International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 04
February 2018

Fuzzy controlled parallel active power filter

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Abstract: *Active filters are widely employed in distribution system to reduce the harmonics produced by non-linear loads. These results in voltage distortion and leads to various power quality problems. Shunt Active Power Filters are the best solution for the elimination of harmonics occurred in the power system. This paper presents the optimization of shunt active power filter parameters based on fuzzy logic control, which is employed to drive the switching signals and also to choose the optimal value of the coupling inductance. The fuzzy control is based on a linguistic description and does not require a mathematical model of the system. It can adapt its gain according to the changes in load. The indirect current control method is used for calculating the compensating currents. A fuzzy logic based controller is developed to control the voltage of the DC side Capacitor. The conventional hysteresis controller gives very fast response and good accuracy, but it causes uneven switching. This work presents and compares the performance of the fuzzy-controller with a conventional controller under constant load. The harmonic distortions are analysed and compared. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, have been analysed. The proposed systems are implemented with Mat lab/Simulink.*

***Keywords: Shunt Active power filters (SAPF), Fuzzy, hysteresis, coupled inductor,Total Harmonic Distortion(THD*)**

I. INTRODUCTION

In recent years power quality distortion has become very serious problem in electrical power system due to the wide increase of nonlinear loads such as power electronic devices. Pollution has been introduced into power systems by nonlinear loads such as transformers etc. however; perturbation rate has never reached the present levels. Most of the pollution issues are created due to the nonlinear characteristics and fast switching of power electronic devices. Approximately 10% to 20% of today's energy is processed by power electronic devices; mainly due to the fast growth of power electronic devices capability. A race is currently taking place between increasing power electronics pollution and sensitivity, on the one hand, and the new power electronics based corrective devices, which have the ability to attenuate the issues created by power electronic devices, on the other hand.

Increase in non-linearity causes different undesirable features like low system efficiency and poor power factor. It also causes disturbance to other consumers and interference in nearby communication networks. The effect of non linearity may become serious problem over the next few years. Hence it is very important to overcome these undesirable features. Classically, shunt passive filters, consisting of tuned LC filters or high passive filters are used

to suppress the harmonics and power capacitors are employed to improve the power factor. But they have the limitations of fixed compensation, large size and can also exile resonance conditions. Active power filters are now seen as a viable alternative over the classical passive filters, to compensate harmonics and reactive power requirement of the non-linear loads. The objective of the active filtering is to solve these problems by combining with a much-reduced rating of the necessary passive components. .

Various topologies of active power filters have been developed so far. The shunt active power filter has been proved to be effective even when the load is highly non linear. To extract the fundamental component of source current indirect current controller technique is used because of its easy mathematical calculations. A conventional PI controller was used for the generation of a reference current template. The PI controller requires precise linear mathematical models, which are difficult to obtain and fails to perform satisfactorily under parameter variations, nonlinearity, etc. Recently, fuzzy logic controllers (FLCs) are used in most of the applications. The advantages fuzzy logic controllers over conventional controllers are that they do not require an accurate mathematical model and can work with imprecise inputs and also having the ability of handling non-linearity. In this paper both PI and fuzzy logic controlled shunt active power filter are implemented. The three-phase currents/voltages are detected using only two current/voltage sensors. The DC capacitor voltage is regulated to estimate the reference current template. The role of the DC capacitor is described to estimate the reference currents. A design criterion is described for the selection of power circuit components. Both the control schemes are compared and performance of both the controllers is investigated.

II. MICRO GRID ARCHITECTURE

Wind diesel hybrid system with the average penetration coefficient is consists of a wind power plant, a diesel generator, a storage, and a set of charges. Diesel generator provides the active and reactive power required by the consumed charge in different modes; however, the main purpose of diesel generators in these systems is to control the voltage and frequency. Therefore, the speed governor regulates the frequency and voltage using the automatic voltage regulator. Speed governor determines a certain amount of fuel for diesel generators in order to keep the speed constant. Diesel generators regulate the frequency by maintaining the momentary balance between active production power and consumption power under the control of speed governor.

Therefore, diesel generators are used as a control source of the active power. Wind power plant consists of a wind turbine and an induction generator (IG), which indirectly connected to the network. The mechanical power produced by the wind turbine is obtained by the following equation:

$$P_{TM} = \frac{1}{2}\rho A v^3 C_p \tag{1}$$

Where ρ is the air density, v, is the wind speed, A is the area and Cp is the power factor. Here, Cp is a function of rotation speed and number of blades. Speed control is based on the TSR method and the equation (2).

$$\mathrm{TSR} = \frac{RW_r}{v} \tag{2}$$

The length of the blades, w_r is the shaft speed of the wind turbines. Since the pitch control is not used in this paper, Cp is just a function of TSR. In addition, changes in the speed interval of IG in the wind power plant are very limited and consequently, Cp may be considered as a function of wind speed, because wind speed is quasi random.

Speed governor determines a certain amount of fuel for diesel generators in order to keep the speed constant. Diesel generators regulate the frequency by maintaining the momentary balance between active production power and consumption power under the control of speed governor. Therefore, the diesel generators are used as a control resource of the active power. There is no method for controlling the active power of the wind power plant; thus, wind power plant can be regarded as an uncontrollable resource of the active power. Reactive power is used by IG. As a result, a capacitor bank is applied as a power compensator. In the average penetration rate, the wind power plant generates P_T that may be more than the consumed power of the charge, P_L. Thus, the active power balance of the system, P_L-P_T,is negative. This means that the power of the diesel generator should be negative (diesel generator power inversion) in order to obtain the equal active power for keeping the constant frequency (consumption production). Because the speed governor cannot regulate the synchronous generators with the consumed power, the diesel generators are not able to adjust the frequency, when P_L-P_T<0 In order to prevent the diesel generator power inversion; the adjustable charge should be included in the system. Wind diesel hybrid system controller commands the adjustable charge to use the extra power in order to keep the required produced power of the diesel generator positive. Thus, the diesel generator can control the frequency. Energy saving system is used for preventing the diesel generator power inversion. Additionally, this system is used for improving the dynamic response. This increases flexibility of the diesel generators, thereby improving the performance of the wind-diesel hybrid systems. Battery based energy saving system consists of a capacitor bank and a power converter that convert DC/AC voltage for different levels of voltage. Energy saving system can store or retrieve the required energy; as a result, it can be used as control resource of the active power.

III. PROPOSED CONTROLLER OF THE PARALLEL FILTER

If the voltage of charge terminal V(t) in a three wire three phase system consists of the positive and negative sequences (V(t)=V+ (t)+V- (t)), the resource current after compensation can be restructures using the optimal method:

$$i_s(t) = \lambda v^+(t) + \lambda v^-(t) = i_s^+(t) + i_s^-(t) \tag{3}$$

$$\lambda = \frac{\bar{p}(t)}{V(t).V(t)} \tag{4}$$

Equation (3) shows that the components of the charge terminal voltages are related to the current sequences of the resource. In other words, even after compensation, the voltage of the negative sequence of the charge,

$v^-(t),\ i_s^-(t)$, causes a current of negative sequence in the resource that imposes the disturbance and imbalance in the resource current and reduces the power factor. In addition, V (t) .V (t) in equation (4)should be considered that causes the fluctuation due to the various harmonics and is added to the average amount and disturbs the resource current (in the form of different harmonics). The complementary theory GTIP(A_GTIP) proposes the following solutions in order to eliminate the errors in the equations of the comprehensive theory of the momentary powers GTIP:

- Solution for overcoming the components of the negative sequence of the replacement

$$i_s(t) = \frac{\bar{p}(t)}{V^+(t).V^+(t)} v^+(t) \tag{5}$$

There are $V(t)$ and $v^+(t)$ in the equation. Therefore, the new current of the resource is obtained using the following relationship:
Although the components of the negative sequence of the current are eliminated in the equation (5), the resource currents will be completely sinusoidal if there is no harmonic component for $V^+(t)$.If $v_1^+(t)$ is considered as the base part of the $v^+(t)$, the resource current will be obtained after compensation as follows:

$$i_s(t) = \frac{\bar{p}(t)}{v_1^+(t).\ v_1^+(t)} v_1^+(t) \tag{6}$$

In this way, $v_1^+(t)$ only contains the average part and the resource produces no 'reactive power'. Clearly, active power provided by the resource is equal to the size of average power transferred to the charge; therefore, the resource currents will be balanced and sinusoidal. The power factor will be unified. The remaining active power required by the charge (fluctuating active power) is provided by the compensator. Using the equation (6), the compensated reference currents using the developed TIP are obtained using the following relationship:

$$i_c(t) = i(t) - \frac{\bar{p}(t)}{v_1^+(t).\ v_1^+(t)} v_1^+(t) \tag{7}$$

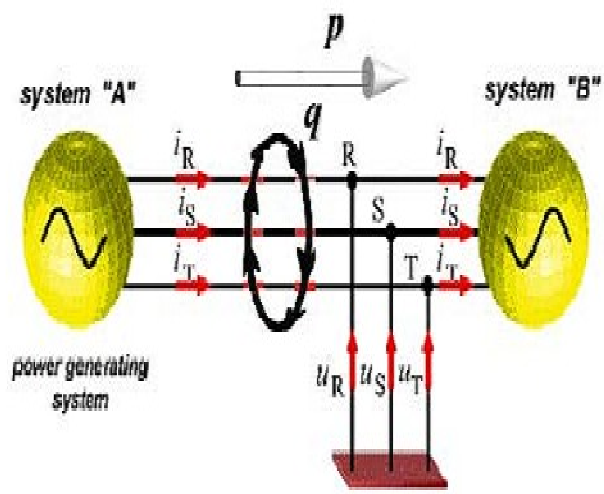

Fig. 1.diagram of the exchange

Power in the three-wire three-phase system. In this figure, power of q is shown in a circle between the phases of a, b, and c. if the real power, p, is positive, it shows the energy current from system A to system B. if it is negative, the energy current is from B system to A system.. The above equations are used for simulation in addition to showing the performance of the active filter and effective control process.

Now, the current harmonics are successfully removed. The equations (5) and (6) should be replaced with the equation (8) in order to facilitate exchanging the saving power with the network by the shunt active filter and controlling the power:

$$i_{s\_new}(t) = \frac{\bar{P}(t)\text{-}\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t)$$
$$i_{c\_new}(t) = i(t) - \frac{\bar{P}(t)\text{-}\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t) \tag{8}$$

Where Pg is the power that should be injected into the network. After adding this power, the amount of the reference current and compensating current are rewritten. So, the Kirchhoff's law is written in the connecting point of the parallel active filter and the network as follows (9):

$$i_{s\_new}(t) = i_s(t) - i_{sh}(t)$$
$$i_{c\_new}(t) = i(t) - i_s(t) + i_{sh}(t)$$
$$i_{sh}(t) = \frac{\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t) \tag{9}$$

Output current of the active filter ic_new (t) is equal to the network current i(t), distracted from the

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e-ISSN: 2348-6848
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reference current is(t), added to the saving current ish(t). In this way, the amount of the saving current in the frequency control strategy is obtained.

IV. FUZZY LOGIC CONTROLLER

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A. Hazed propounded the fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing handwritten characters are some common instances where fuzziness manifests. Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as "FUZZY SETS".

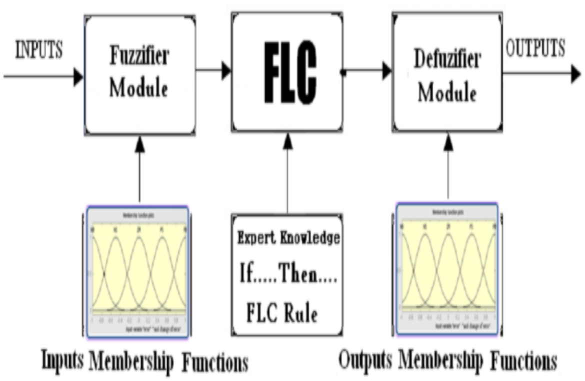

Fig.2.Fuzzy Basic Module

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as "fuzzificaton." The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action.

The results are combined to give a crisp output controlling the output variable and this process is called as "DEFUZZIFICATION."

TABLE I : FUZZY REULES

Control e \ Δe	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NL	NL	NL	NL
NM	NL	NL	NM	NM	NS	NS	NS
NS	NL	NM	NM	NS	NS	NS	ZR
ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR
PS	ZR	PS	PS	PS	PM	PM	PL
PM	PS	PS	PS	PM	PM	PL	PL
PL	PL	PL	PL	PL	PL	PL	PL

V. MATLAB/SIMULATION RESULTS

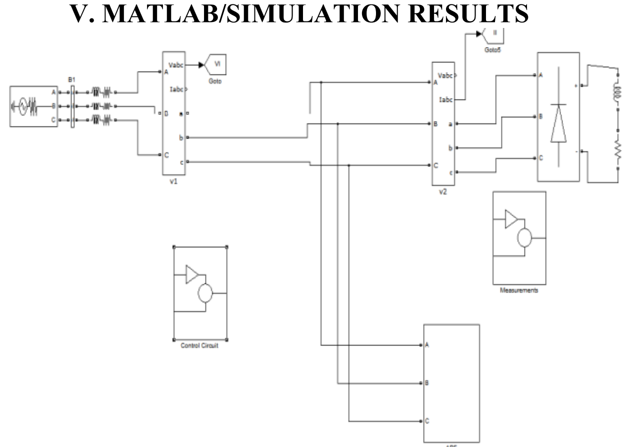

Fig.3. Matlab and Simulink Circuit diagram existing system

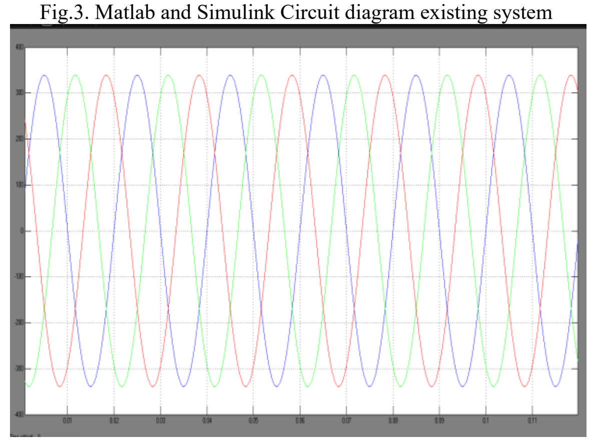

Fig.4. Simulation results for source voltage

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 04
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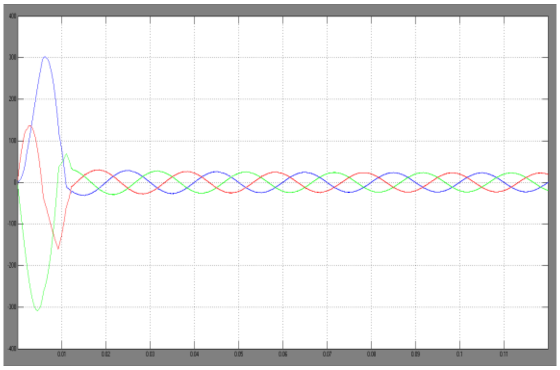


Fig.5. Simulation results for source current

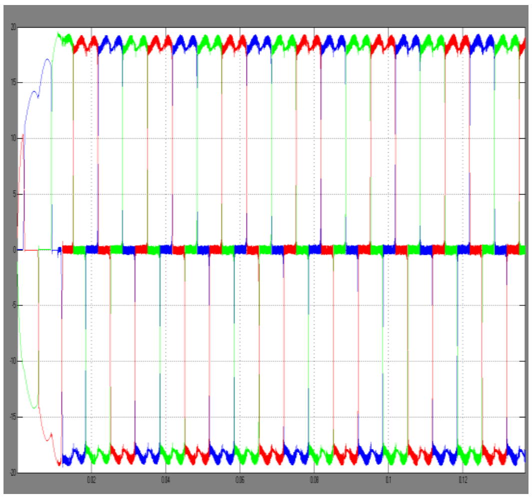


Fig.6. Simulation results for load current

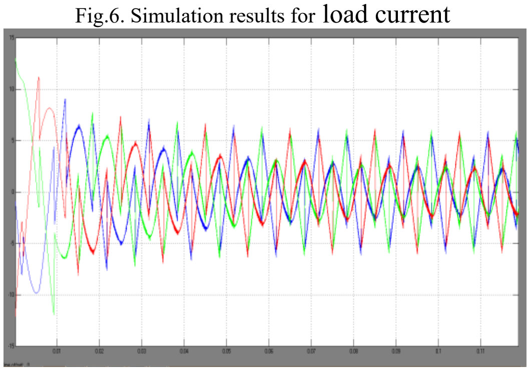


Fig.7. Simulation results for APF1 compensation current

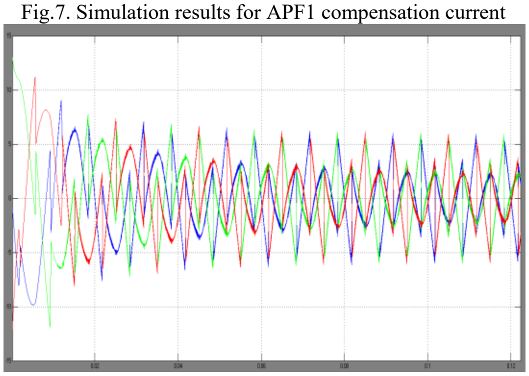


Fig.8. Simulation results for APF2 compensation current

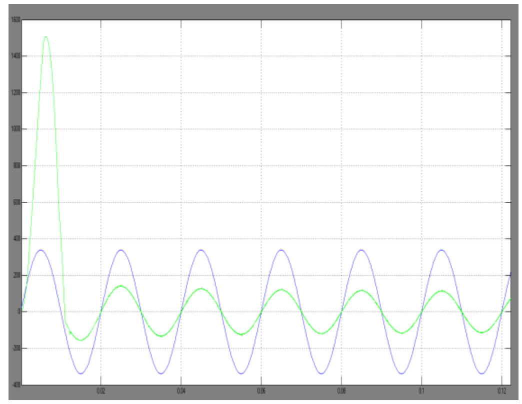


Fig.9. Simulation results for Power factor angle between Source voltage & Current

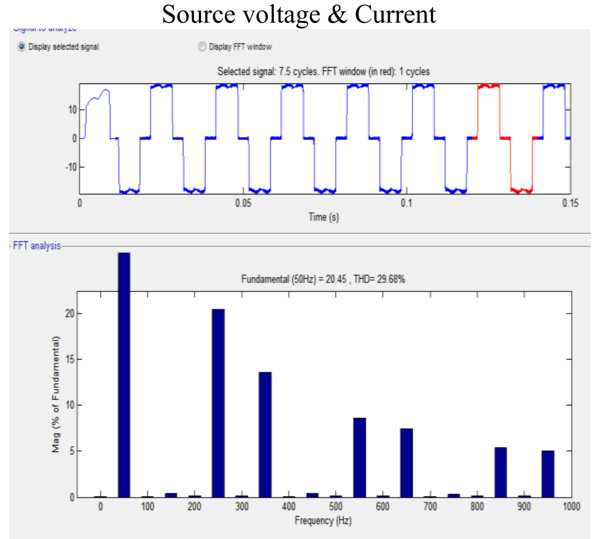
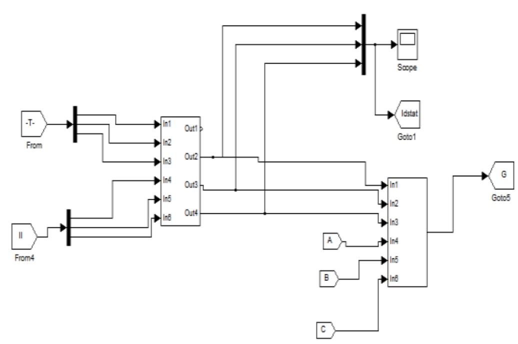
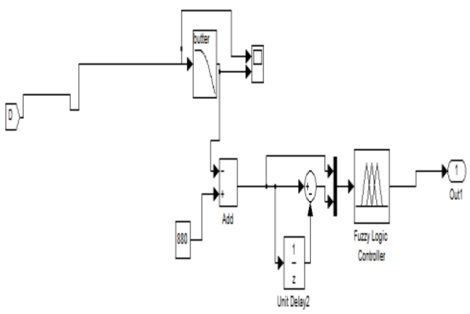


Fig.10. THD waveforms for the PI controller



(A)



(B)
FIG 11 Simulink diagram of fuzzy logic controller

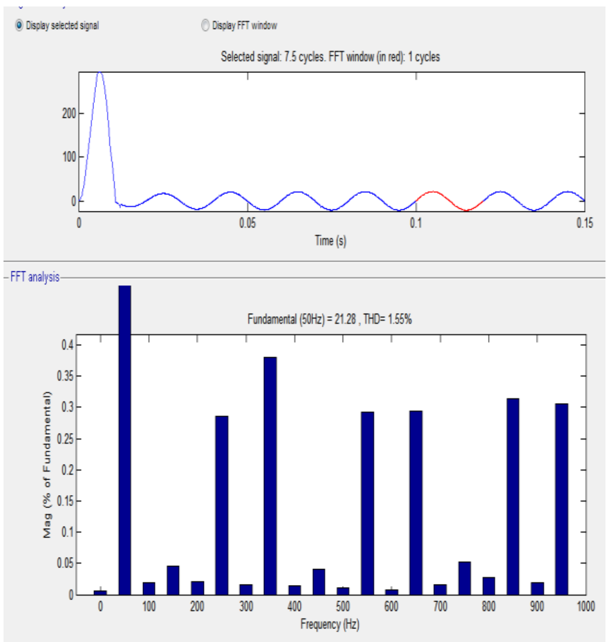


Fig.12. THD waveforms for the PI controller

VI. CONCLUSION

A shunt active power filter has been investigated for power quality improvement. Various simulations are carried out to analyze the performance of the system. Both PI controller and fuzzy logic controller based Shunt active power filter are implemented and compared the harmonic distortion values in percentage. It is found from simulation results that shunt active power filter improves power quality of the power system by eliminating harmonics and reactive current of the load current, which makes the load current sinusoidal and in phase with the source voltage. The fuzzy controller based shunt active power filter has a comparable performance to the PI controller in steady state except that settling time is very less in case of fuzzy controller.

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