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Improved Performance Electrical Distribution System using Dynamic Voltage Restorer

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***Abstract* – The work aims to detect and analyze various power quality improperness that exist in electrical power system and what the major effects seen over defined electrical power network. Here development of a novel voltage controls schemes that can compensate the detrimental effects of the power quality in three-phase power systems.In three-phase power systems the power quality is being affected by the detrimental which can be compensated through development of novel voltage control schemes. The voltage sag and swell occurred by faults in power distribution system can harm power system and user's facility.Serious problems in the entire system obtained when voltage sags occur even for a short duration in sensitive load. Normally, voltage interruption trigger device protect entire system prevent its shutdown. Mitigation of power interruption leads to proposed research is called "DYNAMIC VOLTAGE RESTORER (DVR)."It corrects the voltage of system for sag and swell conditions by boosting the voltage during voltage sag or reducing the input voltage during voltage swell event.To provide compensation for all possible voltage level an inverter, a transformer must be required. It mainly based on the inverter system.Cost and size are the advantages of thismethod over existing methods which is justified through experiments and results.**

***Keywords* – Dynamic Voltage Restorer (DVR), Voltage Sags, Control System, Voltage Source Converter (VSC), Simulationand Power Quality (PQ), Energy Storage Device (ESD).**

I. INTRODUCTION

A power distribution system is similar to a vast network of rivers. The rest of the power distribution service in not damaged or interrupted by remove system faults.If a power distribution system caused with a fault then the voltage interruption occurred in the power system. The majority of events are associated with either voltage sag or a voltage swell, and they often cause serious power interruptions [1].The voltage on one or more phases drops below when voltage sag condition limits, it tolerate the voltage for a short period time.Similarly in voltage swell condition phases rises above,period time.In power distribution system voltage sag and voltage swell are caused by associated with fault.The power distribution system has power interruption during fault because of the effect of a voltage sag and voltage swell produced in the system by the fault. This research is developed with a novel voltage control which compensates the voltage sag and swells condition in three phase power systems.For different user application and sensitivity in wide variety the power supply of power system through to system and voltage sags and swells varies for different application.

The DVR is an electronic device generally known as voltage source inverter and VAR compensation is defined with the management of undesired limit of reactive power which is very problematic for ac systems [1]. The systems and the customer problems are diversified with the VAR compensation

The power quality problems and performance optimization of the electrical power system are the major issues and also intensifying todays. The non-conventional energy resources are entertained as per the industry and domestic requirement of energy. The stability of electrical power system is also an important issue and there must be minimum transients. The disturbances occur in the system due to non-linear loads, sometimes the device is improved for maintaining the power quality which concerns for the defined power quality standards. The IEEE 519 standard concerns with the power quality issues and protecting critical loads [2].

The analysis, design, and voltage injection schemes of the DVR are discussed in and the different control strategies for the DVR have been developed in [8]. Instantaneous symmetrical component theory [3], energy optimized control [4, 6], PQR instantaneous power theory, symmetrical component estimation, etc., for the DVR are reported in the literature. Traditionally,thereactive power compensationhas been done by usingrotating synchronous condensers and fixed or mechanically switched capacitors or inductors. However, in recent years, static VAR compensators are modelled by using thyristor switched capacitors and thyristor controlled reactors to release organ the required reactive power have been developed Also, the self-commutated PWM converters with an suitable adaptive control scheme provides facility for the implementation of static compensators capable of generating or absorbing reactive current components with a time response faster than the fundamental power network cycle [10].

II. CHARACTERIZATION OF DVR:

This section presents the fundamental, positive-sequence, steady-state analysis of a DVR-connected power system as shown in fig.1. The proposed voltage regulation scheme consists of the following:

- DVR: represented voltage sources v_{fa}, v_{fb}, and v_{fc}
- Supply voltage: represented by sources v_{sa}, v_{sb}, and v_{sc}

The DVR is connected between a terminal bus on the left and aload bus on the right. The voltage sources are connected to theDVR terminals by a feeder with an impedance of R+jX studied and assumed that the loads are balanced and the load impedance is given by $Z_l.=R_l+jX_l$. The phasor diagram of the DVR connected system is shown in fig. 2.It is to be noted that the phase angleϕ_l between the load terminal voltagev_l and the line current i_s, depends on the load impedance and is independent of the line impedance or the DVR voltage.

1. The DVR does not supply any real power in the steady state. This implies that the phase-angle difference between DVR

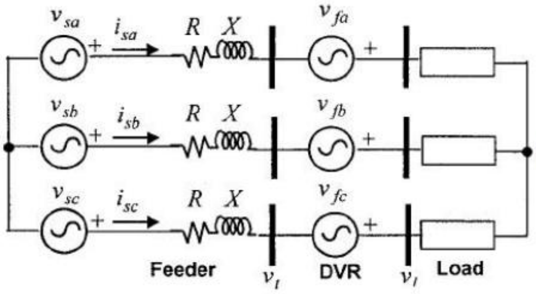

Fig.1. DVR adjustment in the electrical network

To make the magnitude of the load voltage equals to that of the source voltage, the RIs drop must be less than NM. If the drop is less than this limiting value, the DVR must compensate the entire reactive drop in the feeder and provide additional injection such that the source voltage becomes V per unit. It is needless to say that the best choice is the A intersection requiring much smaller voltage injection from the DVR [9], that means all the operating possibilities are recognised with the help of this phasor.

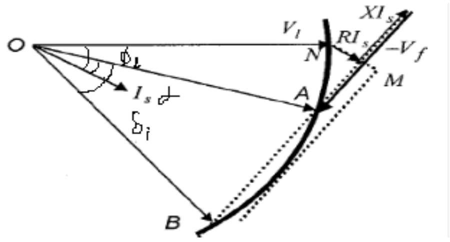

Fig.2. Phasor Diagram Showing Multiple Solutions

DVR aims to regulate the load voltage to 1.0 p.u. Let us assume that the rms load voltage is given by 1.0 p.u. The line current is then

$$I_S = \frac{1\angle 0^0}{R_l + jX_l} \tag{1}$$

For zero DVR power, its voltage must be in quadrature to the line current. We then have-

$$V_f = \left|V_f\right| e^{j\angle I_s + 90^0} \left|V_f\right| \angle \Phi = \left|V_f\right| (a_1 + jb_1) \tag{2}$$

Where $a_1 + jb_1$ is a unit phasor at 90^0, again

$$V_s + V_f = V_l + (R + jX) I_s = V_l + a_2 + jb_2 \tag{3}$$

Where $a_2 + jb_2$ represents the feeder drop. Substituting (1) in (2) and rearranging we get.

$$V_s = V_l + a_2 + jb - \left|V_f\right| (a_1 + jb_1) \tag{4}$$

The following quadratic equation is then obtained from the magnitude condition.

$$\left|V_f\right|^2 - 2\left\{a_1(V_l + a_2) + b_1 b_2\right\}\left|V_f\right| = 0 \tag{5}$$

If P_{in} and $P_{load}$are the input power from the source and the load power respectively and similarly, if Q_{in} and Q_{load} are the input reactive power from the source and load reactive power respectively, then-

$$P_{dvr} = P_{in} - P_{load} = 3.V_2.I.\cos\phi - \sum_i V_{1i}.I_i \cos(\phi - \alpha + \delta_i) \tag{6}$$

$$Q_{dvr} = Q_{in} - Q_{load} = 3.V_2.I.\sin e(\phi) - \sum_i V_{li} I_i.\sin(\phi - \alpha + \delta_i) \tag{7}$$

Where i=1, 2, 3. For minimum power operation and given ϕ, δ, α, V1, and V2 we have

$$\frac{dP_{dvr}}{d\alpha} = 0$$

Then

$$\sum_i V_{li} I_i.\sin(\phi - \alpha + \delta_i) \tag{8}$$

if $P_{dvr} > 0$, then $\alpha_{opt} = \phi + \beta$

Where

$$\beta = \arc\tan \frac{Y}{X}$$

$$X = \sum_i V_{li}.\cos(\delta_i), Y = \sum_i V_{li}.\sin(\delta_i)$$

$$P_{dvr} = 0, \text{then} \tag{9}$$

$$\alpha_{opt} = \phi + \beta - \arc\cos\left(\frac{3.V_2.\cos\phi}{\sqrt{(X^2 + Y^2)}}\right)$$

III. 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 DVR has four modes of operation which are:

i) protection mode
ii) standby mode
iii) injection/boost mode
iv) Buck mode.

i) 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) as shown in fig.3.

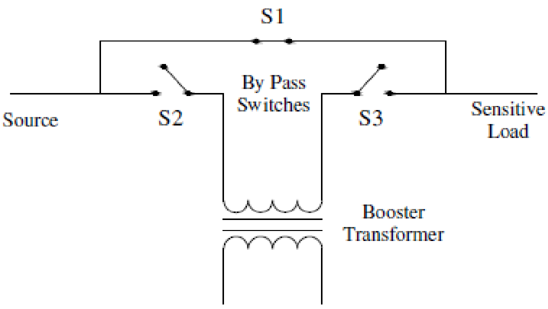

Fig.3. Protection Mode (creating another path for current)

ii) 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.

iii) *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.

iv) Buck Mode

In this mode DVR injecting a compensating voltage phase opposite to the supply voltage, when the voltage output exceeds the desired output

IV. VOLTAGE INJECTION METHODS OF DVR

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, various conditions of load, and different types of voltage sags. Some loads are sensitive towards phase angle jump and some are sensitive towards change in magnitude and others are tolerant to these [12].

The DVR supplies the voltage that is the difference between the pre-sag and sag voltage [5]. While in–phase compensation, the injected DVR voltage is in phase with sagged voltage Pre-sag voltage compensation and in-phase compensation must inject active power to the load almost at all times. The Phase shift compensation method is proposed to reduce the energy storage size [7, 8]. In this method, active power PDVR depends on the angle as the power depends on values of resistive and reactive components.

If P_{in} and P_{out} are the input power from the supply and the load power, respectively, then

$$P_{in} = \sum_{\forall j} V_{lj} I_j . \cos(\phi - \alpha + \delta_j)$$

$$P_{out} = \sum_{\forall j} V_{lj} I_j . \cos(\phi) = 3 V_L I_L \cos\phi \tag{10}$$

Where J=a, b, c, and V_1 and $V_L$are the fault supply voltage vector and restored load voltage vector, respectively. Assuming a balance load (I_{Lj} = I_L) and a balance output voltage (V_{Lj} = V_L).

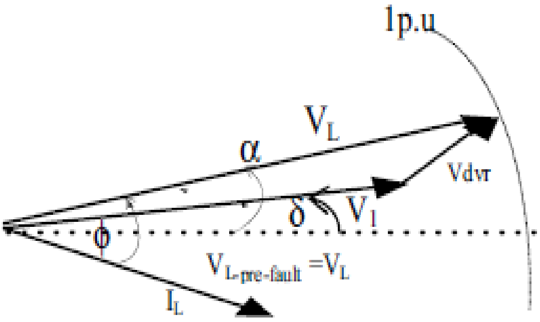

Fig.4. Phase shift compensation

V. BASIC CONFIGURATION OF DVR

The general configuration of the DVR is shown in fig.5, with three phase transmission system consists following sub-parts:

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

The schematic diagram contains all the major parts of the designed actual simulation model. Here PLL plays important role in extraction of phase sequence of line voltage [13].

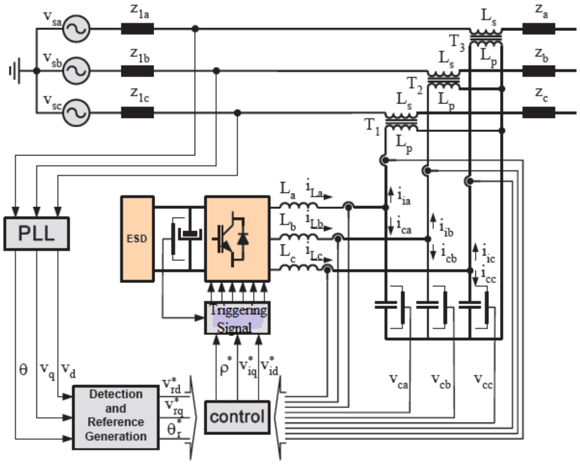

Fig.5. Basic Configuration of DVR

i) 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. These transformers indicated in fig. (5) as T_1, T_2 and T_3 designed especially for high performance system designing.

ii) Harmonic Filter

The main task of harmonic filter is to keep the harmonic voltage content generated by the VSC to the permissible level. These filters are designed with the help of passive components [12]. The lower harmonic frequencies the most of the waveforms have large percentage of harmonic distortion as compared to the high harmonic frequencies. For that reason single tuned filters are designed to suppress these lower harmonic frequencies. For suppressing the harmonics of six pulse ac to dc converter four single tuned filters are used for the5th, 7th, 11th, and 13th harmonics and one second order highpass filter is used for eliminating the high order frequencies [14].

iii) 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.

iv) DC Charging Circuit

The dc charging circuit has two main tasks.

1) The first task is to charge the energy source after a sag compensation event.

2) The second task is to maintain dc link voltage at the nominal dc link voltage.

During the voltage swell and sag compensation maintaining the line voltage of distribution system a capacitor banks or battery sources are used.

v) 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. Therefore the control strategies depend upon the type of load characteristics. These strategies are Pre-sag compensation method, In-phase compensation method and Phase shift compensation method [7].The Pre-sag compensation method strategy is recommended for the non-linear load in which both the voltage magnitude and phase angle need to be compensated. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility [8].

VI. MODELLING & SIMULATION

The Simulink model consists of generating source of 13 kV, which is stepped up to 132 kV. This power has to transmit over two 100 km transmission line again this voltage is stepped down to 10 kV for distribution purpose. Again the power has to be transmitted over two distribution line length of 30 km and 20 km. the detail parameter is given below in the form of table I.

Table 1: System Parameters

S.No.	Parameter	Parameter Value
1.	Main supply Voltage	13 kV
2.	Step-up transformer for feeder	13 kV/ 132kV
3.	3-phase transmission line phase -1	100 k.m Line
4.	3-phase transmission line phase -2	100 k.m Line
5.	Step-down transformer for phase-1	132 kV / 10 kV
6.	Step down transformer for phase -2	132 kV / 11 kV
7.	Distribution line phase-1	30 k.m Line
8.	Distribution line phase -2	20 k.m Line
9.	Load on distribution line phase -1	10 KVA, pf= .85 lag
10.	Load on distribution line phase -2	2 K.W Load, PF= .9 lag
11.	Series Injection Transformer	0.5 kV / 0.5 kV
12.	DC Supply for Inverter	500v
13.	Universal Bridge	3 arm, 6-pulse IGBT

The MATLAB Simulation model is designed inaccordance with the adopted method to get better results. This technique is more efficient than the other adapted methods to design DVR. Whenever the line voltage disturbs in any phase of transmission line the DVR smartly injects or draws approximate level of voltage in the transmission line. During sag in line DVR injects voltage into the line and when swell takes place DVR it store the excess voltage in the storage device instantly.

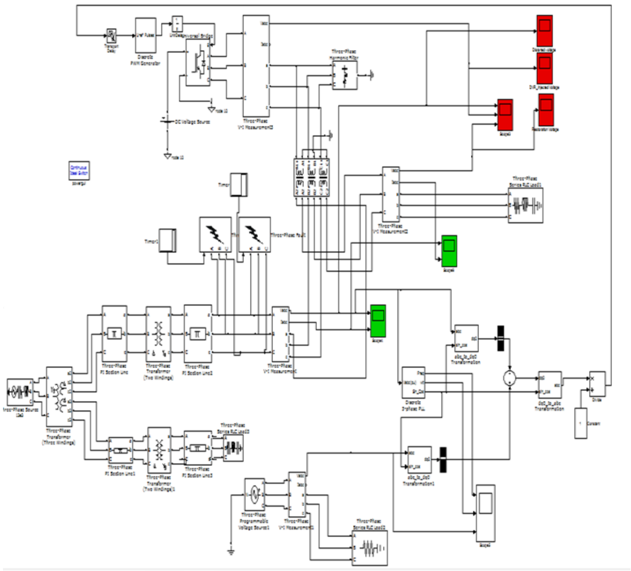

Fig.6. Simulation model

VII. RESULTS AND DISCUSSION

The system parameters are listed in Table I. It is assumed that the voltage magnitude of the load bus is maintained at 1 pu during the voltage sags/swells condition The load has been assumed linear with power factor pf =0.85 lagging and its capacity of 10 KVA.

The first simulation result of single phase voltage sag for fault resistance of .5 ohm isstarted with the supply voltage with .02s. transient and about 10% sagging of defined voltage in phase-1 represented by signal-1 in time duration from .1s to .16s while about 6% swelling of defined voltage is in phase-2 and phase-3 represented by signal-2 and signal-3 respectively for the same time as shown in Figure 8. Again transients start for about .02s and after .32s phase-2 &3 goes under 8% sagging and phase-1 goes 5% swelling of the defined voltage limit, so the disturbances in distribution system takes place. Theseare clearly shown in fig. 7.

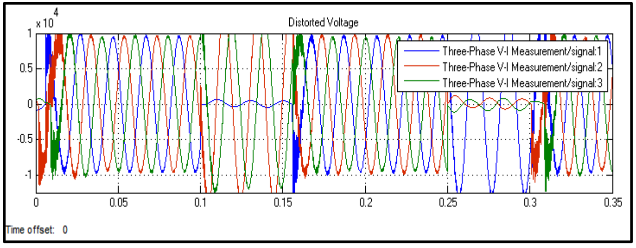

Fig.7. Phase-a voltage sag & phase-b & phase-c voltage swell

Figure 8 shows that the DVR Injected appropriate voltage level, which are being injected from 0.1s to 0.16s and further from .25s to .32s to maintain the load voltage constant. Also it injects the voltage at the starting to reduce transients.

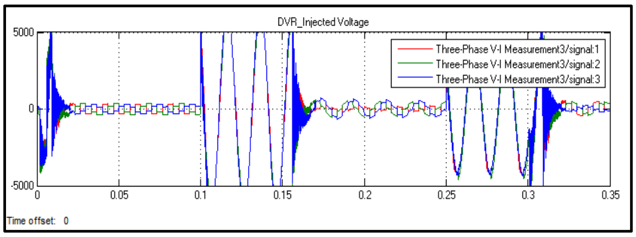

Fig.8. DVR injected voltage

Figure 9 represents the load voltage, which has been obtained after the injection of DVR voltage. Here we can see that the load voltage is free of harmonics, transients and become sinusoidal. The voltage sag effect has been reduced by 45% and swelling by 35% here.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 with phase sequence correction. After the injection of appropriate voltage level which is necessary to load at that instant when the fault is occurring, it is also important that the system must be remains stable.

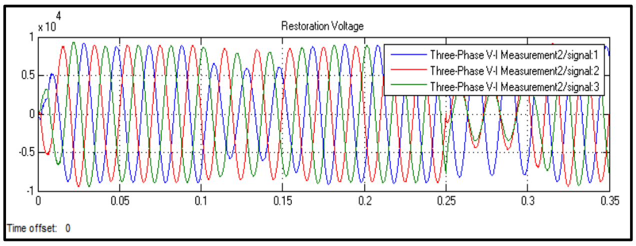

Fig.9. Restoration voltage of DVR

Figure 10 shows the distorted voltage, DVR Injected Voltage, and the Load voltage after restoration. Finally, it can be concluded that the power quality is improved and stabilised system as per the requirement.

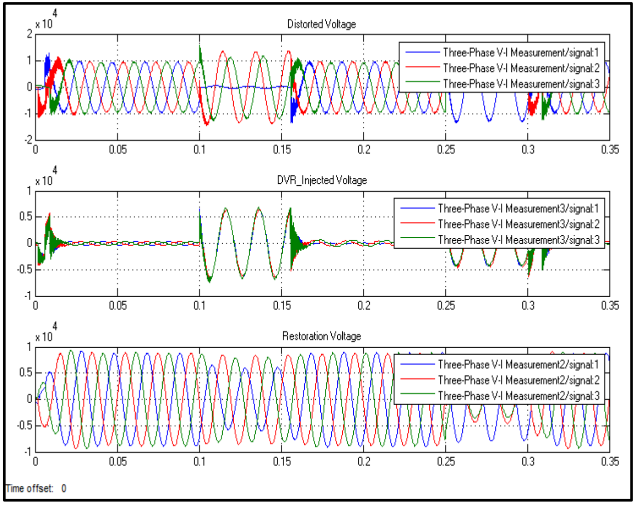

Fig.10 Combination of fig.8, 9, 10

The load voltage is managed with some distortions available in it shown in the figure 11,but these are very less extent.

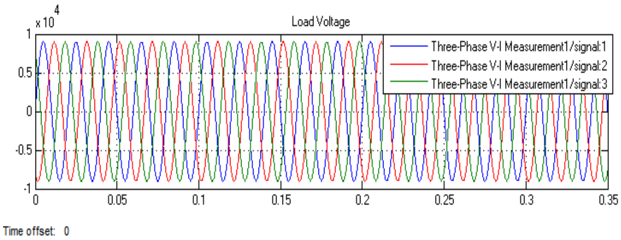

Fig.11. Improved Load Voltage

Mitigation of distortion like sag and swell are done by DVR with advance control method and quality of power is improved under acceptable limit.

Results for different values of fault resistance areshown in table-II given below. Sagging and swelling effects the load voltage and compensated accordingly from 25s to .30s.

Table-II

S.No.	**Load-1 10 KW, 100 KVA pf=.85**				
	Fault Resistance	**Swell**	**Sag**	**Voltage Compensation**	**Voltage Swing**
1.	.5 Ohm	4.5% in phase-I& II	85% in phase-I	99% sagging & 99.5% swelling	1% for sagging & .5% for swelling
2.	.55 Ohm	5.2% in phase-I& II	86.3%in phase-I	98.54% sagging & 99.21% swelling	1.46% for sagging & .79% for swelling
3.	.60 Ohm	6% in phase-I& II	87%in phase-I	98.04% sagging & 99% swelling	1.96% for sagging &1% for swelling

In the above table the results are of proposed technique sing PID with PWM control of VSI for amplitude as well as phase of the load voltage. Another table is represented below which shows results for PD with PWM control of VSI for amplitude as well as phase of the load voltage and with varying fault resistance and .95 power factor of load shown in reference paper [6].

Table-III

S.No.	**Load-1** **10 KW, 100 KVA pf=.95**				
	Fault Resistance	**Swell**	**Sag**	**Voltage Compensation**	**Voltage Swing**
1.	.5 Ohm	4% in phase-I& II	80% in phase-I	98.2% sagging & 98.5 % swelling	1.8% for sagging & 1.5% for swelling
2.	.55 Ohm	5% in phase-I& II	82% in phase-I	97% sagging & 98% swelling	3% for sagging &2% for swelling
3.	.60 Ohm	6% in phase-I& II	83% phase-I	96.25% sagging & 97.22% swelling	3.75% for sagging & 2.78% for swelling

VIII. VALIDATION OF RESULTS AND CONCLUSION

The purpose of this research is to develop voltage sag and swell mitigation device which is more efficient. 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. It is also shown that because of the voltage detection delay, there exists an output voltage overshoot transient at the moment of the voltage recovery. The efficiency and reliability of system can be improved by adapting more powerful VSC operating technique.

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