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NOVEL OPTIMIZATION OF DYNAMIC VOLTAGE RESTORER TO MITIGATE SAG AND SWELL USING ADAPATIVE FUZZY LOGIC CONTROL

P.PRAVEEN [#1] and Prof. K.GOPINATH [*2]

[#] *Final year, M.E, Power systems Engineering, P.S.V College of Engineering and Technology, Krishnagiri (D.T) -635108*

[*] *Assistant Professor, Electrical and Electronics Engineering, P.S.V College of Engineering and Technology, Krishnagiri (D.T) -635108*

***Abstract*— This project aims to design and modeling of Dynamic Voltage Restorer (DVR) for maintaining the Power quality of the system. 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 power sag and 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. This projects presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) using MATLAB. In this project fuzzy optimized PR controller with integrated function of active power transfer, reactive power compensation and voltage conversion is proposed as an hybrid system. A new control technique is proposed to control the capacitor- supported DVR. The control of a DVR is demonstrated with a reduced-rating VSC. The reference load voltage is estimated using the unit vectors. The synchronous reference frame theory is used for the conversion of voltages from rotating vectors to the stationary frame. The compensation of the voltage sag, swell, and harmonics is demonstrated using a reduced-rating DVR. The proposed hybrid system can effectively suppress the voltage fluctuation. The simulation of proposed work is carried out using MATLAB.**

***Index Terms*— Dynamic Voltage Restorer (DVR), PR controller, voltage fluctuation, power distribution networks.**

INTRODUCTION

The technological advancements have proven a path to the modern industries to extract and develop the innovative technologies within the limits of their industries for the fulfillment of their industrial goals. And their ultimate objective is to optimize the production while minimizing the production cost and thereby achieving maximized profits while ensuring continuous production throughout the period. As such a stable supply of un-interruptible power has to be guaranteed during the production process. The reason for demanding high quality power is basically the modern manufacturing and process equipment, which operates at high efficiency, requires high quality defect free power supply for the successful operation of their machines. More precisely most of those machine components are designed to be very sensitive for the power supply variations. Adjustable speed drives, automation devices, power electronic components are examples for such equipment's. Failure to provide the required quality power output may sometimes cause complete shutdown of the industries which will make a major financial loss to the industry concerned. Thus the industries always demands for high quality power from the supplier or the utility. But the blame due to degraded quality cannot be solely put on to the hands of the utility itself. It has been found out most of the conditions that can disrupt the process are generated within the industry itself. For example, most of the non-linear loads within the industries cause transients which can affect the reliability of the power supply. Following shows some abnormal electrical conditions caused both in the utility end and the customer end that can disrupt a process.

- Voltage sags And swell
- Phase outages
- Voltage interruptions
- Transients due to Lighting loads, capacitor switching, nonlinear loads.,
- Harmonics

As a result of above abnormalities the industries may undergo burned-out motors, lost data on volatile memories, erroneous motion of robotics, unnecessary downtime, increased maintenance costs and burning core materials especially in plastic industries, paper mills & semiconductor plants. Among those power quality abnormalities voltage sags and surges or simply the fluctuating voltage situations are considered to be one of the most frequent type of abnormality. Those are also identified as short term under/over voltage conditions that can last from a fraction of a cycle to few cycles. Motor start up, lightning strikes, fault clearing, power factor switching is considered as the reasons for fluctuating voltage conditions.

As the power quality problems are originated from utility and customer side, the solutions should come from both and are named as utility based solutions and customer based solutions respectively. The best examples for those two types of solutions are FACTS devices (Flexible AC Transmission Systems) and Custom power devices. FACTS devices are those controlled by the utility, whereas the Custom power devices are operated, maintained and controlled by the customer itself and installed at the customer premises. Both the FACTS devices and Custom power devices are based on solid state power electronic components. As the new technologies emerged, the manufacturing cost and the reliability of those solid state devices are improved; hence the protection devices which incorporate such solid state devices can be purchased at a reasonable price with better performance than the other electrical or pneumatic devices available in the market. Uninterruptible Power Supplies (UPS), Dynamic Voltage Restorers (DVR) and Active Power Filters (APF) are examples for commonly used custom power devices. Among those APF is used to mitigate harmonic problems occurring due to non-linear loading conditions, whereas UPS and DVR are used to compensate for voltage sag, swell and surge conditions. In this Project work the control of a Dynamic voltage restorer for voltage sags has been studied. Voltage sag and swell may occur from single phase to three phases. Therefore the industries that use three phase supply will undergo several interruptions during their production process and they are compelled to use some form of voltage compensation equipment.

I. Modeling of Power Quality

Most of the more important international standards define power quality as the electric supply protected from any deviation in voltage, current or frequency under normal conditions & don't disrupt or disturb the customer's processes. Quality of power supply is basically defined by its two pivotal factors, voltage quality & supply reliability. These pivotal factors lead to power quality problems when they suffer change in their characteristics due to equipment failure or sudden system disturbances. The increasing trend of non-linear loads in the power system network has lead to the hazardous consequences suffered by the customer. This has further resulted in the slew of forward looking enhancements in system protection using Custom Power devices. They aptly enhance the stability & reliability of the system by reducing the effects of various disturbances.

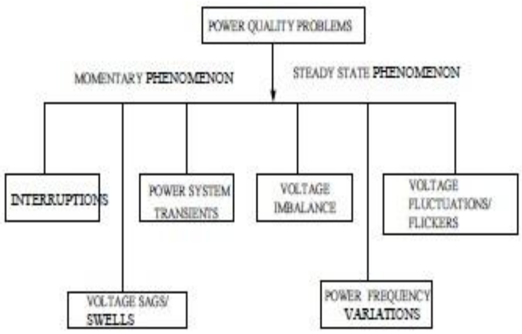
A. Definition

The quality assurance of electric power demands a deep research and study on the subject „Electric Power Quality". The interesting discussions & their respective proposals lead to various definitions of "Power Quality". It is term which different people described in different ways as follows:

- Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment."
- Electric Power Quality (EPQ) is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency. Thus EPQ is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc.
- Power Quality is defined as the set of Parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform).
- Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. This definition embraces two things that we demand from an electrical device: performance and life expectancy.

B. Concern

The variation in the definitions of power quality as given here are much wider than the general interpretation of power quality. This has to do with the fact that power quality in most cases is an issue due to the phrase „bad power quality". A power quality disturbance is only seen as an issue when it causes problems, either for the customer or for the network operator. Voltage sags, Voltage dips and harmonics are the problems encountered which makes power quality, a matter of concern. This is due to the presence of nonlinear elements in the power system (i.e. either in the network or in the loads). The main distortion is due to power-electronic loads like computers, televisions, energy- saving lamps. Such loads can be found in increasing numbers with domestic and commercial customers in a run to increase efficiency & productivity leading to increased distortion in the network. The effect is especially severe for lower-order voltage harmonics at the terminals of rotating machines & higher-order harmonics for capacitor banks. Also adjustable-speed drives and arc furnaces are famous for the distortion they cause. This accounts for the mitigation by improving the immunity of equipment by the use of custom power devices. The ability of the equipment to perform in the installed environment is an indicator of its immunity.



Classification of Power Quality Problems

C. Problems of Power Quality

The users demand higher power quality to use more sensitive loads to automate processes and improve living standards. Some basic criterions for power quality are constant rms value, constant frequency, symmetrical three-phases, pure sinusoidal wave shape and limited THD. These values should be kept between limits determined by standards if the power quality level is considered to be high. The economic losses due to power interruptions and disturbances can be quite high as a result of the important processes controlled and maintained by the sensitive devices. Power quality disturbances can be summarized as follows:

1. **Interruption/under voltage/over voltage:** They are among the very common type of disturbances. During power interruption, voltage level of a particular bus goes down to zero. The interruption may occur for short or medium or long period. Such disturbances are increasing the amount of reactive power drawn or deliver by a system, insulation problems and voltage stability.

2. **Voltage/Current unbalance:** Voltage and current unbalance may occur due to the unbalance in drop in the generating system or transmission system and unbalanced loading. During unbalance, negative sequence components appear. It hampers system performance and in some cases it may hamper voltage stability.

3. **Power system harmonics**: They are low-frequency phenomena characterized by waveform distortion, which introduces harmonic frequency components. Voltage and current harmonics have undesirable effects on power system operation and power system components. In some instances, interaction between the harmonics and the power system parameters (*R*–*L*–*C*) can cause harmonics to multiply with severe consequences.

4. **Power frequency disturbances**-These are low-frequency phenomena that result in voltage sags or swells. These may be source or load generated due to faults or switching operations in a power system.

5. **Power system transients-** They are fast, short-duration events that produce distortions such as notching, ringing, and impulse.

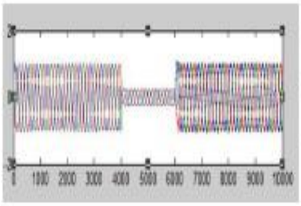
6. **Voltage sag*:*** It is a short duration disturbance. During voltage sag, r. m. s. voltage falls to a very low level for short period of time.

7. **Voltage swell:** It is a short duration disturbance. During voltage sag, r. m. s. voltage increases to a very high level for short period of time.

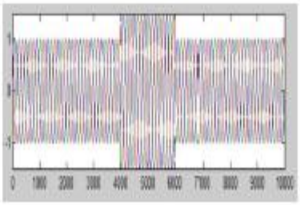
8. **Flicker:** It is visual effect and undesirable frequency variation of voltage in a system.

9. **Ringing waves:** Oscillatory disturbances of decaying magnitude for short period of time is known as ringing wave. It may be called a special type transient.

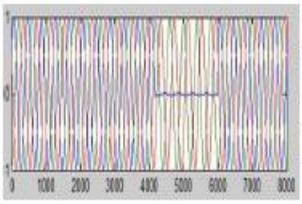
10. **Outage:** It is special type of interruption where power cut has occurred for not more than 60 s due to fault or mal-tripping of switchgear/system.



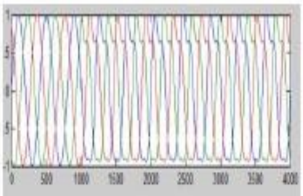
(a) Voltage Sag



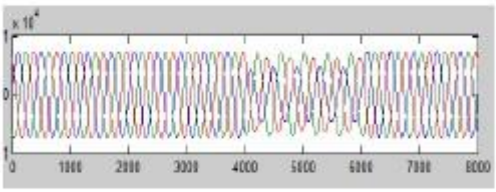
(b) Voltage Swell



(c) Outage



(d) Harmonics



(e): Unbalance

D. Solutions

The integrated solution to the power quality problems encountered in the distribution area is "Custom Power". It focuses on reliability &quality of power flow. Custom power technology, the low-voltage counterpart of the more widely known flexible ac transmission system (FACTS) technology, aimed at high-voltage power transmission applications, has emerged as a credible solution to solve many of the power quality problems relating to continuity of supply at the end-user level . Mitigation is in the harmonic context which is often seen as reduction of harmonic voltage or current distortion. However the problem can also be mitigated by improving the immunity of equipment. The mitigation methods includes reducing the number of faults, faster fault clearing, improved network design & operation, improved end-user equipment. The higher index of reliability & power quality to satisfy the customer has reflected the need for the development & application of compensation systems. Compensating systems also known as the custom power devices offer a handful of protection & security to the system under observation.

A custom power device is a reliable & flexible solution to the consumers regarding the power supply. They tend to absorb the various disturbances by injecting appropriate voltage, current or both into the system; thereby relieving the main source from meeting the reactive power demand of the load. Various custom power devices covering a wide range of flexible controllers & capitalize on evolution of power electronic controllers are widely used to compensate voltage sag/swells in the system .The custom power devices used for transmission system includes static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), interline power flow conditioner (IPFC) & unified power flow conditioner(UPFC) and for distribution system are distribution static synchronous compensator(DSTATCOM), dynamic voltage restorer(DVR), active power filter(APF),unified power quality conditioner(UPQC) etc. There are various other custom power devices such as Battery Energy Storage Systems (BESS), Surge Arresters (SA), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid-State Transfer Switches (SSTS) and Solid State Fault Current Limiter (SSFCL). In this work, the effectiveness of DVR to compensate load voltage is investigated. It is a series compensating device that helps in increasing the immunity of the equipment & reliability of the system by regulation of voltage in the system. The whole work is concentrated around DVR & its various control strategies.

II. Inference Analysis

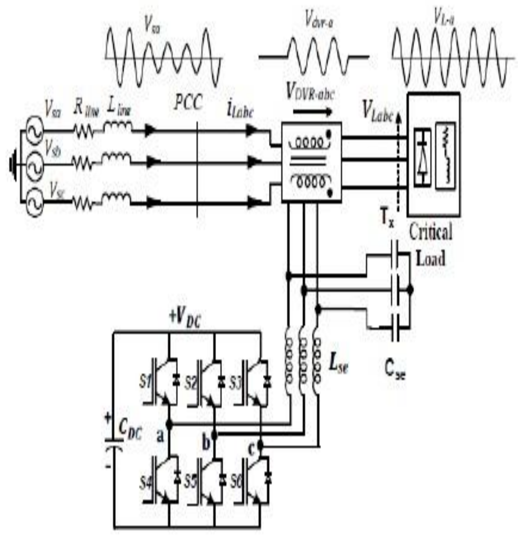
Dynamic Voltage Restoration (DVR) is a method and apparatus used to sustain, or restore, an operational electric load during sags, or spikes, in voltage supply. Often used in manufacturing areas requiring significant power to run tools/equipment, and utility plants, this custom device mitigates potential damage to equipment and undesirable slowdowns to the production line caused by an abrupt change in electric load. This method uses critical devices such as an automatic Transfer switch and IGBT Modules in order to operate. DVR (Dynamic Voltage Restorer) is a static var device that has seen applications in a variety of transmission and distribution systems. It is a series compensation device, which protects sensitive electric load from power quality problems such as voltage sags, swells, unbalance and distortion through power electronic controllers that use voltage source converters (VSC). DVRs have been applied to protect critical loads in utilities, semiconductor and food processing. Today, the dynamic voltage restorer is one of the most effective PQ devices in solving voltage sag problems. However, cost and installation restrictions have limited its implementation to where there is obvious requirement for a stable voltage supply.

The basic principle of the dynamic voltage restorer is to inject a voltage of required magnitude and frequency, so that it can restore the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. Generally, it employs a gate turn off thyristor (GTO) solid state power electronic switches in a pulse width modulated (PWM) inverter structure. The DVR can generate or absorb independently controllable real and reactive power at the load side. In other words, the DVR is made of a solid state DC to AC switching power converter that injects a set of three phase AC output voltages in series and synchronism with the distribution and transmission line voltages. The source of the injected voltage is the commutation process for reactive power demand and an energy source for the real power demand. The energy source may vary according to the design and manufacturer of the DVR. Some examples of energy sources applied are DC capacitors, batteries and that drawn from the line through a rectifier. In normal conditions, the dynamic voltage restorer operates in stand-by mode. However, during disturbances, nominal system voltage will be compared to the voltage variation. This is to get the differential voltage that should be injected by the DVR in order to maintain supply voltage to the load within limits.

A. Control System

In addition, from the transmission viewpoint, the dynamic voltage restorer would extend the voltage range if the load is a constant power type. The combination of direct-connected DVRs, voltage-switched capacitor banks and on-load tap-changing distribution transformers, leads to more current drawn from the transmission system during periods of reactive deficiency and low voltages. Therefore, when applying DVRs, it is vital to consider the nature of the load whose voltage supply is being secured, as well as the transmission system which must tolerate the change in voltage-response of the load. It may be necessary to provide local fast reactive supply sources in order to protect the system, with the DVR added, from voltage collapse and cascading interruptions. A comprehensive simulation study, which includes the transmission system, is highly recommended. SSSC and DVR The SSSC's counterpart is the Dynamic Voltage Regulator (DVR). Although both are utilized for series voltage sag compensation, their operating principles differ from each other. The static synchronous series compensator injects a balance voltage in series with the transmission line. On the other hand, the DVR compensates the unbalance in supply voltage of different phases. Also, DVRs are usually installed on a critical feeder supplying the active power through DC energy storage and the required reactive power is generated internally without any means of DC storage. With the above sufficient study on DVRs. the existing work contains the following elements.

- A family of wind or solar energy systems with integrated functions of active power transfer, reactive power compensation, and voltage conversion and harmonics elimination is presented.
- The wind energy systems and photovoltaic systems using solid-state transformer (SST) can effectively suppress the voltage fluctuation without additional reactive power compensator.
- Anyhow SST design is not our basic work, because it is already suggested in DVR systems



Basic DVR based system configuration.

B. Overview

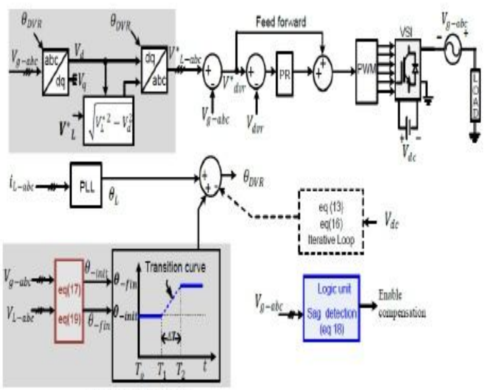
In the industrial distribution systems, the grid voltage disturbances (voltage sags, swells, flicker and harmonics) are the most common power quality problems. Sag being the most frequent voltage disturbance, is typically caused by fault at remote bus and is always accompanied by a phase angle jump. The phase jump in the voltage can initiate transient current in the capacitors, transformers and motors. It can also disturb the operation of commutated converters and may lead to glitch in the performance of thyristor based loads. It is therefore imperative to protect sensitive loads, especially from the voltage sags with phase jump.

PARAMETER	VALUE
Grid Voltage(L-L)(rms)Vbase	415V
Line Frequency	50Hz
Nominal Power(Base KVA)	10 KVA
Nominal Load Power Factor	0.7 Lagging
Maximum Compensation Time	10 cycles
Maximum sag depth	0.5 pu
Maximum phase jump	+45*
Maximum injected Voltage	0.7p.u
Transformer Turns Ratio	1:1
DC link Capacitance value	9000MF

Parameters of DVR in Existing System.

Numerous control strategies for DVR have been reported in the literature . The emphasis is on either reducing the voltage rating of DVR by aligning the injected voltage with the source voltage (i.e. in-phase compensation) or minimizing the dc storage capacity by using reactive power compensation/energy optimized approach. All these methods however cannot correct the phase jump and thus can result in premature tripping of sensitive loads. The only possible way to mitigate the phase jump is to restore the load voltage to the pre-fault value. Such an approach is addressed as pre sag compensation in . However, the phase jump compensation using pre sag method requires a significant amount of active power from the dc link capacitor. Thus, this method will require a larger size capacitor or will result in shorter sag support time. In an interesting technique is proposed to increase the compensation time while mitigating the voltage phase jump. In this method, once the dc link voltage drops to the threshold limit, the magnitude of injected voltage is reduced by synchronizing the phase locked loop (PLL) to grid voltage.

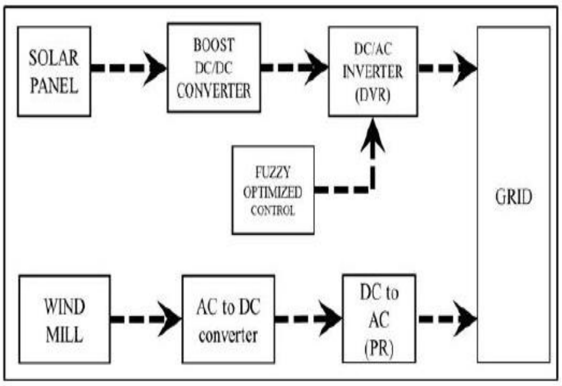
This allows further utilization of dc link capacitor energy and extends the compensation time by some extent. However, it continues to consume energy in dc link capacitor throughout the duration of compensation and imposes limitation on compensation time enhancement. This paper proposes a new control strategy in which the main objective is to enhance the sag compensation time while mitigating the voltage phase jump. The proposed method aims at regulating the contribution of active power to the least possible value. To avoid the problem of over modulation, in case of deeper sag depth, an iterative loop is employed in the control block. It is found that the proposed method can result in more than 50% additional sag support time when compared with the method



Control System of Existing System

Higher cost, increased volume and weight, voltage fluctuations are the drawbacks and the objectives include, To solve the power quality issues (like sag, swell, harmonics etc). To implement this system based on photovoltaic models along with Battery energy storage system. Input membership functions are adaptively varied based on the target power quality.

III. Operational Analysis



Block Diagram of Proposed system

This project deals with improving the voltage quality of sensitive loads from voltage sags and swells using dynamic voltage restorer (DVR). The higher active power requirement associated with voltage phase jump compensation has caused a substantial rise in size and cost of dc link energy storage system of DVR.

• The existing control strategies either mitigate the phase jump or improve the utilization of dc link energy by (i) reducing the amplitude of injected voltage, or (ii) optimizing the dc bus energy support.

• In this project, an enhanced sag and swell compensation strategy is proposed that mitigates the phase jump in the load voltage while improving the overall sag compensation time. The phase jump is achieved faster in this proposed work.

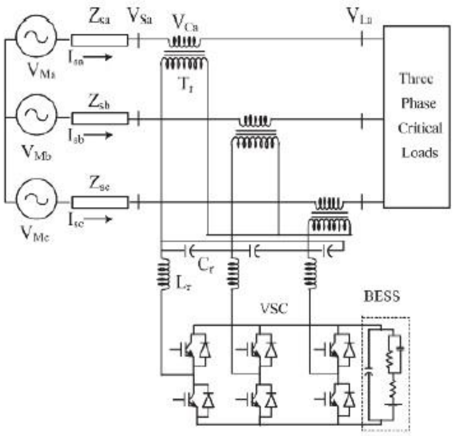
• A serial voltage coupling method is used to both increase and decrease the compensating voltage so as to maintain a constancy in load voltage .

The amplitude and phase angle of the injected voltages are variable, thereby allowing control of the real and reactive power exchange between the dynamic voltage restorer and the distribution system. The DC input terminal of a DVR is connected to an energy storage device of appropriate capacity. As mentioned, the reactive power exchange between the DVR and the distribution system is internally generated by the DVR without AC passive reactive components. The real power exchanged at the DVR output AC terminals is provided by the DVR input DC terminal by an external energy source or energy storage system. Also, there is a resemblance in the technical approach to DVRs to that of providing low voltage ride-through (LVRT) capability in wind turbine generators. The dynamic response characteristics, particularly for line supplied DVRs are similar to LVRT-mitigated turbines.

Moreover, since the device is connected in series, there are conduction losses, which can be minimized by using Integrated Gate-Commutated Thyristor (IGCT) technology in the inverters. Practically, the capability of injection voltage by DVR system is 50% of nominal voltage. This allows DVRs to successfully provide protection against sags to 50% for durations of up to 0.1 seconds. Furthermore, most voltage sags rarely reach less than 50%. The dynamic voltage restorer is also used to mitigate the damaging effects of voltage swells, voltage unbalance and other waveform distortions. DVRs may provide good solutions for end-users subject to unwanted power quality disturbances. However, there is a caution regarding their application in systems that are subject to prolonged reactive power deficiencies (resulting in low voltage conditions) and in systems that are vulnerable to voltage collapse. In many cases, the main protection of the power system against voltage collapse is the natural response of load to decrease demand when system voltage drops. The application of DVRs would tend to maintain demand even when incipient voltage conditions are present. As a result, this reduces the innate ability to prevent a collapse and increases the chance of cascading interruptions. Sag and swell, Time taken to reach stability is reduced (slope of transition is increased). An adaptive fuzzy controller is introduced to improve the angle performance. Reactive power compensation is additionally added into our project. The compensation time has been reduced less than 10 cycles are the parameters improved.

- An analytical study shows that the proposed method significantly increases the DVR sag and swell support time (more than 50%) compared with the existing phase jump compensation methods.
- This enhancement can also be seen as a considerable reduction in dc link capacitor size for new installation. The performance of proposed method is evaluated using simulation study and finally, verified experimentally on a scaled lab prototype.

A. *Control System of DVR*



Schematic of the DVR Connected System

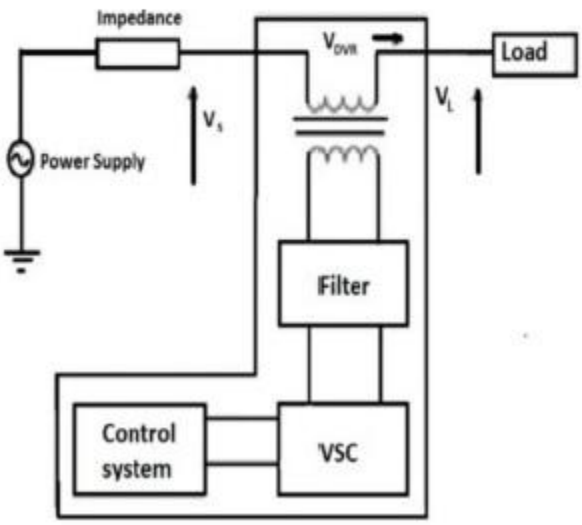
Among the power quality problems (sags, swells, harmonics…) voltage sags and swells are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. DVR is a recently proposed series connected solid state device and is normally installed in a distribution system between the supply and the critical load feeder at the point of common coupling (PCC). It employs a series of voltage boost technology using solid (static) state switches of 3C-PHASE VSC that injects voltage into the system; to restore the load side voltage for compensating voltage sags/swells. Other than voltage sags and swells compensation, DVR can also added other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations. The general configuration of the DVR consists of:

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

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. Its main tasks are:

- It connects the DVR to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.
- In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism)



Schematic diagram of DVR

ii. *Harmonic Filter*

The nonlinear characteristics of semiconductor devices cause distorted waveforms associated with high frequency harmonics at the inverter output. To overcome this problem and provide high quality energy supply, a harmonic filtering unit is used. This can cause voltage drop and phase shift in the fundamental component of the inverter output and has to be accounted for in the compensation voltage.

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. There are four main types of switching devices: Metal Oxide Semiconductor Field Effect Transistors (MOSFET), Gate Turn-Off Thyristors (GTO), Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Each type has its own benefits and drawbacks. The IGCT is a recent compact device with enhanced performance and reliability that allows building VSC with very large power ratings. Because of the highly sophisticated converter design with IGCTs, the DVR can compensate dips which are beyond the capability of the past DVRs using conventional devices. The purpose of storage devices is to supply the necessary energy to the VSC via a dc link for the generation of injected voltages. The different kinds of energy storage devices are Superconductive magnetic energy storage (SMES), batteries and capacitance.

iv. DC Charging Circuit

The dc charging circuit has two main tasks.

- The first task is to charge the energy source after a sag compensation event.
- The second task is to maintain dc link voltage at the nominal dc link voltage.

v. Control and Protection

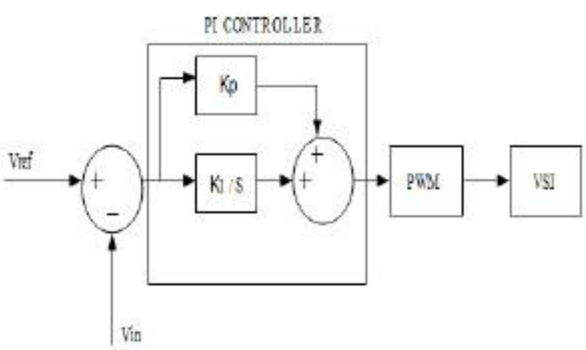
The control mechanism of the general configuration typically consists of hardware with programmable logic. All protective functions of the DVR should be implemented in the software. Differential current protection of the transformer, or short circuit current on the customer load side are only two examples of many protection functions possibility.

B. *Control Philosophies of DVR*

Three control philosophies have been used namely, PI, Fuzzy & PI - Fuzzy. These are discussed as below:

i. Proportional-Integral (PI) controller based DVR

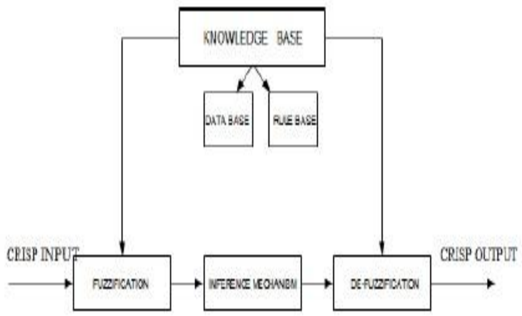
PI is a feedback controller that uses the weighted sum of error & its integral value to perform the control operation. The proportional response can be adjusted by multiplying the error by constant Kp, called proportional gain. The contribution from integral term is proportional to both the magnitude of error and duration of error. The error is first multiplied by the integral gain, Ki and then was integrated to give an accumulated offset that have been corrected previously [8]. The input to the PI controller is difference between the reference value & error value of voltage. As per the comparison of reference value & error value of voltage, linear PI adjusts its proportional & integral gains Kp & Ki in order to reduce the steady state error to zero for a step input as shown in fig.4.1. It is widely used due to simple control structure but suffers a disadvantage of fixed gains i.e. it cannot adapt itself to the varying parameters & conditions of the system.



Control Strategy of PI Controller

ii. Fuzzy Controller based DVR

The drawback suffered by PI controller is overcome by Fuzzy. In comparison to the linear PI controller, this is a non-linear controller that can provide satisfactory performance under the influence of changing system parameters & operating conditions. The function fuzzy controller is very useful as relieves the system from exact & cumbersome mathematical modeling & calculations. The performance of fuzzy controller is well established for improvements in both transient & steady state. The fuzzy controller comprises of four main functional modules namely; Knowledge base, Fuzzification, Inference mechanism & Defuzzification as in fig.



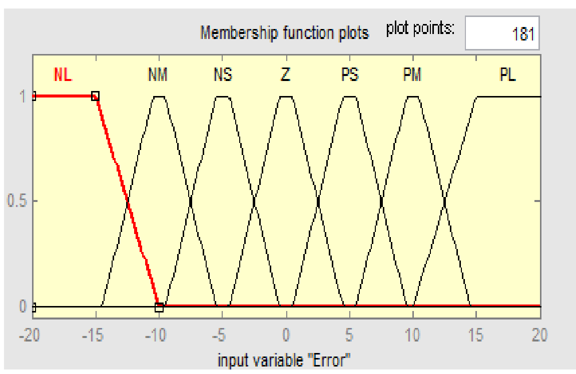
Schematic Diagram of Fuzzy Logic

a.Knowledge base

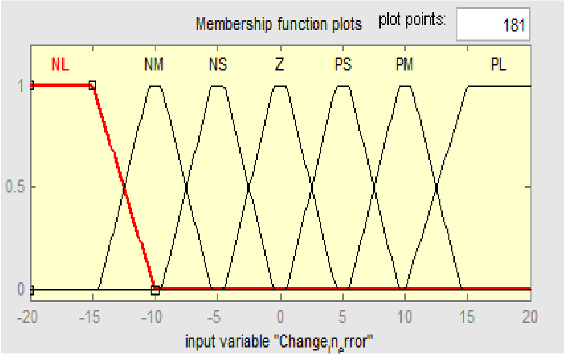
It consists of data base & rule base that maps all the input & output with certain degree of uncertainty in process parameters & external disturbances to obtain good dynamic response. Data base scales the input-output variables in the form of membership functions that defines it in a range appropriate to provide information to the fuzzy rule-based system & output variables or control actions to the system under observation. Fuzzy rule-based system utilizes a collection of fuzzy conditional statements derived from a knowledge base to approximate and construct the control surface.

b.Fuzzification

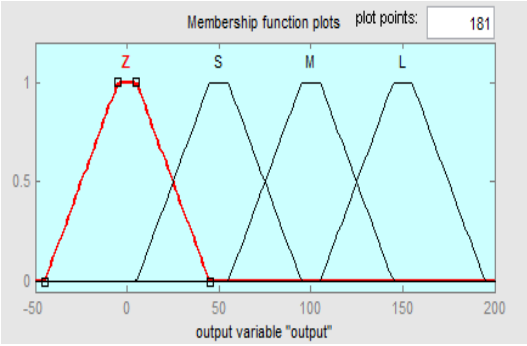
It is the process of defining a crisp data or digital data operating on discrete values of either 0 or 1 in terms of logical variables that take on continuous values between 0 and 1 i.e. fuzzy set. Fuzzy set maps the input-output variables into membership functions & truth values as in fig .



Input Membership Function of "Error"



Input Membership Function of "Change in Error"



Output Membership Function

c. Inference Mechanism

It is referred to as approximate reasoning that uses knowledge to conduct deductive inference of IF-THEN rules. This mechanism encodes knowledge about a system in statements form of linguistic IF -THEN propositions with antecedents & consequents. There are three types of fuzzy inference mechanism:

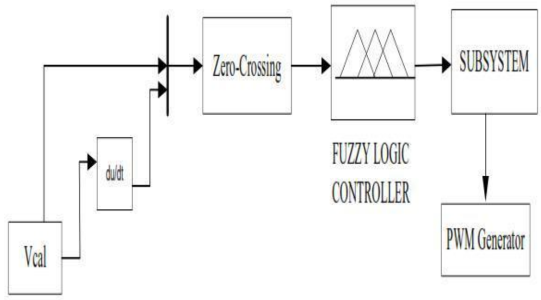
1. Mamdani System (1975)
2. Sugeno models: Takagi and Sugeno(1985) & Sugeno & Kang(1988)
3. Tsukamoto models(1979)

d. Defuzzification

It is a conversion process of fuzzy quantity to a precise quantity and is reverse process of fuzzification. A logical union of two or more membership functions in the universe of discourse requires a crisp decision with approximate solution for the output of fuzzy which is uncertain in nature to be a single scalar quantity Various methods for defuzzyifying the output membership functions have been proposed; out of them four of widely used are summarized as follows:

1. Centroid method
2. Centre of sums method(cos)
3. Weighted average method
4. Mean-max membership

The FLC controller of the tested system exploits the Mamdani type of inference method. It defuzzifies the crisp input-output variables into fuzzy trapezoidal membership function and reverse process of Defuzzification is based upon the Centroid method. The controller core is the fuzzy control rules as shown in table which are mainly obtained from intuitive feeling and experience.

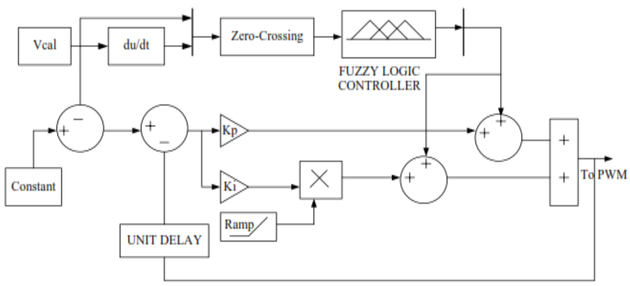


Control Strategy of Fuzzy Controller

"e" "ce"	NL	NM	NS	Z	PS	PM	PL
NL	L	L	L	M	Z	S	Z
NM	L	L	M	Z	Z	Z	S
NS	L	M	S	Z	Z	S	S
Z	M	S	S	Z	S	S	M
PS	S	S	Z	Z	S	M	L
PM	S	Z	Z	Z	M	L	L
PL	Z	S	Z	M	L	L	L

Fuzzy Rule Based System

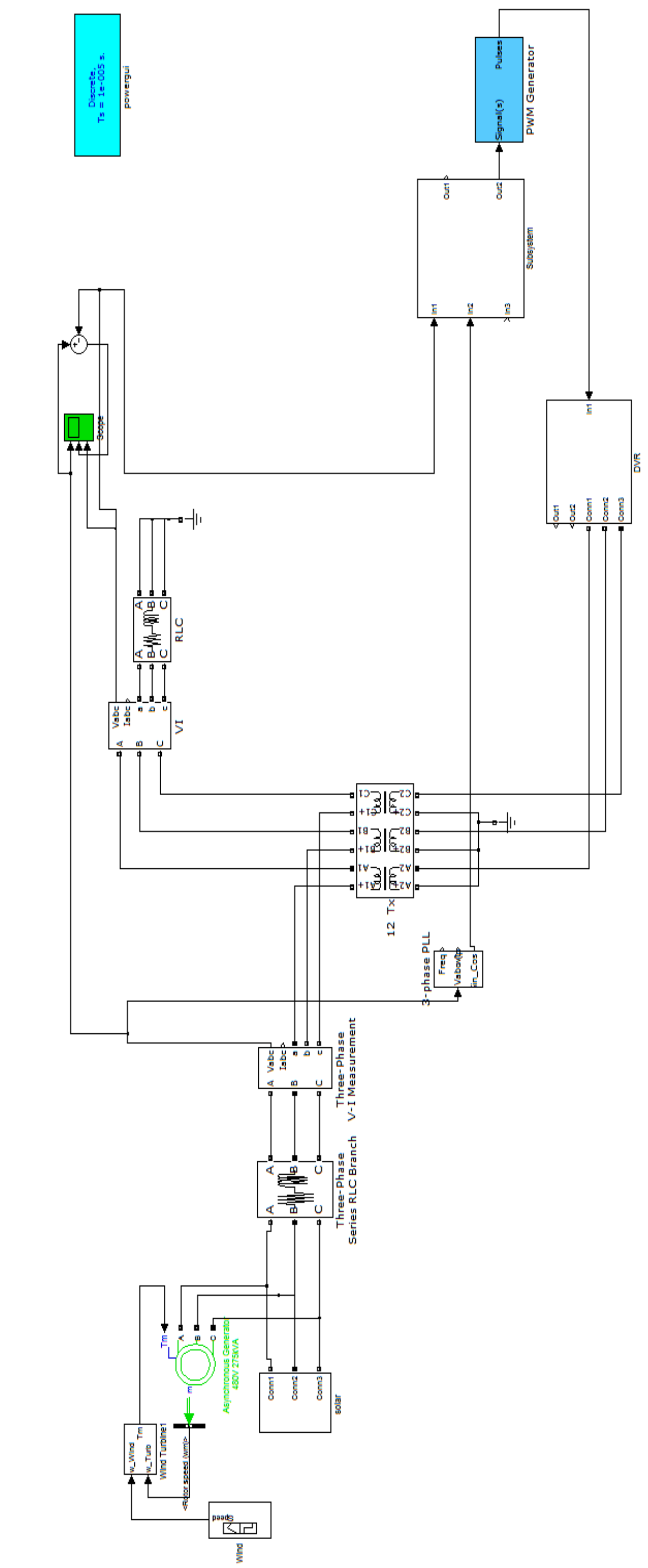
iii. Hybrid PI-Fuzzy based DVR



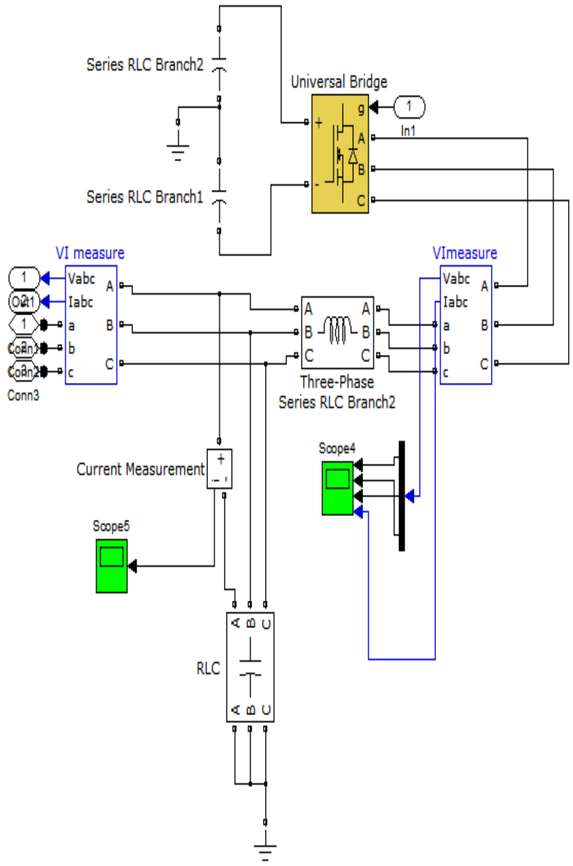
Control Strategy of PI-Fuzzy Controller

The hybrid PI-Fuzzy control scheme uses to adjust the parameters of proportional gain Kp and integral gain Ki based on the error e and the change of error Δe. PI-Fuzzy based Controller has been designed by taking inputs as error which is difference between measured voltage and reference voltage of DVR for voltage regulator.

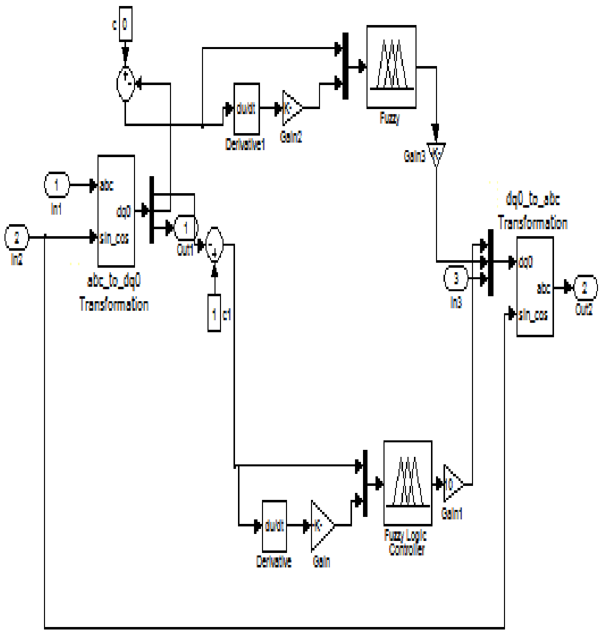
IV. Simulation Results



DVR Simulink model



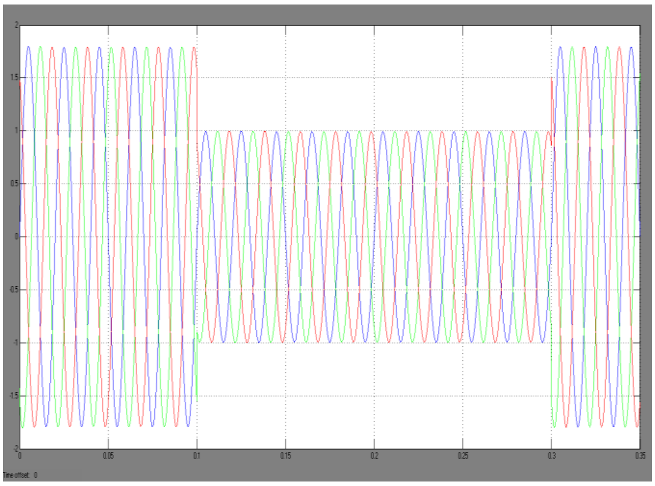
DVR model



Controller model

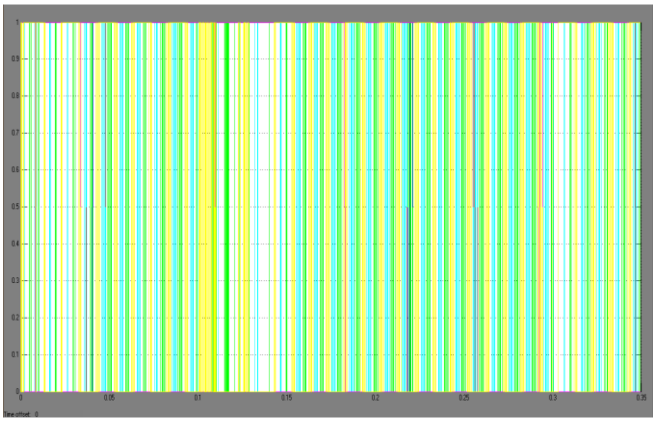
A new control technique (AFC) to detect and compensate for the voltage sags was developed and simulated using the MATLAB software. Combination of both the pre-sag and in-phase compensation techniques was used in the above developed control to optimize the real power requirement during compensation.

In the said control technique the system generates a random reference voltage waveform with the nominal voltage amplitude and the frequency with automated synchronising control.



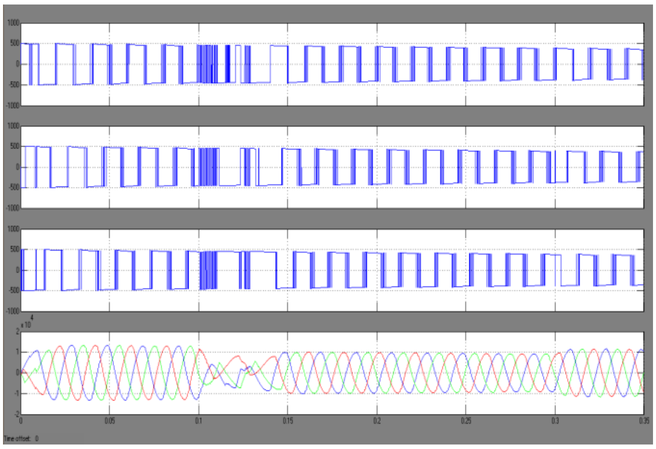
Source supply with Sag

Once the DVR is connected to the system, the phase angle of this reference signal is synchronized with the supply voltage phase angle by continuously monitoring the reference phase angle using a feedback synchronising control loop.



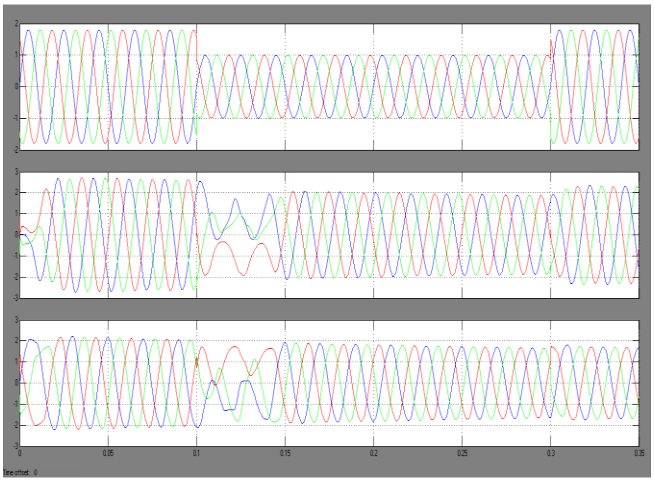
PWM output for VSI

Then by comparing this reference voltage waveform with the measured voltage waveform, any occurrence of voltage abnormalities was detected as an error. As the system detect any voltage sags as error, the power circuit in the DVR generates a voltage waveform to compensate for the voltage sag.



DVR's Output

The design of the power circuit parameters and the control circuit is discussed in the preceding chapters in detail. The simulation results show the very good performance of the controller .



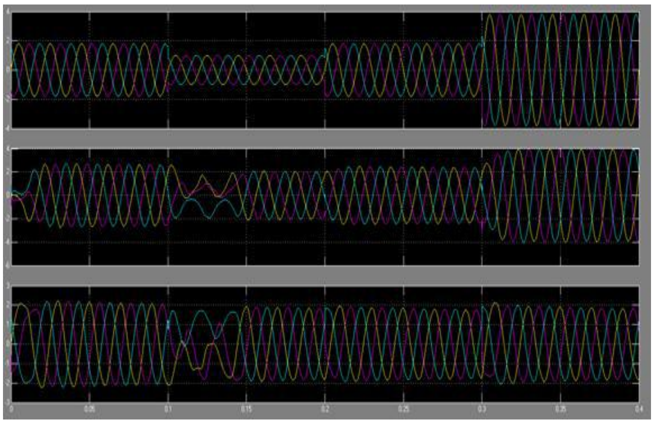
Simulation results

The simulation results show that at the normal operating conditions, the injected voltage becomes less and their affect on the load voltage due to distortion is less. Therefore this thesis has contributed a strong knowledge to the research and development targeting industrial application to compensate the voltage sags.

During and after the voltage sag and swell

When considering the systems 1-4 simulated above the following observations can be made.

- During the sag, the injected voltage increased and compensated the voltage sag.
- The stepped nature of the injected voltage is still prevailing during the sag.
- During the first few cycles (<1 cycles) the load voltage waveform contains some transients, and it has the same shape of the injected voltage during the sag. Hence it can be identified that the transient nature of the load voltage is directly due to the abnormalities in the injected voltage during this transient period.
- When the sag prevails for longer time duration, the transient nature disappears and the load voltage obtained almost the same shape of the reference voltage. I.e. The level of compensation improved within one cycle.
- After the supply restores the voltage to the normal condition, during the first two cycles the injected voltage has the harmonic nature. But the load voltage is not much affected from it.



DVR Performance On Voltage Sag And Swell.

V. CONCLUSION & FUTURE WORK

Voltage sags, swells and surges are a common problem faced by the electricity consumers. As many industries have already making their product from the raw materials, solution to this electricity problem has been identified as the potential issue to reduce their production cost. The commonest solution for the above problem is moving into a full UPS system, which is a costly alternative. In the above project voltage sag and swell compensation using Dynamic Voltage Restorer was considered. Even though three phase DVR system and its control techniques are popular among the researchers, very less consideration was given to single phase DVRs and its control techniques. This Phase work describes a voltage sag compensation technique for a single phase DVR. The control technique was designed by combining both the in-phase and pre- sag compensation techniques to minimize the requirement of real power and voltage ratings of the DVR when the voltage sag and swell prevails for a longer period of time .It uses a closed loop control system to detect the phase angle and magnitude errors between the voltages during and before the sag and swell.

The designed control system was implemented using the MATLAB software. The system was simulated for several cases. To cover all possible voltage sags, the sags were created with and without phase angle shift, and it was initiated at different point of the supply voltage waveform. Finally the supply voltage with harmonic content also checked in the simulation. In all results, the developed adaptive FUZZY control technique with the propose DVR circuit has shown a very good level of voltage compensation. In the above work, due to the time limitation hardware implementation was not carried out. The control circuit can be implemented using electronic components and power electronic switches can be used to generate DVR injected voltages. Then the simulation results can be compared with that of the hardware and the effectiveness of the simulated model can be ensured. The above simulated work was done without giving much attention to the cost factor of the components (such as PWM components, injection transformer) involved. By selecting the ratings of the components with worst case analysis, the cost and the performance are optimized, better results could be obtained. It can be seen from the simulation results for the voltage sag 100% compensation was not achieved. However this was within the acceptable limit in this study, when the DVR rating is increased then the drop increases and thus affects the load voltage. The reason for this is there is no continuous monitoring and feedback is carried out at the load voltage. This problem can be eliminated by introducing another separate feedback control loop for checking the load voltage magnitude compensation to improve the compensation.

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