Power Quality Improvement by using Various Voltage Sag and Swell Controller

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ABSTRACT
Distribution system needs to be protected against voltage sags, swells that adversely affect the reliability & quality of power supply at the utility end. These problems can be mitigated with voltage injection method using custom power device, Dynamic Voltage Restorer (DVR). In this paper we design a Dynamic Voltage Restorer (DVR) which is utilized for power quality improvement. The main power quality problems like voltage sag and swell are studied in this paper. The device used to phase out voltage sags and a swell in the distribution lines is the Dynamic Voltage Restorer (DVR). The DVR can restore the load voltage within few milliseconds by injecting series voltage which is actually missing voltage in to system through series connected booster transformer, when it is subjected to voltage sags. Generally DVR can be connected to grid through inverter topologies such as Voltage Source Inverter (VSI) or Current Source Inverter (CSI).This device can be implemented to protect a group of medium or low voltage consumers. This study present compensation of sags and swells voltage during single line to ground, double line to ground and three phase line to ground faults. By using DVR technology, power quality enhances, which is shown in simulation waveform.

Keywords
Dynamic Voltage Restorer, Voltage Sags, Voltage Swells, Power quality

1. INTRODUCTION
Various power quality problems have originated due to the increasing use of non linear and power electronic loads. Harmonics and voltage distortion occur due to these loads. The power quality problems can cause malfunctioning of sensitive equipments, protection and relay system. Distribution system is mainly affected by voltage sag and swell power quality issues. Short circuits, lightning strokes, faults and inrush currents are the causes of voltage sags. Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers, single line to ground fault on the system lead to voltage swells. The electric power system consists of three major functional blocks: - generation, transmission and distribution. As per reliability consideration in power system, generation unit must generate adequate amount of power, transmission unit should supply maximum power over long distances without overloading and distribution system must deliver electric power to each consumer’s premises form bulk power systems. Distribution system is located at the end of electric power system and is directed to the consumer, So the power quality depends upon the state of distribution system. The reason for this is that failure in the electric distribution network accounts for about 91% of the average consumer’s interruptions. Earlier, power system reliability focussed on generation and transmission system due to capital investment in these. But now these days, distribution system is receiving more attention as reliability is concerned. Different approaches exist to limit the costs caused by voltage dips and one Interesting approach considered here is to use voltage source convertors connected in series between supply system and the sensitive load, this type of devices are often termed a Dynamic Voltage Restorer (DVR). It can restore the load voltage within a few milliseconds and hence avoiding any power disruption to that load. The main idea of the DVR is detecting the voltage sag and injecting the missing voltage in series to the bus by using an Injection Transformer.

2. POWER QUALITY PROBLEMS
There are several types of power quality problems that a customer may encounter and may classified according or depending on how the voltage waveform is being distorted. There are transients, short duration of variations (sags, swells, and interruption), long duration variations (sustained interruptions, under voltages, over voltages), voltage imbalance, waveform distortion (dc offset, harmonics, inter harmonics, notching, and noise), voltage fluctuations and power frequency variations.

2.1 Sources of poor Power Quality are listed as follows:
- Lightning Strike
- L-G fault
- Non- linear load
- Arching devices
- Straining of large motors
- Power electronic devices
- Sensitive equipment
- Line Capacitor, Load switching Office equipment’s
- Environmental related danger
- Transformation energization

2.2 Types of Power Quality problems
Power Quality problems encompass (include) a wide range of disturbances such as voltage sags, swells, harmonics distortion, flicker, notching, and interruptions. These power quality problems are defined below with their causes and effects.

2.2.1 Voltage Sag
Voltage Sag is the most severe problem in the power quality. Voltage sag is the decrease in voltage between 10% and 90% of nominal voltage for half cycle to one minute. Sags account for the vast majority of power problems experienced by end users they can be generated both internally and externally from an end users facility. External causes of sags primarily come from the utility transmission and distribution network. Sags coming from the utility have a variety of cause including lightning, animal and human activity, and normal and abnormal utility equipment operation.

2.2.2 Voltage Swell

A swell is the opposite of a sag - an increase in voltage above 110% of nominal for half cycle to one minute. Although swells occur infrequently when compared to sags, they can cause equipment malfunction and premature wear. Swells can be caused by shutting off loads or switching capacitor banks on.

3. CUSTOM POWER DEVICES

Today, electrical power systems are more complex in operation and more unstable with uncontrolled power flows and higher losses. The major reason behind this is increase in demand and less generation as well as constraints on the construction of new transmission lines. Also, a number of high voltage power systems are operating below their thermal rating because of voltage and stability limits. Conventional electric power delivery systems are not designed to handle the control requirements of complex interconnected power system. This situation necessitates the review of traditional power delivery methods and practices and the creation of new concepts. In this context, the concept of custom power was introduced to improve the power quality and enhance the reliability of power supply. The term 'custom power' describes the value added power that electric utilities will offer their customers. Just like FACTS, the CPDs (custom power devices) are power electronic switching equipments and controllers to enhance the reliability of electrical energy supplied to consumers in the form of less interruptions and small voltage variations. These devices have the ability to provide remedial measures to power quality (PQ) problems.

3.1 Classification of Custom Power Devices

Custom power devices can be classified into two main categories; first one being network configuring type and the other is compensating type. The former one changes the configuration of the power system network for power quality enhancement. The devices widely used in this category are SSCL (Solid State Current Limiter), SSCB (Solid State Circuit Breaker) and SSTS (Solid State Transfer Switch). SSCL is an IGBT based device that inserts an inductor in series with a power system and limits the fault current and once the fault is cleared the inductor is removed from the circuit. SSCB acts as a protection device which isolates the fault circuit from the system. SSTS performs rapid transfer of the load from a fault line to an alternative line to protect a sensitive load. All these devices use self-commutating principle like GTO's or IGCT's. The compensating type devices are mainly used for active filtering, load balancing, power factor correction and voltage regulation. The compensating devices are DVR, DSTATCOM and UPQC. DSTATCOM has a similar structure as that of STATCOM in the transmission system and is connected in shunt with the power system. DVR is a series connected device which injects a rapid series voltage to compensate the supply voltage. UPQC is a similar structure to that of UPFC which injects series voltage and shunt current to the system. The scope of the thesis work is related to the use of compensating devices, therefore compensating type custom power devices are discussed here: There are different types of Custom Power devices used in electrical network to improve power quality problems. Each of the devices has its own benefits and limitations. A few of these reasons are as follows. The SVC pre-dates the DVR, but the DVR is still preferred because the SVC has no ability to control active power flow. Another reason include that the DVR has a higher energy capacity compared to the superconductive magnetic energy storage (SMES) and UPS devices. Furthermore, the DVR is smaller in size and cost is less compared to the DSTATCOM and other custom power devices. Based on these reasons, it is no surprise that the DVR is widely considered as an effective custom power device in mitigating voltage sags. In addition to voltage sags and swells compensation, DVR can also add other features such as harmonics and Power Factor correction. Compared to the other devices, the DVR is clearly considered to be one of the best economic solutions for its size and capabilities. This device has very fast response time as compare to other power quality devices(i.e.less than ¼ cycles).DVR can supply active power for longer time.DVR can provides active as well as reactive power to the uncompensated line .

4. DYNAMIC VOLTAGE RESTORER

The DVR was first installed in 1996 DVR (also known as Static Series Compensator) maintains the load voltage at a desired magnitude and phase by compensating the voltage sags/swells and voltage unbalances. A Dynamic Voltage Restorer (DVR) is a type of switching converter which is basically DC-to-AC solid-state switching converter [3,4,5]. It is used to maintain distribution side voltage where sensitive equipments are connected. Basically it injects three single phase AC output voltages. This is in series with the distribution feeder. The important condition is that this voltage should be in synchronisms with the voltages of the distribution system. DVR can restore the voltage quality by injecting required amount of voltages which is also called as missing voltage. This injected voltage is having controllable magnitude, phase angle, and frequency into the distribution feeder on instantaneous real time basis via a series-injection transformer. . In order to overcome these problems the concept of custom power devices is introduced recently one of these devices is the Dynamic Voltage Restorer (DVR). A Dynamic Voltage Restorer (DVR) is a recently proposed series connected solid state device that injects voltage into the system in order to regulate the load side voltage. DVR is the most efficient and effective modern custom power device used in power distribution networks.

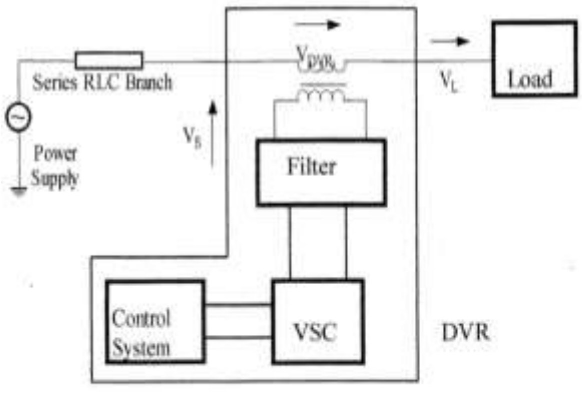

Figure 1 shows schematic diagram of DVR.

Other than voltage sags and swells compensation, DVR can also add other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations. In order to mitigate voltage quality problems, DVR injects voltages of suitable magnitude and phase in series with the line. During standby operation, DVR neither absorbs nor delivers real power. However, when voltage sag/swell occurs in the system, DVR delivers/absorbs real power Due to the sensitivity of the loads the DVR is required to respond at a very high speed the main components of DVR are an injection/ Booster transformer, A filter unit, storage Device, inverter circuit. Following fig.1 shows schematic diagram of DVR.A DVR is a solid state power electronics switching device consisting of either GTO or IGBT, a capacitor bank as an energy storage device and injection transformers. It is connected in series between a distribution system and a load. The basic idea of the DVR is inject a controlled voltage generated by a forced commuted converter in a series to the bus voltage by means of an injecting 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 $V_{L.}$ A DC capacitor bank or a DC source which acts as an energy storage device, provides a regulated dc voltage source. When voltage sag occurs in the distribution system the DVR control system calculates and synthesizes the voltage required to maintain output voltage to the load by injecting a controlled voltage with a certain magnitude and phase angle into the distribution system to the critical load[6,7].Note that the DVR capable of generating or absorbing reactive power but the reactive power injection of the device must be provided by an external energy source or energy storage system. The response time of DVR is very short and is limited by the power electronics devices and the voltage sag detection time.

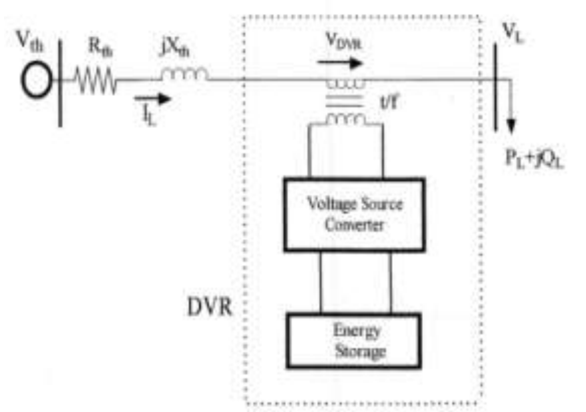

Figure 2 Schematic diagram of a DVR

Figure 2 shows the schematic representation of Dynamic Voltage Restorer. The circuit on left hand side of the DVR represents the Thevenin equivalent circuit of the system. 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 V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained [1, 2]. The series injected voltage of the DVR can be written as, (from Figure 2)[8,9]

$$V_{DVR} = \mathbf{V}_L + \mathbf{Z}_{th}\mathbf{I}_L - V_{th} \quad (1)$$

V_L is the desired load voltage magnitude,
Z_{th} is the load impedance,
I_L is the toad current,
V_{th} is the system voltage during fault condition.

5. RESULT AND DISCUSSION

5.1 Simulation parameters

S. No.	**System quantities**	**Standards**
1.	Source	3-phase, 415V, 50Hz
2.	Inverter parameters	IGBT based, 3-arm, 6-Pulse, Carrier Frequency=2000 Hz, Sample Time=5 µs
3.	DC voltage PV source	100V
4.	RL load	Active power = 25kW, Inductive Reactive Power=400 VAR
5.	Transformer 2	12 Terminal or 3(1-Phase)two winding T/F.100MVA,50HZ
6.	Source resistance and inductance	0.1ohms, 0.005mh

5.2 Results under Different Fault Conditionsof DVR on MATLAB simulink

Three different fault conditions are considered for the test system as shown in Figure. Test System consist of static RLC load and the controller. The faults that occur in the system are tested. It may be LG fault which mostly occur or LLG and LLLG fault which occur rarely in the system. The three different fault conditions are single line to ground, double line to ground and three phase line to ground fault. The results for each fault condition are given one by one.

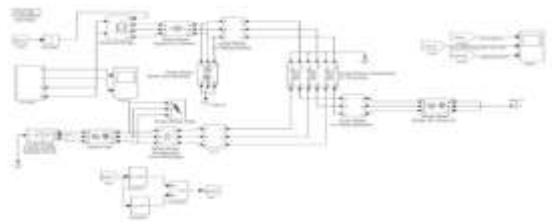

Figure-3 MATLAB Simulink model of DVR under voltage sag.

b) Fault under Sag Condition:

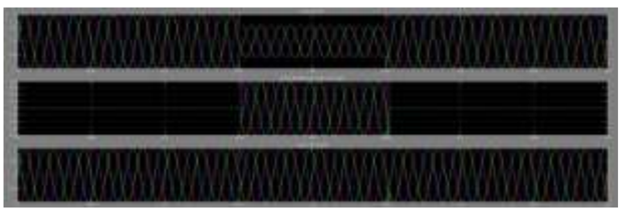

Figure-4 Fault Sag condition

In the third case a triple line to ground fault is considered. Here the fault resistance is 0.1 ohm and the ground resistance is 0.1 ohm. The fault is created for the duration of 0.15s to 0.25s.In the first waveform shows triple lines to ground fault due to which voltage sag occures on the three phases shows in yellow, purple & green waves in first waveform.In the second waveform DVR provides the compensating voltage for mitigating the level of voltagethat caused by the fault.In the third waveform the resultant load voltage is shown which is also the results of mitigating voltage provided by DVR i.e with compensation.

c) Single Line to Ground Fault Condition.

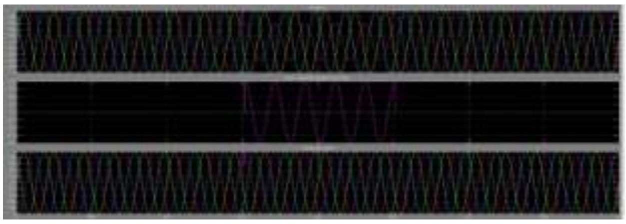

Figure-5 Matlab simulink results of DVR for LG fault

In first case a single line to ground fault is considered. Here the fault resistance is 0.1 ohm and the ground resistance is 0.1 ohm. The fault is created for the duration of 0.15s to 0.25s.In first waveform, shows single line to ground fault due to which voltage sag occures on the single phase.In second waveform, DVR provides the compensating voltage for mitigating the level of voltage that caused by the LG fault.In the third waveform the resultant load voltage is shown which is also the results of mitigating voltage provided by DVR i.e with compensation. Here output waveform clearly shows that the voltage in the phases where fault is created is decreasing during the fault duration & it uncompensated,where as whenDVR is connectedit is compensating the voltage clearly.

d) Results under voltage swell Conditions of DVR for static RLC load on MATLAB simulink.

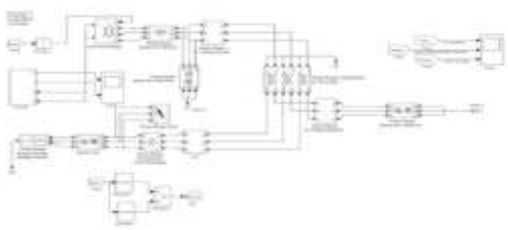

Figure-6 MATLAB Simulink model of DVRunder voltage swell.

e) Fault condition of voltage Swell

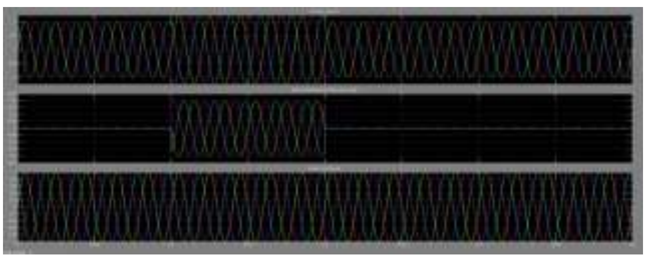

Figure-7 Result of Load voltage after mitigation of voltage swell

It is noted that the DVR has successfully kept the load voltage at 1 p.u. In Figure-7 shows the case of unbalanced voltage swell where the voltages of the supply are programmed to have 10 %voltage swell. The grid voltage is depicted where a swell of 10% is made for 5 fundamental cycles from 0.1sto 0.2s. The proposed DVR responds to this swell within one cycle by injecting voltage shifted in phase, such that the resultant voltage will be subtracted. On detection of voltage recovery, the DVR switches off to keep conduction losses to minimum. Waveform 2 shows the injected voltage or compensating voltage provided by DVR and the load voltage is displayed after mitigating the voltage swell waveform third. Although the swell is unbalanced, the DVR can keep the load voltage balanced. As the measured voltage swells are not relatively large, they have not influenced the dc voltage.

6. CONCLUSION

This research has studied the characterization of voltage unbalances and its impact with special attention on the mitigation techniques. The design of a dynamic voltage restorer (DVR) which incorporates PV array module act as DC voltage source to mitigate voltage sags, swells in low voltage three phase distribution systems has been presented. The modelling and simulation of DVR using MATLAB Simulink has been presented. The simulation results show the performance of a DVR in mitigating different faulty conditions. The DVR handles both balanced and unbalanced situations easily and injects the appropriate voltage component to correct rapidly any anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value. The simulation result shows that DVR performance is satisfactory in mitigating the voltage variations.

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