International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.3., Issue.6., 2015
(Nov.-Dec.,)

RESEARCH ARTICLE

ISSN: 2321-7758

ARTIFICIAL NEURAL NETWORK CONTROLLED DYNAMIC VOLTAGE RESTORER FOR VOLTAGE SAGS/SWELLS MITIGATION

Y. RAMA KULLAYISWAMY[1], K. VIMALA KUMAR[2]

[1]M.Tech, EEE department, JNTUACE Pulivendula, Kadapa, Andhra Pradesh, India.

[2]Assistant Professor in EEE department, JNTUACE Pulivendula, Kadapa, Andhra Pradesh, India.

Y. RAMA KULLAYISWAMY

K. VIMALA KUMAR

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 equipment. One of the major problems dealt here is the voltage sag and voltage swell.

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. The control for DVR based on Artificial Neural Network Control is discussed. The proposed control scheme is simple to design. Simulation results carried out by MATLAB/SIMULINK verify the performance of the proposed method.

Key Words—Artificial Neural Network, Programmable logic controller, Electronic drives, Dynamic voltage restorer

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 equipment.

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.

A North American analysis of power quality included data collection from 1057 site-months at 112 locations from 1990 to 1994. The measured data were analyzed and classified according to the standards of ANSI C84.1-1989 and the Computer and Business Equipment Measurement Association (CEBEMA) curve, illustrated in Fig.1. More than 160,000 power disturbances were recorded over the four monitoring periods, which showed the unavailability of commercial power with an estimated mean value of 6.17 hour per site, per year. The power disturbances were categorized into four major events; low RMS events, high RMS events, transients and interruptions. The transient events took a major part with around 60%, while the interruption took minor part with around 1%. The transients mainly came from capacitive switching operations, when the utility applies a large bank of capacitors on a high voltage power line to help to regulate voltage and to compensate for a poor power factor. More than 26% of the power disturbances came from the low RMS events, while 13% of that came from the high RMS events. Some of the high RMS events were suspected to come from the incorrect setting of the transformers. The majority of the low RMS events (90%) lasted less than one minute, while 4% lasted more than thirty minutes.

Voltage dips can cause tripping of sensitive loads and the cost associated with short duration voltage dips can in some cases justify the insertion of power electronic equipment to compensate for poor power quality.

Some of the issues, which have renewed and triggered the interest in power quality can be stated as:

- Higher demand on supreme power quality. IT technology, automated production plants and commercial activities require a good and reliable power supply.

➢ De-regulating and commercializing of the electric energy markets have made power quality a parameter of interest to achieve a higher price per kilowatt, to increase the profit and share of the market.

➢ Decentralization of the production of electricity with integration of alternative energy source and small generation plants have increased certain power quality problems like surplus of power, voltage variations and flickers.

➢ The improvements in the power electronics area and data processing capability have made improvement in power quality by means of relative cost-effective power electronic controller.

These trends have triggered interest in different types of power electronics controllers to mitigate power quality problems.

II. POWER ELECTRONIC CONTROLLERS

There are two general approaches to mitigate power quality problems. One approach is to ensure that the process equipment is less sensitive to disturbances, allowing it to ride-through the disturbances. The other approach is to install a custom power device to suppress or counteract the disturbances.

Many CUPS devices are commercially available in the market today such as, active power filters (APF), battery energy storage systems (BESS), distribution static synchronous compensators (DSTATCOM), distribution series capacitors (DSC), dynamic voltage restorer (DVR), power factor controller (PFC), surge arresters (SA), super conducting magnetic energy storage systems (SMES), static electronic tap changers (SETC), solid-state transfer switches (SSTS), solid-state circuit breaker (SSCB), static var compensator (SVC), thyristor switched capacitors (TSC) and uninterruptible power supplies (UPS).

Focusing on the compensation of voltage dips the number of devices can be narrowed down, and in three types of devices have been compared, they are:

➢ UPS: Uninterruptible Power Supply- This could be a static converter with double conversion to mitigate most type of power quality disturbance. The topology is illustrated in Fig.1.

- DVR: Dynamic Voltage Restorer is a series-connected device, which corrects the voltage dip and restore the load voltage in case of a voltage dip. The topology is illustrated in Fig. 2.
- SSTS: Solid State transfer switch to change from a faulted feeder to a healthy feeder. The topology is illustrated in Fig.3.

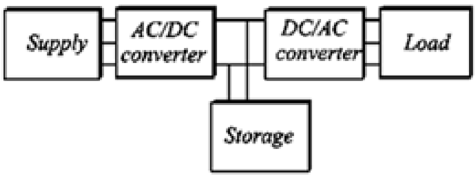

Figure 1: Double conversion Uninterruptible Power supply (UPS) with an energy storage

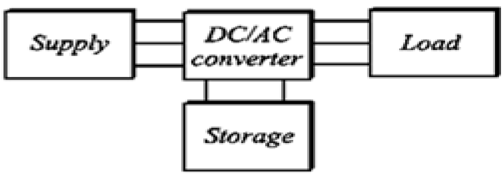

Figure2: Series connected dynamic voltage restorer with an energy storage.

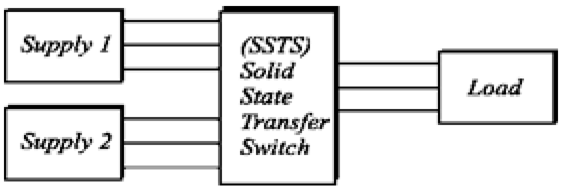

Figure 3: Solid state transfer switch (SSTS) to switch between two supply lines

of the three solutions have been investigated regarding the expected savings, cost of solution per kVA, annual operating cost, total annual cost and a benefit/cost ratio. The SSTS has the highest benefit/cost ratio if a secondary independent feed is present and if not the DVR is considered to be the most cost effective solution.

III. DYNAMIC VOLTAGE RESTORER

The dynamic voltage restorer is a series connected device, which by voltage injection can control the load voltage. In the case of a voltage dip the DVR injects the missing voltage and it avoids any tripping the load. Fig. 4 illustrates the operation principle of a DVR.

The DVR is still very rarely inserted in the grid and only relative few devices have been inserted around the world. Most of the described projects include limited information about potential problems and a detailed description of the design and control aspects.

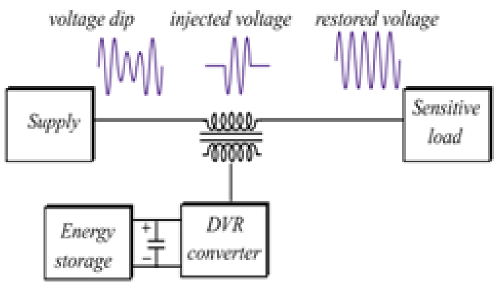

Figure 4: Operation principle of a DVR.

Even though the DVR is commercially available today, the DVR is not a matured technology and several areas regarding the design and control of this type of device are at the basic research level. The design of a DVR has been treated in [1] with focus on the sizing of the voltage, power and current rating. DVR structures have been treated in [4] addresses the design considerations for the line-filter for a DVR. The control strategies to limit the energy storage have been treated in some control issues regarding series compensation of unbalanced supply voltages have been treated.

Additionally, the DVR is a series connected device and one of the drawbacks with series connected devices is the difficulties to protect the device during short circuits and avoid interference with the existing protection equipment.

Some basic concepts of the DVR are presented. Also describes the fundamentals of Neural Networks. I presented a briefly discusses the application of Neural Network control in the field of PWM converter. The voltage error and its derivative are the Neural Network controller input crisp values.

The main function of the DVR is the protection of sensitive loads from voltage sags/swells coming from the network. The DVR is shown in Figure 5 which consists of the injection transformer, filter unit, voltage source converter, and energy storage and control system that is used to mitigate voltage sag in power distribution system [5].Figure 5 Shows the Schematic diagram of DVR. The DVR is connected in series between the source voltage or grid and sensitive loads through injection transformer. There are several types of energy storage that has been used in the DVR such as battery, super conducting coil and flywheels. These types of energy storages are very important in order to supply active and reactive power to the DVR. The controller is an important part of the DVR for switching purposes. The switching converter is responsible to do conversion process from DC to AC. The inverter ensures that only the swells or sags voltage is injected to the injection transformer [2,7].

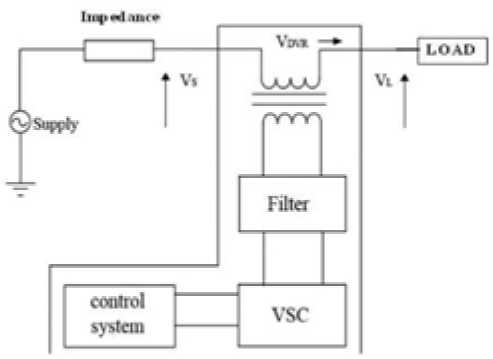

Figure 5: schematic diagram of a DVR

The three-phase transformers connection used in the three-phase DVR can be configured either in delta/open or star/open connection as shown in Figure 5. In case of asymmetrical fault in the high voltage side, the zero sequence current flowing almost zero, if the distribution transformer connection in Δ-Y with the grounded neutral. As such connection, the DVR only mitigates the positive and negative sequence components [6].

One of the efficient methods to inject the DVR compensating voltage is pre-sag compensation method. The Pre-sag compensation method is to track supply voltage continuously and compensates load voltage during fault to pre-fault condition. Figure 6 shows the single-phase vector diagram of the pre-sag compensation. In this method, the load voltage can be restored ideally, but injected active power cannot be controlled and is determined by external conditions such as the type of faults and load condition.

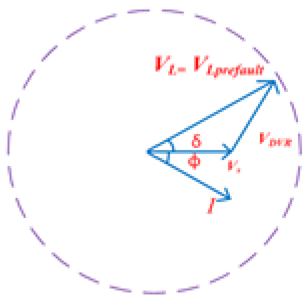

Figure 6: Vector diagram of pre-sag compensation

IV. REALIZATION OF COMPENSATION TECHNIQUE

Discrete PWM-Based Control Scheme

In order to mitigate the simulated voltage sags in the test system of each compensation technique, also to compensate voltage sags in practical application, a discrete PWM-based control scheme is implemented, with reference to DVR. The aim of the control scheme is to maintain a constant voltage magnitude at the sensitive load point, under the system disturbance. The control system only measures the rms voltage at load point, for example, no reactive power measurement is required.

The DVR control system exerts a voltage angle control as follows: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle δ to drive the error to zero, for example; the load rms voltage is brought back to the reference voltage. It should be noted that, an assumption of balanced network and operating conditions are made. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

$VA = \sin(\omega t + \delta)$

$VB = \sin(\omega t + \delta - 2\pi/3)$

$VC = \sin(\omega t + \delta + 2\pi/3)$

TEST SYSTEM OF DVR

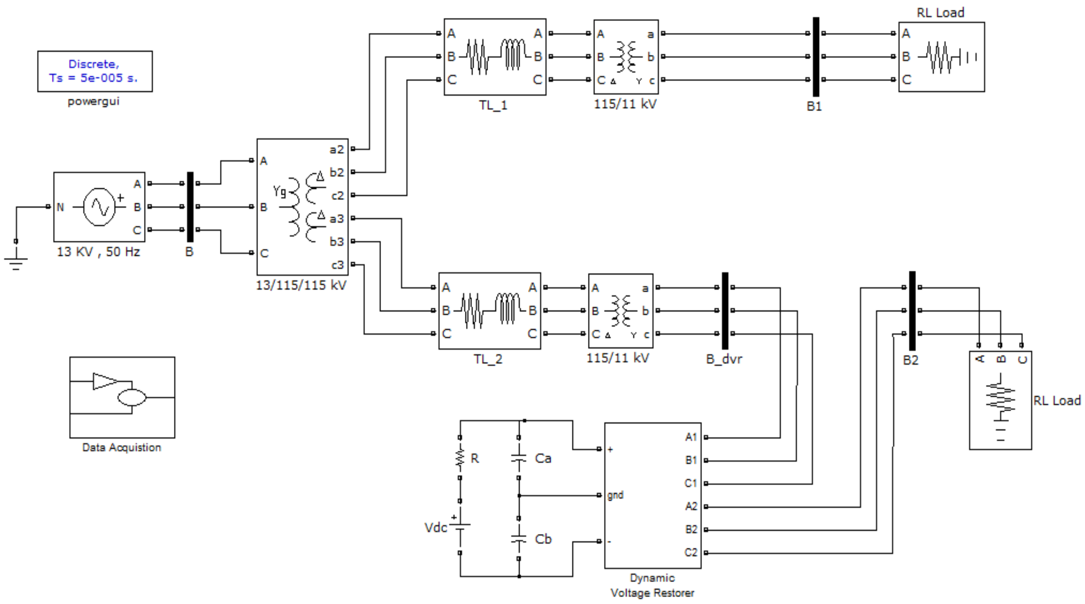

Fig 7: DVR Test System MATLAB/SIMULINK

Single line diagram of the test system for DVR is composed by a 13 kV, 50 Hz generation system, feeding two transmission lines through a 3 winding transformer connected in $Y/\Delta/\Delta$, 13/115/115 kV. Such transmission lines feed two distribution networks through two transformers connected in Δ/Y, 115/11 kV. To verify the working of DVR for voltage compensation a sag, swell and harmonics are applied for time duration of 200 msec.

V. NEURAL NETWORK BASED CONTROLLERS

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. ANN's, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurons. This is true of ANN's as well.

A.THE MODEL OF A NEURAL NETWORK

The basic functional outline before mentioned has many complexity and exceptions, but then the most ANN models only these simple characteristics. They typically consists of many hundreds of simple processing units, which are wires together in a complex communication network. Each node or unit is simplified model of a simple neuron which fires, if it receives a sufficiently strong input signal from other node.

These nodes can be grouped it to different layers. A layer of processing elements makes independent decision or computation on data and passes the result to another layer. The next layer in turn makes its independent computation and passes the result to another layer. Each processing elements makes the computation based upon sum weights of its inputs. The first layer is the input layer and the last layer is output layer. The layers that are placed in between are called hidden layers.

Figure 8 shows general idea how an artificial neural network works

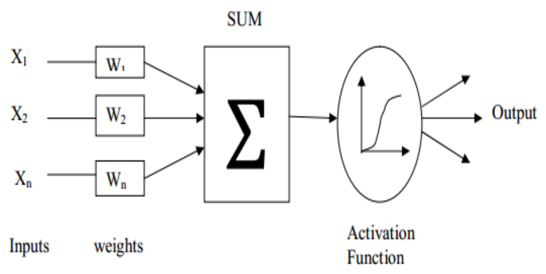

Figure 8: Artificial Neural Network

Here a set of input labeled X_{1s} X_2....X_n is applied to the artificial neuron. These inputs collectively referred to as the vector 'X', corresponds to the signals into the synapse of a biological neuron. Each signal is multiplied by an associated weight W_1, W_2, … ,W_n before it is applied to the summation block. Each weight corresponds to the strength of a single biological synaptic connection. The set of weight is referred collectively as the vector 'W'. The summation block refers to the biological cell body, adds all the weighted inputs algebraically, producing an outputthat we call SUM. This may be compactly stated in vector notation as

SUM = X*W

OR

$SUM = X_1*W_1 + X_2*W_2+ \quad ....+ X_n*W_n$.

The sum output is then multiplied by the activation function to get desired output.

B. NEURO CONTROLLER

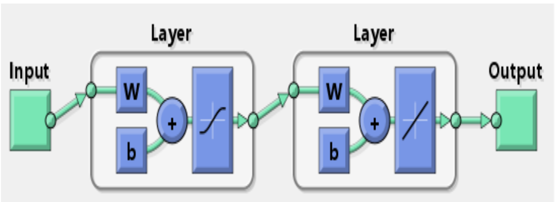

Figure 9: Simulink of Neural Network Controller

The basic objective of a controller is to provide the desired output for any system. Since neural networks have learning and self-organizing abilities allowing them to adapt changes in data, the input-output data necessary for the off-line training of the neural network have been obtained in the present work using reference and plant models.

Trials have been carried to obtain maximum accuracy with minimum number of neurons per layer. The feed forward neural network controller developed consists of three layers, with one neuron in the input layer, 20 neurons in the hidden layer and one neuron in the output layer. The activation function used for the hidden layer is bipolar sigmoid while the activation function of the output layer is linear. Back propagation algorithm is used for training of the created network. This algorithm is the most popular supervised learning rule for multi-layer feed forward networks. Quasi-Newton method applied for updating weights is a one-dimensional minimization related numerical interpolation method which has a fast convergence property known as quadratic convergence and hence it exhibits super linear convergence near target. With back propagation algorithm, the input data is repeatedly presented to the neural network. With each presentation the output of the neural network is compared to the desired output and an error is computed. This error is then fed back to the neural network and used to adjust the weights such that the error decreases with each iteration and the neural model gets closer and closer to producing the desired output. This process is known as "training".

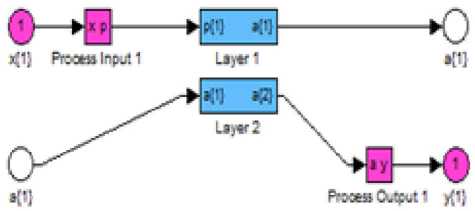

Figure 10: Simulink Block of Neural Network used as ANN Controller

For back propagation training algorithm, the derivative of the activation function is needed. Therefore the activation function selected must be differentiable. The logistic or sigmoid function satisfies this requirement and it is the commonly used soft- limiting activation function. It is also quite common to use linear output nodes to make learning easier and using linear activation in the output layer does not compress the range of output. MSE is the performance criteria used in this work that evaluates the network according to the mean of square of error between target and computed output.

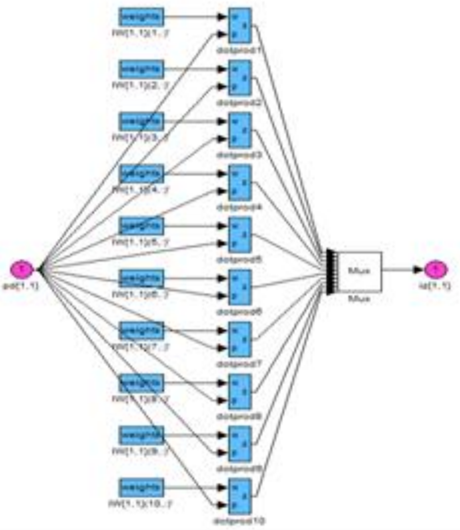

Figure 11: Simulink Block of hidden layer of ANN

VI. SIMULATIONS AND RESULTS

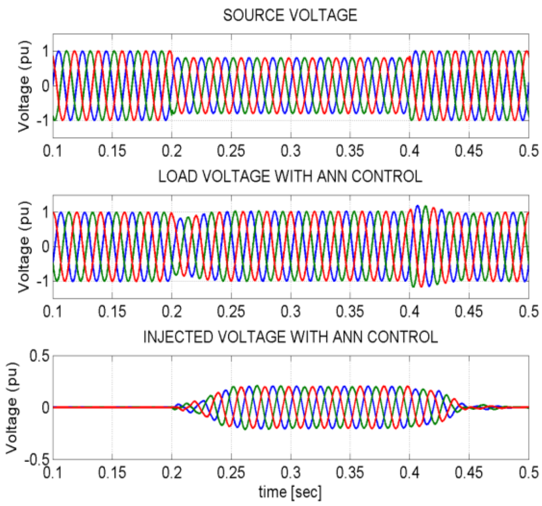

Figure 12: Mitigation of Load Voltage Sag with ANN Control

The first simulation was done with no DVR and a voltage sag of 20% is introduced into the system (ie., by reducing supply voltage) for 0.2 sec. Here DVR is injecting the voltage to nullify the sag and then controller will calculate the required delay delta so that DVR can obtain required injected voltage so as to maintain flat voltage profile.

A voltage swell of 20% was introduced into the system (ie., by increasing supply voltage) for 0.2 sec. Here DVR is injecting the negative voltage to nullify the swell and then controller will calculate the required delay delta so that DVR can obtain required injected voltage so as to maintain flat voltage profile.

Here also an unbalance in voltage is created into the system. DVR is properly injecting the required voltage into each phase so as to maintain flat voltage profile.

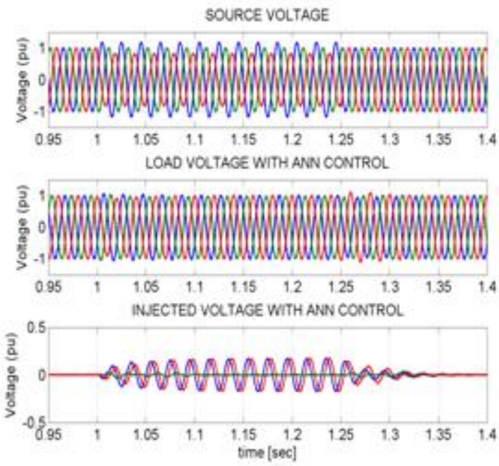

Figure 14: Voltage Response with ANN Control for harmonic in Grid Voltage

Over proportional plus integral control the Ann control show better time response characteristics.

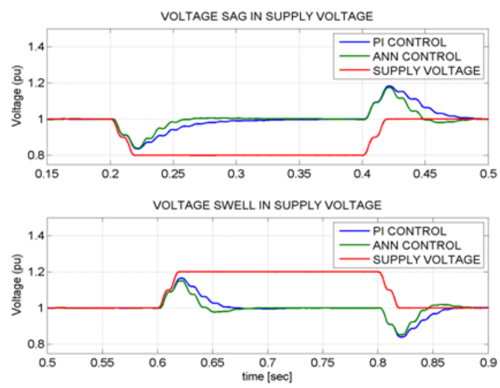

Figure 15: Comparing the performance of PI Control and ANN Control for Voltage Sag and Swell

VII. CONCLUSION

This paper has presented the power quality problems such as voltage dips, swells, distortions and harmonics. Compensation techniques of custom power electronic devices DVR was presented. The design and applications of DVR for voltage sags and comprehensive results were presented. A PWM-based control scheme was implemented. As opposed to fundamental frequency switching schemes already available in the MATLAB/ SIMULINK, this PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. Ann controlled dynamic voltage restorer is presented here to improve the power quality. The corresponding simulation results showed in MATLAB/ SIMULINK.

REFERENCES

[1]. D. Daniel Sabin, Senior Member, IEEE, And Ambra Sannino, IEEE "A Summary of the Draft IEEE P1409 Custom Power Application Guide" Transmission and Distribution Conference and Exposition, IEEE PES, vol. 3, pp. 931-936, 2003.

[2]. H. Hingorani "Introducing custom power" IEEE spectrum, vol.32 no.6 June 1995 p 4148.

[3]. http://www.ijceronline.com/papers/Vol3_issue1/AD03101770183..pdf

[4]. G. Yalcinkaya, M.J.H Bollen, P.A Crossley, "characterization of voltage sags in industrial distribution system", IEEE transaction on industrial applications, vol.34, pp. 682-688 july-aug. 1998.

[5]. M. H. Haque, "Compensation of Distribution System Voltage Sag by DVR andDSTATCOM", IEEE Porto Power Tech Conference, vol. 1, 2002.

[6]. S. S. Choi, B. H. Li, and D. D.Vilathgamuwa, "Dynamic Voltage Restoration with Minimum Energy Injection," IEEE Trans. Power Syst, vol. 15, pp. 51–57, Feb. 2000.

[7]. Michael D. Stump, Gerald J. Keane "The role, of custom power products in enhancing power quality at industrial facilities", Energy Management and Power Delivery, vol. 2, pp. 507-517, International Conference1998.

[8]. http://www.academia.edu/6649810/Design_of_PI_and_Fuzzy_Controllers_for_Dynamic_Voltage_Restorer_DVR_

[9]. http://www.academia.edu/6653003/DESIGN_OF_DSTATCOM_AS_VOLTAGE_CONTROLLER_WITH_DIRECT_AND_INDIRECT_CONTROL_STRATEGIES