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A Brief Analysis of a Dynamic Voltage Restorer to Compensate Voltage Sag and Long Interruption for Enhancing Power Quality

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Abstract-*The issue of voltage sag and its extreme effects on sensitive loads is surely understood. To take care of this issue, The DVR is a cutting edge and essential custom power device for remuneration voltage Sags in power distribution system. The Dynamic Voltage Restorer (DVR) is quick, flexible and effective response for voltage Sag issues. The DVR is a solid state compensating device used to mitigate voltage Sags and to reestablish load voltage to its evaluated esteem. In this paper, a diagram of the DVR, its capacities, arrangements, segments, working modes, voltage injection techniques of the DVR yield voltage are looked into alongside the device abilities and constraints.*

Keywords: Power Quality, Voltage Sag ,Long interruption, Dynamic Voltage Restorer (DVR), Energy storing device, Voltage Source Converter

1. Introduction

Power quality is an essential issue because of its effect on power suppliers, gear makes and clients. "Power quality is depicted as the variety of voltage, current and recurrence in a power system. It alludes to a wide assortment of electromagnetic wonders that describe the voltage and current at a given time and at a given area in the power system". Both, electric utilities and end clients of electrical power are turning out to be progressively worried about the nature of electric power. Touchy loads, for example, PCs, programmable logic controllers (PLC), variable speed drives (VSD)- and so forth require top notch supplies. Power quality is an umbrella idea for large number of individual sorts of power framework unsettling influences. Nature of Supply might be classified as in Figure-1.

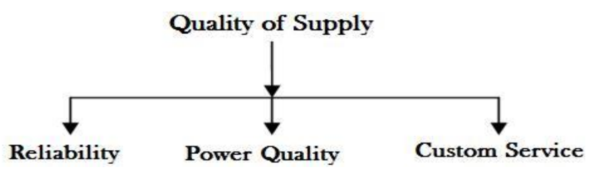


Fig- 1 Quality of Supply Categories

Power conveyance frameworks, ought to in a perfect world furnish their clients with a continuous stream of vitality with a smooth sinusoidal voltage at the contracted greatness level and recurrence. In this paper mainly we deals with two kinds of power quality problems. They are voltage sag and long interruption. Both the cases were seen independently. But a special case is also seen where a voltage drops at a nominal value to obtain voltage sag but soon after voltage drops and opt almost zero voltage at load side to obtain voltage interruption of 5 seconds. In this paper both the case were compensated by DVR very efficiently.

1.1 Power Quality Problems

There are many power quality problems such as voltage sag, voltage swell, interruptions, harmonics, Flickers and so on. But in this paper we tackle voltage sag and long interruption as major power quality problems which founds normally.

Voltage Sag: A Voltage Sag is a flitting diminishes in the root mean square (RMS) voltage between 0.1 to 0.9 for every unit with a term extending from half cycle up to 1 min. It is considered as the most major issue of power quality. It is caused by issues in the voltage basis or by the beginning of substantial actuation engine.

Voltage Interruptions: These interruptions are of two types.

Short interruption: A voltage disturbance caused by a fault or a short circuit of few milliseconds to 1 or 2 seconds.

Long interruptions: A longer voltage disturbance occurs more than 1 or 2 seconds.

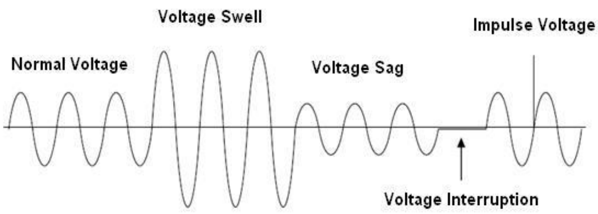


Fig-2 Power Quality problems

2. Dynamic Voltage Restorer:

Among the power quality issues (Sag, swells, Harmonics…) voltage Sag are presumably the most extreme aggravations .With a specific end goal to defeat these issues the idea of custom power device has ended up presented as of late. One of those devices is the Dynamic Voltage Restorer (DVR), which is a standout amongst the most effective and cutting edge custom power device utilized as a part of power appropriation systems. A DVR is an arrangement - associated solid state device that injects voltage into the system so as to direct the supply side voltage. It is typically introduced in an appropriation system between the supply and a basic burden feeder at the alleged point of common coupling (PCC).Its essential capacity is to quickly help up the supply - side voltage in case of a voltage sag with a specific end goal to maintain a

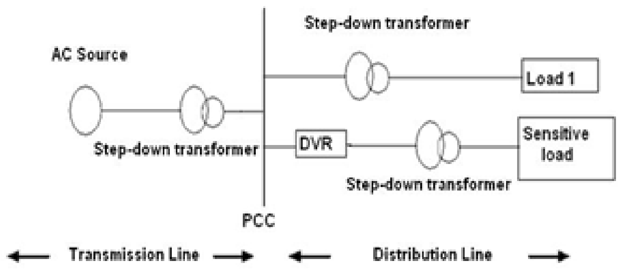


Fig-3 (DVR) in an electrical power system.

strategic distance from any power interruption to that supply. There are different circuit topologies and control plots that can be utilized to actualize a DVR Together with voltage sag and interruption remuneration, DVR can likewise have different components like: line voltage sounds pay, decrease of homeless people in voltage and flaw current constraints. Figure-3 demonstrates the area of dynamic voltage restorer (DVR) in an electrical power system. The DVR is a power-electronic-converter-based device capable of protecting sensitive loads from most supply -side disturbances. As shown in Figure 4 the general configuration of the DVR.

(A) Injection/Booster transformer: The Injection/Booster transformer has two purposes. It interfaces the DVR to the distribution system through the HV-winding and changes and couples the injected compensating voltages produced by the voltage source converter (VSC) in arrangement with the approaching supply voltage. Moreover, the Injection/Booster transformer effectively isolates the supply from the system (VSC and control component). In a transformer - less DVR taking into account the multilevel inverter is introduced. As a consequence of utilizing this inverter, the proposed DVR has lower number of switches in comparison with other multilevel DVR topologies. In the proposed transformer - less DVR can acceptably relieve the voltage sag issues. It likewise has an superior voltage regulation property and has lower losses.

(B) Harmonic Filter: The principle undertaking of the harmonic filter is to keep the harmonic voltage content produced by the voltage source converters (VSC) below the allowable level.

(C) Energy Storage Unit: It is in charge of the vitality stockpiling in DC structure. Flywheels, batteries, superconducting magnetic energy storage (SMES) and super capacitors can be utilized as energy storage device. It will supply the genuine power prerequisites of the system when DVR is utilized for compensation

(D) Voltage Source Converter (VSC) : A voltage-source converter is a power electronic system comprising of switching devices like: Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Gate Turn - Off-Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT), which can create a sinusoidal voltage at any required recurrence, greatness, and stage point .The yield voltage does not should be of a solitary recurrence. Voltage source converters are generally utilized as a part of Variable - speed drives (VSD), yet can likewise be utilized to alleviate voltage plunges. The VSC is utilized to either completely supplant the supply voltage or to infuse the „missing voltage". The „missing voltage" is the contrast between the ostensible voltage and the genuine one. Regularly the VSC is utilized for voltage dip relief, as well as for other power quality issues, e.g. flicker and harmonics .

(E) Control System: The primary motivation behind the control system is to keep up a constant voltage magnitude at the point where a sensitive load is associated, under system disturbances. It will likewise take care of the D.C. link voltage utilizing The DC-charging unit.

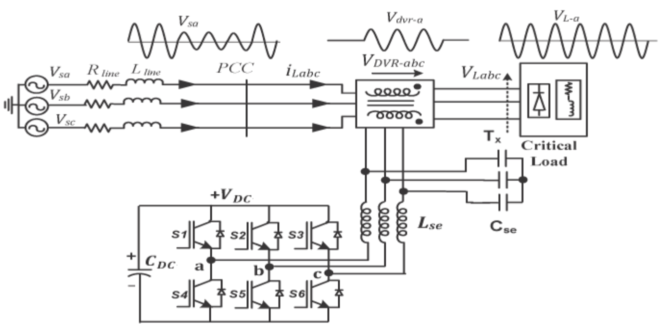


Fig 4: Basic configuration of a DVR

2.1 Analysis of a Dynamic Voltage Restorer:

A dynamic voltage restorer (DVR) is a custom power solid state converter based on injection of voltage in series with a power distribution system. The DC side of DVR is connected to an [ESD] energy storage device, while its ac side is connected to the distribution feeder by a 3-φ injection transformer. A single line diagram of a DVR connected power distribution system is shown in the fig-8. In this figure, $V_s(t)$ represents supply voltage, $V_t(t)$ represents terminal voltage and $V_l(t)$ represents the load voltage. Since DVR is a series connected device, the source current, $i_s(t)$ is same as load current, $i_l(t)$. Also note that in the fig., $V_f(t)$ is DVR injected voltage in series with line such that the load voltage is maintained at sinusoidal nominal rate.

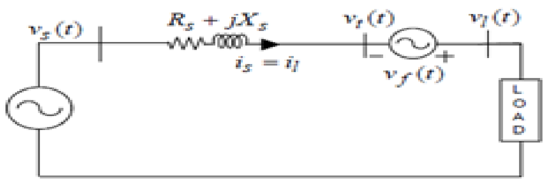


Fig-8: A single line Diagram of a DVR compensated system

The three-phase DVR compensated system is shown in Fig. 6 below. It is supposed that the transmission line has same impedance in all three phases.
These elements are shown in Fig.7. Some other important problems i.e., how much voltage should be injected in series using proper algorithm, choice of suitable power converter topology to synthesize voltage and designing of filter capacitor and inductor components have to be addressed while designing the DVR circuit.

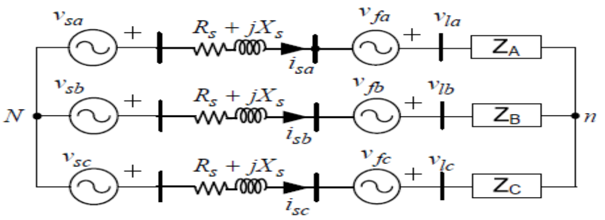


Fig-6: A single line diagram of a DVR compensated system

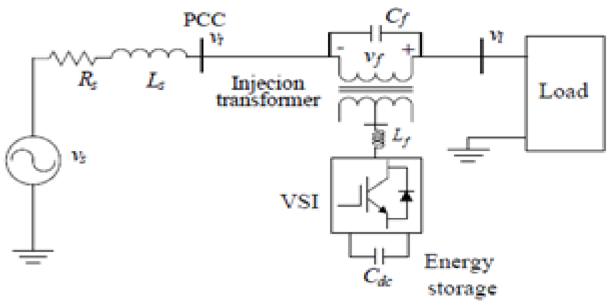


Fig-7: A schematic diagram of a DVR based compensation in a distribution system.

2.2 Operating Principle of DVR

Consider a single phase DVR based compensation in a distribution system as shown in Fig.8. Let us assume that source voltage is 1.0pu and we want to regulate the load voltage to 1.0pu. Let us denote the phase angle between V_s and V_l as δ. In this analysis, the harmonics are not considered. More we assume that during DVR operation, real power is not required excepting some losses in the inverter and the non-ideal filter components. These losses for the time being are measured to be zero. This condition indicates that the phase difference between V_f and I_s should be 90°.let's consider a general case to understand the logic. The DVR equivalent circuit with fundamental voltages and current is shown in Fig. 8. Applying Kirchhoff's voltage law in the circuit,

$$\begin{aligned} \overline{V}_s + \overline{V}_f &= \overline{I}_s\,(R_s + jX_s) + \overline{V}_l \\ &= \overline{I}_s\,Z_s + \overline{V}_l. \end{aligned}$$

Note that in above circuit $\bar{I}_s = \bar{I}_l = \bar{I}$. The load voltage $\bar{V}_l$ can be written in expressions of load current and load impedance as shown below.

$$\overline{V}_s + \overline{V}_f = \overline{I}\,(Z_s + Z_l)$$

Using (above equations) the source voltage can be expressed as in the following.

$$\overline{V}_s = \overline{V}_l + \overline{I}\,R_s - (\overline{V}_f - j\overline{I}\,X_s)$$

With the help of above equation, the relationship between load voltage and the source and DVR voltages can be expressed as below.

$$\overline{V}_l = \left(\frac{\overline{V}_s + \overline{V}_f}{Z_s + Z_l}\right) Z_l$$

2.3 Realization of DVR voltage using Voltage Source Inverter

In the earlier section, a reference voltage of DVR was extracted using discussed control algorithms. This is understood with the help of power electronic converter based voltage source inverter. Various elements of the DVR were listed in the beginning of this paper. They are exposed in detail in the Fig.9. The transformer injects the required voltage in series with the line to maintain the bus load voltage at the rated value. The injecting transformer not only reduces the voltage requirement but also provides isolation between the inverter circuit. The filter elements of the DVR such as external inductance (Lt) which includes the leakage of the transformer on the primary side and ac filter capacitor on the secondary side plays a significant role in the performance of the DVR. The same DC link can be extended to other phases as shown in Fig. 9. The single phase equivalent circuit of the DVR is shown in Fig. 10. In Figs. 9 and 10, V_{inv} denotes the switched voltage generated at the inverter o/p terminals, the inductance ($L_{t)}$, denotes the total inductance and resistance including leakage inductance and resistance of the transformer. The resistance, R_t models the switching losses of the inverter and the copper loss of the connected transformer. The voltage source inverter (VSI) is +functioned in a switching band voltage control mode to path the reference voltages generated using control logic as mentioned below.

Let V_f^* be the reference voltage of a phase that DVR wants to inject in series with the line, with the help of a voltage source inverter mentioned above. We form a voltage hysteresis band of ±h above this reference value. Thus, the upper and lower limits within which the DVR has to track the voltage can be written as following.

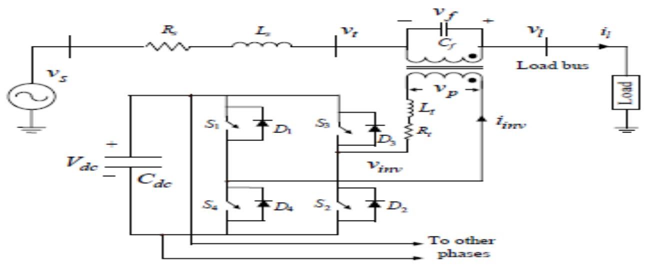


Fig-9: The DVR Circuit Details

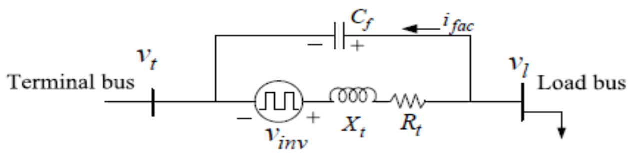


Fig-10: Equivalent Circuit of the DVR

$V_f up = V_f^* + h$
$V_f dn = V_f^* - h$

The following switching logic is used to synthesize the reference DVR voltage.

If $V_f \geq V_f up$
S1 – S2 OFF and S3 – S4 ON (‘-1’ state)
else if
$V_f \leq V_f dn$
S1 – S2 ON and S3 – S4 OFF (‘+1’ state)
else if
$V_f dn \geq V_f \leq V_f up$
retain the current switching status of switches
end.

It is to be noted that switches status S1 – S2 ON and S3 – S4 OFF is denoted by ‘+1’ state

And it gives $V_{inv} = +V_{dc}$. The switches status S1 – S2 OFF and S3 – S4 ON corresponds to ‘-1’ state providing $V_{inv} = -V_{dc}$ as shown in Fig.9. The above switching logic is very basic and has scope to be experienced. For example ‘0’ state of the switches of the VSI as presented in Fig.9, can also be used to have smooth switching and to decrease switching losses. In the zero state, $V_{inv} = 0$ and refers switches status as S_3D_1 or S_4D_2 for positive inverter current ($Í_{inv} > 0$). Similarly, for negative inverter current ($Í_{inv} < 0$), ‘0’ state is achieved through $S_1 D_3$ or $S_2 D_4$. With the adding of ‘0’ state, the switching logic becomes as follows.

If $V_f^* > 0$
If $V_f \geq V_{fup}$
‘0’ state
else if $V_f \leq V_{fdn}$
‘+1’ state
end
else if $V_f^* < 0$
if $V_f \geq V_{fup}$
‘-1’ state
else if $V_f \leq V_{fdn}$
‘0’ state
end
end.

In order to improve the switching performance one more term is added in the above equation based on the feedback of filter capacitor current.

$V_{f\,up} = V^*_f + h + \alpha_{if\,ac}$
$V_{f\,dn} = V^*_f - h + \alpha_{if\,ac}$

Where α is a proportional gain assumed to smoothen and stabilize the switching performance of the VSI . The measurement of α is Ω and is equivalent to virtual resistance, whose effect to damp out and smoothen the DVR voltage curve resulted from the switching of the inverter. The value of hysteresis band (h) should be selected in such a way that it limits switching frequency within the prescribed maximum value. This type of voltage control using VSI is called as switching band control. The genuine DVR voltage is compared with these upper and lower group of the voltage ($V_{f\ up}$, $V_{f\ dn}$) and therefore switching commands to the power switch are produced. The switching control logic is defined in the Table 2.1. To reduce switching frequency of the VSI, three level logic has been proposed. For this an additional check of polarities of the reference voltage are taken into consideration. Based on this switching status, the inverter supplies $+V_{dc}$, 0 and $-V_{dc}$ levels of voltage corresponding to the 1, 0 and -1shown in the table, in order to synthesis the reference voltage of the DVR.

Now withstanding switching band control, an additional loop is required to correct the voltage in the dc storage capacitor against losses in the inverter and transformer. During transients, the dc capacitor voltage may increase or decrease from the reference value due to real power flow for a short duration. To correct this

Conditions		Switching values
$V_f^* \geq 0$	$V_f > V_{up}$	0
$V_f^* \geq 0$	$V_f < V_{dn}$	1
$V_f^* < 0$	$V_f > V_{up}$	-1
$V_f^* < 0$	$V_f < V_{dn}$	0

Table 2.1 Three level switching logic for the VSI

voltage fluctuation, a small amount of real power must be drawn from the source to replenish the losses. To finish this, a basic corresponding in addition to basic controller (PI) is utilized. The signal u_c is generated from this PI controller as given below.

$u_c = K_p e_{V dc} + K_i \int e_{V dc} \, dt$

Where, $e_{V dc} = V_{dc ref} - V_{dc}$. This control loop need not to be too quick. It might be overhauled once in a cycle ideally synchronized to positive zero crossing of phase-a voltage. Taking this data the variable u_c will be involved in generation of the fundamental of DVR voltage as given below.

$V_{f1} = V_{f1}\angle(\angle\bar{I}_s + 90° - u_c) = V_{f1}(\tilde{a}_1 + j\tilde{b}_1)$

Then the equation, is modified to the following.

$V^2_{f1} - 2\tilde{a}1 V_l V_{f1} + V_l^2 \text{-} V^2_{t1} = 0$

The above equation is used to find the DVR voltage. It can be initiate that the phase difference between line current and DVR voltage differs slightly somewhat from 90° with a specific end goal to account the losses in the inverter.

2.4 Voltage injection methods of DVR:

The dynamic voltage restorer (DVR) or a series booster is used during the voltage injection mode depends on many preventive factors like DVR power rating, load conditions, and voltage sag type. For example, some types of loads are sensitive to phase-angle jumps, and some others are sensitive to a change in voltage magnitude . Therefore the control strategies applied are totally depends upon the load characteristics. The four different methods used for DVR voltage injection are:

(A) Pre-sag/dip compensation method:

The pre-sag/dip method track the supply voltage continuously and if detects any type of disturbances in that voltage it injects the missing voltage b/w the sag or voltage at the PCC and the ideal pre-fault condition. In this procedure, restored the load voltage back to the pre-fault conditions. Compensation of voltage sags in phase -angle and an amplitude sensitive load has to be achieved by pre-sag compensation method. In this method, the active power injected by the DVR, and the injected power cannot be controlled and is determined by the external conditions such as the type of faults and load conditions. Figure shows the single phase vector diagram of this compensation method

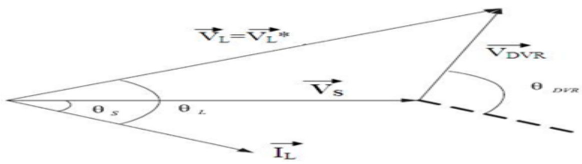
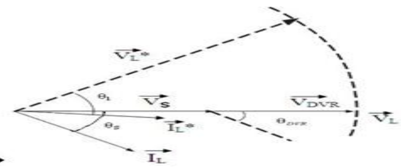


Fig-2.4 (a): Pre-sag compensation method

(B) In-phase compensation method:

In this method the injected voltage is in phase with the PCC voltage of the load current and pre fault voltage. The phase angles of the pre-sag and load voltage are different but the main aim is placed on maintaining a constant voltage magnitude on the load. One of the advantages of IPC 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 loads but which are not sensitive to phase-angle jumps. Figure shows the single-phase vector diagram of this method .



Where V Pre-sag voltage, ⟶ Pre-sag load current, $\theta_1 = \theta_S$ ⟶

Fig-2.4 (b): Single-phase vector diagram of the IPC method

(C)In-phase advanced compensation method:

This method the real power spent by DVR is minimized by decreasing the power angle between the load current and the sag voltage. In the two previous cases, namely pre -sag and in-phase compensation, the active power is injected into system by the DVR during disturbances. The active power supplied is limited to the stored energy in the DC link and this is one of the most expensive parts of the DVR. By making the injection voltage phasor is perpendicular to the load current phasor we achieved minimization of injected energy. In this process the values of load current and voltages are fixed in the system so that one can change only the phase of the sag voltage . In short, IPAC method uses only reactive power and unluckily, not all the sags can be mitigated without real power; as a result, this method is only suitable for a limited sag range.

(D) Voltage tolerance method with minimum energy injection:

Generally voltage magnitudes between 90%-110% of the nominal voltage and phase angle deviations between the 5%-10% of the normal state will not disturb the operation characteristics of loads. This method will maintain the load voltage and in this method the tolerance area with minor change of voltage magnitude as shown in figure.

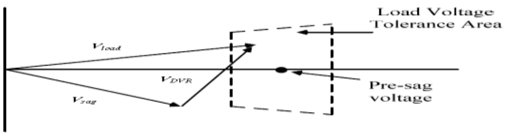
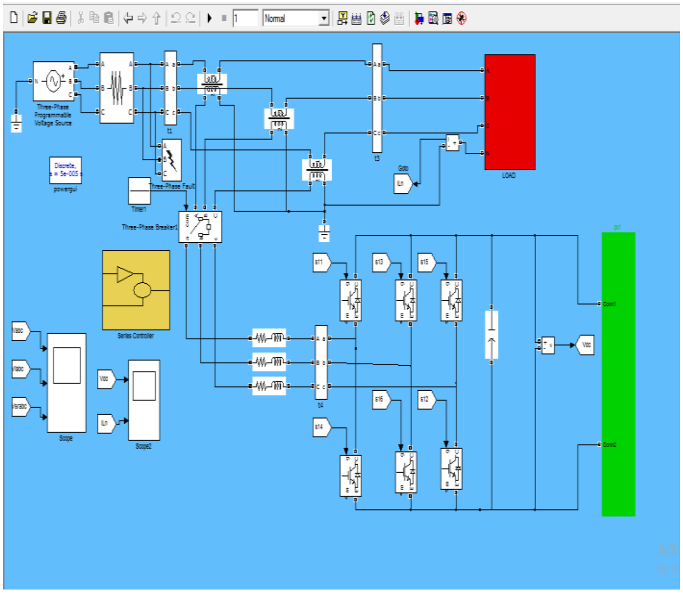


Fig-2.4 (d): Voltage tolerance method with minimum energy injection.

3. Simulation Model



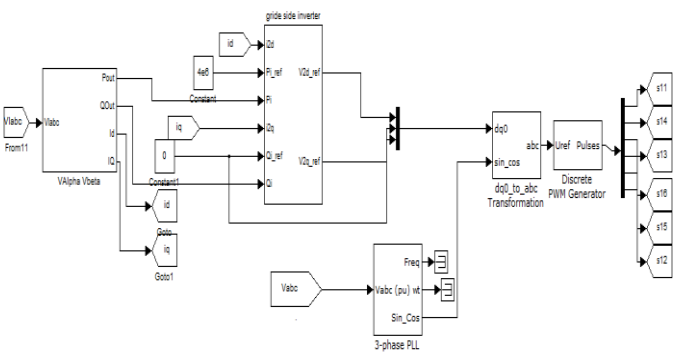


Figure- Subsystem of a Series Controller

3.1 Simulation Results:

In this research paper the main aim is to mitigate voltage sag of 10 seconds and long interruption of 5 seconds. After installing DVR in a circuit we finds that it compensates the drop voltage very efficiently and makes our system stable.

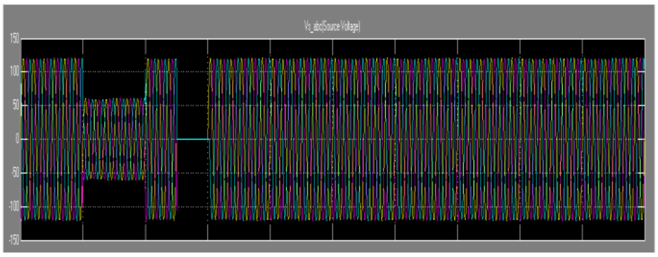


Fig- Uncompensated Voltage

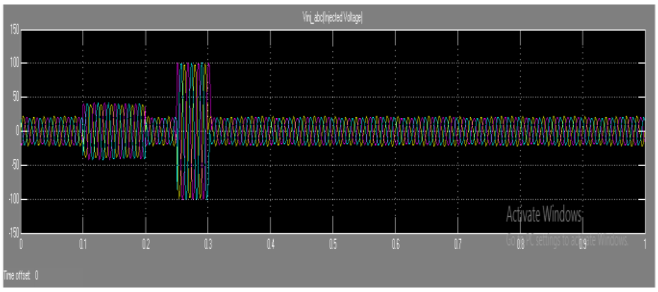


Fig- DVR injected Voltage

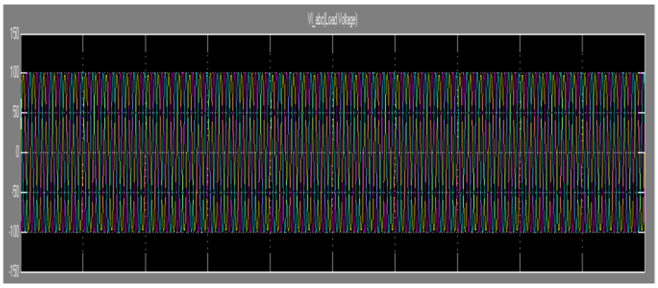


Fig- Compensated load Voltage

Figure-3.1 (a): Waveforms of Sag and long interruption

This paper corresponds to the work done by dynamic voltage restorer to compensate voltage sag as well as long interruption whenever system gets fault. The data analysis of a DVR is shown above we calculate very easily the uncompensated voltage and a compensate voltage through a DVR. In this paper a Sag duration is seen between 0.1 to 0.2 seconds and a long interruption is mitigated at 0.25 sec to 0.30 seconds. Sometimes we often see a maximum voltage drop i.e. long interruption followed by voltage sag. Through this simulation we have seen a long interruption of 5 seconds followed by voltage sag of 10 seconds.

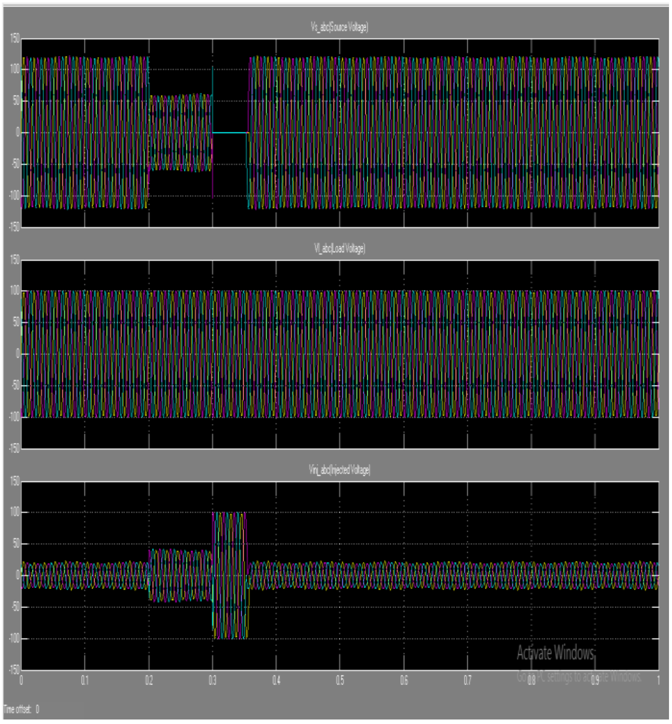


Figure-3.2(b): Waveforms of Long interruption immediately followed by Voltage Sag

4. Conclusion:

The proposed scheme of a DVR has been confirmed through simulation using MATLAB software along with Simulink and sim power system. The performance of DVR has been observed to be satisfactory for various power quality problems in supply voltage like voltage sag and long interruption. Moreover, it is able to provide self-supported dc bus of the DVR through power transfer from ac line at essential frequency. These result also shows that the DVR compensation is fast and flexible. The three phase fault can be compensated by series voltage injection/linear transformer. The main advantage of this DVR is low cost and its mechanism is simple. It can mitigate long duration voltage sags/interruption efficiently. Future work will include a soft commuting technique like genetic algorithm, neural network based DVR to get better results and reliability. Many researchers works to mitigate voltage sag and swell but in this paper the major work done is how we can compensate long duration interrutions.at the last DVR finds a successful results on long duration interruptions also.

References

[1] Shazly A. Mohammed, Aurelio G. Cerrada, Abdel-Moamen M. A, and B. Hasanin"Dynamic Voltage Restorer (DVR) System for Compensation of Voltage Sags, State-of-the-Art Review" *International Journal Of Computational Engineering Research (ijceronline.com) Vol. 3 Issue. 1*

[2] Abdul Mannan Rauf and Vinod Khadkikar, Member, IEEE, "An Enhanced Voltage Sag Compensation Scheme for Dynamic Voltage Restorer, "*IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 62, NO. 5, MAY 2015*.

[3] Dr. Mahesh Kumar Professor, Department of Electrical Engineering, Indian Institute of Technology Madras, Chennai"NPTEL Course on Power Quality in Power Distribution Systems"*Chapter 5 series compensation:voltage compensation using DVR (Lectures 36-44)*.

[4] Pratheeksha .R, K.M.Kavitha, Sridhar N. H, Manaswi K. J"Modeling & Simulation of a Dynamic Voltage Restorer (DVR) " ***© May 2016 IJSDR | Volume 1, Issue 5*** *IJSDR1605127 International*.

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