

## Solution of Power Quality Disturbances in Electrical Distribution Structure with the Introduction of Dynamic Voltage Restorer based on SRFT Control Algorithm

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**Abstract** - Voltage sag is a frequent problem associated with electrical distribution structure. The Dynamic Voltage Restorer (DVR) is economic, high-speed, supple and proficient response to the voltage sag (under voltage) difficulty. DVR is utilized in electrical energy distribution system using for voltage enrichment after taking place interruption in the power system. For shielding the complete plant including loads the DVR is intended in the choice of a few MVA. A number of control techniques are anticipated for this Flexible AC Transmission System (FACTS) device. Investigate the performance of DVR using Synchronous Reference Frame Theory (SRFT) and their derivatives are also studied for Balanced Three Phase Linear load under different unbalance conditions. For successful operation of DVR, MATLAB is highly developed simulation software.

**Keywords:** DVR, Power Quality, Synchronous Reference Frame Theory, Compensation, Faults, Voltage Sags, VSI.

### I. INTRODUCTION

Power Quality troubles include a broad range of conflicts for example voltage sags/swells, voltage disturbance, flicker, impulse transient, harmonics distortion, and interruptions [1]. Electrical Power distribution structure should preferably offer their consumers with a continuous supply of electrical power by way of a smooth alternating voltage at the agreement scale point and frequency. On the other hand, in actual fact, power structure, particularly distribution networks, have various nonlinear devices, which considerably have an effect on the excellence of the supply of electrical energy. Accordingly of these nonlinear devices, the wholesomeness of waveform (graphical representation) of the electrical power supply is missing in numerous load areas. Due to this lots of power excellence difficulty generates. [2], [3].

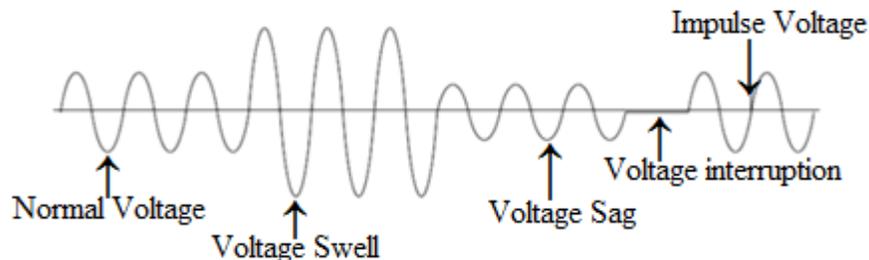


Figure 1: Power- quality issues in Electrical power system.

### II. OPERATION

Dynamic Voltage Restorer is a FACTS apparatus use to remove the voltage turbulences at consumer end. DVR is a mechanism so as to utilize electronic equipments, and connect in sequence to the convenience main division circuit. Electrical distribution system, control circuit and inverter circuit are three main parts of this power device. DVR as well recognized and accepted in the field of electrical engineering for the solution of voltage crises at the same time while SVB, SSC etc. custom power devices available in this field.

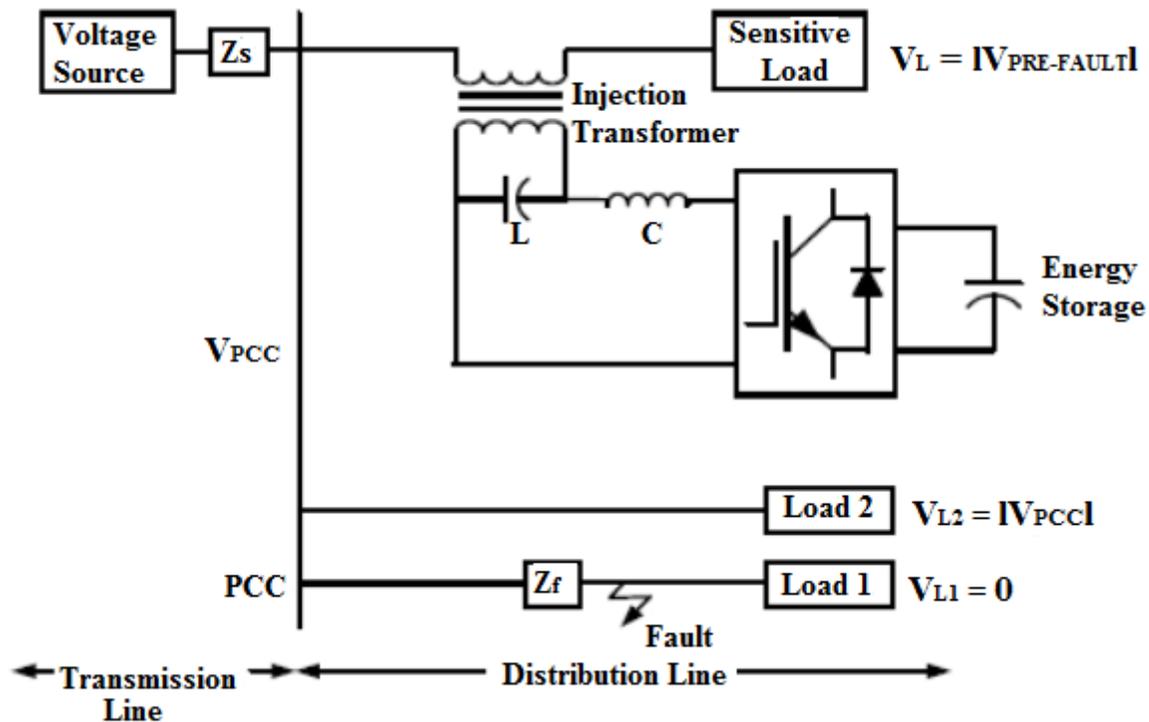


Figure 2: Position of the DVR in the electrical distribution structure.

DVR maintain the voltage at the load terminal at a preferred magnitude in addition with phase angle by means of reimburse the electrical supply problems like under voltage, occurs due to sudden load applied or by means of short circuit, offered at the fault location known as point of common coupling. Voltage of the line, which is used to feed the load 1, falls down to zero when short circuit takes place. Load 2 face the problem of voltages sag having magnitude level is identical to the PCC voltage. At the same time sensitive load feed with the maintained voltage by means of the DVR quick action without any interruption.

### III. Design and Components

The DVR design required the selection of the switching frequency, magnitude of DC bus voltage, Voltage Source Converter (VSC) rating, rating of series injection transformer, rating of DC bus capacitor and elements of the ripple filter. On the bases of Insulated Gate Bipolar Transistor (IGBT) switching frequency of VSC ripple filter components can be design. Rating of the DC bus capacitor depends upon the energy prerequisite under the abnormal conditions. The magnitude of the DC bus voltage based on prerequisite of most horrible case sag (under voltage) reimbursement. On the other hand 40% practical limit on highest sag reimbursement using self supported DVR. Due to wrong selection of capacitance rating imperfect energy storage space observed in the capacitor. The selection criterion of ratings of injection transformer and VSC is the rated current of the load and it is the requirement for voltage compensation under most horrible condition that means voltage sag or under voltage.

#### A. Selection of switching frequency:

Harmonics peak order is taken in to for selecting a switching frequency, therefore harmonics can be control. The value of switching frequency should be two times of the maximum frequency of the harmonics. The switching frequency and speed of processor selection are enormously associated as the sampling frequency which is based on the processor speed. The universal range of switching frequency is from 5 KHz to 20 KHz. The maximum achievable switching frequency is supposed to be selected.

**B. Selection of DC bus voltage**

The magnitude of the DC bus voltage based on precondition of most horrible case sag (under voltage) reimbursement. The relationship of Terminal voltage, load power factor, the phasor relationship and voltages represents from steady state condition given in the following equations:

$$V_L = V_T + |V_C| (a + j b) \tag{i}$$

Unit vector ( a + j b ) leads the positive sequence  $I_L$  by  $90^\circ$ . Therefore DVR voltage leads  $I_L$  by  $90^\circ$  and hence the active power flowing through this sequence will become zero.

Assume  $V_L = |V_L| \angle 0^\circ$

$$|V_C|^2 - 2 a |V_L| |V_C| + |V_L|^2 - |V_T|^2 = 0 \tag{ii}$$

The required voltage of load is not practicable due to conjugate pair of roots. From equation (ii), capacitor voltage reveals two real and similar results only when:

$$|V_L| = \frac{|V_T|}{\sqrt{1-a^2}} \tag{iii}$$

Equation (iii) represents the required load voltage when voltage sag occurs then DVR output voltage is shown in equation (iv).

$$|V_C| = a |V_L| \tag{iv}$$

Equation (iii) becomes under no loss condition.

$$|V_L| = \frac{|V_T|}{\cos \phi_L} \tag{v}$$

Here  $\cos \phi_L$  is the power factor of load.

Voltage per turn is same either side of transformer. Therefore secondary side voltage as well as determine easily. If T is the transformer ratio of a series injection transformer and  $|V_C|$  shows the maximum compensated voltage by the injection transformer. VSC generates the Voltage is  $|V_C| / T$ . The peak phase voltage with sinusoidal Pulse Width Modulation (PWM) control represents by

$$|V_{vsc \max}| = \frac{V_{dc}}{2} \tag{vi}$$

Equation (vi) can be used to determine DC bus voltage. To get maximum phase voltage  $|V_{vsc \max}| = \frac{V_c}{T}$ .

**C. kVA rating of Series Injection Transformer selection criterion:**

The selection criterion of kVA rating of a series injection transformer depends on the load current  $I_L$  and maximum compensating voltage  $V_c$ .

$$kVA \text{ Rating of Transformer} = V_c I_L / 1000 \tag{vii}$$

In the distribution structure the 3-phase series injection transformers are attached in the form delta/open connection. Positive and negative sequence voltages permits only by delta - open connection while positive, negative and zero sequence voltages are boost up only by transformer star - open connection.

#### **D. Voltage Source Inverter (VSI)**

The injected voltage of high current and low voltage ratings inverters are boost up by Step up transformers. DC voltage modify in to a convenient ac voltage by means of VSI. For inverter switches firing PWM scheme is normally utilize. Furthermore, if voltage sag occurs on one line of three phase systems could produce effect on another phase in the form of swell. Accordingly sags and swells problems are treating by VSI at the same time. Multi inverter connection in the form of series connection utilize in a special manner. Therefore most wanted output voltage of inverters will get by adding the voltage of inverters connected in cascade manner.

#### **E. Ripple filter elements selection criterion**

R, L and C are used to design the ripple filter and its application is to eliminate switching ripples having high frequency those are generated by the operation of VSC. The rating of an inductor elected so that switching ripples faces more impedance having frequency comparatively higher or identical to the one-half of the switching frequency and propose minimum opposition passageway to the rated frequency. Resistor value help to design a high pass filter having switching frequency as cut-off frequency. At the inverter output terminal waveforms with high frequency harmonic obtained because of nonlinear performance of semiconductor devices. For the elimination of unwanted signals or transients passive filters are positioned at the region of high voltage in the circuit of DVR.

#### **F. Choice of energy storage device:**

There are many devices like SMEs, flywheels or Batteries may be used as energy storing devices to provide real power for compensation. When voltage goes very low or sag occur real power compensation is necessary by means of energy storing devices. The DVR boost up the electrical energy and compensate the voltage feed to the load satisfactorily. Therefore a resource of electrical energy required for continuity and reliability of power supply. Techniques available for voltage compensation are: First one utilizes batteries stored electrical energy for the purpose of compensate the voltage delivered to the load. Second technique: electrical supply received from the input mains and delivered to the load through the shunt converter. The DVR should not feed any real power in healthy condition. This reveals that, in steady state condition, the phase angle must be 90° between instantaneous DVR voltages and instantaneously line currents.

#### **G. DC bus capacitance rating selection**

DVR contain a heavy DC capacitor to make sure fixed DC voltage input to the inverter. Efficiency of energy transformation is very low between DVR system and the load feeder during the transient state. The voltage of DC bus goes low exponentially for the duration of voltage disturbance reimbursement. Hence the capacity of the DVR to support the system is deteriorates against the severe sags. Therefore the DC bus voltage can be utilized just reduce a specific electrical energy stage, representation given by the equation (vii).

$$\Delta V_{dc} = \frac{1}{2} C_{dc} (V_{dc2}^* - V_{dc2}) \quad (vii)$$

Here  $V_{dc}^*$  is the original voltage dc link and  $V_{dc}$  is least amount allowable voltage of dc link in DVR systems

#### **H. Choice of By-Pass Switch**

When short circuit occurs in the distribution network current go beyond a tolerable set limit. Then the DVR will be out-of-the-way from the existing power system with the bypass switches and make available another way for current.

IV. Model of DVR based on MATLAB software

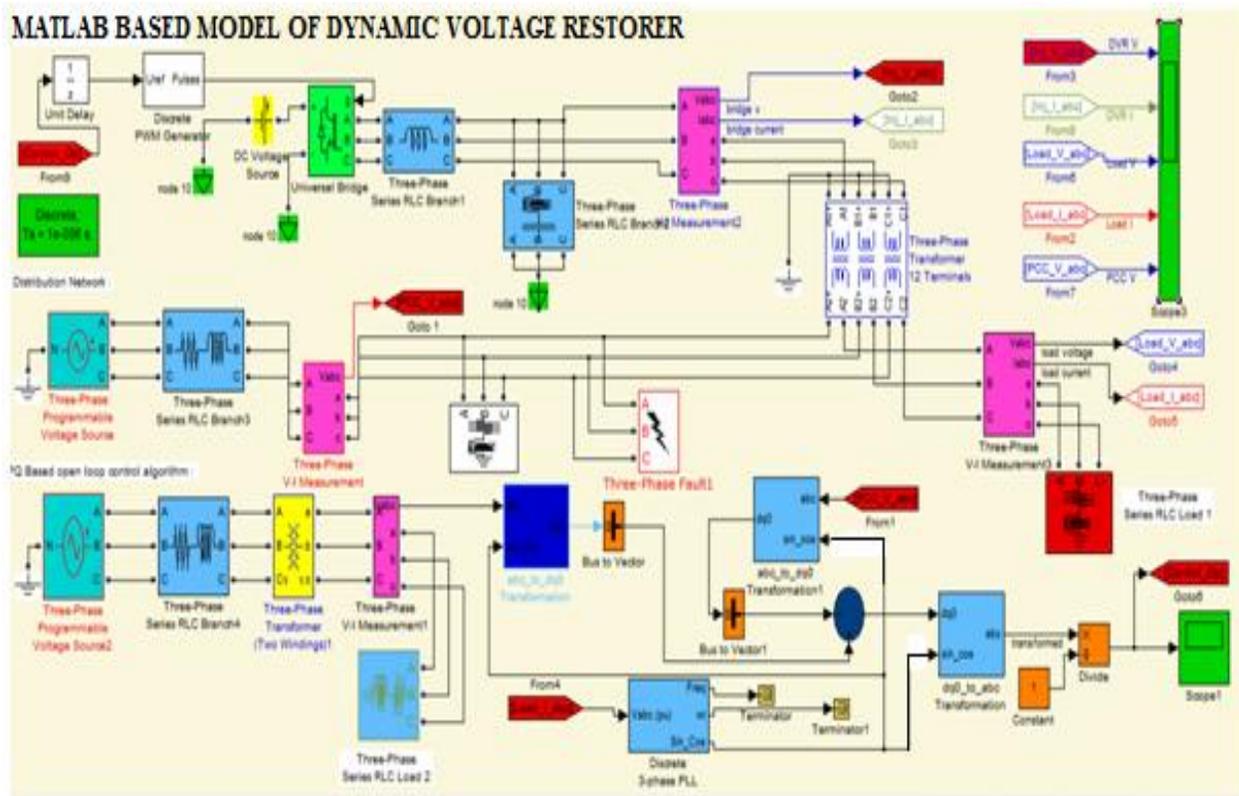


Figure3: DVR model configuration.

A. Control Scheme:

Synchronous Reference Fram Theory is basically applicable to reference signal judgment. DVR simulation based on this theory known as Park's Transformation . At the time of fault occurring in the electrical distribution system voltage ( $V_t$ ) at PCC is convert in to d-q. After Controller actions the result is transformed back to a-b-c structure (reference signals) judge at load bus and compared with genuine load Voltage ( $V_L$ ). PWM generator fed with different signals. PWM technique applicable to direct the IGBT based convertor by means of a series generation of six pulses. Here  $V^*L_d$  is a real voltage constituent and  $V^*L_q$  is a reactive voltage component of authenticated rated load voltage  $V_L$  in the described d-q structure.  $V_{tq\_dc}$  and  $V^*td\_dc$  represents the active and imaginary value of source voltage. The discrete PI controller outputs are shown by  $V_{cd}$  and  $V_{cq}$  known as obligatory active and reactive voltage component respectively.

$$V^*_{Ld} = [V_{td\_dc} - V_{cd}] \tag{viii}$$

$$V^*_{Lq} = [V_{tq\_dc} + V_{cq}] \tag{ix}$$

$$V_{LP} = \sqrt{\frac{2(VLa^2 + VLb^2 + VLc^2)}{3}} \tag{x}$$

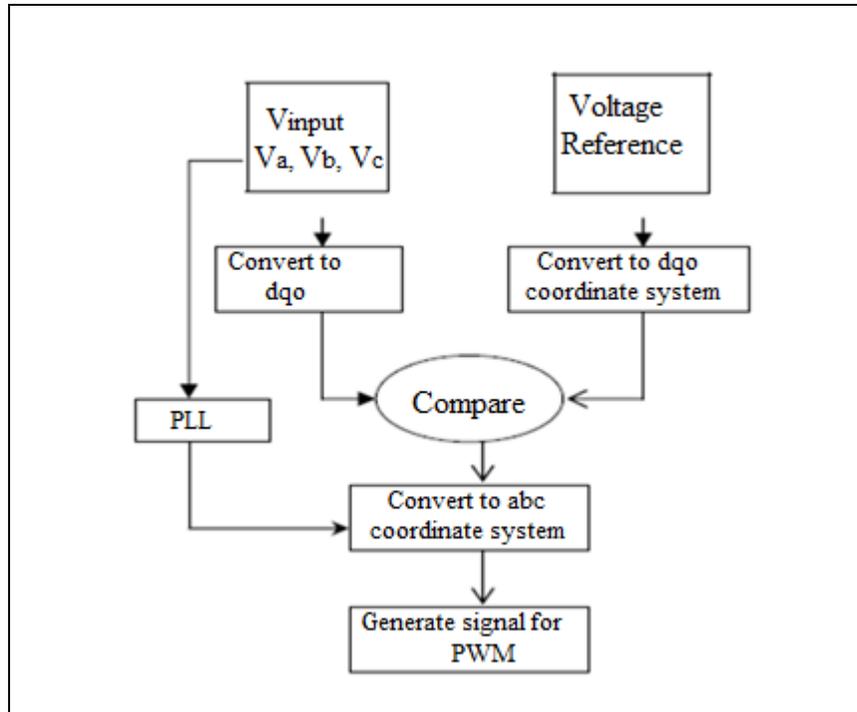


Figure 4: dqo transformation technique SRFT based flow chart for DVR.

Where  $V_{LP}^*$  is the base value of load voltage.  $V_{LP}$  represents the scale of the resulted voltage of the load. These values are represents in per unit system for the convenience. The d-q framed constituents at PCC are obtained by means of park transformation control scheme.

#### V. DVR model Simulation outcomes

By using MATLAB/SIMULINK software in respect to validate the deed DVR model simulation successfully performed. The rated voltage comes into view across the load during healthy condition. The comparator examine the load voltage regularly either the load is run in healthy condition or in abnormal state. When system is overloaded or short circuit takes place the voltage sag trouble comes in picture. Then comparator send a command to the control circuit. Then microcontroller send a signal to the DVR circuit. Now DVR compensate the voltage and feed to the load. The functioning of the DVR is starts with the introduction of voltage disturbances due to single line to ground (L-G) and double line to ground fault (L-L-G) faults occurrence.

##### Case-I

Control circuit of the DVR functioning very accurate and quickly and DVR restores the voltage effectively during fault occurrence. When one line of 3-phase system comes in contact with ground means an unsymmetrical fault is applied to the system DVR circuit compensate the voltage within shortest time period as shown in figure 5.

##### Case-II:

When two lines comes in contact with ground also known as unsymmetrical fault occurs in the system, DVR circuit compensate electrical energy within shortest time period and feed to the sensitive load without minor interruption as shown in figure 6.

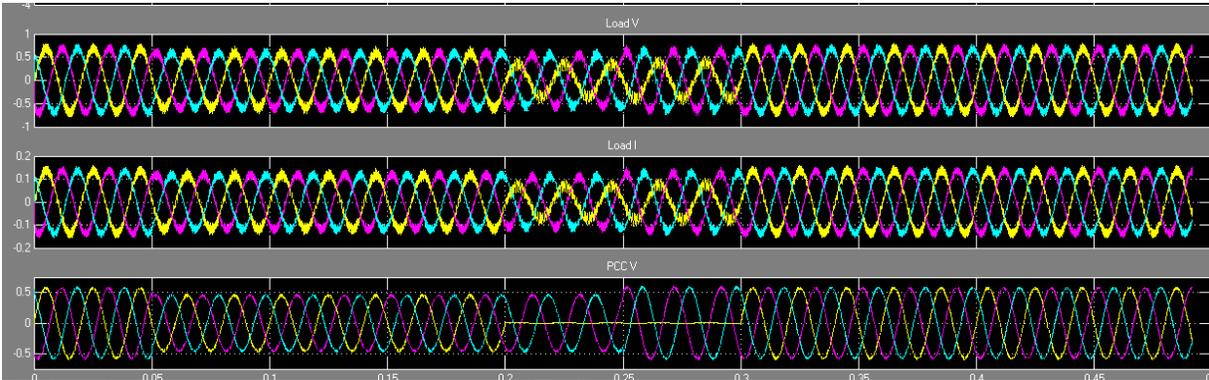


Figure 5: MATLAB SIMULINK result during L-G fault.

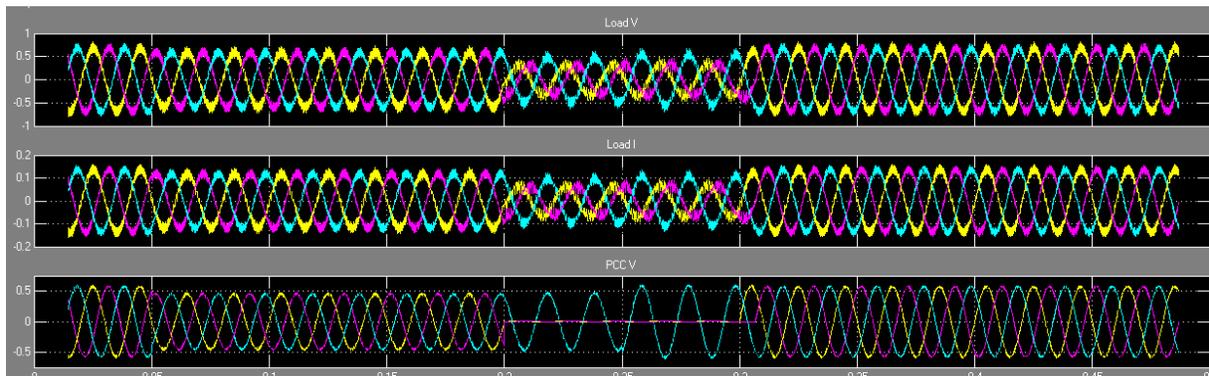


Figure 6: MATLAB SIMULINK result during L-L-G fault.

## VI. Conclusion

DVR model gives the convenient result against the disturbance occurrence as we have examined in above two cases. This model works accurately for the customary margins of harmonics without interruption. We have applied voltage sag from 0.2 to 0.3 sec one phase collapse as shown in figure 5 and two phases collapse as shown in figure 6. During this time period DVR model restore the voltage and feed to the sensitive load.

Table1. Input data for dynamic voltage restorer model.

System Element	Scaling
Input Supply Source	10 kVA, 440 V, 3 – Phase AC, 50Hz, Sinusoidal.
Injection Transformer	170/250 V, 10KVA
DC Link Voltage	170 V [Direct Current]
Load	5KW, 440V, Power Factor = 0.9 lagging
Universal Bridge	Insulated Gate Bipolar Transistor [IGBT] based, Pulse Width Modulation [PWM] Range of switching Frequency = 5 kHz to 20 kHz
<b>Controller Design</b>	DVR design may be changes with the variation in control algorithm.
<b>Filter Elements</b>	Rating of the filter element given as: $R = 3 \Omega$ , $L = 3 \text{ mH}$ & $C = 10\mu\text{F}$

## References

- [1] N.G. Hingorani, "Introducing Custom Power in IEEE Spectrum", 32p, pp 41-48, 1995.
- [2] P. Boonchiam, and N. Mithulanathan "Understanding of Dynamic Voltage Restorers through MATLAB Simulation" *Thammasat Int. J. Sc.Tech.*, Vol. 11, No. 3, pp. 1-6, July-September 2006.
- [3] C. Benachaiba, and B. Ferdi "Voltage quality improvement using DVR", *Electrical Power Quality and Utilization, Journal Vol. XIV*,
- [4] Mahmoud A. El-Gammal, Amr Y. Abou-Ghazala, and Tarek I. El-Shennawy "Dynamic Voltage Restorer (DVR) For Voltage Sag Mitigation", *International Journal of Electrical Engineering and Informatics*, Volume 3, Number 1, 2011.
- [5] 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, ISSN 2250-3005, Jan.2013.
- [6] A. Visser, J. Enslin and H. Mouton, "Transformer-less Series Sag Compensation With a Cascaded Multilevel Inverter", *IEEE Trans. Industrial Electronics*, Vol. 49(4), pp. 824-831, Aug. 2002.
- [7] P. Loh, M. Vilathgamuwa, S. Tang and H. Long, "Multilevel Dynamic Voltage Restorer", *IEEE Power Electronics Letters*, Vol. 2(4), pp. 125-130, Dec. 2004.
- [8] P. Roncero-Sánchez, E. Acha, J. E. Ortega-Calderon Vicente Feliu, A. García-Cerrada, "A versatile control scheme for a dynamic voltage restorer for power-quality improvement", *IEEE Trans., Power Del.*, vol. 24, no. 1, pp. 277-284, Jan. 2009.
- [9] R.Omar, N. A. Rahim, and M. Sulaiman "New control technique applied in dynamic voltage restorer for voltage sag mitigation", *American J. of Engineering and Applied Sciences* 3 (1): pp.42-48, 2010.
- [10] P. R. Sanchez, and E. Acha "Dynamic voltage restorer based on flying capacitor multilevel converters operated by repetitive control", *IEEE Transactions on power delivery*, Vol.24, No.2, pp. 951-960, April 2009.
- [11] R. Amrita, and A. K. Nadir, "Modeling & Simulation of dynamic voltage restorer (DVR) for enhancing voltage sag", *Sensors & Transducers Journal*, Vol. 87, Issue 1, January 2008, pp. 85-93, 2008.
- [12] Pradeep Kumar Bhardwaj and Dr. M. P Dave, "Design and simulation of self supported DVR using SRFT," *AKGEC International Journal of Technology*, Vol. 5, No. 2, pp. 35-41, July-Dec 2014.
- [13] M. A. Bhaskar, S. S. Dash, C. Subramani, M. J. Kumar, P. R. Gireesh, M. V. Kumar "Voltage quality improvement using DVR", *2010 International Conference on Recent Trends in Information, Telecommunication and Computing*, pp. 378-380, IEEE, 2010.
- [14] Subhro Paul, SujaySarkar, SurojitSarkar, Pradip Kumar Saha, Gautam Kumar Panda, "By Dynamic Voltage Restorerfor Power Quality Improvement", *International Journal Of Engineering And Computer Science ISSN:2319-7242 Vol.2*, pp. 234-239 Issue 1 Jan 2013.
- [15] M. V. Kasuni Perera, "Control of a dynamic voltage restorer to compensate single phase voltage sags" *Master of Science Thesis, KTH Electrical Engineering, Stockholm, Sweden*, 2007.
- [16] Ray Arnold "Solutions to Power Quality Problems" *power engineering journal* pages: 65-73. 2001.
- [17] T. Devaraju, V. C. Veera Reddy, and M. V. Kumar "Role of custom power devices in power quality enhancement: A Review", *International Journal of Engineering Science and Technology*, Vol.2 (8), pp. 3628-3634, 2010.
- [18] R. Ibrahim, A. M. Haidar, M. Zahim, "The Effect of DVR Location for Enhancing Voltage Sag" *Proceedings of the 9th WSEAS International Conference on Applications of Electrical Engineering*, pp. 92-98.
- [19] R. Omar, and N. A. Rahim, "Modeling and simulation for voltage sags/swells mitigation using dynamic voltage restorer (DVR)", *Power Engineering Conference, 2008. AUPEC '08*. pp. 1-5 Dec.2008.
- [20] K. R. Padiyar, "FACTS controllers in power transmission and distribution", *New Age International (P) Ltd.*, 2007.