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RESEARCH ARTICLE

FAST ACTING DVR FOR THE IMPROVEMENT OF POWER QUALITY USING FUZZY LOGIC.

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Abstract

In modern distribution system, there are a number of voltage-based power quality (PQ) problems caused by substantial pollution and abnormal operating conditions due to non linear load. Some of these voltage-related power quality problems are voltage spikes, surges, flickers, sags, swells, notches, fluctuations, voltage imbalance, current and voltage waveform distortion, and so on. The active series compensators are extensively used to inject the required magnitude of voltage and restore the voltage across the loads. Reference voltage generation and further to evolve the gate pulse required by the DVR for its operation. Ultra capacitor is used in spite of normal capacitor for more energy in short span of time UCAP can deliver more amount of energy with in short span of time..When compared to normal capacitor the charging and discharging time taken by UCAP is very low and life time is very high .The reference voltage generation is to be monitored by controller from time to time .This work presents the discussion of sag mitigation by conventional PI controller and intelligent fuzzy controller. The simulation results are demonstrated using MATLAB software.

Introduction:-

Power quality problems are arising due to increase use of the non-linear (power electronic) loads, faults in distribution network, starting and stopping of heavy loads causing power quality events like sag, swell, voltage and current deviations etc. Among voltage sag, swell, and reactive power compensation are considered as major power quality problems.

The concept of using inverter based dynamic voltage restorer (DVR) for preventing the consumers form the small momentary voltage disturbance on the consumer side is introduced. The DVR as power quality equipment has gained the significant importance from the time when it came into existence. The usage of the DVR with rechargeable energy storage at the DC-terminal side to meet the power required during the power interruption. The cost of energy storage devices is decreasing rapidly due tremendous development in semi conductor technology.

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One of the serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry users as well as domestic users. These devices, which need high-quality energy to work properly, at the same time, are the most responsible ones for injections of harmonics in the utility system.

Therefore, devices that discuss this problem has to be developed. DVR is one of them. It consists of series-active filter. This combination allows a simultaneous compensation of the load voltages. In this paper energy storage integration into the power conditioner topology is being proposed which will allow the integrated system to provide additional functionality.

Energy storage systems (ESS) for power utility applications have received considerable attention due to their characteristics such as rapid response (milliseconds), high power (Megawatts) and high efficiency. Energy storage systems can provide improved system reliability, dynamic stability and enhanced power quality. Emerging power electronics applications in the millisecond and longer life time are projected to have a broad application need for electrochemical chemical double layer capacitors (UCAPs). Especially for compact sizes as this technology has the potential of achieving energy densities of many kJ/kg for discharge times of seconds.

Among the rechargeable energy storage technologies superconducting magnet energy storage (SMES), flywheel energy storage system (FESS), battery energy storage system (BESS), and ultra capacitors (UCAPs), UCAPs are ideal for providing active power support for events on the distribution utility which require active power support in the *seconds* to *minutes* time scale like voltage sags/swells, active/reactive power support, and renewable intermittency smoothing.

The PI controllers are widely applied. This is mainly because PI controllers have simple control structures, and are simple to maintain. The drawback of such PI controllers is that their performance degrades as the system operating conditions change. The fuzzy logic controller has a number of distinguishing advantages over conventional controllers. It is not so sensitive to variations of system structure, parameters and operation points and can be easily implemented in a large scale nonlinear system. Furthermore, the fuzzy logic controller is a sophisticated technique that is easy to design and implement. In addition, in the past decade, many researchers have attempted to combine conventional PID controllers with fuzzy logic to improve controller performance.

Three-Phase Inverters:-

Power stage:-

The single diagram of the system is shown in the Fig 1.The three phase voltage source inverter, which is connected in series to the grid and is responsible for compensating the voltage sag as well as swell .The inverter system consist of an insulated gate bi polar transistor (IGBT) module, its gate–driver, LC filter and an isolation transformer. UCAP directly not connected to dc link because UCAP charging and discharging is not always constant so we are going through the bi-directional DC-DC converter. We want to maintain stiff Dc link, so the dc-link voltage is maintained at 260V for optimal performance of the converter.

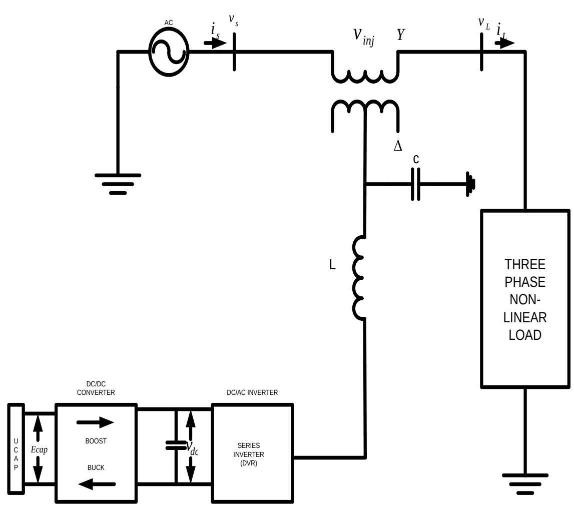


Fig 1:- One Line Diagram DVR connected To Non Linear Load With UCAP Energy Storage Device.

Where *n* is the turns ratio of the isolation transformer .Substituting *n* as 2.5 , the required modulation index is calculated as 0.52. Therefore, the output of the dc–dc converter should be regulated at 260 V for providing accurate voltage compensation. The objective of the integrated UCAP DVR system with active power capability is to compensate for *temporary voltage sag* (0.1–0.9 p.u.) and *voltage swell* (1.1–1.2p.u.), which last from 3 s to 1 min.

Controller Implementation:-

The series inverter controller implementation is based on the in-phase compensation method that requires PLL for estimating θ, and this has been implemented using the fictitious power method . Based on the estimated θ and the line–line source, voltages V_{ab}, V_{bc}, V_{ca} (which are available for this delta-sourced system) are transformed into the d–q domain and the line–neutral components of the source voltage V_{sa}, V_{sb}, and V_{sc} which are not available can then be estimated using

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_q}{\sqrt{3}} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_{refa} \\ V_{refb} \\ V_{refc} \end{bmatrix} = m * \begin{bmatrix} \sin\left(\theta - \frac{V_{sa}}{169.7}\right) \\ \sin\left(\theta - \frac{2\pi}{3}\right) - \frac{V_{sb}}{169.7} \\ \sin\left(\theta + \frac{2\pi}{3}\right) - \frac{V_{sc}}{169.7} \end{bmatrix} \quad (2)$$

$$P_{dvr} = 3 V_{inj\ 2a(rms)} I_{La\ (rms)} \cos \emptyset \quad (3)$$

$$Q_{dvr} = 3 V_{inj\ 2a(rms)} I_{La\ (rms)} \sin \emptyset \quad (4)$$

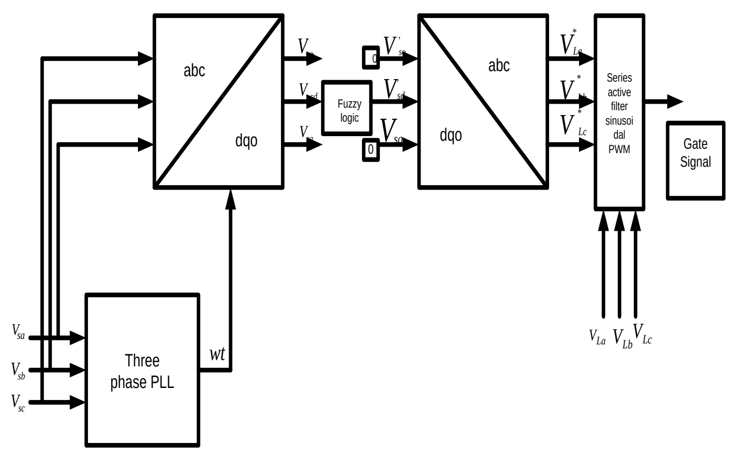


Fig 2:- SRF Block Diagram with Fuzzy Logic.

These voltages are normalized to unit sine waves using line– neutral system voltage of $120V_{rms}$ as reference and compared to unit sine waves *in-phase* with actual system voltages *Vs* to find the injected voltage references V_{ref} necessary to maintain a constant voltage at the load terminals, where *m* is 0.52 . Therefore, whenever there is a voltage sag or swell on the source side, a corresponding voltage *V*inj2 is injected in-phase by the DVR and UCAP system to negate the effect and retain a constant voltage V_L at the load end. The actual active and reactive power supplied by the series inverter can be computed , the rms values of the injected voltage *V*inj2*a* and load current $I_{La,}$ and ϕ is the phase difference between the two waveforms.

Bidirectional Dc–Dc Converter:-

A bidirectional dc–dc converter is required as an interface between the UCAP and the dc-link, since the UCAP voltage varies with the amount of energy discharged, while the dc-link voltage has to be stiff. . The dc–dc converter should operate in Discharge mode, while providing active/reactive power support and voltage sag compensation. The dc–dc converter should also be able to operate in bidirectional mode to be able to charge or absorb additional power from the grid during intermittency smoothing. In this paper, the bidirectional dc–dc converter acts as a boost converter, while discharging power from the UCAP and acts as a buck converter while charging the UCAP from the grid.

Average current mode control, which is widely explored in literature, is used to regulate the output voltage of the bidirectional dc–dc converter in both Buck and Boost modes while charging and discharging the UCAP bank. This method tends to be more stable when compared with other methods like voltage mode control and peak current mode control. This is how DVR connected to non linear load as shown in Fig 3

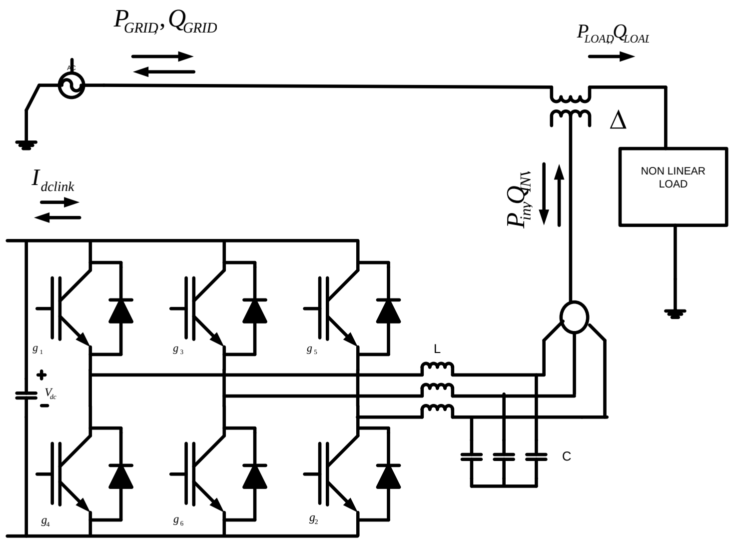


Fig 3:- DVR Connected To Non Linear Load.

Ultra Capacitor (UCAP):-

The choice of the number of UCAPs necessary for providing grid support depends on the amount of support needed, terminal voltage of the UCAP, dc-link voltage, and distribution grid voltages. In this paper, the experimental setup consists of three 48 V, 165F UCAPs manufactured by Maxwell Technologies, which are connected in series. Therefore, the terminal voltage of the UCAP bank is 144 V and the dc-link voltage is programmed to 260 V. This would give the dc–dc converter a practical operating duty ratio of 0.44–0.72 in the *boost mode* while the UCAP is discharging and 0.27– 0.55 in the *buck mode* while the UCAP is charging from the grid through the dc-link and the dc–dc converter. It is practical and cost-effective to use three modules in the UCAP bank. Assuming that the UCAP bank can be discharged to 50% of its initial voltage ($V_{uc,ini}$) to final voltage ($V_{uc,fin}$) from 144 to 72 V, which translates to depth of discharge of 75%, the energy in the UCAP bank available for discharge is given by

$$E_{ucap} = \frac{1}{2} * c * \left(\frac{V^2_{uc,ini} - V^2_{uc,fin}}{60} \right) \quad (5)$$

Fuzzy Logic Controller:-

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The objectives include excellent rejection of input supply variations both in utility and in generating system and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate.

The rule base developed is reliable since it is complete and generated sophistically without using extrapolation. In this project, fuzzy control is used to control the firing angle for the switches of the VSI of DVR. In this design, the fuzzy logic based DVR has two inputs „change in voltage(ΔV)‟ and ‚change in error signal and control output.

Firstly the input values will be converting to fuzzy variables. This is called fuzzification . After this, fuzzy inputs enter to rule base or interface engine and the outputs are sent to defuzzification to calculate the final outputs. Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium),PS (positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big). We use Gaussian membership functions [7] and 49 control rules are developed, which are shown in table1.

Fuzzification**:** : It is the process of representing the inputs as suitable linguistic variables .It is first block of controller and it converts each piece of input data to a degree of membership function.

It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

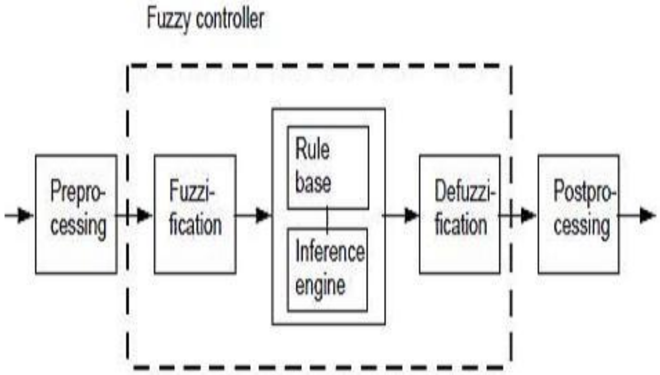
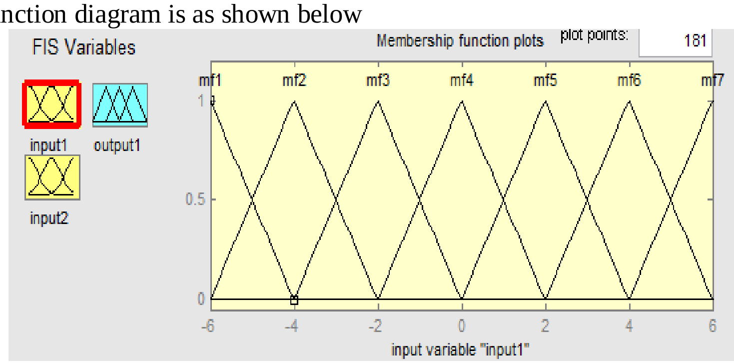


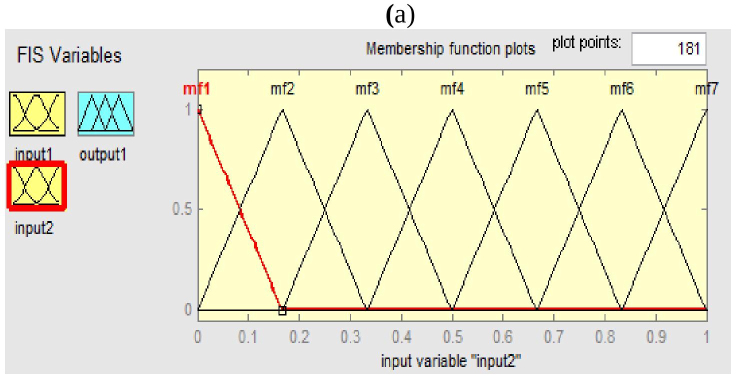
Fig 4:- Fuzzy control block diagram.

The number of fuzzy levels is not fixed and it depends on the input resolution needed in an application. The larger the number of fuzzy levels, the higher is the input resolution. The fuzzy control implemented here uses sinusoidal fuzzy-set values. Decision making: The control rules that associate the fuzzy output to the fuzzy inputs are derived from general knowledge of the system behavior. However, some of the control actions in the rule table are also developed using "trial and error" and from an "intuitive" feel of the process to be controlled.

Two input member ship function diagram is as shown below



(a)



(b)

Fig 5:- input membership functions

Output member ship function is as shown below.

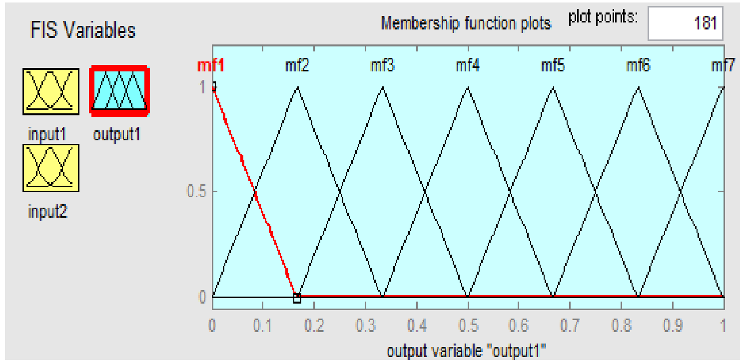


Fig 6:- Output member ship function.

Table 1:- Control Rules.

ΔI / ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Defuzzification: It is the Process of converting fuzzy flied output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed. This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated. Correspondingly the grid current changes and improves the power quality.

MATLAB/Simulink Results:-

Simulation model of DVR with linear load is as shown in below. The input are 208V line to line voltage 50Hz connected to linear load

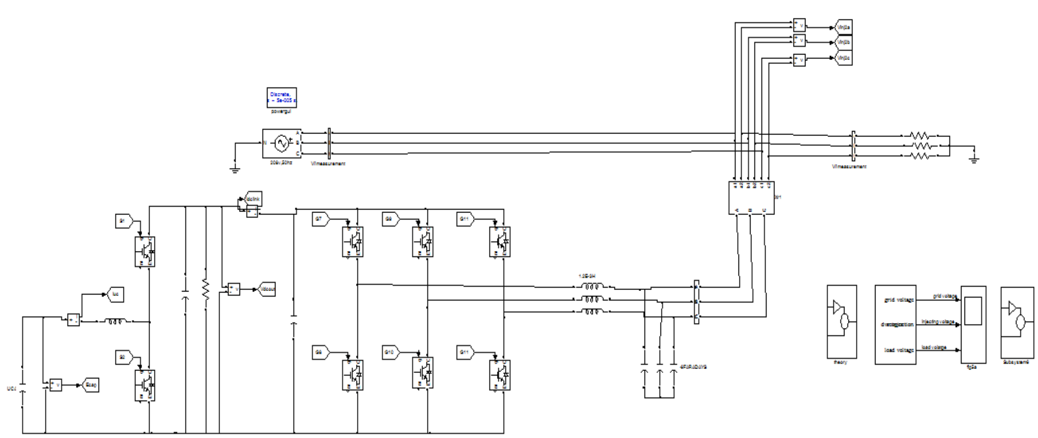


Fig 7:- MATLab/Simulink Model Of DVR Connected To Linear Load.

Control strategy for the DVR is as shown below in this we are generating reference gate signal required by the DVR operation in this we are using pi controller

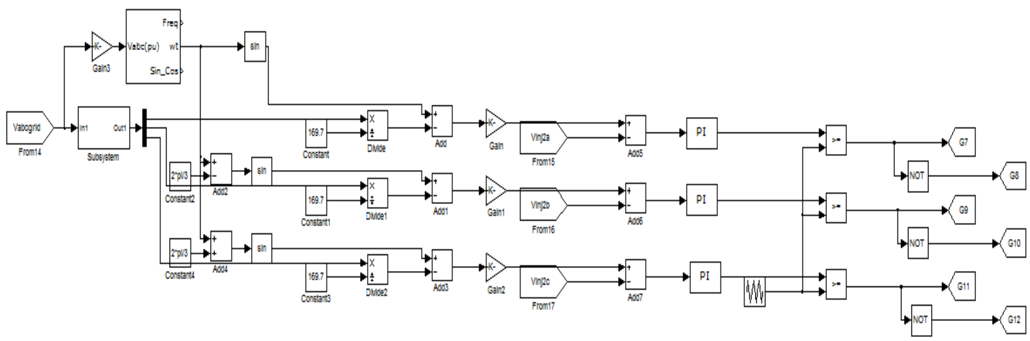


Fig 8:- Control Strategies of DVR with PI Controller.

Waveforms of input voltage, injecting voltage and output voltage is as shown below

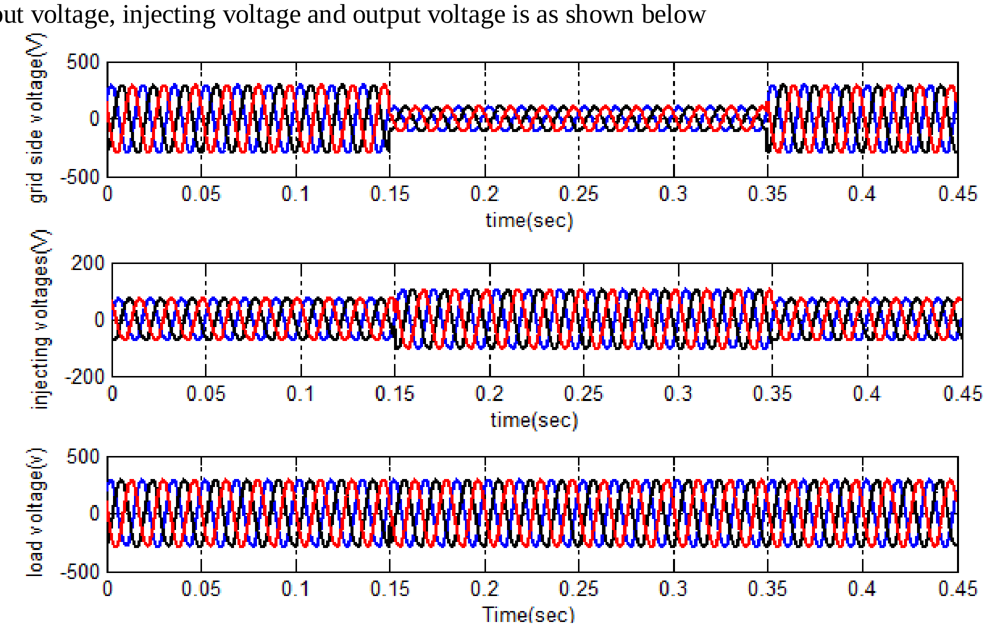


Fig 9:- Source Voltage,Injecting Voltage and Load Voltage During Sag.

Waveform of source and load voltage (V_{rms}) is as shown below

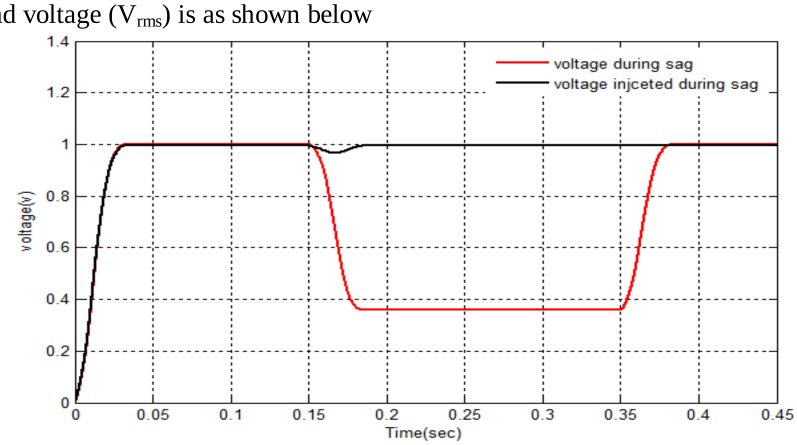


Fig 10:- Source and Load RMS Voltages.

Waveforms shown below is for the voltage across DC link and the UCAP

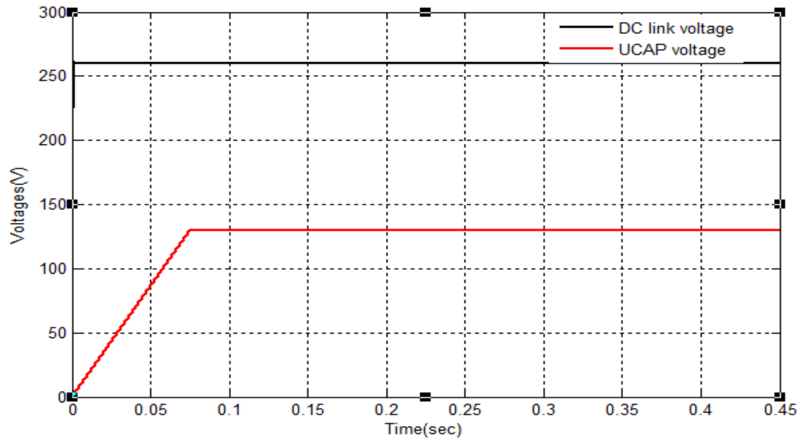


Fig 11:- Voltage across DC Link and UCAP.

Simulation model of DVR with non linear load is as shown in below. The input are 208V line to line voltage 50Hz connected to non linear load. SRF theory is used for the gate pulse generation in this mode

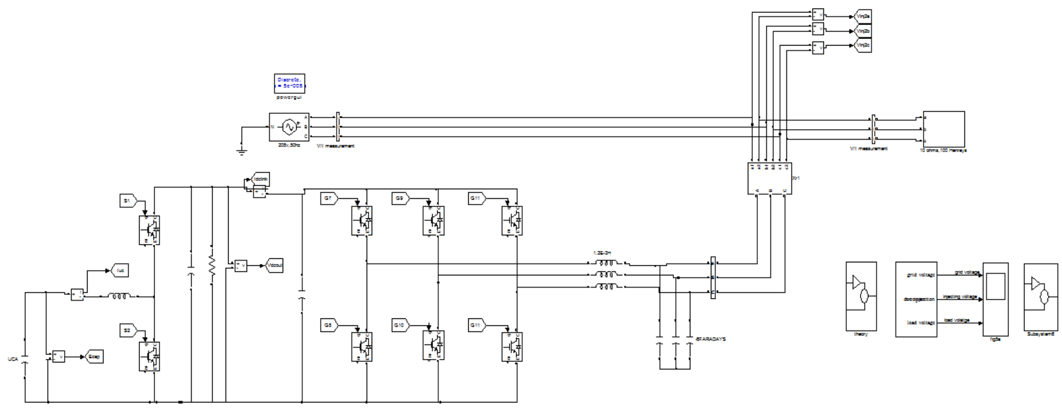


Fig 12:- MATLab/Simulink Model of DVR Connected to Non Linear Load.

Control strategy for the DVR is as shown below in this we are generating reference gate signal required by the DVR operation in this we are using pi controller

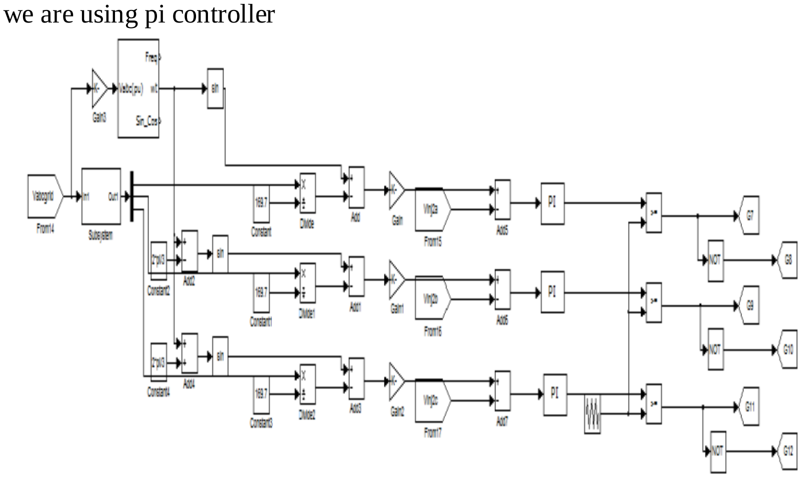
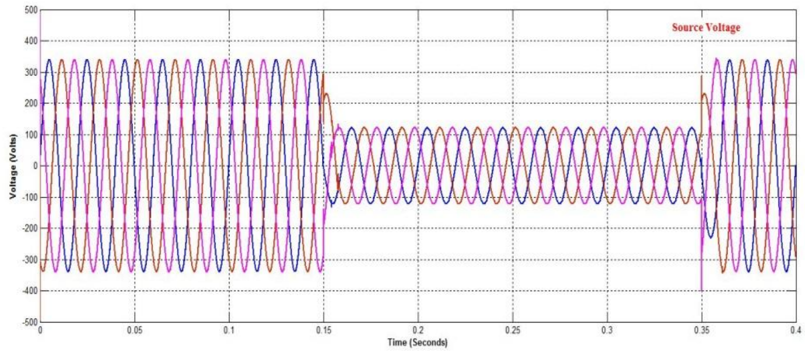
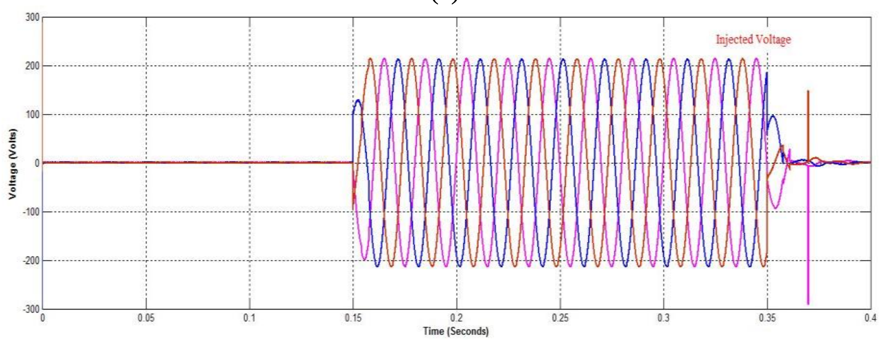


Fig 13:- Control Strategies of DVR with PI Controller.

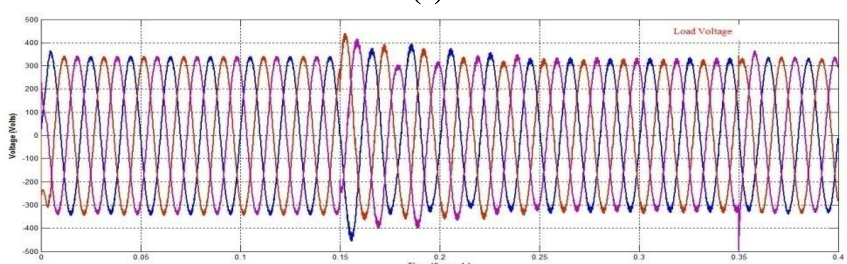
Simulation results for the DVR with non linear load in this we can see source side voltage,injecting voltage and load side voltage



(a)

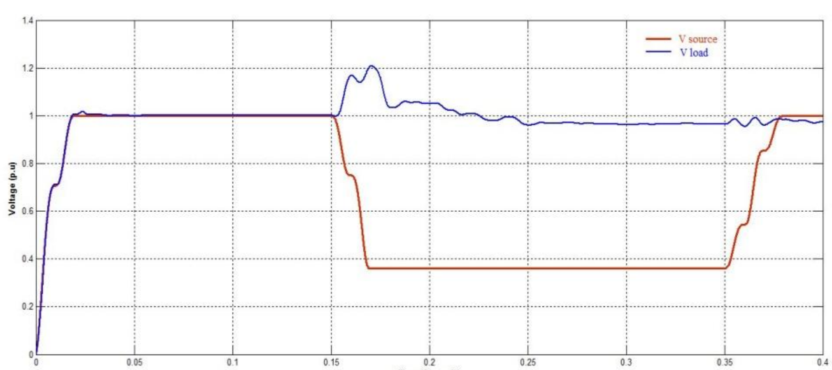


(b)

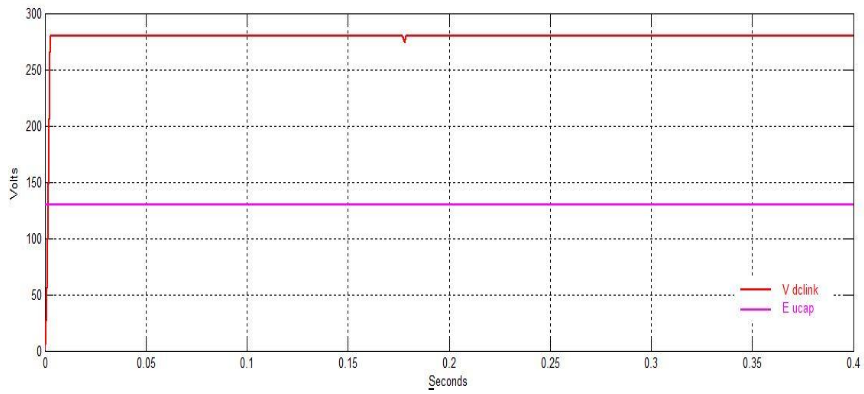


(c)

Fig 14:- (a) Source Voltages. (b) Injected Voltages (c) Load Voltages.



(a)



(b)

Fig 15:- (a)Source And Load(Vrms) Voltages (b) Voltages Of UCAP And DC Link.

MATLab/Simulink Model Connected To Non Linear Load With Fuzzy Logic

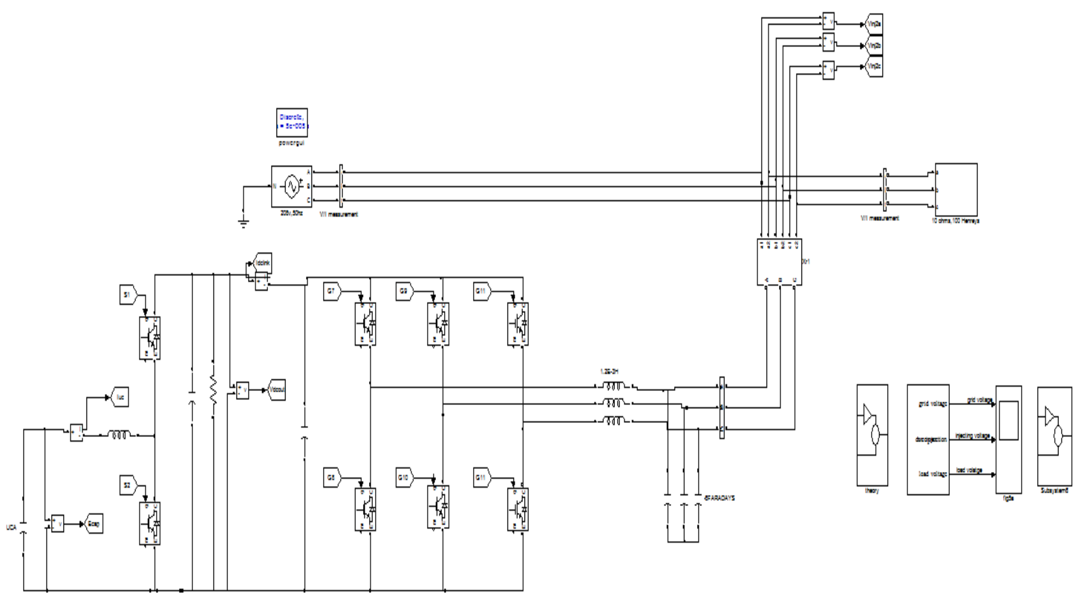


Fig 16:- MATLab/Simulink Model Of DVR Connected To Non Linear Load With Fuzzy Logic.

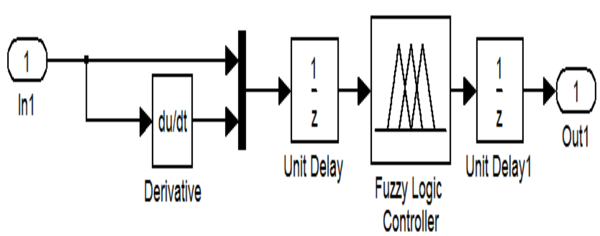
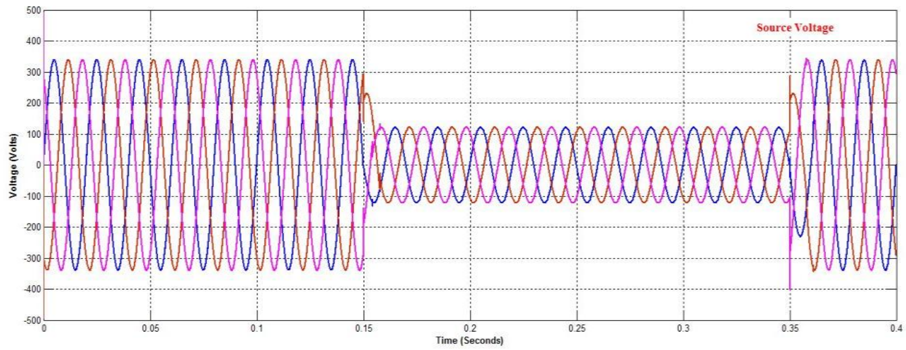
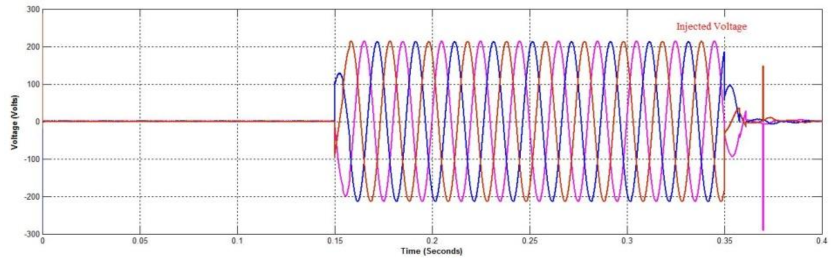


Fig 17:- Control Strategies of DVR with Fuzzy Controller.



(a)



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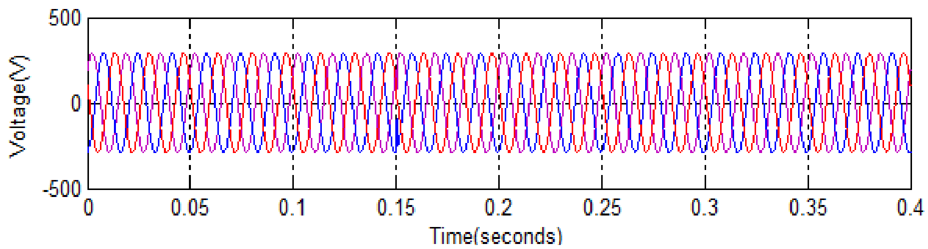
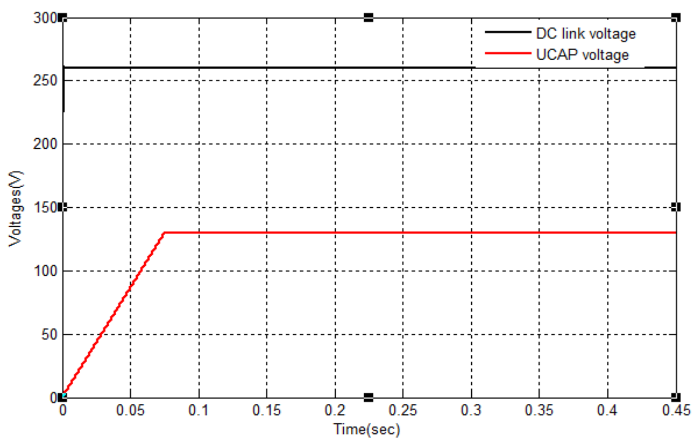
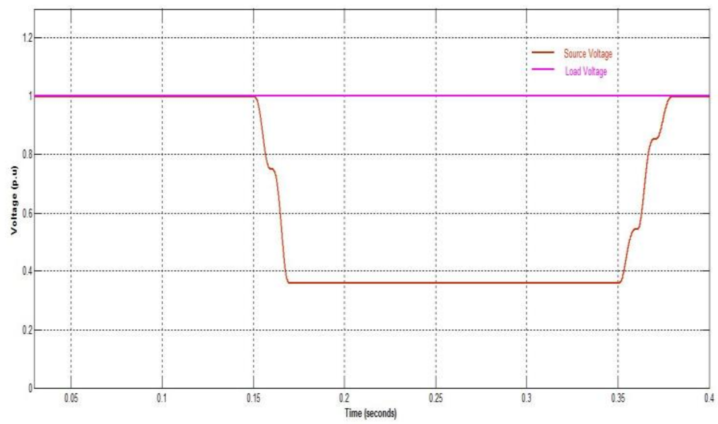


(c)

Fig 18:- Source, DVR And Load Voltage Waveforms With Fuzzy Logic Controller



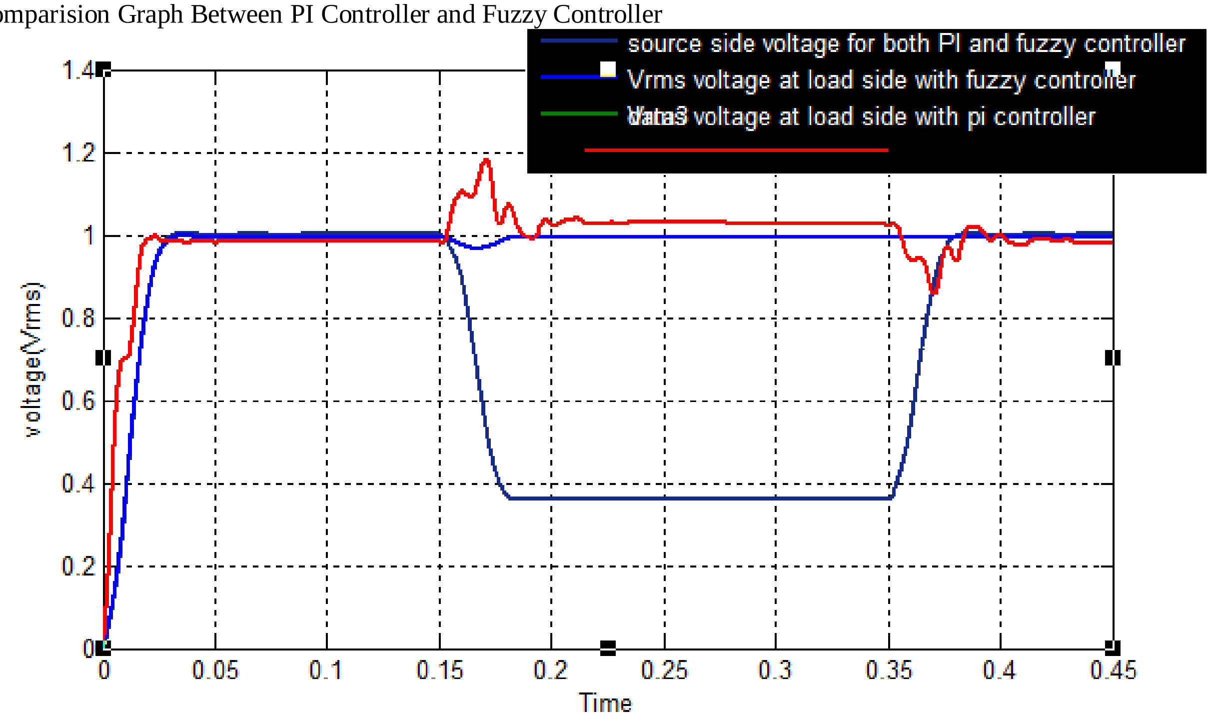
(a)



(b)

Fig. 19:- (a) Voltage Across Dc Link And UCAP (b) Source And Load(Vrms) Voltage.

Comparision Graph Between PI Controller and Fuzzy Controller



Conclusion:-

In this paper we are concentrating to improve performance of DVR which is connected to UCAP is discussed. It consist of UCAP which is connected through Bi-Directional DC-DC converter and followed by the series filter. The series active filter is connected to non linear load for the power quality improvement. UCAP is connected through the bi directional DC-DC converter for the stiff maintenance of the dc link.

UCAP is connected through Bi–directional converter because we want output if we connect UCAP directly to DVR we will get continuous change in voltage so we want standard one as input to DVR so we are going for Bi-Directional dc –dc converter.

We are using SRF theory for the gate pulse generation in this we are using PI controller Calculation of Kp and Ki every time for the system is difficult so we using fuzzy logic.In fuzzy logic we Give certain boundary value so it will check all that values and it take the Kp and Ki value.

By using fuzzy logic time response is increased so the output get stabled very speedly. Effectiveness of the proposed topology has been validated through extensive simulation.

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