Hybrid Active Filter with Variable Conductance for Harmonic Resonance Suppression in Industrial Power Systems

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Abstract- Unintentional series and/or parallel resonances, due to the tuned passive filter and the line inductance, may result in severe harmonic distortion in the industrial power system. This paper presents a hybrid active filter to suppress harmonic resonance and to reduce harmonic distortion. The proposed hybrid filter is operated as variable harmonic conductance according to the voltage total harmonic distortion; therefore, harmonic distortion can be reduced to an acceptable level in response to load change or parameter variation of the power system. Since the hybrid filter is composed of a seventh-tuned passive filter and an active filter in series connection, both dc voltage and kVA rating of the active filter are dramatically decreased compared with the pure shunt active filter. In real application, this feature is very attractive since the active power filter with fully power electronics is very expensive. A reasonable tradeoff between filtering performances and cost is to use the hybrid active filter. Design consideration are presented, and experimental results are provided to validate effectiveness of the proposed method. Furthermore, this paper discusses filtering performances on line impedance, line resistance, voltage unbalance, and capacitive filters.

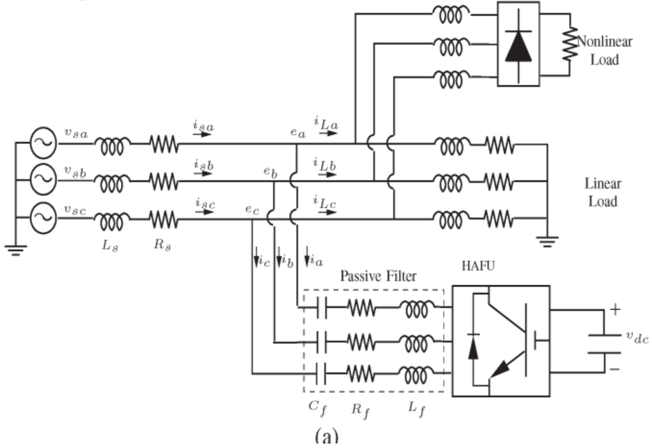
Keywords- Harmonic resonance, hybrid active filter, industrial power system

I. INTRODUCTION

In this paper, we further present designing consideration of the hybrid filter. A prototype circuit of the hybrid filter based on 220-V/10-kVA system has been established to verify theoretic analysis, including steady-state behavior, transient response, and stability analysis. The filtering performance of the hybrid filter is discussed considering *X/R* ratio and magnified variations of line impedance. We also focus on filtering deterioration due to line resistance, voltage unbalance, and capacitive filters in the power system. In many cases, an active power filter is designed to compensate harmonic current produced by a specific nonlinear load, in such a way that it needs to measure the load current to be compensated

This paper proposes a hybrid active filter to suppress the harmonic resonance in industrial facilities as well as mitigate harmonic current flowing into the utility. The proposed hybrid active filter is composed of an active filter and a power factor correction capacitor in series connection. The active filter operates as variable damping conductance at harmonic frequencies. The harmonic conductance is determined according to the voltage total harmonic distortion (THD) at the installation location of the hybrid active filter. Based on this control, the damping performance of the active filter can be dynamically adjusted to maintain harmonic voltage distortion at an allowable level in response to load change and power system variation, where the allowable voltage THD can be regulated according to the harmonic voltage limit.

Many types of control schemes and controllers are available. The control algorithms are stationary reference frame theory, indirect current control method, Hysteresis current control, Band-reject filter method, and Synchronous-detection algorithm. Along with these, different soft computing techniques are used such as Artificial Neural Network (ANN), Genetic Algorithm (GA). Here linear current control scheme with PI and fuzzy logic controllers are discussed. This paper presents an alternate and effective method for controlling shunt active power filter. A fuzzy logic control based (FLCB) shunt active filter (SAF) capable of reducing harmonic distortion in power system proposed. The proposed method has advantage that the control block becomes simpler. The dc link fuzzy control has better dynamic behavior than conventional PI controller. The factors should be analyzed are total harmonic distortion (THD) and power factor(PF) improvement. The shunt active filter control seems to be an attractive solution for harmonic current pollution problem. Here, harmonics reduction in the source current and power factor improvement are considered.



(a)

II. SHUNT ACTIVE POWER FILTER WITH NON-LINEAR LOAD

Shunt active filter is used in the load side of the system. Because non-linear loads is to generate harmonics in the current waveform.

A. Basic concept of active power filter

Fig.1shows the configuration of active power filters with non-linear load. The basic operating principle of active power filter is that a non sinusoidal waveform at a bus can be corrected to sinusoidal by injecting current of proper magnitude and waveform.

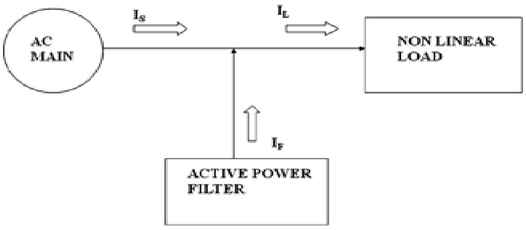


Fig.1: Basic concept shunt active filter

The basic concept of APF is explained in fig

$$I_L = I_S + I_F \qquad (1)$$

The load current having fundamental and harmonic content, and I_F is the harmonic compensating current.

$$I_L + I_H = I_S + I_H \qquad (2)$$

Filter provide harmonic requirement of the load

$$I_L + I_H = I_S + I_H \qquad (3)$$

$$I_L = I_S \qquad (4)$$

Thus the supply current represents the fundamental waveform input output harmonics. Fig.2. shows the configuration of active shunt filter with non-linear load and the full bridge converter. This is almost widely used to eliminate current harmonics, reactive power compensation and balancing the unbalanced currents.

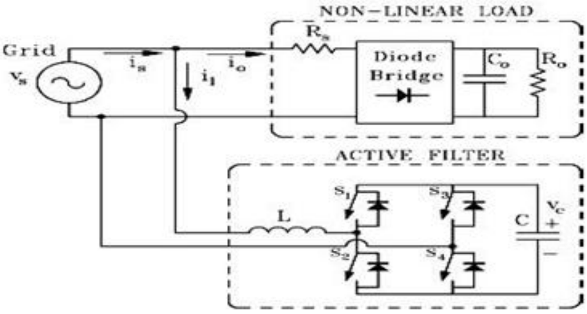


Fig.2: Shunt APF with non-linear load and the full-bridge converter

B. Non-linear loads

Non-linear loads are considered as the second category of loads. The application of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for non-linear devices. In this system the nonlinear load consists of a diode bridge, a series resistance (R_s), a load resistance (R_o) and a load capacitance (C_o), Induction motor load, and DC motor load.

III. CONTROL LOOPS

This section reviews the, indirect current control method, based on the outer voltage loop and inner current loop.

A. Design of the outer voltage loop

For an indirect current control method, outer voltage loop is mainly used for capacitor voltage regulation. The capacitor is mainly used at the load side. For the design of outer voltage loop cut off frequency and phase margin is essential. Its value should be 2.5Hz and 56^0 based on the small signal model analysis.

B. Inner current loop

For this linear current control scheme inne current loop is used for reference current tracking. Based on that reference is subtracted from the actual current, error current is produced. And then error current is compensated by PI controller.

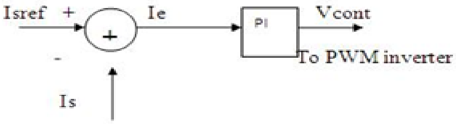


Fig.3: Inner current loop

The control signal Vcont is the input of a pulse width-modulation. It will drives the power switches.

C. Reference generator

A reference generator is used to produce reference current signal by using the controller H_1(s) and H_2(s). Source current and reference current are subtracted. This operation is based on the closed loop Loop operation of notch filters.

$$H_1(s) = \frac{2\xi\omega_1\kappa_1 s}{s^2 + 2\xi\omega_1 s + \omega^2_1}$$

$$H_2(s) = \sum_{n=3}^{h} \frac{2\xi n\omega_1\kappa_n s}{s^2 + 2\xi n\omega_1 s + (n\omega_1)^2}$$

The generalized integrators can be expressed as The filter current is used in the inner current loop in order to track the load current harmonics. As an alternative the indirect method generates a sinusoidal reference signal by means of grid-voltage sensing.

IV. SAPF WITH PI CONTROLLER

The main drawback of using repetitive current control is, there is no control action, to avoid the distortion from the grid voltage. In-order to overcome this drawback, it needs some additional algorithm.

A. Conventional method

The PI controller operation with shunt active filter is shown in figure.6.source voltage and source current values are given to the reference generator. It will produce I_{ref} and given to PI controller. Using PI controller error should be compensated.

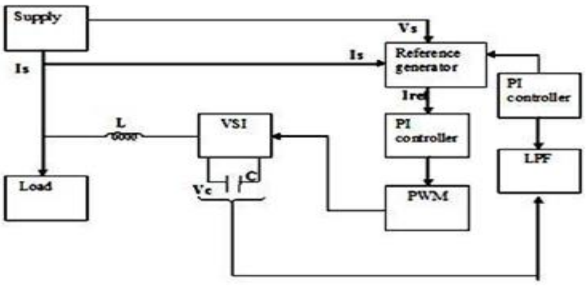


Fig.4: Structure of PI controller

A low-pass filter is used to attenuate the frequencies higher than the cutoff frequency. It is sometimes called a high-cut filter, or treble cut filter when used in audio applications. A filter with low pass crossover frequency 10Hz is used. Based on the PWM signal the switches will be operated. And the signal is given to the Inverter Bridge.

V. SAPF WITH FUZZY LOGIC CONTROLLER

The Fuzzy Logic tool is a mathematical tool for dealing with uncertainty. It is important to observe that there is an intimate connection between Fuzziness and Complexity.

A. Fuzzy Logic Controller

Fuzzy logic controller (FLC) are suitable for systems that are structurally difficult to model due to naturally existing non linear ties and other model complexities. This is because ,unlike a conventional controller such as PI controller, rigorous mathematical model is not required to design a good fuzzy controller. The database, consisting of membership functions. Basically membership value should lies between 0 to 1. The operations performed are fuzzification, interference mechanism and defuzzification. The interference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally defuzzification is used to convert the fuzzy outputs into required crisp signals.

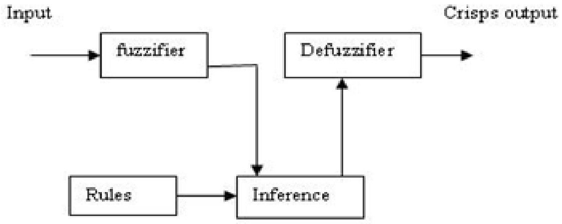


Fig.5: Fuzzy controller block diagram

B. Fuzzification

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy (crisp to fuzzy).By identifying some of the uncertainties present in the crisp values, we form the fuzzy values. The conversion of fuzzy values is represented by the membership functions.

C. Defuzzification

Defuzzification means the fuzzy to crisp conversions .The fuzzy results generated cannot be used as such to the applications; hence it is necessary to convert the fuzzy quantities into crisp quantities for further processing.

D. FLC Design Methodology

Design of fuzzy logic controller comprises the following steps.

1. Identifying the input signals to FLC.
2. Determining the number of membership function, and
3. Decide upon the type of membership function.

E. Membership function

The number of membership function determines the quality. The number of membership function determines the quality of control which can be achieved using fuzzy logic controller(FLC). As the number of membership function increase, the quality of control improves at the cost of increased computational time and computer memory. Investigations are carried out considering seven membership function for each input and output signal.

e de	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

Table 1: Fuzzy rule Base

F. Fuzzy control scheme for APF

In the fuzzy logic control algorithm for APF two inputs are required. The inputs are error and chancge in error. The two inputs were related by member functions. Basically forty nine rules are there. Based on the operation it will be used. The membership functions are expressed in negative large (NL), negative middle (NM), negative small(NS), zero(ZE), positive small(PS), positive middle(PM) and positive large(PL). Actual voltage is compared with the reference voltage, based on that error will be produced. It can be compensated by using fuzzy logic controller. Actual current is compared with the reference current, and error is compensated by fuzzy controller. Fuzzy sets support a flexible sense of membership functions.

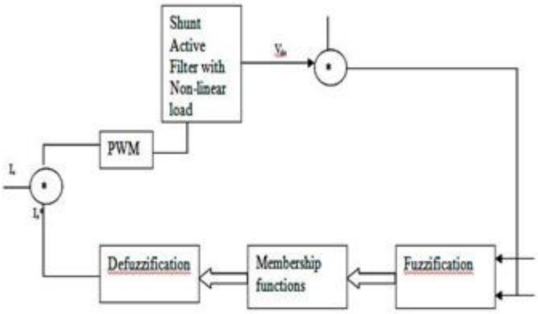
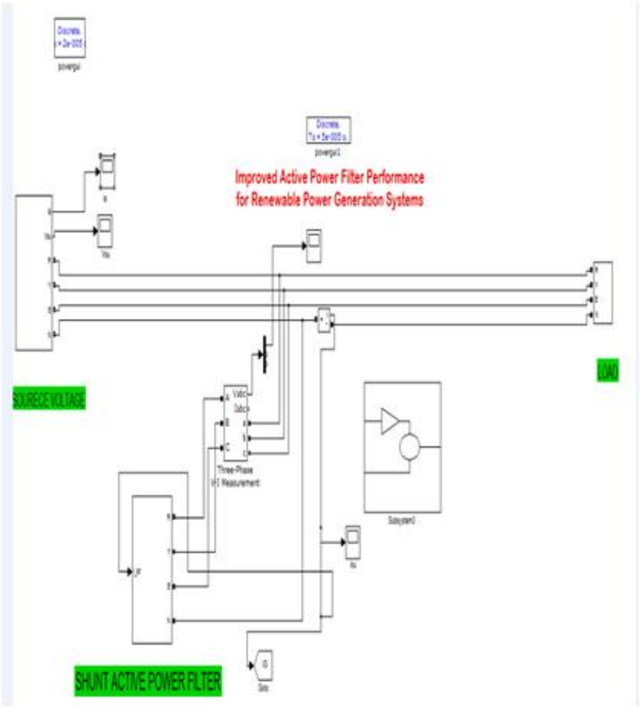


Fig.6: Structure of the fuzzy for APF controller

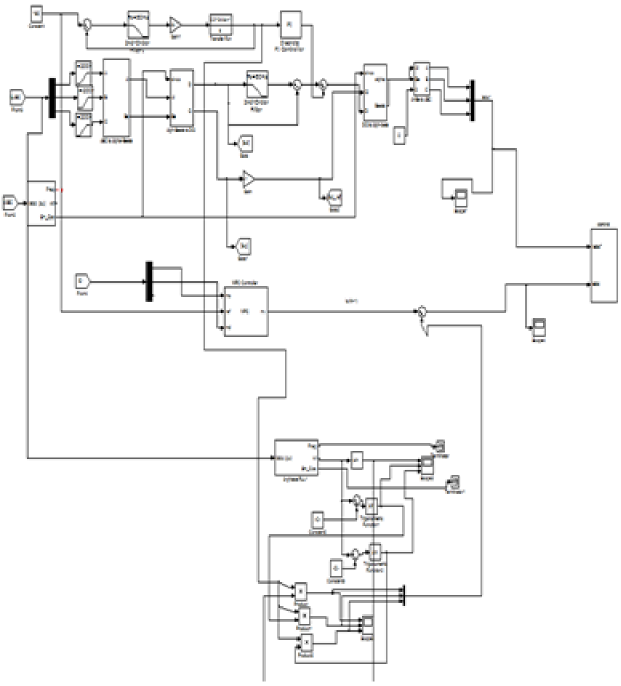
A triangular membership function has the advantage of simplicity and easy implementation and is adopted in the application. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The centroid method of defuzzification is generally used, but disadvantage of this method is, it is computationally difficult for complex membership functions. Here bisector method of defuzzification is used. The advantages of bisector method are, it is fast and generally produces good results.

VI. SIMULATION RESULTS

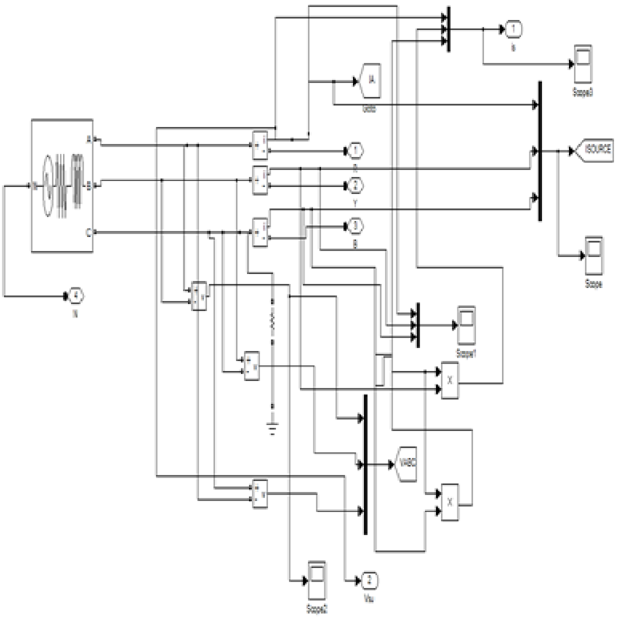
The simulation is carried out with three phase four wire system with non-linear load. Here the diode rectifier is used as non-linear load. The comparisons are done for PI controller and FUZZY controller. The THD value is high because of pi controller in this circuit.



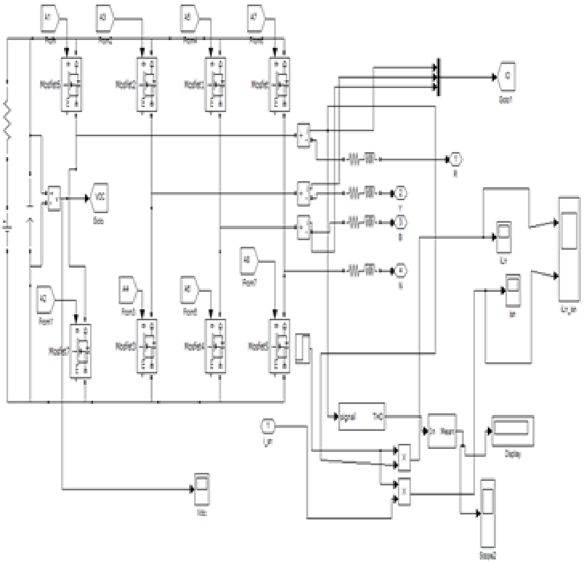
Subsystem



Source Voltage



Shunt Active power filter



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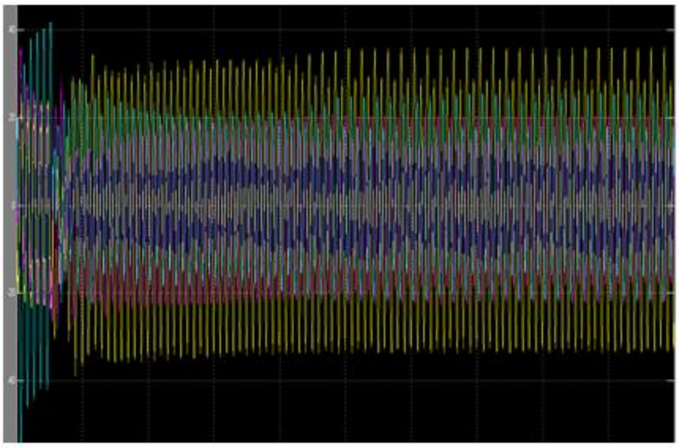
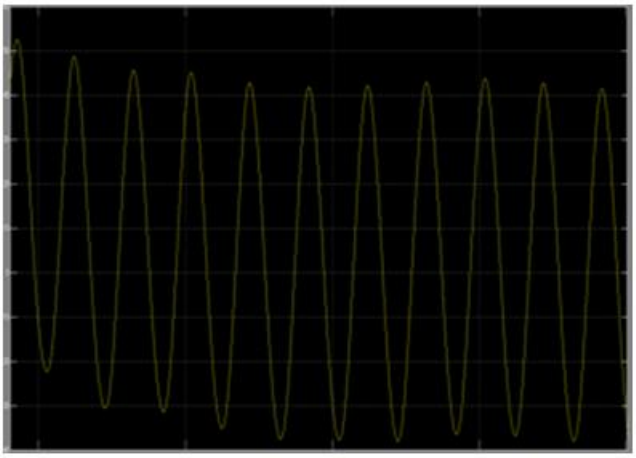
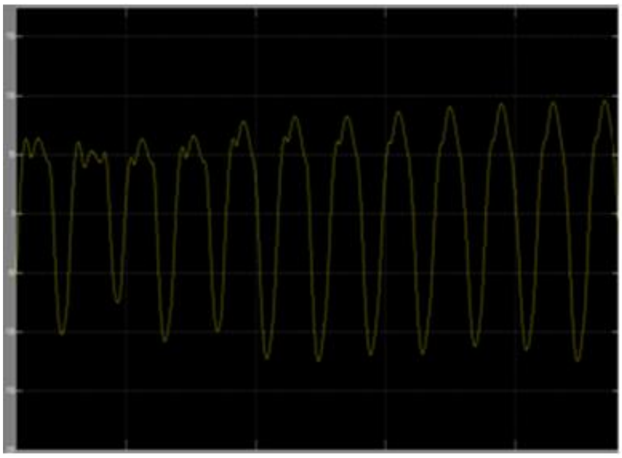


Vsu :



Vabc :



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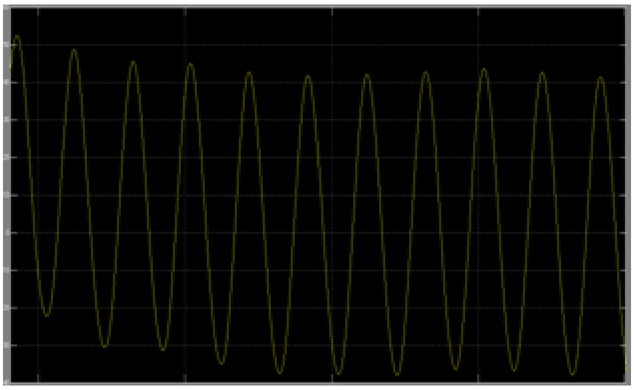
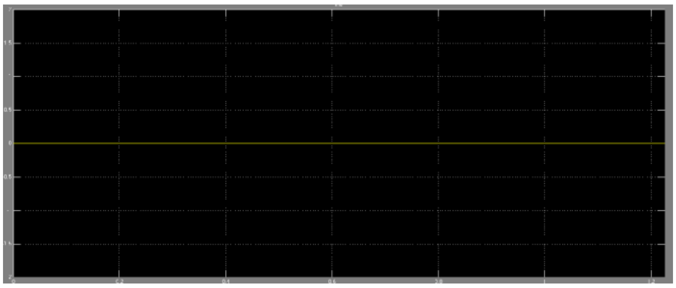
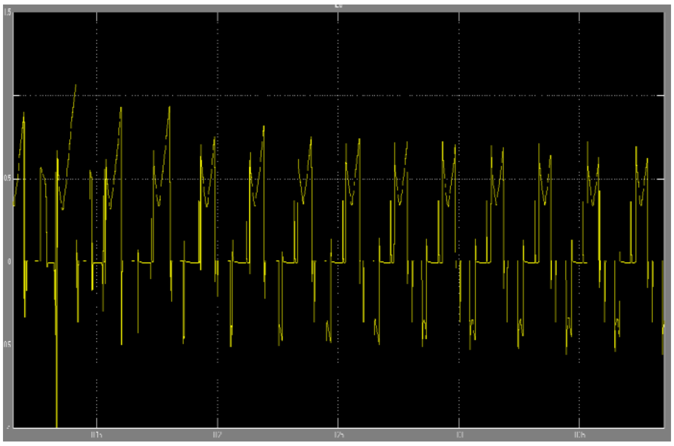


DC current :

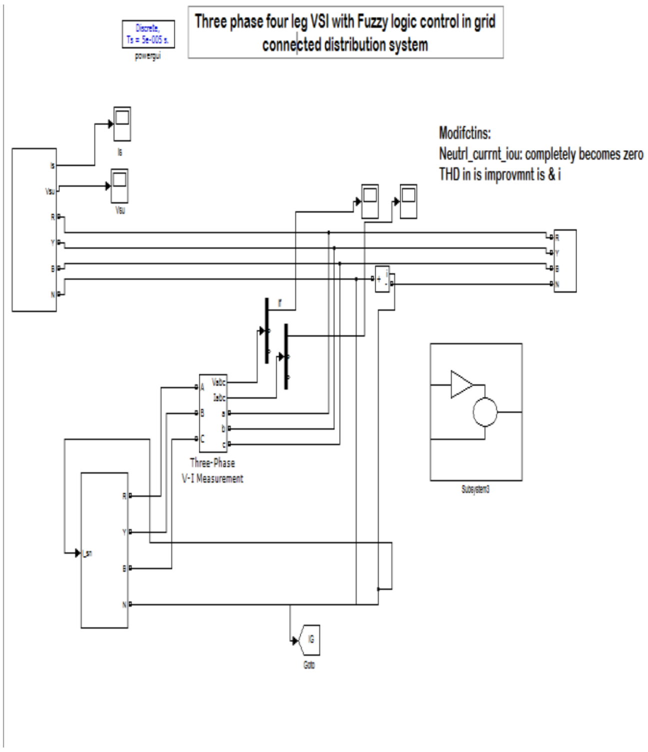
Iou :



ilu :

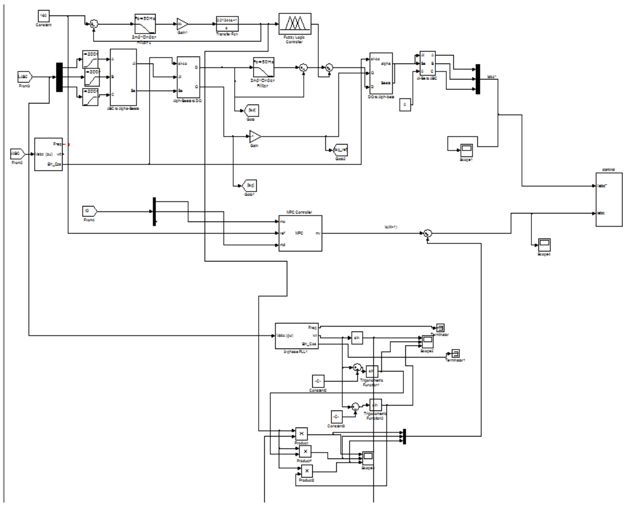


EXTENSION



Modifications:
Neutrl_ current_iou: completely becomes zero
THD in is improvement is & is

With Fuzzy controller



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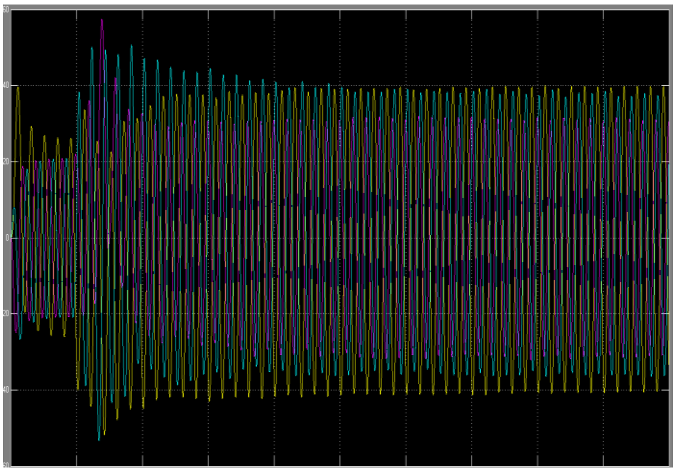
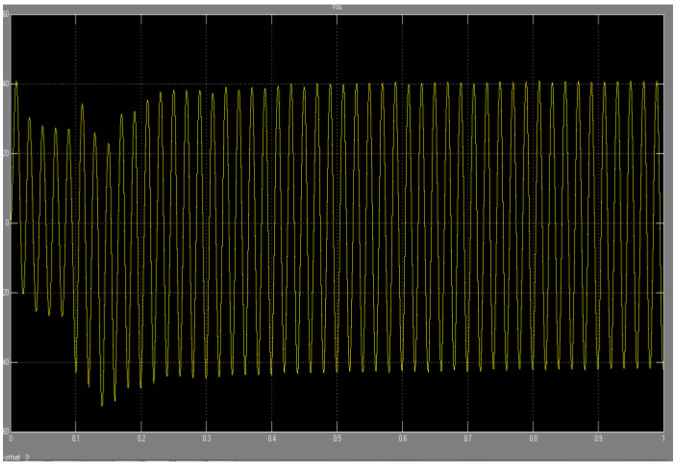
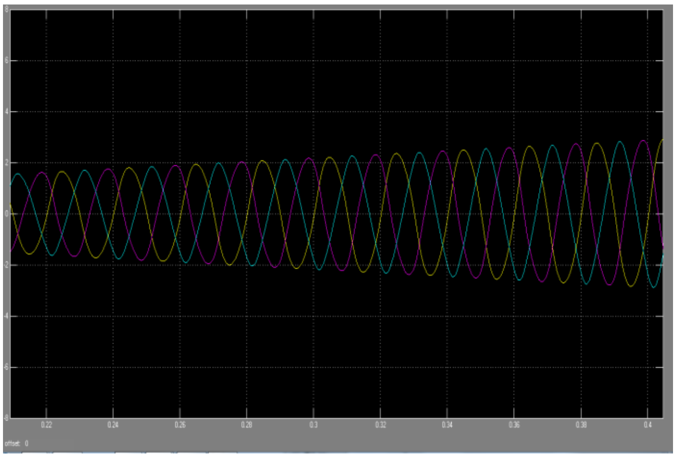


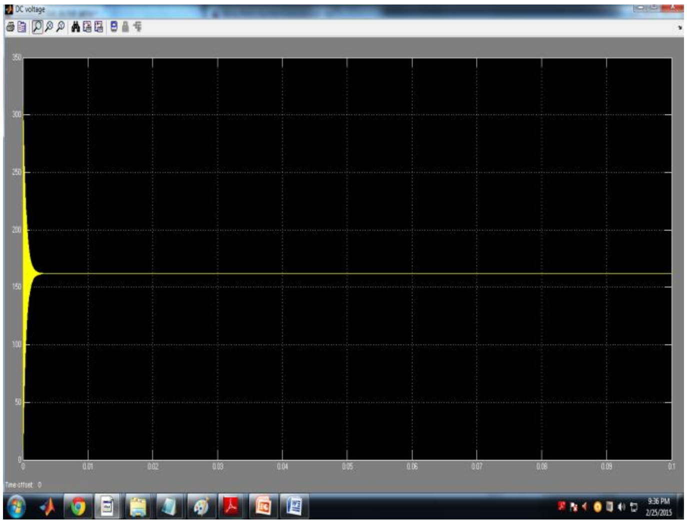
Vsu



Output voltage



DC current :



VII. CONCLUSION

In the present paper two controllers are developed and verified for three phase four wire systems. Even though both of the Presented controllers are capable of compensating line current harmonics in 3 phase 4-wire systems, it can be seen that the Fuzzy logic controller has a better dynamic performance than the conventional PI controller. Hysteresis current control is used for quick response for generating gate pulses. Additionally, in contrast to the different control strategies; the d-q method is used for obtaining the reference currents in the system. This is due to the verity that the angle _θ‘is considered directly from the main voltage which enables an operation which is frequency independent. As a result, this technique avoids large number of synchronization problems. It can also be seen that the DC voltage regulation system is a stable and steady-state error free system. Thus with fuzzy logic and the (d-q) approach, a shunt active filter can be developed. Simulation results are presented to validate the performance of the shunt active filter.

VIII. REFERENCES

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