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DYNAMIC VOLTAGE RESTORER FOR VOLTAGE SAG MITIGATION

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Abstract: Power quality is one of major concerns in the present era. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. One of the major problems dealt here is the power sag. To solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. This paper presents modelling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. In this model a PI controller and Discrete PWM pulse generator was used.

I. INTRODUCTION

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipments.

Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly.

Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

II . POWER QUALITY PROBLEMS

2.1 Sources and effects of power quality problems

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems.

While power disturbances occur on all electrical systems, the sensitivity of today’s sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valueable components. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions.

- Voltage dip: A voltage dip is used to refer to short-term reduction in voltage of less than half a second.
- Voltage sag: 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: Voltage swell is defined as an increase in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min.
- Voltage 'spikes', 'impulses' or 'surges': These are terms used to describe abrupt, very brief increases in voltage value.
- Voltage transients: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.
- Harmonics: The fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency.
- Flickers: Visual irritation and introduction of many harmonic components in the supply power and their associated ill effects.

2.1.1 Causes of dips, sags and surges

1. Rural location remote from power source
2. Unbalanced load on a three phase system
3. Switching of heavy loads
4. Unreliable grid systems
5. Equipments not suitable for local supply

2.1.2 Causes of transients and spikes

1. Lightening
2. Arc welding
3. Switching on heavy or reactive equipments such as motors, transformers, motor drives
4. Electric grade switching

2.2 Solutions to power quality problems

There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. However, with the restructuring of power sector and with shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions will play a major role in improving the inherent supply quality; some of the effective and economic measures can be identified as following:

Lightening and Surge Arresters:
Arresters are designed for lightening protection of transformers, but are not sufficiently voltage limiting for protecting sensitive electronic control circuits from voltage surges.

Thyristor Based Static Switches:
The static switch is a versatile device for switching a new element into the circuit when the voltage support is needed. It has a dynamic response time of about one cycle. To correct quickly for voltage spikes, sags or interruptions, the static switch can used to switch one or more of devices such as capacitor, filter, alternate power line, energy storage systems etc. The static switch can be used in the alternate power line applications.

Energy Storage Systems:
Storage systems can be used to protect sensitive production equipments from shutdowns caused by voltage sags or momentary interruptions. These are usually DC storage systems such as UPS, batteries, superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators .The output of these devices can be supplied to the system through an inverter on a momentary basis by a fast acting electronic switch. Enough energy is fed to the system to compensate for the energy that would be lost by the voltage sag or interruption.

Though there are many different methods to mitigate voltage sags and swells, but the use of a custom Power device is considered to be the most efficient method. For example, Flexible AC Transmission Systems (FACTS) for transmission systems, the term custom power pertains to the use of power electronics controllers in a distribution system, specially, to deal with various power quality problems. Just as FACTS improves the power transfer capabilities and stability margins, custom power makes sure customers get pre-specified quality and reliability of supply.

This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, low harmonic distortion in load voltage, magnitude and duration of overvoltage and under voltages within specified limits, acceptance of fluctuations, and poor factor loads without significant effect on the terminal voltage There are many types of Custom Power devices. Some of these devices include: Active Power Filters (APF), Battery Energy Storage Systems (BESS), Distribution static synchronous compensators (DSTATCOM), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid-State Transfer Switches (SSTS), Solid State Fault Current Limiter (SSFCL), Static Var Compensator (SVC), Thyristor Switched Capacitors (TSC), and Uninterruptible Power Supplies (UPS).

III. DYNAMIC VOLTAGE RESTORER (DVR)

3.1 Introduction

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks.

DVR is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. It is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

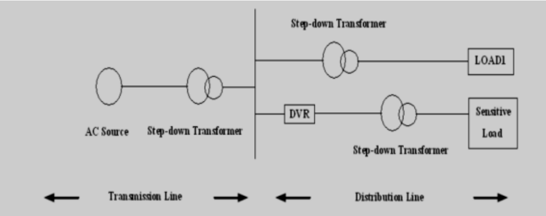


Fig. 3.1: Location of DVR

3.2 Basic Configuration of DVR

The general configuration of the DVR consists of:

i. An Injection/ Booster transformer
ii. A Harmonic filter
iii. Storage Devices
iv. A Voltage Source Converter (VSC)
v. DC charging circuit
vi. A Control and Protection system

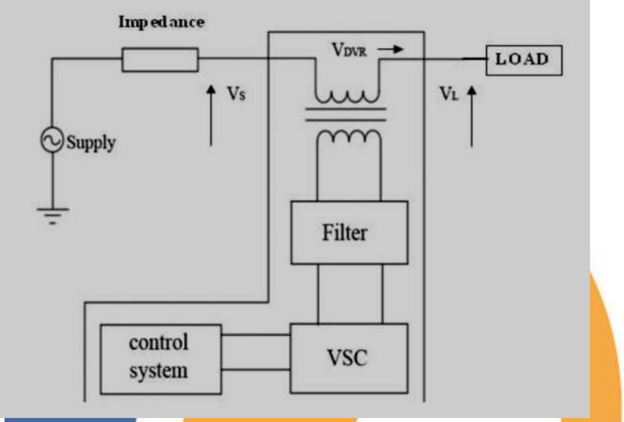


Fig. 3.2: Schematic diagram of DVR

3.2.1 Injection/ Booster transformer

The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its main tasks are:

- It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.
- In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

3.2.2 Harmonic Filter

The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level.

3.2.3 Voltage Source Converter

A VSC is a power electronic system consists of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle.

In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.

There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices.

The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

3.2.4 DC Charging Circuit

The dc charging circuit has two main tasks.

- The first task is to charge the energy source after a sag compensation event.
- The second task is to maintain dc link voltage at the nominal dc link voltage.

3.2.5 Control and protection

The control mechanism of the general configuration typically consists of hardware with programmable logic. All protective functions of the DVR should be implemented in the software. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility.

3.3 Equations related to DVR

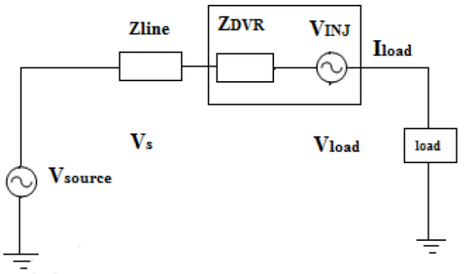


Fig. 3.3 Equivalent circuit diagram of DVR

The system impedance Zth depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage VDVR through the injection transformer so that the desired load voltage magnitude VL can be maintained. The series injected voltage of the DVR can be written as

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

Where

V_L : The desired load voltage magnitude

Z_{TH} : The load impedance.

I_L : The load current

V_{TH} : The system voltage during fault condition

The load current IL is given by,

$$I_L = \frac{[P_L + jQ_L]}{V}$$

When VL is considered as a reference equation can be rewritten as,

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

∝, β, δ are angles of respectively and θ is Load power angle

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right)$$

The complex power injection of the DVR can be written as,

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

It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power.

3.4 Operating modes of DVR

The basic function of the DVR is to inject a dynamically controlled voltage VDVR generated by a forced commutated converter in series to the bus voltage by means of a booster transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage VL. This means that any differential voltages caused by transient disturbances
in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer.

The DVR has three modes of operation which are: protection mode, standby mode, injection/boost mode.

3.4.1 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 (S2 and S3 will open) and supplying another path for current (S1 will be closed).

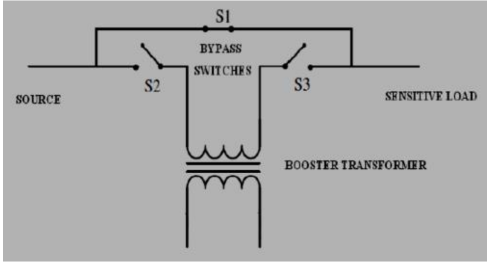


Fig. 3.4: Protection Mode (creating another path for current)

3.4.2 Standby Mode: (VDVR = 0)

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 will pass through the primary.

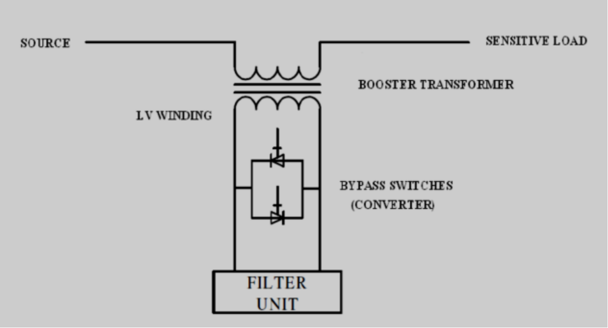


Fig. 3.5: Standby Mode

3.4.3 Injection/Boost Mode: (VDVR>0)

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.

3.5 Voltage injection methods of DVR

Voltage injection or compensation methods by mea ns of a DVR depend upon the limiting factors such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angel 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 methods of DVR voltage injection which are

i. Pre-sag compensation method
ii. In-phase compensation method
iii. In-phase advanced compensation method
iv. Voltage tolerance method with minimum energy injection

3.5.1 Pre-sag/dip 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 load voltage can be restored back to the pre-fault condition. Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation method. In this method the injected active power cannot be controlled and it is determined by external conditions such as the type of faults and load conditions

$$V_{DVR} = V_{prefault} - V_{sag}$$

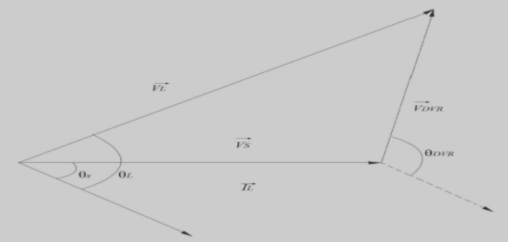


Fig. 3.6: Pre-sag compensation method

3.5.2 In-phase compensation method

This is the most straight forward method. In this method the injected voltage is in phase with the supply side voltage irrespective of the load current and pre-fault voltage. The phase angles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage are satisfied.

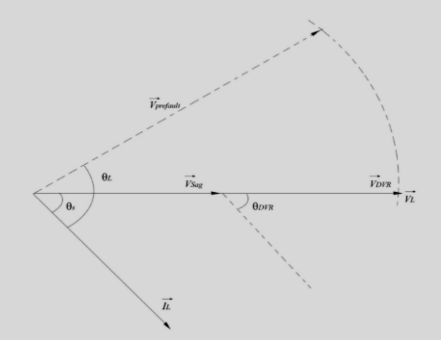


Fig. 3.7: In-phase compensation method

$$|V_L|=|V_{prefault}|$$

One of the advantages of this method is that the amplitude of DVR injection voltage is minimum for a certain voltage sag in comparison with other strategies. Practical application of this method is in non-sensitive loads to phase angle jump.

3.5.3 In-phase advanced compensation method

In this method the real power spent by the DVR is decreased by minimizing the power angle between the sag voltage and load current. In case of pre-sag and in-phase compensation method the active power is injected into the system during disturbances. The active power supply is limited stored energy in the DC links and this part is one of the most expensive parts of DVR. 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 this method the values of load current and voltage are fixed in the system so we can change only the phase of the sag voltage. IPAC method uses only reactive power and unfortunately, not al1 the sags can be mitigated without real power, as a consequence, this method is only suitable for a limited range of sags.

3.5.4 Voltage tolerance method with minimum energy injection

A small drop in voltage and small jump in phase angle can be tolerated by the load itself. If the voltage magnitude lies between 90%-110% of nominal voltage and 5%-10% of nominal state that will not disturb the operation characteristics of loads. Both magnitude and phase are the control parameter for this method which can be achieved by small energy injection.

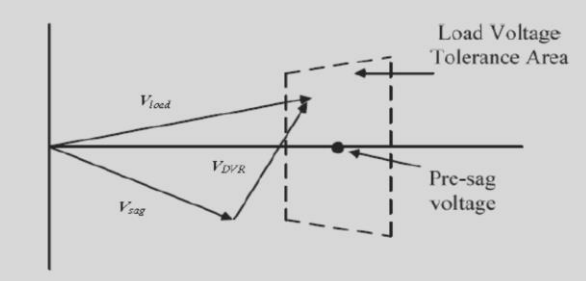


Fig. 3.8: Voltage tolerance method with minimum energy injection

IV. CUSTOM POWER DEVICES

The term custom power (CP) pertains to the use of power electronic controllers for distribution systems. Just as FACTS improves the reliability and quality of power transmission by simultaneously enhancing both power transfer volume and stability, the custom power enhances the quality and reliability of power that is delivered to customers. Under this scheme a customer receives a pre specified quality power. This pre specified quality may contain a combination of specifications of the following

- Frequency of rare power interruptions.
- Magnitude and duration of over and under voltages within specified limits.
- Low harmonic distortion in the supply voltage.
- Low phase unbalance.
- Low flicker in the supply voltage.
- Frequency of the supply voltage within specified limits.

There are many custom power devices. The compensating power electronic devices are either connected in shunt or in series or a combination of both. In addition there are current breaking devices that are power electronic based, Anyone or a combination of two or more of these devices are used to fulfill each one of the above mentioned objectives. The power electronic controllers that are used in the custom power solution can be network reconfiguring type or compensating type. The network reconfiguration devices are usually called switchgear and they include current limiting, current breaking and current transferring devices. The solid state or static versions of the devices are called

- Solid state current limiter (SSCL)
- Solid state breaker (SSB)
- Solid state transfer switch (SSTS)

The compensating devices either compensate a load, i.e., correct its power factor, unbalance etc. or improve the quality of the supplied voltage. .These devices are either connected in shunt or in series or a combination of both. The devices include

- Distribution STATCOM (DSTATCOM)
- Dynamic voltage restorer (DVR)Unified power quality conditioner (UPQC)

4.1 Solid State Current Limiter (SSCL)

The schematic diagram of a solid state current limiter is shown in Figure 4.1. It consists of a pair of opposite poled switches in parallel with the current limiting inductor Lm. In addition, a series RC combination with a resistance of Rs and a capacitance of Cs is connected in parallel with the opposite poled switch. This RC combination constitutes the unpolarized snubber network. The current limiter is connected in series with a feeder such that it can restrict the current in case of a fault downstream. In the healthy state the opposite poled switch remains closed. These switches are opened when a fault is detected such that the fault current now flows through the current limiting inductor. Let us illustrate its operating principle with the help of the following example.

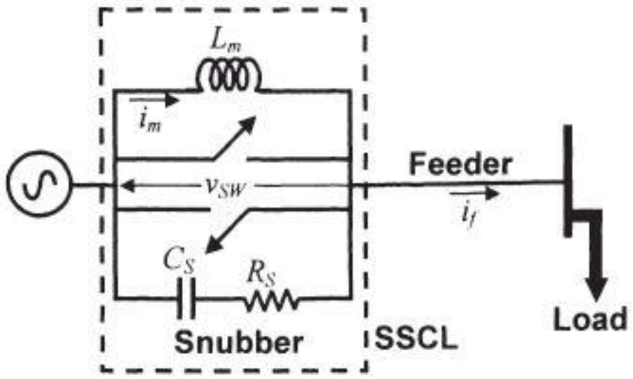


Fig. 4.1 Schematic diagram of a solid state current limiter

Let us consider the circuit of Figure 4.1 in which the source voltage is assumed to have a peak of 1.0 per unit and has a frequency of 50 Hz. The feeder has an impedance of 0.05 + jO.2 per unit, while the load impedance is given by 2.0 + jl.5 per unit. The SSCL parameters are Xm== (ωLm== 0.5 per unit, Rs== 0.1 per unit and Xs= 1/ωCs == 1.0 per unit. where (ω is the system frequency in radians. It is assumed that the system is operating in the steady healthy state when a fault occurs at the load bus.

In the absence of the current limiter, the fault current will have a steady state value of 5.0 per unit but it can shoot up to about 20-25 per unit depending on the instant of the occurrence of the fault. To limit the fault current, the opposite poled switch opens once the occurrence of the fault is detected. In this case we have assumed that the fault is detected the moment it has occurred. This however is not a valid assumption and more realistic.

The system response is shown in Figure 3.2, which depicts the fault current through feeder If; the voltage across the switch Vsw and the current through the limiting inductor 1m (see Figure 3.1). It can be seen that before the occurrence of the fault, both Vsw and 1m are zero. Once the fault occurs and the opposite poled switch opens, the capacitor Cs starts charging and the current through the limiting inductor rises linearly. The feeder current during this period rises sharply. However, the initial transient dies out quickly and the fault current is limited by the series combination of the SSCL and the feeder impedances. This condition persists if the fault is not cleared.

4.2 Solid State Transfer Switch (SSTS)

The schematic diagram of a solid state transfer switch (SSTS) is shown in Figure 3.4. This device, which is also known as a static transfer switch (STS), is used to transfer power from the preferred feeder to the alternate feeder in case of voltage sag/swell or fault in the preferred feeder. The transfer switch would be used to protect sensitive loads. An SSTS contains two pairs of opposite poled switch. In this case the switch is made of thyristors. These switches are denoted by Sw1and SW2. Suppose the preferred feeder supplies the power to the load. This is done through the switch Sw1while the switch SW2remains open.

If sudden voltage sag occurs in the preferred feeder, the SSTS then closes the switch SW2 such that current starts flowing through the alternate feeder to the load. The switch Sw1is then switched off. This switching scheme is known as make before break (MBB) switching in which the switch Sw1 is disconnected only after the switch SW2 is connected. Note that if the local bus voltages appearing in both the preferred feeder side and the alternate feeder side have the same magnitude and phase there will be no transient in the load when the switch is operated in MBB. However this condition cannot be usually satisfied and in those cases a transient in the load current is unavoidable. Also note that it is not always possible to operate the device in MBB fashion when there is a fault in the preferred feeder. Depending on the direction of the current it may have to be operated in break before make (BBM) fashion otherwise the alternate feeder may start feeding the fault.

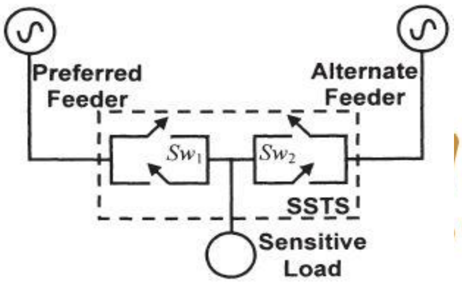


Fig. 4.2 Schematic diagram of a static transfer switch

4.3 Load compensation using DSTATCOM

The schematic diagram of a distribution system compensated by an ideal shunt compensator (DSTATCOM) is shown in Figure 4.3. In this it is assumed that the DSTATCOM is operating in current control mode. Therefore its ideal behavior is represented by the current source If It is assumed that Load-2 is reactive, nonlinear and unbalanced. In the absence of the compensator, the current J, flowing through the feeder will also be unbalanced and distorted and, as a consequence, so will be Bus-1 voltage.

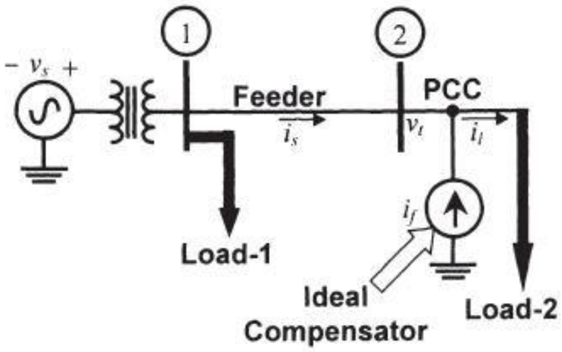


Fig. 4.3 Schematic diagram of ideal load compensation

To alleviate this problem, the compensator must inject current such that the current I, becomes fundamental and positive sequence. In addition, the compensator can also force the current II to be in phase with the Bus-2 voltage. This fashion of operating the DSTATCOM is also called load compensation since in this connection the DSTATCOM is compensating the load current. From the utility point of view, it will look as if the compensated load is drawing a unity power factor, fundamental and strictly positive sequence current.

The point at which the compensator is connected is called the utility customer point of common coupling (PCC). Denoting the load current by I,the KCL at the PCC yields

$$i_s + i_f = i_l \text{ So } i_s = i_l - i_f \qquad (4.1)$$

The desired performance from the compensator is that it generates a current If such that it cancels the reactive component, harmonic component and unbalance of the load current.

Let us first demonstrate the working principle of the DSTATCOM assuming that the source voltage is stiff. This implies that the source is connected at the point of common coupling and the feeder, Load-1 and the coupling transformer of Figure 3.5 is missing. The source voltage is assumed to be 50 Hz, balanced with the peak value of 21/2 per unit. It is supplying a three phase unbalanced RL load that are given by Za= 5 + j5 per unit, Zb= 5 + j1 per unit and Zc= 3 + j2 per unit where the subscripts a, band c indicate the three phases. In addition to the RL, a three-phase controlled rectifier is also connected to the load. The rectifier draws a square wave current with a peak of 0.1 per unit and has a delay angle of 30°. The distribution system is assumed to be a 3-phase, 4-wire system.

The ideal compensator now injects currents that cancel harmonics from load current and also balances the load. Furthermore, it also forces the current drawn from the source to be unity power factor. these currents are injected, the source currents become balanced, harmonic free and unity power factor . In this figure a scaled version of the voltage of phase-a (denoted by vsa) is also plotted to illustrate the source current of the corresponding phase is in phase with the voltage. It can be seen that while the power supplied by the source (Ps) is constant, the power injected by the compensator has a zero mean. This implies that the compensator neither requires a real power from the source nor does it supply a real power to the load. The oscillating part of the load power is supplied by the compensator and the average part is supplied by the source such that the load power (Ps) is the sum of powers Ps and Pt.

4.4 Voltage Regulation using DSTATCOM

The schematic diagram of an ideal shunt compensator acting as a voltage regulator. In this the ideal compensator is represented by a voltage source and it is connected to the PCC. However it is rather difficult to realize this circuit and the alternate structure. It can be seen that this is the same structure as used for load compensation. It has the advantage that the harmonics can be bypassed by the filter capacitor C.

The basic idea here is to inject the current id in such a way that the voltage VI follows a specified reference. The compensator must be operated such that it does not inject or absorb any real power in the steady state. The magnitude of the voltage VI can be arbitrarily chosen. However its phase angle must be chosen such that the relation Is= Ilpis satisfied.

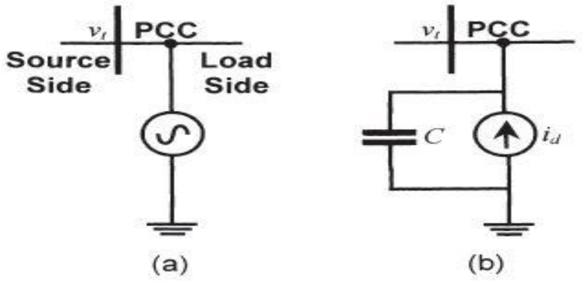


Fig. 4.4(a) Ideal voltage controller and, (b) its practical realization

4.5 Protecting Sensitive Loads using DVR

A dynamic voltage restorer (DVR) is used to protect sensitive loads from sag/swell or disturbances in the supply voltage. The world's first DVR was installed in August 1996 at a 12.47 kV substation Anderson, South Carolina. This was installed to provide protection to automated rug manufacturing plant. Prior to this connection, the DVR was first installed at the Waltz Mill test facility near Pittsburgh for full powertests. The next commissioning of a DVR was in February 1997 at a 22 kV distribution system at Stanhope, Victoria, Australia. This was done to protect the diary milk processing plant. The saving that may result from the installation of this DVR is estimated to be over $100,000 per year. In the next phase of development, DVRs that can be mounted on an overhead platform supported by two poles were fabricated.

The schematic diagram of a sensitive load protected by an ideal series compensator (DVR).In this the DVR is represented by an ideal voltage source that injects a voltage VI in the direction shown. There are two different ways of constructing this device. The DVR can be constructed such that it is either capable or not capable of supplying or absorbing real power. The DVR voltage control is simple if it is capable of supplying or absorbing real power.

$$V_t + V_f = V_l \qquad (4.2)$$

Where V_l is the load bus voltage. The DVR then can regulate the bus voltage to any arbitrary value by measuring the terminal voltage V_t and supplying the balance through V_f.

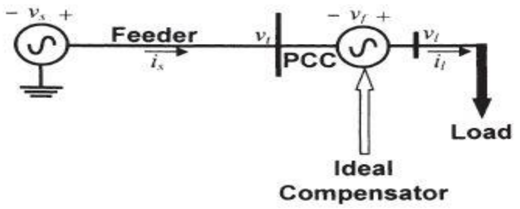


Fig. 4.5 Schematic diagram of a sensitive load protected by a DVR

The solution to this problem however is not as straightforward when the DVR is not capable of supplying or absorbing any real power in the steady state. It may instead have to supply or absorb real power during transients. The current through the line Isis the same as the current through the load it. Also the phase angle difference between the load current Iland the load voltage Vt is dictated by the power factor of the load. Also for no real power injection or absorption, the positive sequence fundamental frequency component of the voltage Vt must be in quadrature with the positive sequence fundamental frequency component with the load current It. The following example illustrates the DVR operation.

1. First extract the fundamental positive sequence of the voltages Vt and Vl and the current It. Then compute the power factor angle.
2. Generate the fundamental positive sequence component of the voltage Vfthat is in quadrature with the line current from the measurements of step 1 such that the load terminal voltage is regulated to the desired value.
3. Since the load terminal voltage must be balanced sinusoidal, subtract the harmonic and unbalanced component of the terminal voltage from the fundamental positive sequence of the voltage Vfobtained from step 2 such that the injected voltage cancels out these components.

It can be seen that both the load terminal voltage and, as a consequence, the load currents become balanced sinusoids within one cycle of the connection of the compensator at0.02 s. The power through the compensator is oscillating with a mean of zero. Therefore the compensator neither absorbs nor injects any real power.

4.6 Unified Power Quality Conditioner (UPQC)

The schematic diagram of a unified power quality conditioner (UPQC) compensated distribution system is shown in Figure 4.6 (a). This is useful when both source and load are unbalanced and distorted. For example assume that the source voltage Vs is both unbalanced and distorted. Also the load current h is also unbalanced and distorted. As a consequence the terminal voltage Vt, the load voltage Vl and the source current Is will also be unbalanced and distorted. Now suppose there are other customers connected to the load bus that draw purely balanced sinusoidal currents. Then both the source and load unbalance and distortion affect them. Again if there is a load bus upstream from the point of common coupling, the customers on that bus will equally get affected. A UPQC can alleviate this problem.

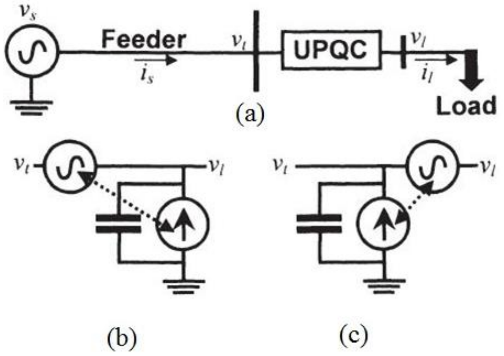


Fig. 4.6 (a) Schematic diagram of a UPQC compensated system, (b) &(c) two alternateconnections

A UPQC combines a series and a shunt compensator together. It can therefore yield the benefits of both these devices. For example it can tightly regulate the load bus voltage Vl, shown in Figure 4.6 (a). Therefore all loads including the unbalanced and nonlinear load will have a supply voltage that is balanced and sinusoidal. The UPQC can also make the current drawn from the supply (Is) balanced, sinusoidal and in phase with the terminal voltage (Vt).Therefore the voltage of any bus upstream from the PCC will not be affected due to a nonlinear and unbalanced load. However it will be impossible to correct the unbalance and distortion produced by the source voltage using this device. Therefore the upstream bus voltages will remain unbalanced and distorted.

There are two different ways of connecting a UPQC. These are shown in Figure 4.6 (b) and (c). In the connection of Figure 4.6 (b) the series device is placed before the shunt device while it is placed after the shunt device in Figure 4.6 (c). The dotted line in these figures indicates any energy exchange path between the devices. Usually the inverter realizing the series device is supplied by a dc capacitor. Similarly the shunt inverter is also supplied by a dc capacitor. In a UPQC both these inverters are supplied by a common dc capacitor in the same way as a unified power flow controller used in bulk power transmission. The energy exchange between the series and the shunt device takes place through this common dc capacitor.

V. SIMULATION MODEL OF DVR

The configuration of the proposed DVR design using MATLAB/SIMULINK, where the outputs of a three-phase half-bridge inverter are connected to the utility supply via wye-open connected series transformer. Once a voltage disturbance occurs, with the aid of dqo transformation based control scheme, the inverter output can be steered in phase with the incoming ac source while the load is maintained constant. As for the filtering scheme of the proposed method, output of inverter is with capacitors and inductors installed with capacitor.

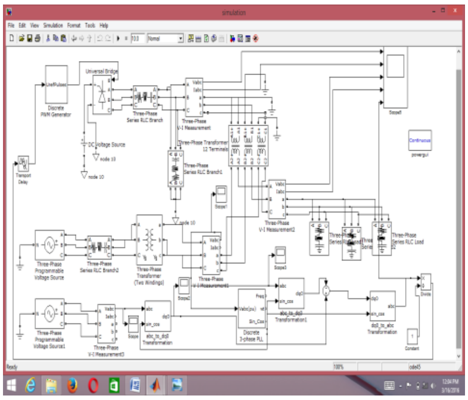
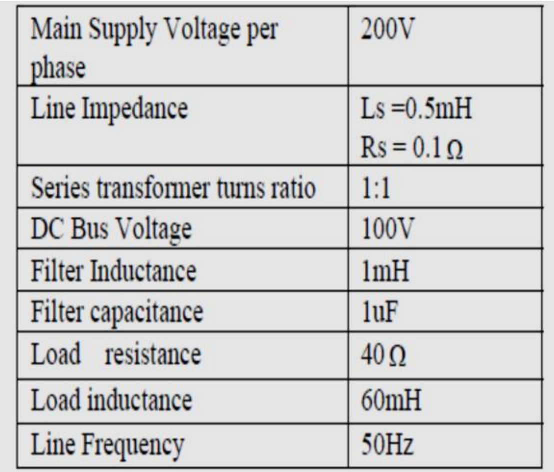


Fig. 5.1 Simulation Model of DVR

Table 5.1 System Parameters and Constant Values



Main Supply Voltage per phase	200V
Line Impedance	Ls =0.5mH Rs = 0.1 Ω
Series transformer turns ratio	1:1
DC Bus Voltage	100V
Filter Inductance	1mH
Filter capacitance	1uF
Load resistance	40 Ω
Load inductance	60mH
Line Frequency	50Hz

VI . 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 rigger 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 ay 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. he dqo transformation or Park's transformation [6-7] is used to control of DVR. The dqo method gives the sag depth and phase shift information with start and end times. The quantities re expressed as the instantaneous space vectors. firstly convert the voltage from a-b-c reference fame to d-q-o reference. For simplicity zero phase sequence components is ignored.

Flow chart the feed forward dqo transformation for voltage sags/swells detection. The detection is carried out in each of the three phases. control scheme for the proposed system is based on the comparison of a voltage reference and theme assured terminal voltage (Va,Vb,Vc).The voltage sags is detected when the supply drops below 90% of the reference value whereas voltages wells is detected when supply voltage increases upto 25% of the reference value. The error signal issued as a modulation signal that allows to generate 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 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 a commutation pattern for the power when supply voltage increases up to 25% of the reference value. The error signal issued as a modulation signal that allows to generate 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.

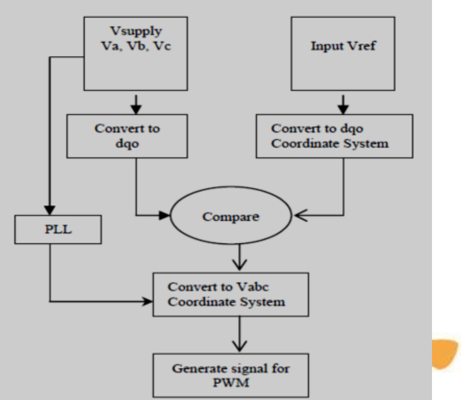
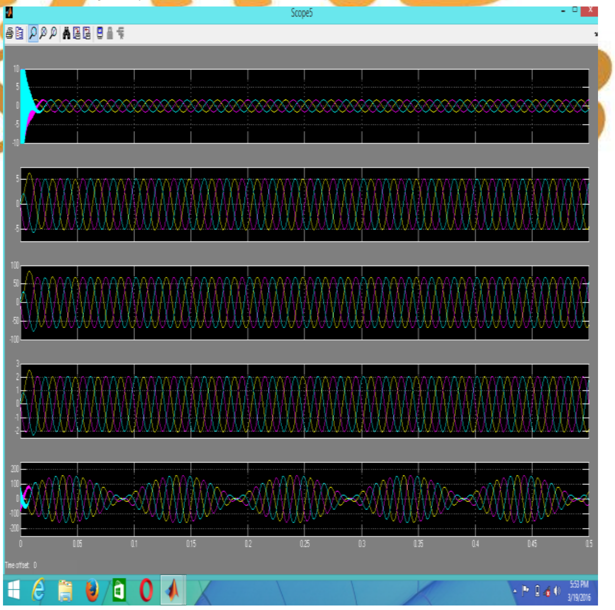


Fig. 6.1 Flow chart of feed forward control technique for DVR based on dqo transformation

VII. SIMULATION RESULT



VIII. CONCLUSION

The purpose of this research was to develop voltage sag and swell mitigation device with low cost and high reliability. The scheme consisting of a linear control scheme has been proposed. This topology, a more cost-effective and reliable sag and swell supporter has been achieved primarily by reducing the number of switching components.

A literature survey and a discussion of various existing methods were presented. The usage and operation principles were addressed, and deficiencies in the existing methods were mentioned, as well. The use of Dynamic voltage restorer gives rise to many possibilities for controlling the voltage and regulating power. From the literature survey, it was found that FACTS devices such as DVRs and STATCOMs yield good performance in controlling the output voltage.

This research has as its first priority, the development of a low-cost system that has a performance that is competitive to the FACTS devices. Therefore, an alternative topology from an inverter-based system was devised.

A voltage detection method known as "peak detection" was chosen to be the most appropriate for the application under study. This method was chosen since methods relying on a DQ transformation require three-phase voltage information, and the output of the DQ transformation has ripples in the case of an unbalanced three-phase supply. It was shown that because of the filtering of the ripples, there is no difference between the detection time of the DQ method and that of the peak detection method. Next, a voltage controller based on a linear controller was presented, and it was shown that the controller that includes feed-forward and anti-windup results in a fast dynamic response and an acceptable output voltage overshoot.

When the voltage controller detects the sag or the swell condition, the transition from bypass mode to PWM mode must be done as quickly as possible. Since the thyristors are not self-commutable devices, the commutation depends on the condition of the input voltage and the thyristor current. The simulations were done under various conditions of the input voltage and the thyristor current for positive and negative polarities. The commutation logic using the input current and the input voltage provides a low-cost solution, because the current sensor located at the input terminal requires a lower voltage isolation level than that located in the thyristor assembly.

The simulations have been done to show that the proposed voltage sag and swell supporter scheme regulates the output voltage with quick reaction and high precision during voltage sag and swell events. It was also shown that because of the voltage detection delay, there exists an output voltage overshoot transient at the moment of the voltage recovery.

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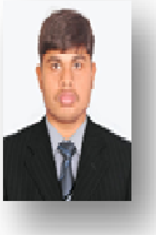

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