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Dynamic Voltage Restorer for Voltage Sag Compensation Using Fuzzy Pi Controller

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Abstract:
One of the major concerns in electricity industry today is power quality. It becomes especially important with the introduction of advanced and complicated devices, whose performance is very sensitive to the quality of power supply. The electronic devices are very sensitive to disturbances and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage sags, voltage flickers, harmonics and load unbalance etc. At present, a wide range of very flexible controllers, which capitalize on newly available power electronics components, are emerging for custom power applications. Among these, the distribution static compensator (D-STATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) which is based on the VSC principle are used for power quality improvement. The main aim of my project is to design DVR which is used to compensate voltage quality problems and fuzzy logic controller is used to control the inverter. A new fuzzy PID controller is developed to improve the magnitude of load voltage. The results are compared with conventional controller. The results will be analyzed using mat lab / Simulink software.

Index Terms: DVR, Active Power Filter (APF), Hysteresis Control, DC Capacitor.

INTRODUCTION:
A DVR is used to compensate the supply voltage disturbances such as sag and swell. The DVR is connected between the supply and sensitive loads, so that it can inject a voltage of required magnitude and frequency in the distribution feeder.

The DVR is operated such that the load voltage magnitude is regulated to a constant magnitude, while the average real power absorbed/ supplied by it is zero in the steady state. The capacitor supported DVR is widely addressed in the literature [11]. The instantaneous reactive power theory (IRPT) [6], sliding mode controller [9], instantaneous symmetrical components [2] etc., are discussed in the literature for the control of DVR. In this project a new control algorithm is proposed based on the current mode control and proportional-integral (PI) controllers for the control of DVR. 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 maintasks are:

1. 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.
2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

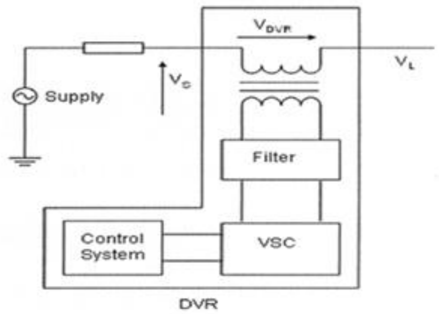

Figure 1.Block diagram of DVR

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DVR Control Strategy:

The proposed algorithm is based on the estimation of reference supply currents. It is similar to the algorithm for the control of a shunt compensator like DSTATCOM for the terminal voltage regulation of linear and nonlinear loads [6]. The proposed control algorithm for the control of DVR is depicted in Fig 5.1.

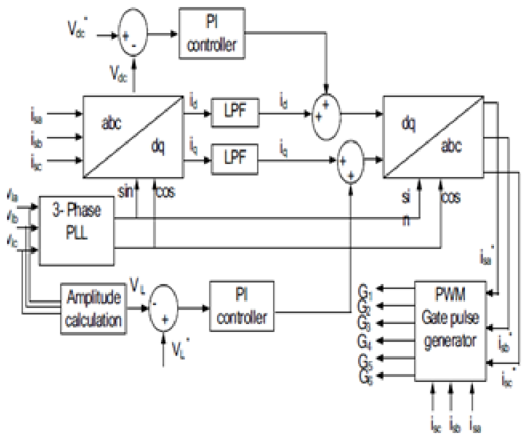

Figure 2. Control scheme of the DVR

The series compensator known as DVR is used to inject a voltage in series with the terminal voltage. The sag and swell in terminal voltages are compensated by controlling the DVR and the proposed algorithm inherently provides a self-supporting dc bus for the DVR. Three-phase reference supply currents (i^*_{sa}, i^*_{sb},i^*_{sc}) are derived using the sensed loadvoltages (v_{la}, v_{lb}, v_{lc}), terminal voltages (v_{ta}, v_{tb},v_{tc}) and dcbus voltage (v_{dc}) of the DVR as feedback signals.The synchronous reference frame theory based methodis used to obtain the direct axis (i_d) and quadrature axis (i_q)components of the load current. The load currents in thethree-phases are converted into the d-q-0 frame using the Park's transformation as,

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (5.1)$$

A three-phase PLL (phase locked loop) is used to synchronies these signals with the terminal voltages (v_{ta}, v_{tb},v_{tc}). The d-q components are then passed through lowpass filters to extract the dc components of $i_d$andi$_q$. Theerror between the reference dc capacitor voltage and thesensed dc bus voltage of DVR is given to a PI (proportional-integral) controller of which output is considered as the loss component of current and is added to the dc component of id. Similarly, a second PI controller is used to regulate the amplitude of the load voltage (V_t). The amplitude of the load terminal voltage isemployed over the reference amplitude and the output ofPI controller added with the dc component of i_q. Theresultant currents are again converted into the referencesupply currents using the reverse Park's transformation.Reference supply currents (i^*_{sa}, i^*_{sb},i^*_{sc}) and the sensed supply currents (i_{sa}, i_{sb},i_{sc}) are used in PWM current Controller to generate gating pulses for the switches. The PWM controller operates at a frequency of 10 kHz and the gating signals are given to the three-leg VSC for the control of supply currents.

PWM CONTROL OF ACTIVE POWER FILTER:

The main aim of an active power filter (APF) is to generate compensating currents into the power system for canceling the current harmonics contained in the nonlinear load current. This will thus result in sinusoidal line currents and unity power factor in the input power system.

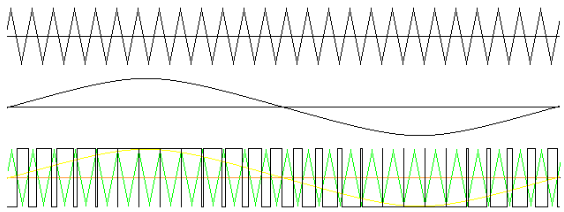

Figure 3. PWM technique

PI Controller shown in Fig. 4 is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value [8]. The proportional response can be adjusted by multiplying the error by constantK_p, called proportional gain.

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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].

1) Proportional-Integral (PI) Controller

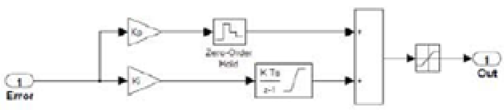

Figure 4. Discrete PI controller

INTRODUCTION TO FUZZY LOGIC:

The logic of an approximate reasoning continues to grow in importance, as it provides an in expensive solution for controlling know complex systems. Fuzzy logic controllers are already used in appliances washing machine, refrigerator, vacuum cleaner etc. Computer subsystems (disk drive controller, power management) consumer electronics (video, camera, battery charger) C.D. Player etc. and so on in last decade, fuzzy controllers have convert adequate attention in motion control systems. As the later possess non-linear characteristics and a precise model is most often unknown. Remote controllers are increasingly being used to control a system from a distant place due to inaccessibility of the system or for comfort reasons. In this work a fuzzy remote controllers is developed for speed control of a converter fed dc motor. The performance of the fuzzy controller is compared with conventional P-I controller.

Unique features of fuzzy logic:

The unique features of fuzzy logic that made it a particularly good choice for many control problems are as follows, It is inherently robust since it does not require precise, noise – free inputs and can be programmed to fail safely is a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations. Since the fuzzy logic controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.

Fuzzification and Normalization:

Fuzzification is related to the vagueness and imprecision in a natural language. It is a subjective valuation, which transforms a measurement into a valuation of an objective input space to fuzzy sets in certain input universes of discourse. In fuzzy control applications, the observed data are usually crisp. Since the data manipulation in a fuzzy logic controller is based on fuzzy set theory, fuzzification is necessary in an earlier stage. The fuzzification module (FM) performs the following functions:

Membership functions:

Generally in fuzzy system used ‘4’ different shapes of MF’s., those are Triangular, Gaussian, Trapezoidal, sigmoid, etc.

Triangular Membership Function:

The simplest and most commonly used membership functions are triangular membership functions, which are Symmetrical and asymmetrical in shape Trapezoidal membership functions are also symmetrical or asymmetrical has the shape of truncated triangle.

Gaussian Membership Function:

Two membership functions Triangular and Trapezoidal are built on the Gaussian curve and two sided composite of two different Gaussian curves.

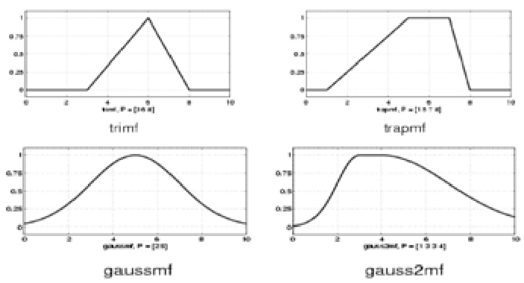

Figure 5. Membership functions

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Inference Engine:

There are two basic types of approaches employed in the design of the inference engine of fuzzy logic controller:

Composition based inference (firing):

In this case, the fuzzy relations representing the meaning of each individual rule are aggregated into one fuzzy relation describing the meaning of the overall set of rules. Then interference of firing with this fuzzy relation is performed via the operation composition between the fuzzified crisp input and the fuzzy relation representing the meaning of the overall set of rules. As result of the composition one obtains the fuzzy set describing the fuzzy value of the overall control output.

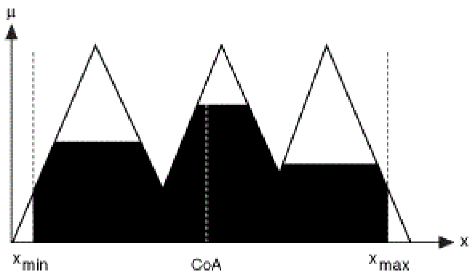

Figure 6.Center of – area, method of defuzzification

Figure 6 shows the above operation in a graphical way, it can be seen that this defuzzification method takes into account the area of U as whole. Thus if the area of two clipped fuzzy sets constituting 'U' overlap, then the over lapping are is not reflected in the above formula. This operation is computationally rather complex and therefore results in quite slow inference cycles. Denormalization is the process to convert per unit quantities into actual quantities.

SIMULATION RESULTS

Base System

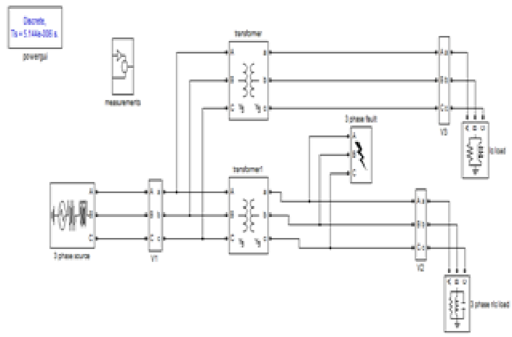

Figure 7.Base System

This is the block diagram showing source, load and transmission line in faulty conditions. The fault can be of any nature like L-G, L-L-G, L-L or 3-PHASE FAULT. In these conditions severe fault currents flow through the lines and there is a drastic drop in line and load voltages.

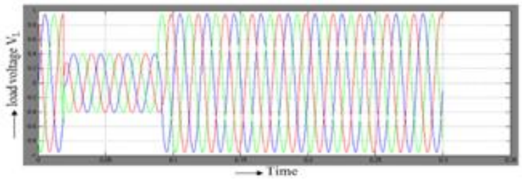

Figure 8. Load Voltage

The drop in the load voltage can be seen in above wave form due to fault in transmission line.

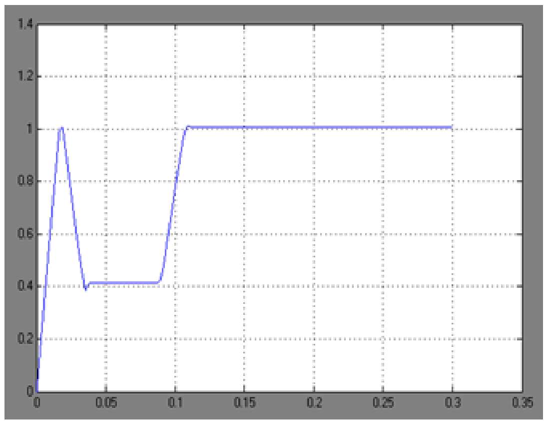

Figure 9. Voltage Sag

The sag in the voltage waveform which can be clearly observed in the above figure which is deviating from the actual voltage curve.

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Base System with PI Controller

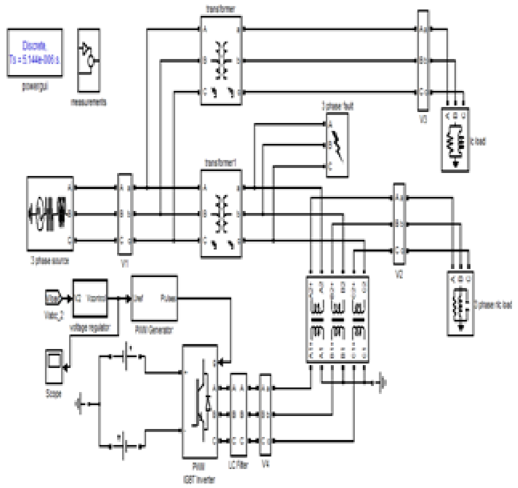
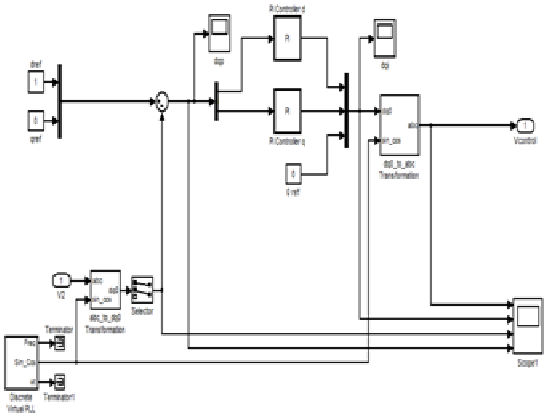


Figure 10. Base System with PI Controller

This is the block diagram showing source, load and transmission line in faulty conditions. The type and intensity of fault can be identified and corrected with the DVR and its control mechanism. And bring back the voltage levels to the normal operating value before the occurrence of fault.



The controller used in the above simulation circuitry is **pi controller**. Since pi being a conventional controller there is a difficulty in tuning the controller, hence fuzzy controller is employed.

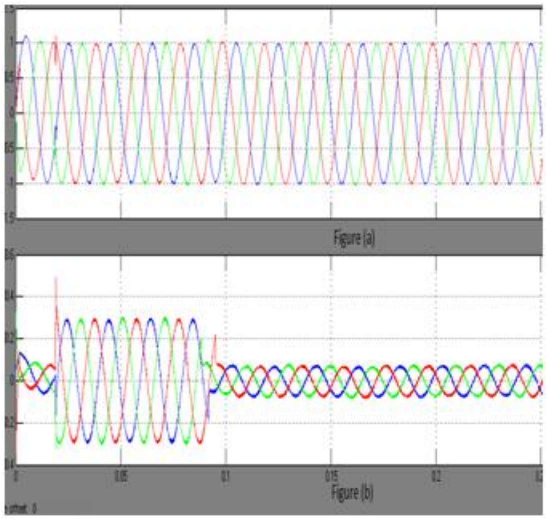


Figure 11. Injected voltage by the DVR

In the above figure the first waveform implies the compensated load voltage at the consumer side. The second waveform implies the injected voltage by the DVR into the lines to compensate the voltage drop.

Base System with Fuzzy Controller

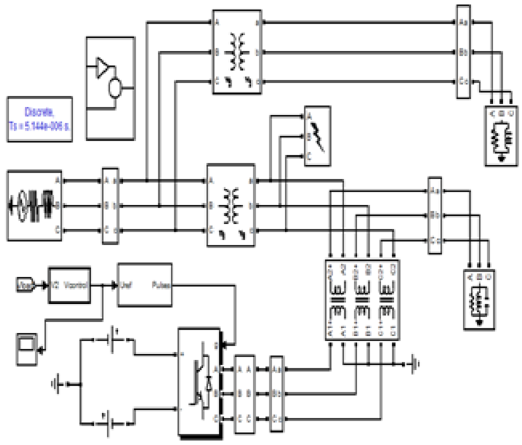


Figure 12. Base System with Fuzzy Controller

This is the block diagram showing source, load and transmission line in faulty conditions. The type and intensity of fault can be identified and corrected with the DVR and its control mechanism. And bring back the voltage levels to the normal operating value before the occurrence of fault.

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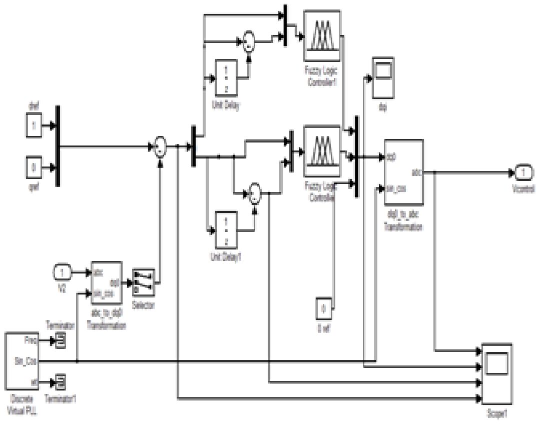
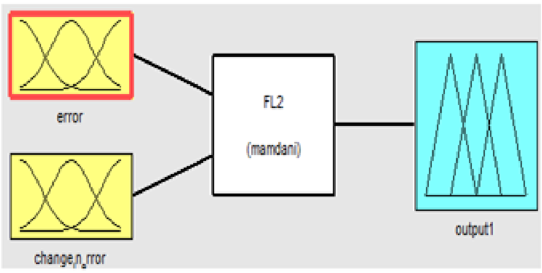


Figure 13.Subsystem of Fuzzy Controller

The controller used in the above simulation circuitry is fuzzy controller .Since fuzzy being an advanced controller there is no need of tuning the controller, hence fuzzy controller is preferred to conventional controllers.

Design and Simulation of Fuzzy Controller



FIS editor

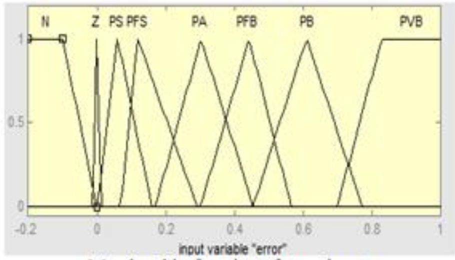
Figure 14.FIS Editor

FIS editor is used for giving the number of input and output variables for the fuzzy controller.

FAM table

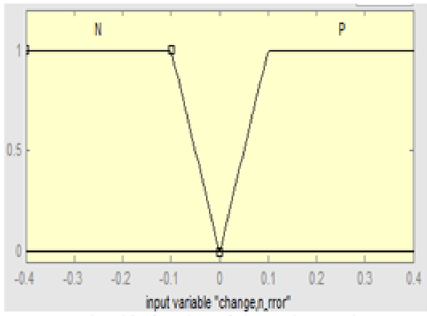
E / DE	N	Z	PS	PFS	PA	PFB	PB	PVB
N	N	Z	PS1	PFS1	PA1	PFB1	PB1	PVB
P	N	Z	PS2	PFS2	PA2	PFB2	PB2	PVB

The input and output variables are plotted in the form of membership functions with the help of FAM table only. FAM table is a collection of statistical data regarding the system used in simulation.



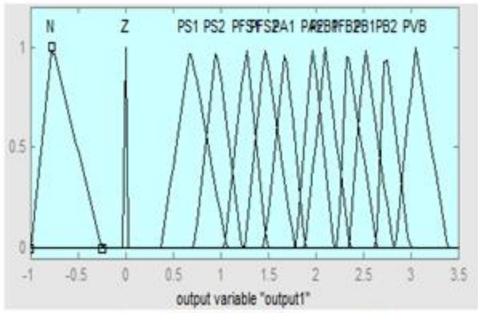
Membership function of error input

Figure 15. MF of error



Membership function of change in error input

Figure 16. MF of change in error



Membership function of output variable

Figure17. MF of output

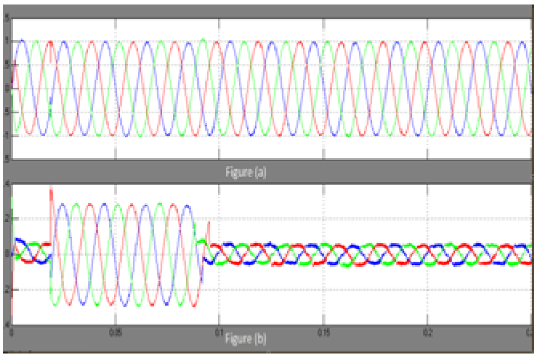


Figure 18. Injected voltage by the DVR fuzzy

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In the above figure the first waveform implies the compensated load voltage at the consumer side.The second waveform implies the injected voltage by the DVR into the lines to compensate the voltage drop.

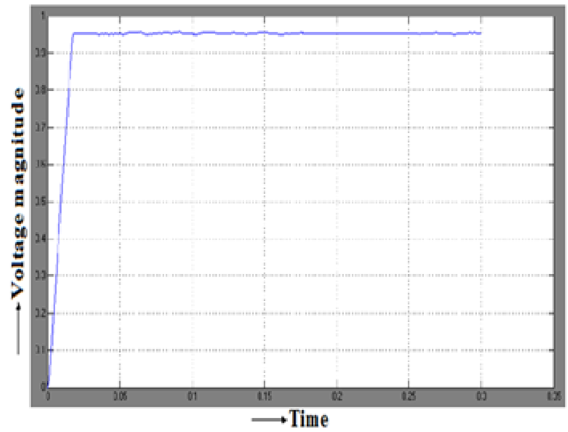
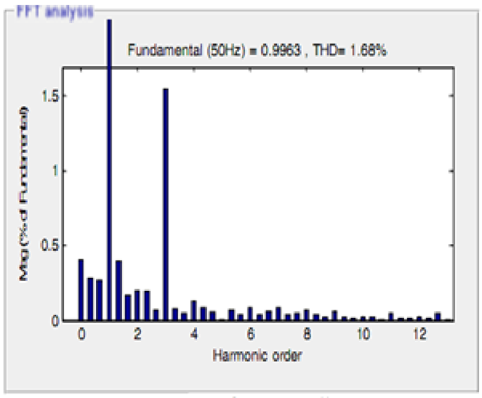


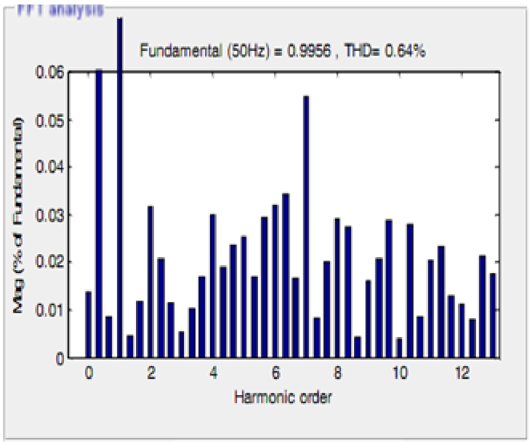
Figure 19. Voltage sag with fuzzy

With the usage of fuzzy controller in the control circuitry of DVR we are able to eliminate the voltage drop in the lines and consumer side providing a constant voltage at the load end. This can be concluded by observing the above voltage graphs.



THD for PI controller

Figure 20. THD with PI



THD for Fuzzy controller

Figure 21.THD with Fuzzy

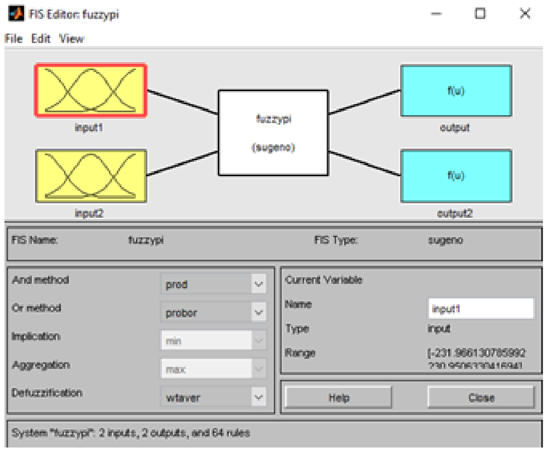


Figure 22. Fuzzy PI controller

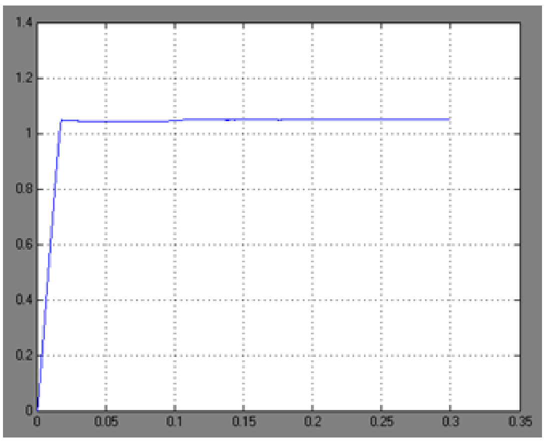


Figure 22. Load voltage magnitude after compensation using fuzzy PI controller

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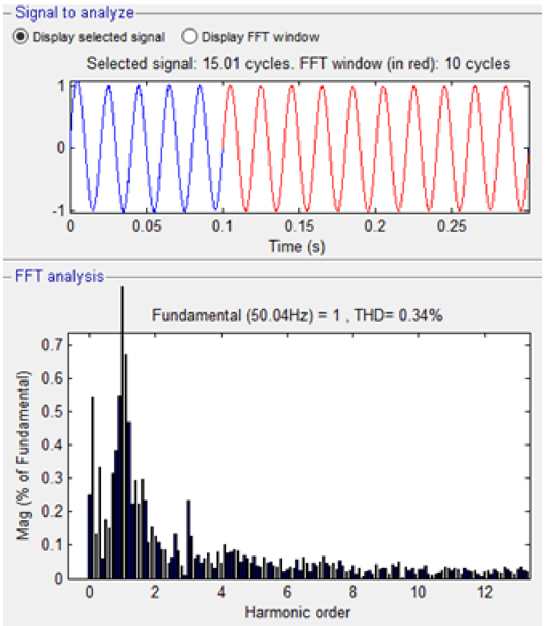

Figure 23: THD using Fuzzy PI controller

CONCLUSION:

In this study, the modeling and simulation of DVR controlled by PI and FL Controller has been developed using Mat lab/Simulink. For both controller, the simulation result shows that the DVR compensates the sag quickly (70µs) and provides excellent voltage regulation. DVR handles all types, balanced and unbalanced fault without any difficulties and injects the appropriate voltage component to correct any fault situation occurred in the supply voltage to keep the load voltage balanced and constant at the nominal value. Both controllers show an excellent performance and generate low THD (<5%). However, it can be seen that FL Controller gives better performance with THD generated with only 0.64%whilst PI generated 1.68% THD. Combined fuzzy PI controller is developed to improve the per unit magnitude to above 1pu.

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