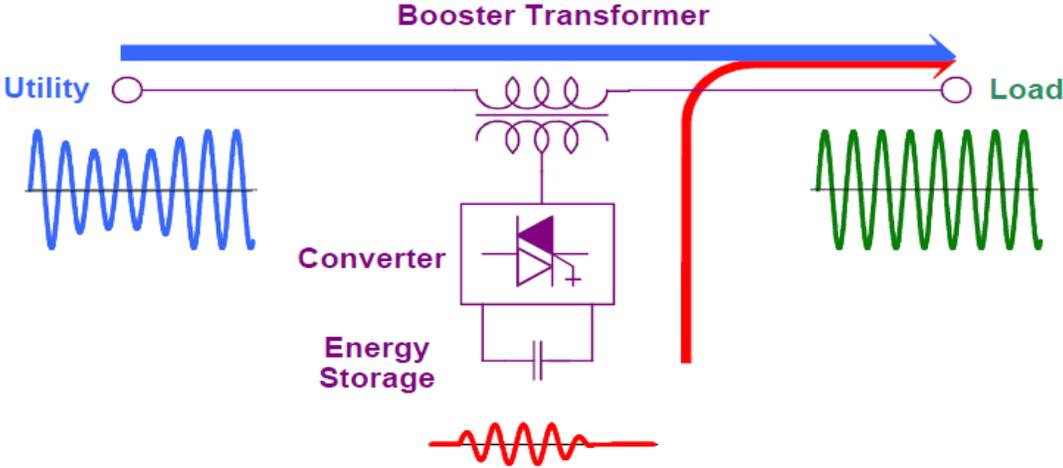


Fig-4.6 Principle of DVR System

The DVR is made up from solid state power electronics devices mainly by GTO & IGBT; capacitor bank is employed for storage of energy & injecting reactive power in transformer & load. The DVR is connected with distribution system & load in series manner as shown in figure [4.6]. The very important pattern about DVR is that to inject a controlled voltage being produced by commutated converter connected in series with bus voltage with the help of injecting transformer. This voltage is being modulated by means of a DC-AC inverter by the use of sinusoidal PWM technology. To neutralize the potential drop of injection transformer and devices loss while running in normal operating condition the Dynamic voltage restorer introduce only a partial amount of voltage. Whenever voltage sag arises in the network, the Dynamic voltage restorer performs calculation and also produces the voltage which is sufficient to protect voltage which appears at output to the load by means of a injection of a controlled voltage having a definite magnitude and phase angle, within the distribution system to the severe load. The response time of DVR is very short and it is limited by power electronic devices. The anticipated response time is about 25 milli second, and it is considerably less than that of the other classical method of voltage correction such as changing transformer.

4.3-Basic configuration of DVR:-

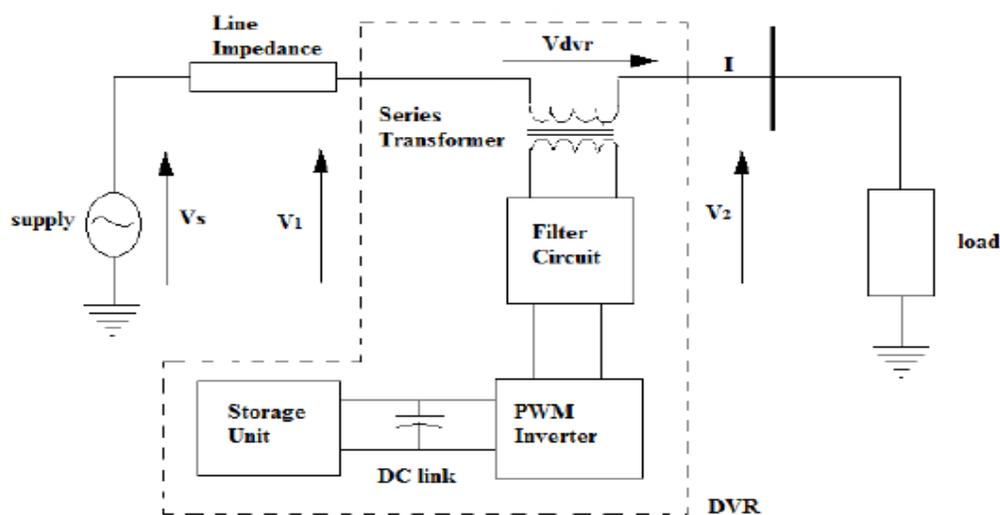


Figure 4.3- Schematic diagram of DVR

The general configuration of DVR consisting of following:-

- a. An injection transformer/ booster transformer
- b. DC charging unit
- c. Harmonic filter
- d. Voltage source converter (VSC)
- e. A control and protection system
- f. Storage devices

4.3.1 An injection transformer/ booster transformer:-

It is a specially designed transformer whose role is to limit the behavior of sudden changes beside the sending end to the receiving end and also it reduces the coupling of unwanted sound. A part from this the major function of booster or injection transformer is as following:

- ❖ the injection or booster transformer connects the dynamic voltage restorer to the end user by means of high-voltage winding and also its function is to alter and couple the injected voltage which is developed by VSC with the incoming supply voltage
- ❖ Furthermore By means of this, the injection or booster transformer also serves the function of separating the load from the system (VSC and control mechanism).

4.3.2- DC charging unit:-

There are mainly two task assigned to the DC charging unit which is given as

- ❖ The very first and important task which is assigned to the charging unit is to charge the energy sources whenever a sag compensation incident takes place.

- ❖ The second task of this unit is to keep maintain the DC link voltage at a specified DC link voltage..

4.3.3- Harmonic filter unit

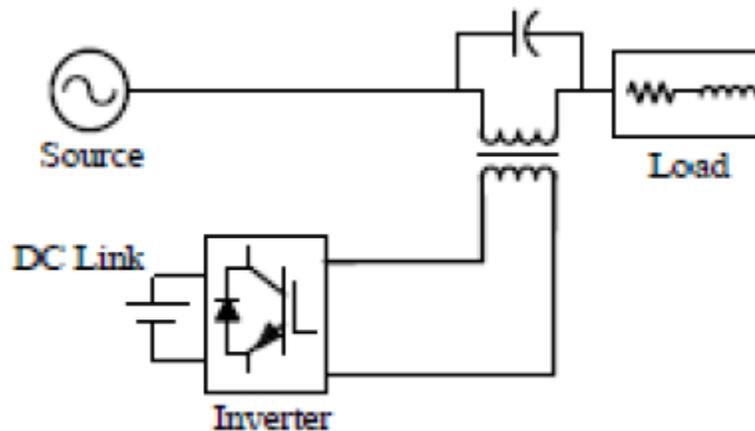


Fig 4.4- DVR with load side filter

The most important purpose of the harmonic filter is nothing but to maintain the harmonic voltage at ease which is produced by the voltage source converter at a permitted value. The semiconductor device which has nonlinear characteristics becomes causes of distorted waveform which are correlated with high frequency harmonics at the output side of the inverter. The harmonic and filter unit is used just to mitigate this problem and to have better power attributes. This unit can be installed either in inverter side or line side as shown in above figure [4.4]

4.3.4- Voltage source converter (VSC):-

A voltage source converter (VSC) is a solid state power electronic system which consists of normally with a switching device and storage device. This can produce a voltage of sinusoidal nature at a suitable frequency, voltage magnitude and phase angle. In DVR application the voltage source converter (VSC) is mainly applied to generate absence of supply voltage, or to temporarily change the supply voltage. The mean of storage device

is to supply the needed energy to the VSC via DC link for the formation of injected voltages. The various family of energy storages are Batteries, capacitances and superconductive magnetic energy storage (SMES).

There are four leading sort of switching devices namely, Gate Turn-Off Thyristor (GTO), Integrated Gate Commuted Thyristor (IGCT), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), and Insulated gate Bipolar Transistor (IGBT). Individual kind has its own perfection and drawbacks. The IGCT is a modern compact device with enhanced attainment and authenticity that allows building VSC with very wide power rating, By means of very high sophisticated converter scheme with IGCTs, the DVR can amend dips which are above the capability of past DCRs using predominant devices.

4.3.5- A control and protection system:-

A controller is also applied for the proper action of the DVR system. In this unit load voltage is compared and then it is transmitted to sequence analyzer. The application of pulse width modulated (PWM) control is implemented for inverter switching because of achieving a 3-phase having frequency 50 Hz and sinusoidal nature of voltage at the end terminal. Chopping frequency is kept fixed in advance having order of a few Kilo HZ. The PI controller in addition with IGBT inverter is implemented to carry 1 PU voltage in magnitude very close to the load terminal. The controller input is the difference between the reference voltages (V_{ref}) and actual voltage (V_{in}) and it is an actuating signal. The main advantage of proportional plus integral is that at the step input, it originates the steady-state error almost to zero. The typical arrangement of the control mechanism contains hardware with programmable logic. The software implements all the defensive job of Dynamic voltage restorer. The main two example of many defensive action carried out by software is Differential current security of transformer and short circuit current at the end user side.

4.3.6-Energy storage unit:-

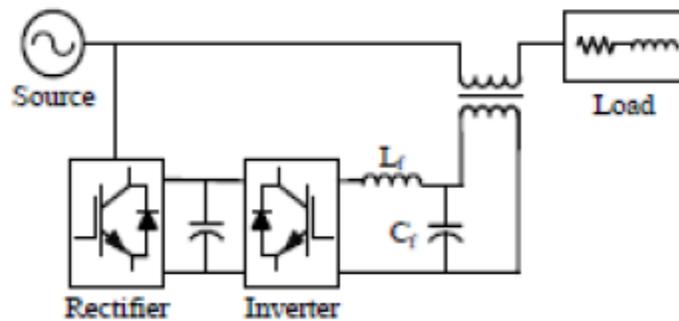


Fig 4.5- DVR with supply rectified energy

Whenever voltage sag occurs in the system, the DVR is used to inject a voltage to restore the supply voltage, the DVR requires an energy source for doing so and for this act there are two types of system arrangement is taken into account. One type of arrangement uses stored energy to delivered the power, whereas the other arrangement is quite a bit difference in which energy is to be bring out from the incoming supply through a shunt converter as shown in above figure [4.5] such arrangement does not have any internal energy storage.

4.4- Operating mode of DVR:-

The fundamental role of DVR is to establish a dynamically controlled voltage V_{DVR} produced by forced commuted converter in a manner of series to line voltage by means of booster transformer. The temporary amplitude of the phase-voltage which has been injected is being controlled at the same time to reduce undesirable effects of line fault to the load voltage V_L . it shows that if there is a any degree of difference in voltages caused by sudden changes in system in AC feeder, it will be satisfied by an equivalent voltage which is being generated by the converter and implanted on the medium voltage network by means of a booster transformer. The DVR has three operational mode viz standby mode, Injection/ boost mode and protection mode.

4.4.1- Standby mode ($V_{dvr} = 0$):-

In the standby mode the low voltage winding of booster transformer is shorted through the converter. In this mode of operation no switching of semiconductor arises and the full load current will pass through primary.

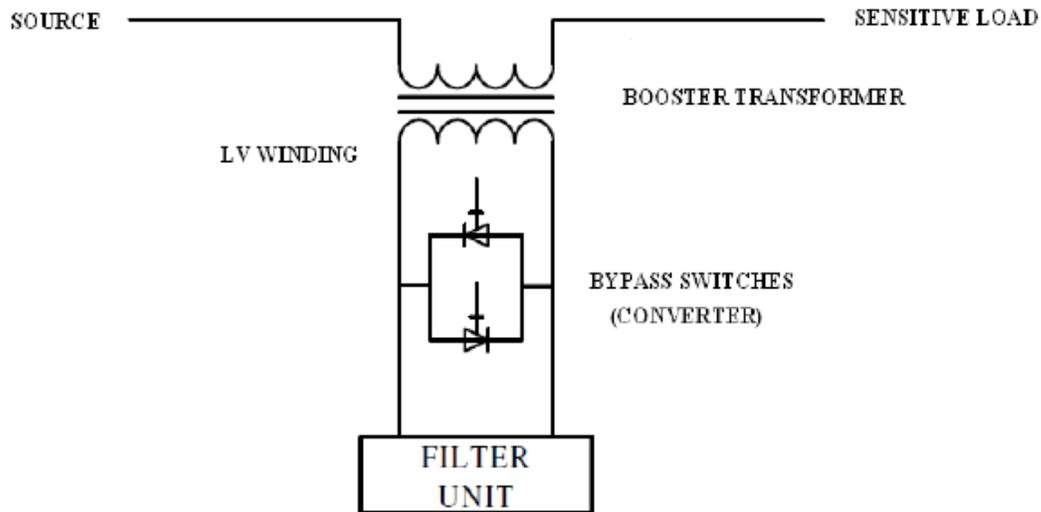


Fig 4.7- Standby Mode

4.4.2 – injection mode ($V_{dvr} > 0$):-

In the injection/ boost mode the DVR is implanting a compensating voltage through the booster transformer for the sake of exposure of a disturbance in the supply voltage.

4.4.3- Protection mode:-

If the over current on the load side pass a permissible limit due to short circuit on the load or huge inrush current, the DVR will be isolated from the system by using the bypass switches (S2 and S 3 will open) and supplying alternate path for current (S 1 will be closed).

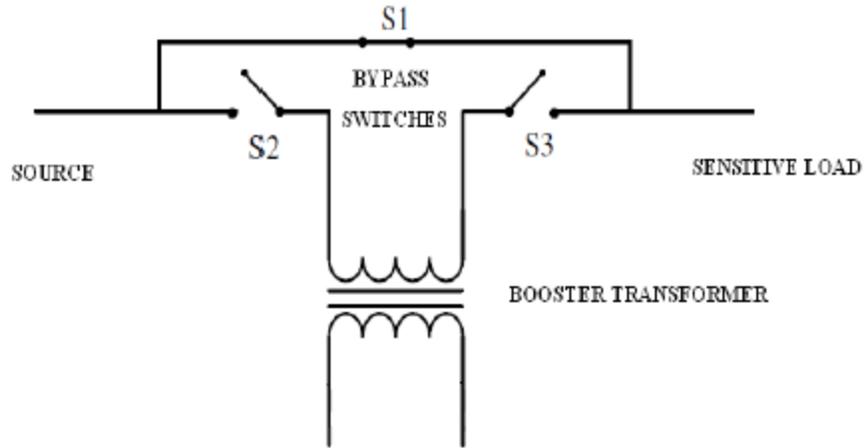


Fig [4.8]- protection mode (creating another path for current)

4.5-Equation related to DVR:-

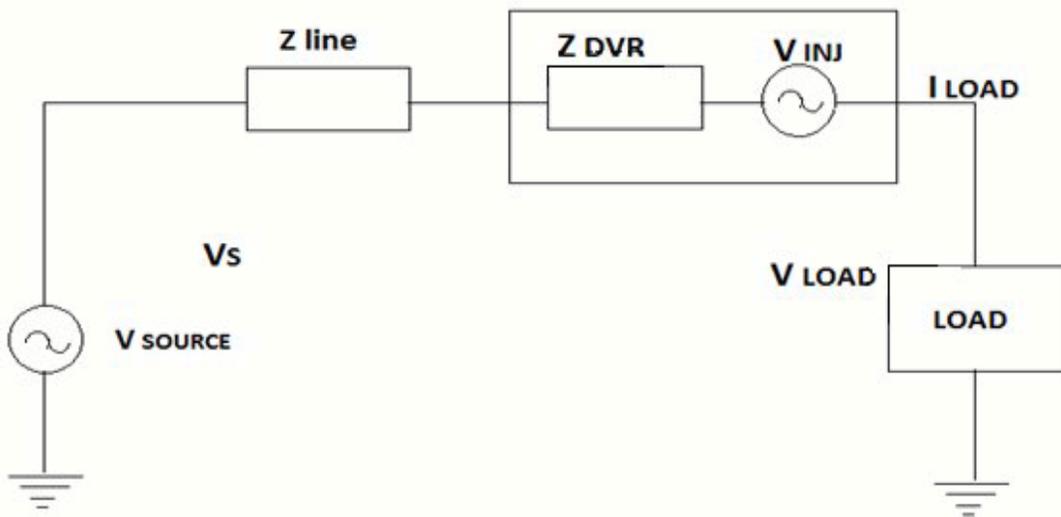


Figure [4.9]-Equivalent circuit model of DVR

Above circuit shows the equivalent circuit diagram of dynamic voltage restorer. From the above circuitry the impedance Z_{LINE} is dependent on the fault level of the load bus. When there is a reduction or drop occur in system voltage which is given as V_{SOURCE} from a prescribed value the DVR implant a series voltage given as V_{DVR} with the help of

injection transformer, so that we can maintain the load voltage V_{LOAD} up to a desirable magnitude. Now the voltage magnitude of DVR which is being implanted is given by,

$$V_{DVR} = V_L + Z_{TH}I_L - V_{TH}$$

OR

$$V_{dvr} = V_{load} + Z_{line} I_{load} - V_{source}$$

Where;

V_{load}/V_L = Magnitude of load voltage which is desirable.

Z_{line}/Z_{TH} = Load or line impedance

I_{load}/I_L = Load current

V_{source}/V_{TH} = It is the voltage which appears during fault condition.

Hence the load current I_L may be expressed as

$$I_L = \frac{(P_L + jQ_L)}{V}$$

If V_L is taken as a reference equation then,

$$V_{DVR} \angle 0 = V_L \angle 0 + Z_{TH} \angle (\beta - \theta) - V_{TH} \angle \delta$$

In the above equation the α , β and δ is the angle with respect to V_{DVR} , Z_{TH} , and V_{TH}

If θ represents the load power angle then,

$$\theta = \tan^{-1} (\theta_L / P_L)$$

The complex equation for the DVR power injection is given as,

$$S_{DVR} = V_{DVR} I_L^*$$

From the above equation we may say that it needs only reactive power to inject and the DVR itself having the capability of generating reactive power.

4.6 Compensation Strategies / Voltage injection methods of DVR

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, different types of voltage sags, and various conditions of load. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics.

There are four different method of DVR voltage implantation which is:

- A. In- phase compensation method
- B. In- phase advanced compensation method
- C. Pre-sag compensation method
- D. Voltage tolerance method with minimum energy injection

4.6.1 - In- phase compensation method:-

This is the simplest method. In this method the voltage which is injected by DVR is always in phase with the supply voltage irrespective of the load current and pre-sag voltage (V_o). This control strategy results in the minimum value of the injected voltage (magnitude). However, the phase of the load voltage is distributed. This control strategy results in optimum utilization of the voltage rating of the DVR. The main advantage of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies.

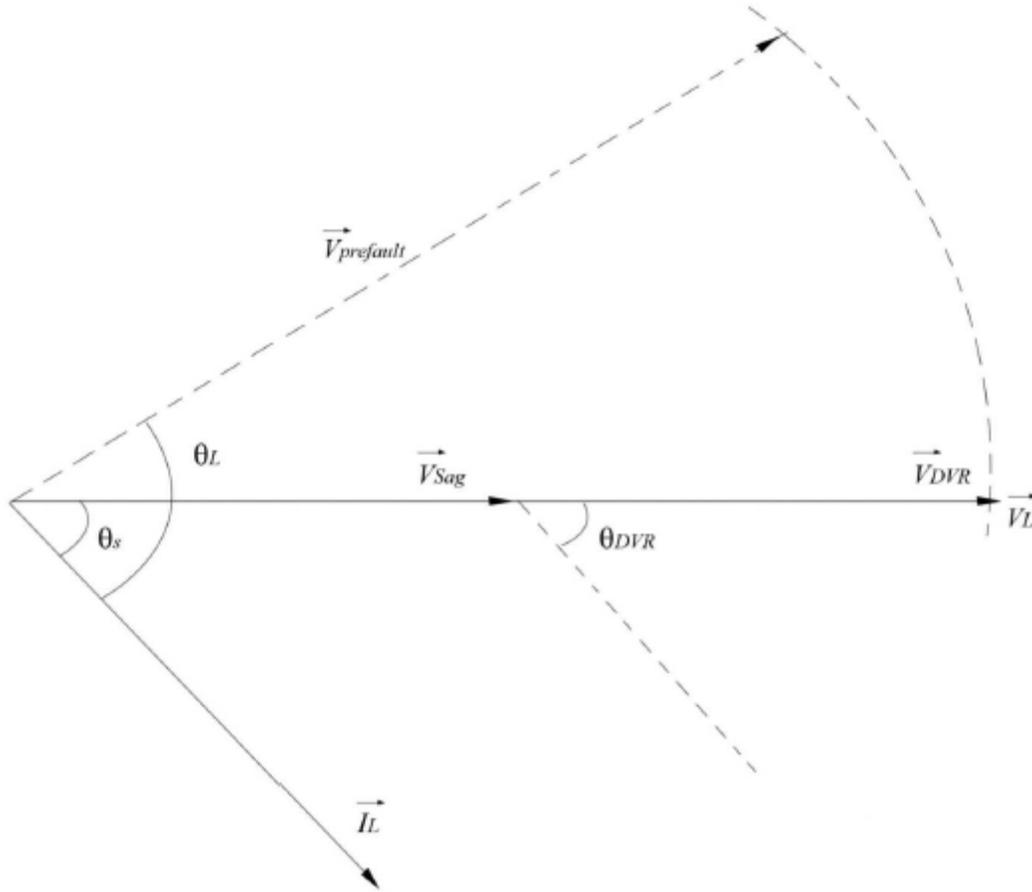


Figure 4.10- In phase compensation method

4.6.2- In phase advance compensation method:-

In this technique the standards of voltage and load current is being fixed in advance to the system, now through this we can alter only the phase of sag voltage. This methodology implies only reactive power and that is the reason unfortunately we fail to mitigate all the sags, because of not including the real power. Hence the significance of such method is only appropriate for some degree of sag. In this method the real power sent by DVR is decreased by minimizing the power angle between the sag voltage and load current. The minimization of injected energy is achieved by making the active power component zero by having the injection voltage phasor perpendicular to the load current phasor. In case of pre-sag and in-phase compensation method the active power is injected into the system during disturbances.

4.6.3- pre-sag compensation method:-

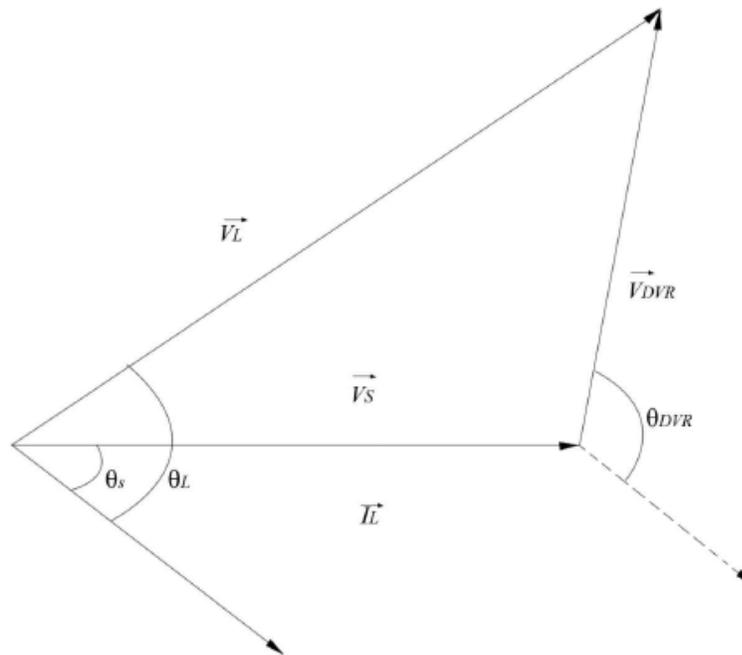


Fig- [4.11]- pre-sag compensation method

The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, so that the voltage which appears at load side can be restored back again to the pre-fault condition. By this method we fail to control the active power which is being injected, and this can be determined by the external situation like load conditions and types of faults .

$$V_{dvr} = V_{\text{prefault}} - V_{\text{sag}}$$

4.6.4- Minimum energy injection method

With the help of this technique very little amount of voltage drop and very small jump in phase angle can be maintained by the load itself. The characteristics of load have no effect till amount of voltage i.e voltage magnitude comes between the range of 90 to 110 percent of nominal voltage, and 5 to 10 percent of nominal state. The two control

parameter which is nothing but both magnitude and phase may be obtained by small energy injection technique.

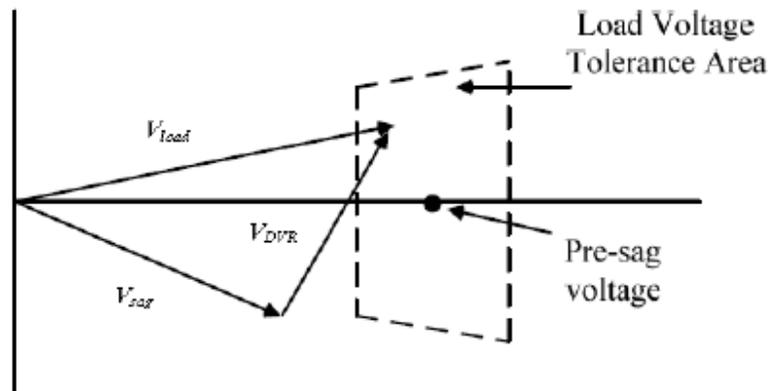


Fig-[4.12]-Minimum energy injection method

4.7-Sag detection technique:

As the name implies, the sag detection technique is used to detect the occurrence of voltage sag, the sag detection techniques allow us to know the incident of voltage sag, its starting point, the end point, magnitude of sag and the phase shift. The various techniques involved in sag detection is categorized as:-

- A. Peak value method
- B. Root mean square (RMS) method
- C. Fourier Transform (FT)
- D. Space vector method

4.7.1 Peak value method:-

The simplest method of monitoring the supply is to monitor the peak, or amplitude, of the supply voltage, then comparing it with a reference. A controller could be set to

recognize if there is a difference greater than a specified value (10%) and switch in the inverter.

4.7.2 Root Mean Square (rms) method:-

The start time of the sag can be defined as the first point of V_{rms} when drops below 0.9 pu. To find the end time of the sag, search for an interval where V_{rms} drops below 0.9 pu for at least half a cycle. The recovery time is then chosen as the first point in this interval.

4.7.3- Fourier Transform (FT):-

The FT is achieved through orthogonal decomposition of power system signal. In general, a trigonometrically orthogonal function set or exponential orthogonal function set is utilized. By applying FT to each supply phase, it is possible to obtain the magnitude and phase of each of the frequency components of the supply waveform. For practical digital implementation Windowed Fast Fourier Transform (WFFT) is used, which can easily be implemented in real time control system. The only drawback of this method is that it takes one cycle to return the accurate information about the sag depth and its phase, since FT uses an averaging technique.

4.7.4- Space Vector method:-

The three phase voltages V_{abc} are transformed into a two dimension voltage V_{dq} , which in turn can be transferred into magnitude and angle. Any deviation in any quantity reveals the occurrence of an event. Comparing these quantities with reference ones will quantify the disturbance in the dq-frame, which had to be transformed back to the abc frame. This method has no time delay, yet requires complex controller.

4.8-Proposed controller for the DVR:-

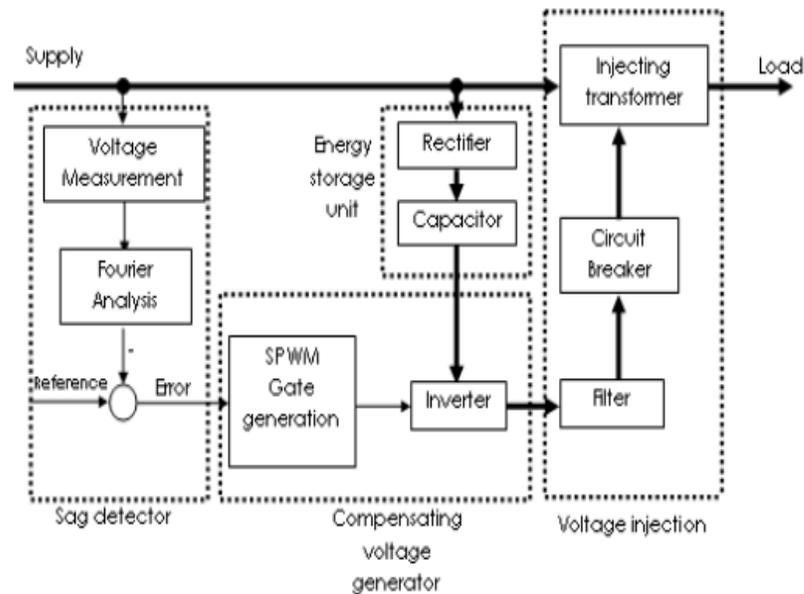


FIG [4.13]- The block diagram of the proposed controller for the DVR

4.8.1 Sag Detector:-

Sag detector includes the attenuation of sag, their start point, end point, magnitude of sag as well as it determines the phase jump angle. A comparator is used for the computation purpose of compensating voltage with one input as a variable system voltage and the other input is the fixed reference voltage. Since this technique is in-phase method, this comparison is for magnitude only. The comparator output tell us the amount of voltage which needs to inject by the DVR, and termed as error signal.

4.8.2 Generation of compensating voltage:-

The inverter is one of the most vital components in DVR circuit, and its controlling action greatly affects the performance of the DVR system. The basic concept behind the PWM is to compare the sinusoidal control signal of normal frequency (50 HZ) with higher frequency. When it compares control signal greater than of carrier signal, three

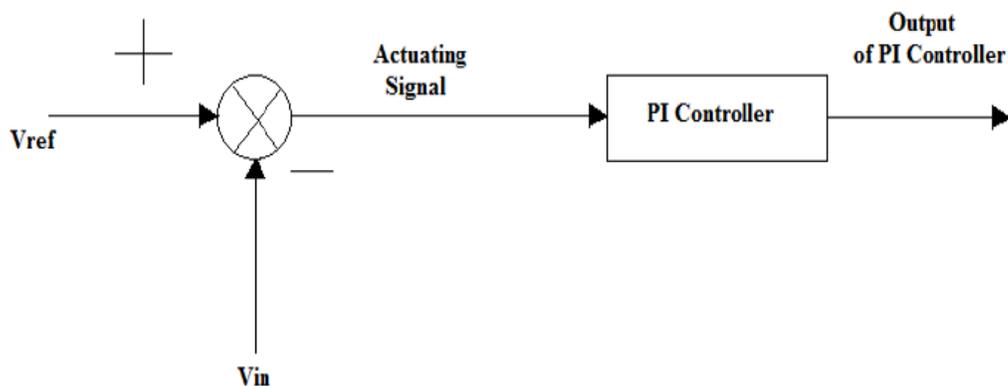
switches from the three is turned on, and the counter switches are off. Hence control signal is an error signal; therefore output of inverter will show the required compensation voltage.

4.8.3-Injection of the compensation voltage:-

Once the magnitude of error signal increases up to the tolerance limit for dynamic voltage variation, the circuit breaker break the circuit close to connect the DVR via series connected injecting transformer. Compensation of any drop in series voltage injection is mainly done to count for the voltage drop and phase shift introduced by the injecting transformer and filter.

5.1- Dynamic voltage restorer with PI controller:-

We have so far discussed about the fact devices and custom power devices which are being used broadly now days for the betterment of power quality. The Dynamic Voltage Restorer (DVR) is also come into the category of one of the custom power devices whose main task is to mitigate the voltage sag from power system. Such devices are located at the distribution side network, it become familiar because its response time is quite fast. As far as the mitigation capability of any particular DVR is concern, it is totally depends upon the factor like maximum value of voltage injection and the active power which is being given by the DVR. If there is any disturbances occur in voltage of DVR the distribution network should be given an active power or energy from the injected DVR voltage. As we have seen the configuration of DVR, it contains a DC system connected with the inverter input, and it has a large capacitor for the purpose of energy storage, and it also offer reactive power to the load when a fault take place, and this is not to mention whenever the energy will be taken out from the capacitor, which was being stored at the capacitor, the terminal voltage of the capacitor will be weak or reduce. Hence we came to know that the size and the capacity of capacitor plays an important role for the DVR circuit

5.2-Controlling action:-**Fig-[5.1] Schematic representation of simple PI controller**

To control and to operate properly when a fault take place a controller is necessarily required. These controller allow us to measure the load voltage and then after it passed this voltage to sequence analyzer, where its magnitude is being compared from reference voltages (V_{ref}). Here for the purpose of inverter switching a pulse width modulated (PWM) control system is being introduced in the system so as it may generate a sinusoidal voltage of three phase, 50 HZ at the load terminal. The value of chopping frequency is selected in a range of a few KHZ. To balance the voltage at 1 pu at the load terminal IGBT inverter is controlled with the help of PI controller. One of the most important significance to have a proportional plus integral controller is that the integral term of such controller causes the steady-state error to be zero for step input. The input of PI controller is an actuating signal and it is the difference in reference voltage (V_{ref}) and input voltage (V_{in}). The output which we obtain from this controller block is in the term of an angle δ which tell us additional phase-lag/lead in the system voltage. The output of the error detector is the difference of reference voltage (V_{ref}) and input voltage (V_{in}), Where, V_{ref} is the voltage which is equal to 1 pu and V_{in} is the voltage in pu which appears at the load terminal.

5.3- Single line diagram of the realized DVR system.

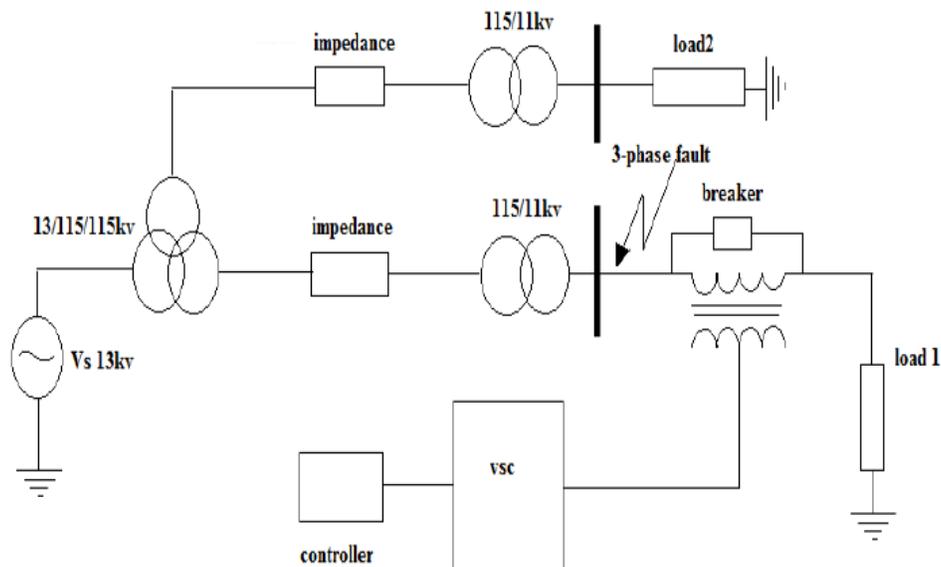


Fig-[5.2] single line representation of realized DVR system

From above shown simulink model [5.3], which we design shows the two parallel connected feeders, as well as in both the feeders loads are also connected in parallel. The one of the feeder implies DVR in series connection, whereas the other feeder which is parallel connected to first feeder is left as it is. In this realized model DVR is connected to the distribution side with an booster transformer and PI controller is used for the controlling action.

Result of simulink model [5.3]:-

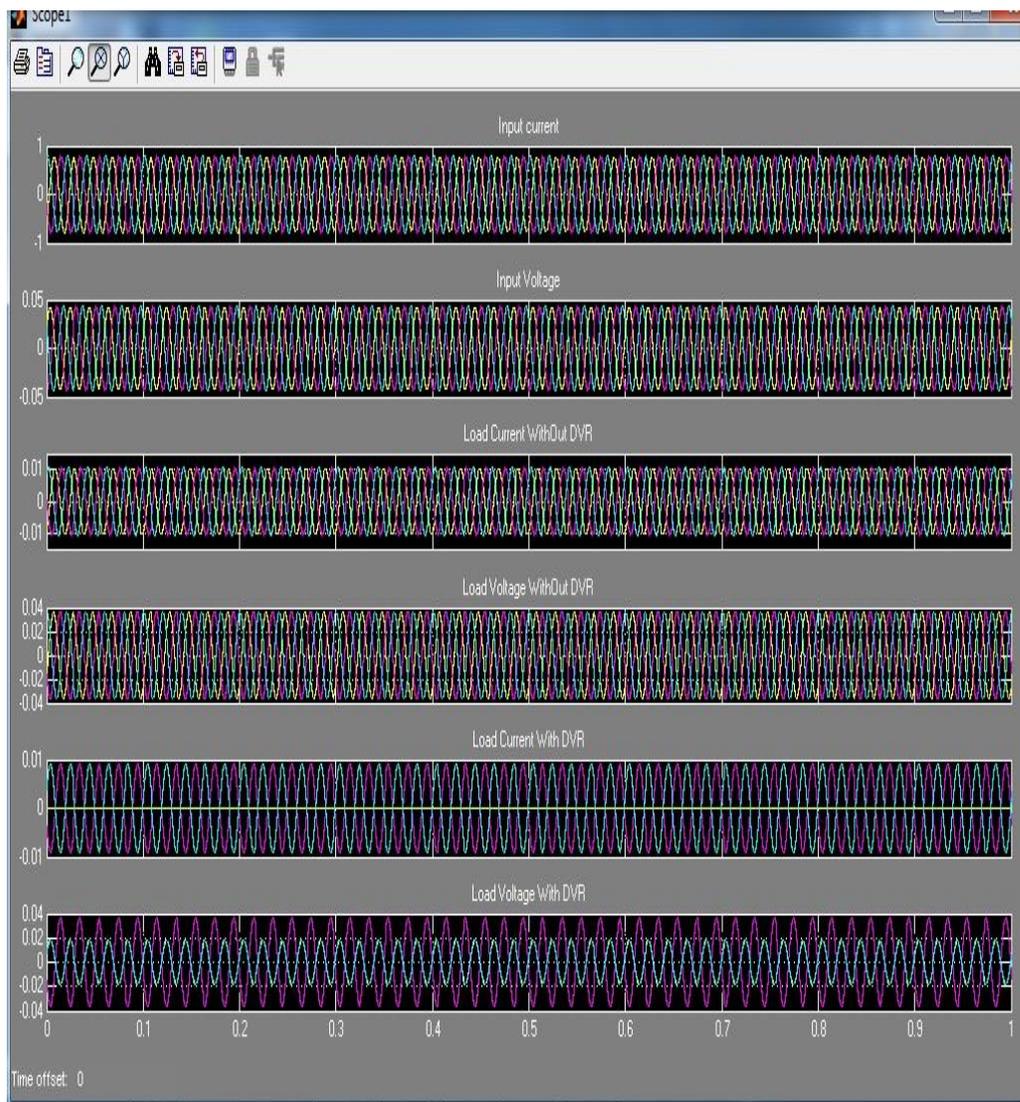


Fig [5.4] output waveform of simulink model of DVR with linear load

the result of the load voltage in either feeder with DVR or without DVR of above simulink [5.4.1] is shown below fig [5.6]

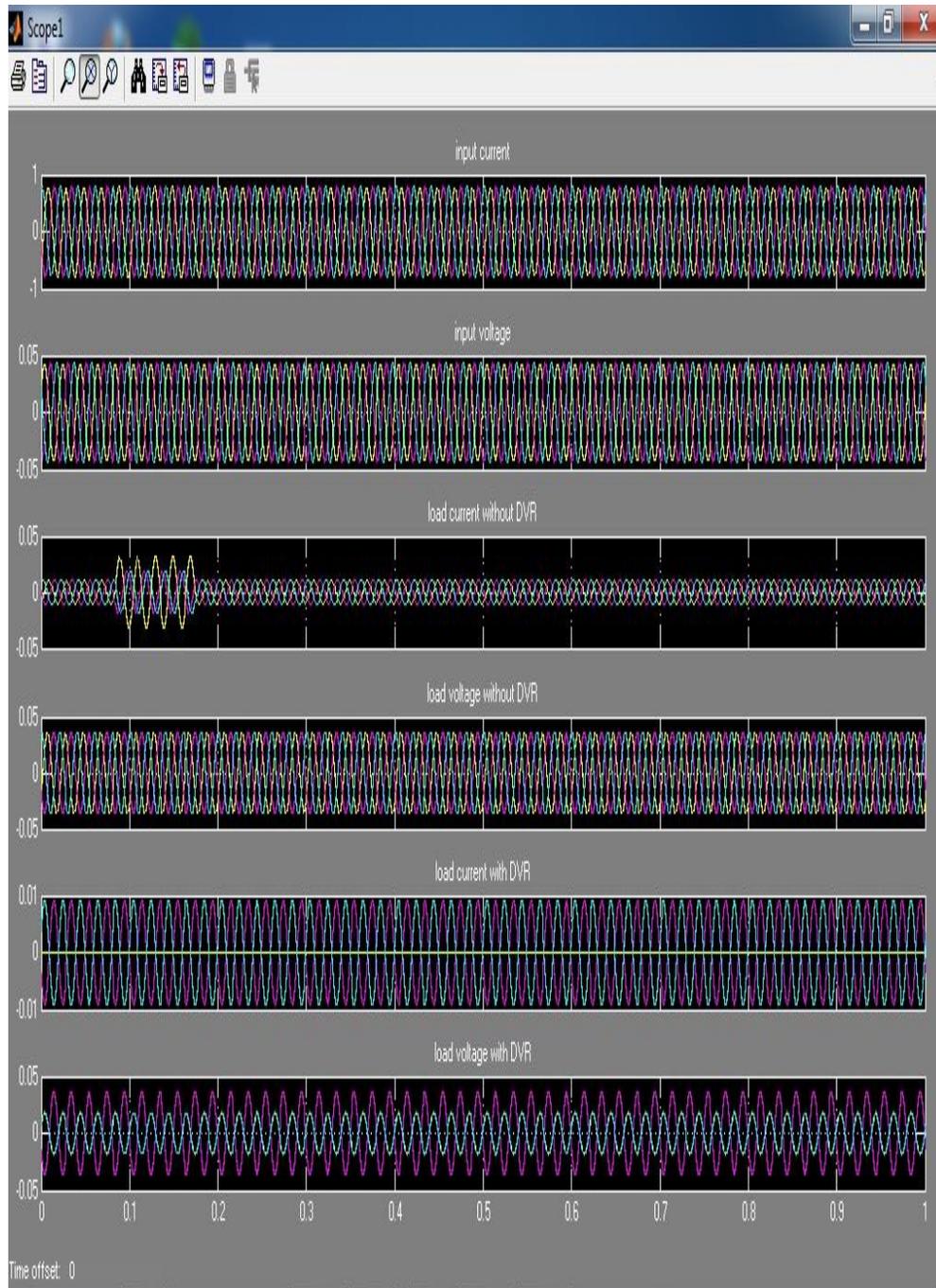


Fig [5.6]-output waveform of simulink DVR model with L-G fault

Output wave form of load voltage in case of L-G fault:-

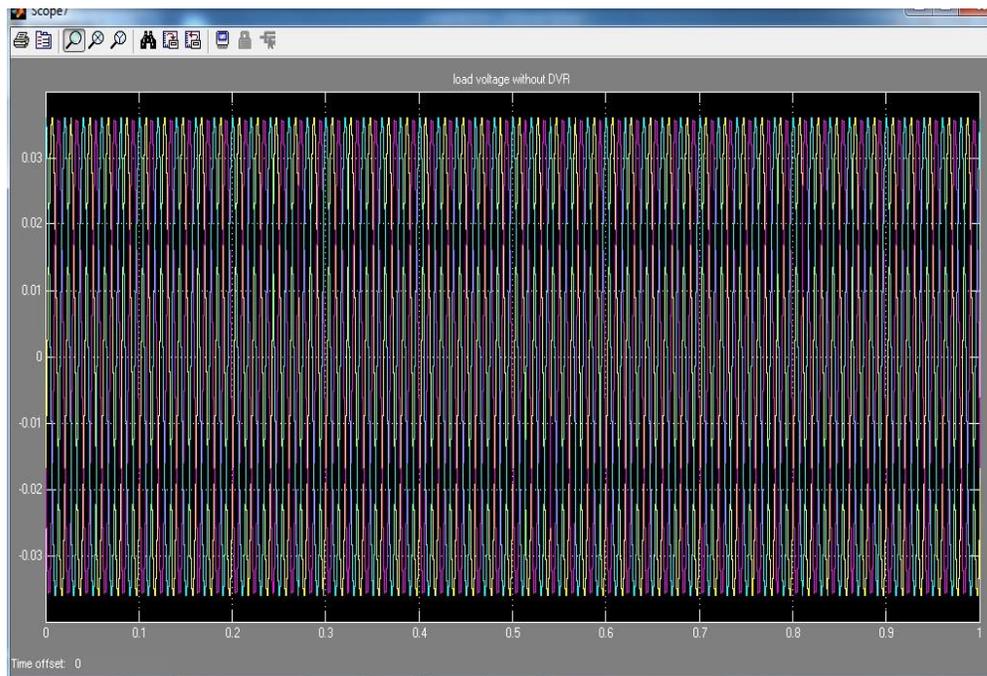


Fig [5.8] output waveform of load voltage without DVR

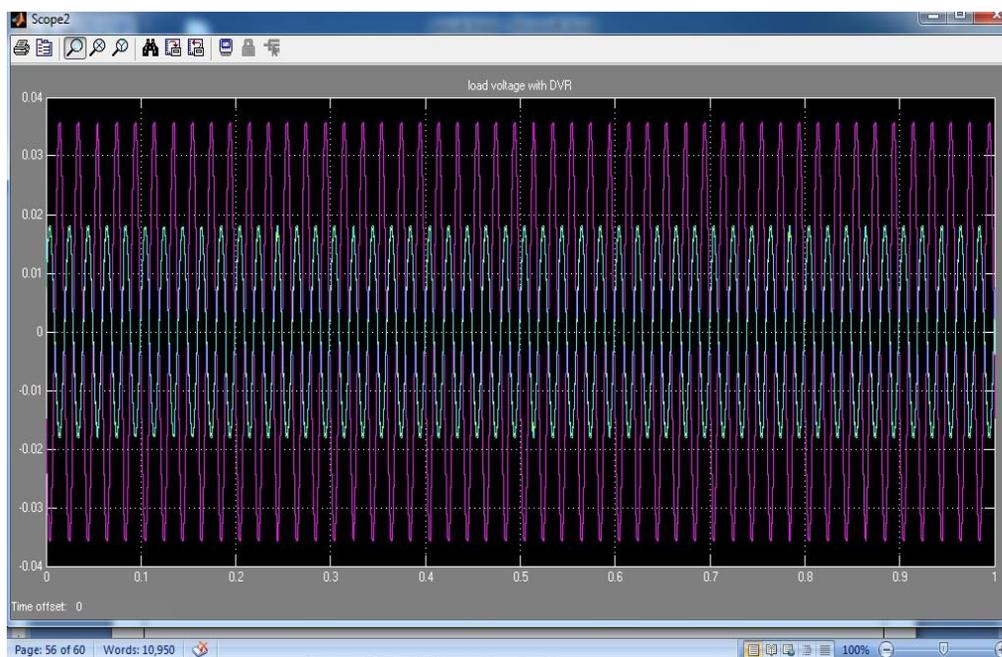


Fig [5.9]- Output waveform of load voltage with DVR

5.4.3 -Simulink model of the realized system with double line to ground (L-L-G) Fault:-

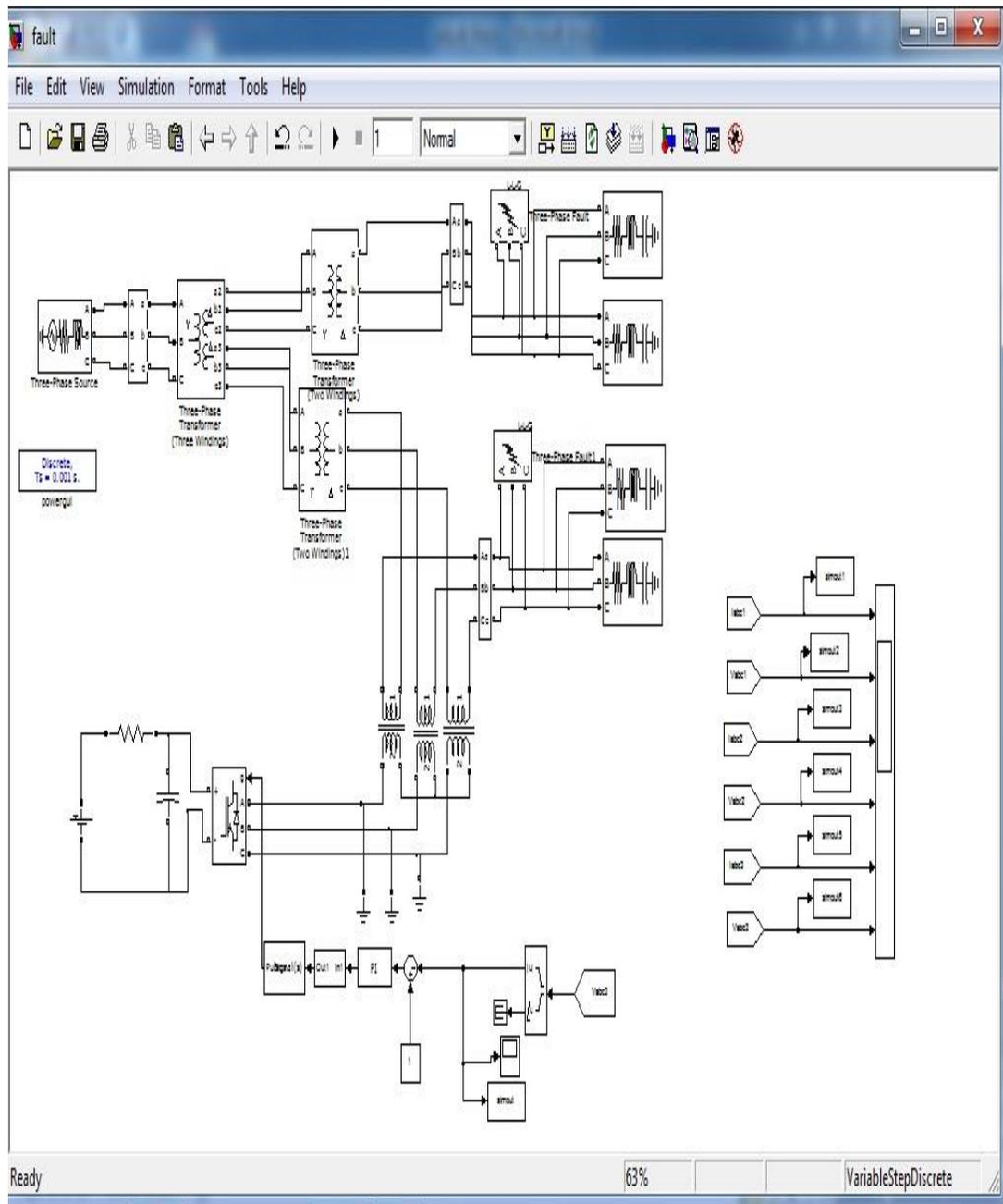


Fig [5.10]- Simulink model of DVR with L-L-G fault

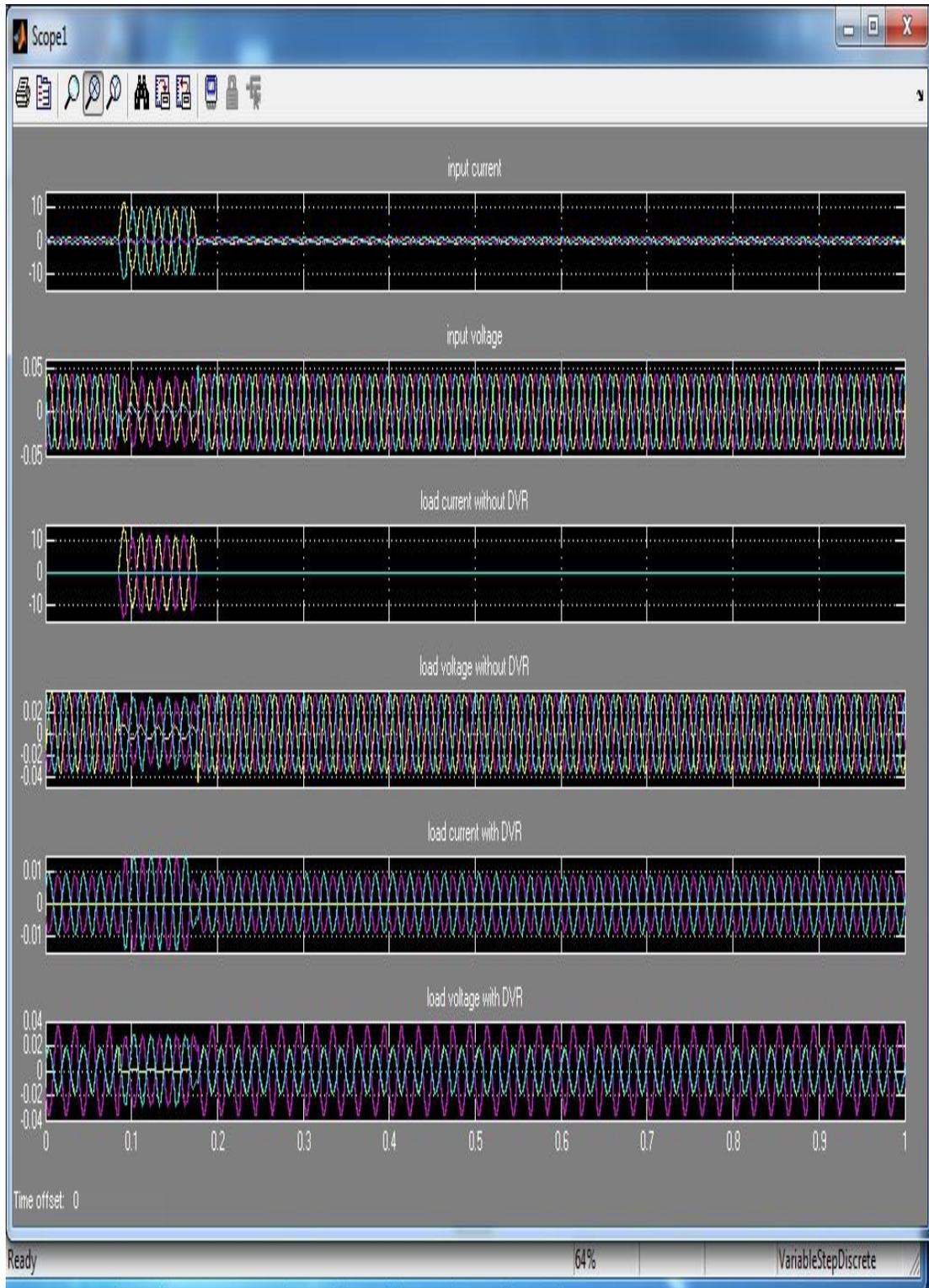


Fig [5.11] output waveform simulink model of DVR with L-L-G fault

5.4.4 - Simulation circuit for load voltage comparison L-L-G fault

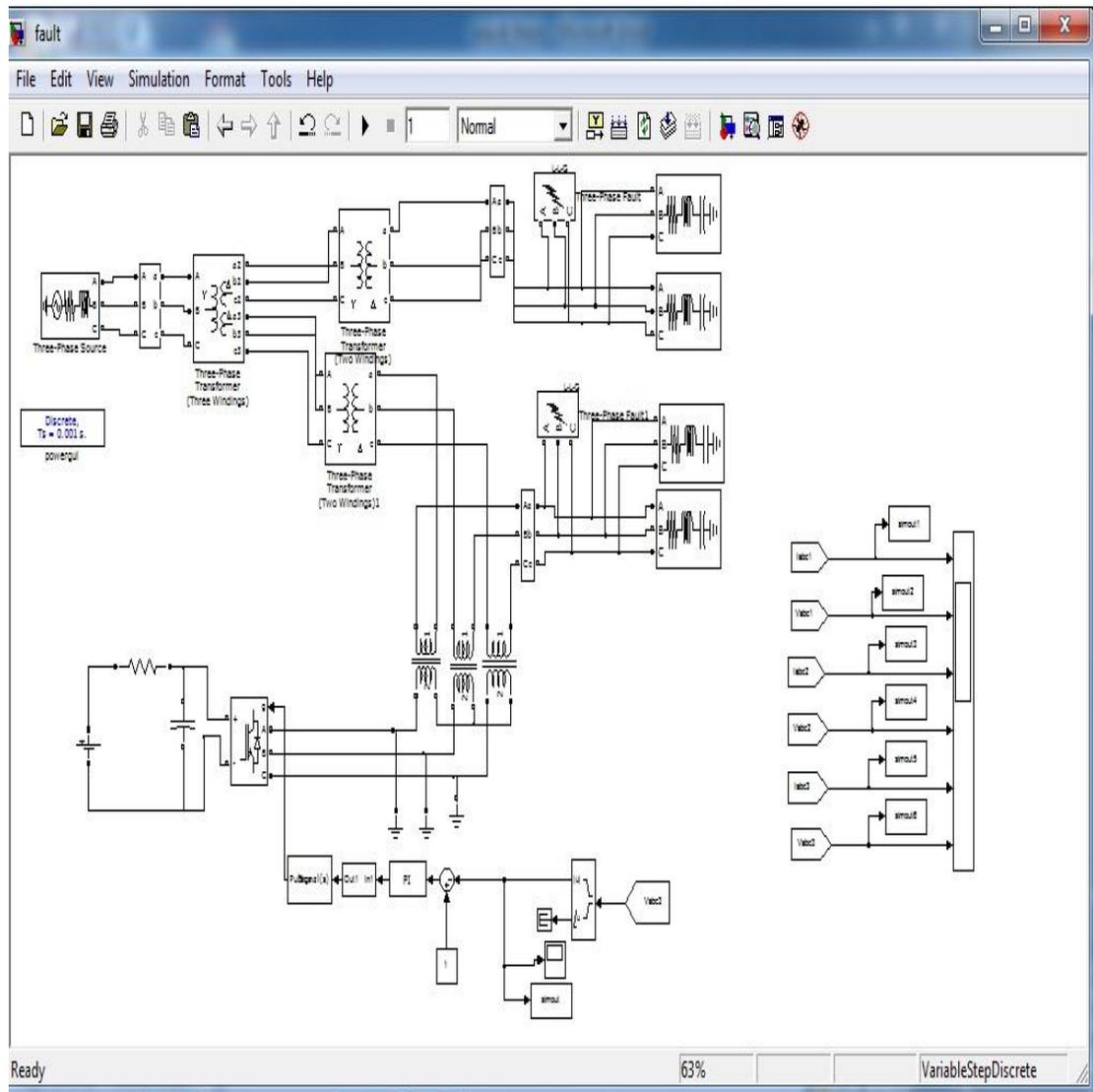


Fig [5.12]- Simulation model to compare load voltage in case of L-L-G fault.

Here we have taken the same model as we have in case of above Double line to ground (L-L-G) fault measurement, but the only difference is made here is that, to measure the load voltage without and with DVR individual scope is added with each block in the original circuit shown in case of L-L-G fault. Its behavior is examined and shown in below fig [5.13] & [5.14].

Output of simulated circuit for load voltage comparison L-L-G FAULT

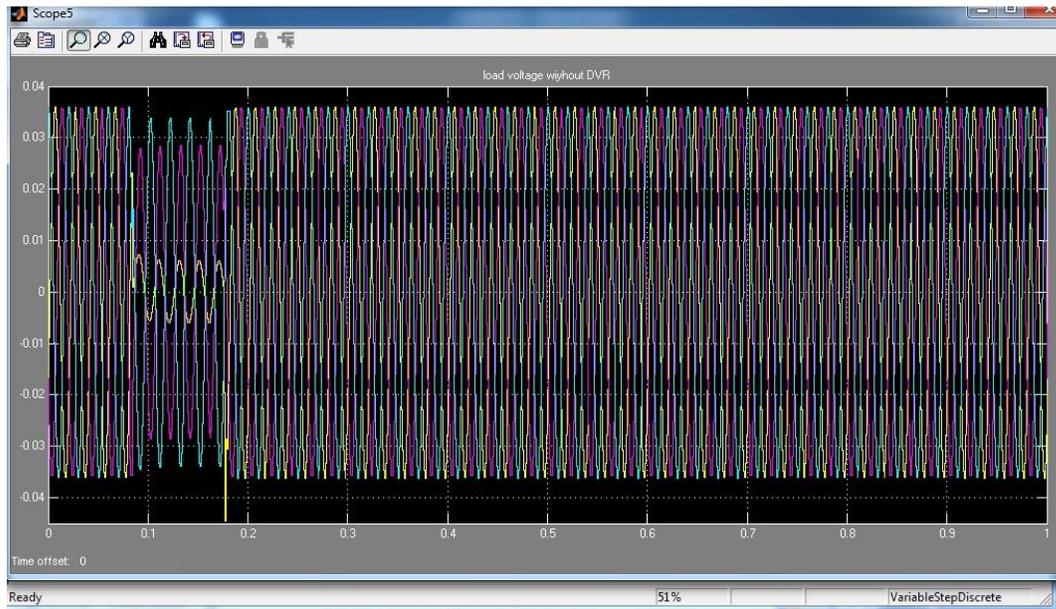


Fig [5.13]- Output wave form of load voltage without DVR

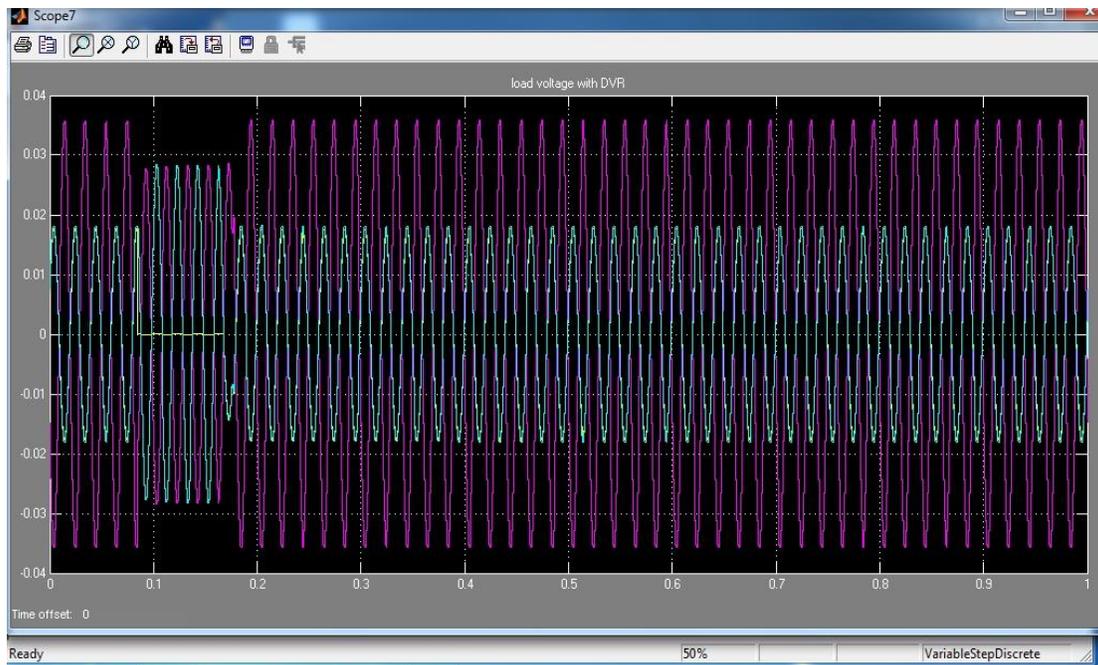


Fig [5.14]- output wave form of load voltage with DVR

6.1- Conclusion:-

In this my paper work, we have discuss the various issues which are concern with power quality, and its mitigation technique. We also described here in brief the CPD'S and the benefit of CPD'S on the power quality. Here we have given our more attention on sag mitigation, and for the mitigation purpose DVR is used. DVR is realized in the work and its behavior for different cases is examined. The effectiveness of DVR with PI controller for both cases above discuss is being established.

Future work:-

Here we have realized the DVR circuit with PI controller for linear load and for different fault condition; the following point may be taken for the given circuit for the future work:

- ❖ The use of multi-level DVR can be carried to establish its behavior.

- ❖ The other controller like fuzzy logic and adaptive PI fuzzy logic may be introduced in the DVR compensation strategy.

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