Power Quality Improvement In Microgrid Using Active Power Conditioner

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***Abstract*—This paper presents a three-phase Active Power Conditioner to improve power quality in microgrids based on renewable energy. A microgrid is a weak electrical grid which can be easily subject to disturbances. The Active Power Conditioner (APC) presented in this paper acts as an interface between renewable energy sources and the AC bus of a microgrid. The control strategy which is using in this paper compensates the power quality problems such as current harmonics and corrects the power factor. Moreover, the proposed control strategy allows the line current at the point of common coupling (PCC) to be balanced and sinusoidal even when the load is unbalanced. Consequently, the voltage at the PPC becomes balanced. A Fuzzy controller is using to improve the response. Simulation results show the validity of the innovative control strategy**

I. INTRODUCTION

Harmonic pollution caused by nonlinear loads such as electric arc furnaces, electric arc welders, adjustable speed drives and switch mode power supplies has become a serious problem in electrical power systems. These loads generate a lot of harmonic currents, which are injected into the power system. The power electronic interface allows renewable sources to be connected with the distribution grid or interconnected with other renewable and non-renewable generators, storage systems and loads in a microgrid[1]. A microgrid is different from a main grid system which can be considered as an unlimited power so that load variations do not affect the stability of the system. On the contrary, in a microgrid, large and sudden changes in the load may result in voltage transient of large magnitudes in the AC bus. Active power conditioners (APC) connected to grid using renewable sources become more popular now a day.

Conventionally, passive filters have been used to limit the harmonic currents in power distribution systems. However, they have several drawbacks such as the inability to compensate random frequency variations in currents, degradation of the filtering performance due to parameter variations, tuning problems, and parallel resonance.

This paper presents an APC used to improve the power quality in a microgrid. The attention will be mainly focused on the innovative control strategy, which allows injecting energy in the microgrid, compensating the current harmonics, correcting the power factor and balancing the supply voltage at the PCC. The validity of the control strategy has been proved through many simulation tests using SimPowerSystems from MATLAB

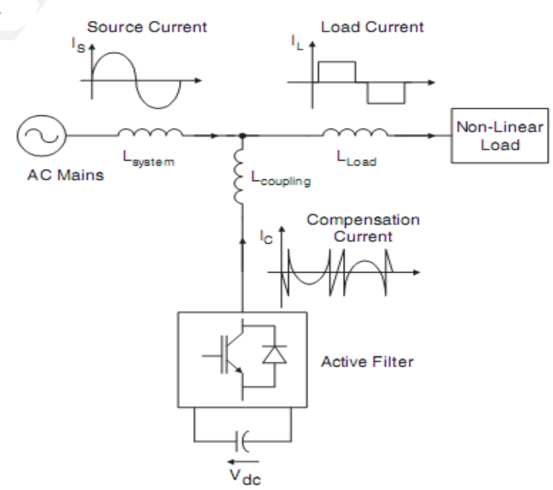

Fig.1 Schematic diagram grid connected APC

II. ACTIVE POWER CONDITIONER

Active filters have been recognized as a valid solution to harmonic and reactive power compensation due to the presence of non-linear loads. The principle of operation of active filters is based on the injection of the harmonics required by the load. An active filter generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling and forces the source current to be pure sinusoidal. As a consequence, the characteristics of the harmonic compensation are strongly dependent on the filtering algorithm employed for the calculation of load current harmonics [2].

The converter type used for active conditioner can be either CSI or VSI bridge structure. The topology can be shunt, series or a combination of both. The third classification is based on the number of phases, such as two-wire (single phase) and three- or four-wire three-phase systems. In this paper three –leg four wire topology is using as shown in fig.2. In order to provide the neutral point, two capacitors are used to split the DC-link voltage and tie the neural point to the mid-point of the two capacitors. This topology allows the current to flow in both directions through the switches and the capacitors, causing voltage deviation between the DC capacitors

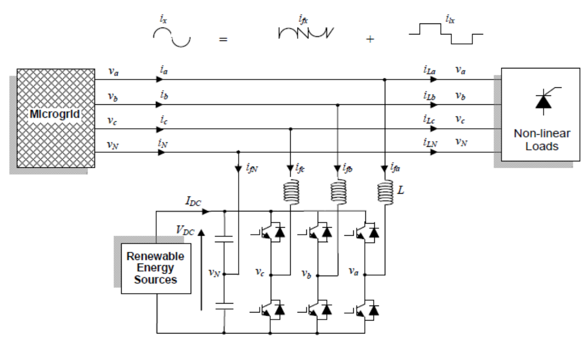

Fig.2 APC topology

$$i_{fa}+i_{fb}+i_{fc}=i_{fn} \qquad (1)$$

i_{fa} =APC phase-a current
i_{fb} =APC phase-b current
i_{fc} =APC phase-c current
i_{fn} =APC neutral current

For the investigated topology presented in Fig. 2, the current at (PCC) is:

$$i_{sx} = i_{lx} + i_{fx} \qquad (2)$$

where:

isx, ilx, ifx are the microgrid side current, the load current, and the APC current respectively. The x index points the a, b and c current phases.

The instantaneous load current is:

$$i_{la} = i^{1}_{lx}+ i_{lxk} + i_{lxq} \qquad (3)$$

where:

- i^{1}_{lx} the fundamental active current component;
- i_{lxk} the addition of current harmonics;
- i_{lxq} the reactive current component.

The three-phase APC current is given by:

$$i_{fx} =i^{1}_{fx}+i^{\sim}_{fx} \qquad (4)$$

i^{1}_{fx} - the fundamental conditioner current component;
$i^{\sim}_{fx}$ - the deforming component of the current.
As shown in Fig. 2 the current drawn from the grid has to be sinusoidal and moreover, in phase with the voltage at PCC. Consequently, the control strategy for the APC has to be designed in order to ensure a sinusoidal wave for the grid current:

$$i^{1}_{lx}+ i_{lxk} + i_{lxq}+ i^{1}_{fx}+i^{\sim}_{fx}= i_{sx} \qquad (5)$$

The APC switches generate undesirable current harmonics around the switching frequency and its multiples. Considering the switching frequency of the APC sufficiently high, these undesirable current harmonics can be filtered with the LR passive filter.

III. PHOTOVOLTAIC SYSTEM

A Photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors. A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light[8]. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited

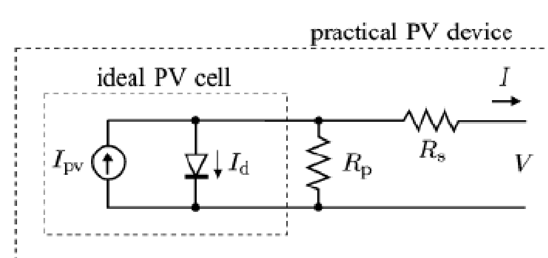

Fig.3 Equivalent Circuit of a PV Device including the Series and Parallel Resistances.

The net cell current I is composed of the light-generated current Ipv and the diode current Id.

$$I = I_{pv} - I_d$$

Where
$I_d = I_0 \exp(qv/akT)$
Io = leakage current of the diode
q= electron charge
k = Boltzmann constant
T= temperature of pn junction
a= diode ideality constant

From the circuit , the current I is

$$I = Ipv - \left[\exp\left(V + \frac{RsI}{Vta}\right) - 1\right] - \frac{V + RsI}{Rp}$$

Vt = NskT/q is the thermal voltage of the array with Ns cells connected in series. Cells connected in parallel increase the current and cells connected in series provides great output voltages.

IV.CONTROL OF THE ACTIVE POWER CONDITIONER

A. Control Strategy

The proposed control algorithm[4][5] is a compensation method that makes the APC compensate the current of a non-linear load by forcing the microgrid side current to become sinusoidal and balanced. The controller requires the three-phase grid current (i_a, i_b, i_c), the three-phase voltage at the PCC (v_a, v_b, v_c) and the DC-link voltage (V_{DC}).

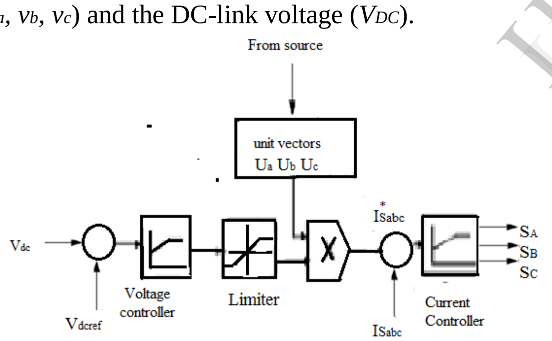

Fig.4 Block diagram of current controller

As shown in Fig. 3, the sinusoidal waveform and the phase of the grid current reference (i_a*, i_b*, i_c*) comes from the line voltage thanks to a PLL.

$$U_{a=} \sin(\omega t)$$

$$U_{a=} \sin(\omega t - 2\pi/3)$$

$$U_{a=} \sin(\omega t - 4\pi/3)$$

The magnitude of the same current is obtained by passing the error signal between the DC-link voltage (V_{DC}) and a reference voltage ($V_{DC}*$) through a Voltage controller. This magnitude is multiplied with unit vectors which are generated by PLL.

$$i_a* = I_m \sin(\omega t)$$

$$i_b* = I_m \sin(\omega t - 2\pi/3)$$

$$i_c* = I_m \sin(\omega t - 4\pi/3)$$

Now this reference signal is subtracted with the grid current and the result is given to the hysteresis current controller. This hysteresis current controller gives gating signals to the APC.

B. Hysteresis current control

Hysteresis band PWM control is basically an instantaneous feedback current control method of PWM, where the actual current continuously tracks the command current within a hysteresis band. A reference sine wave current wave is compared with the actual phase current wave[3]. When the current exceeds a prescribed hysteresis band, the upper switch in the inverter bridge is turned off and the lower switch is turned on, and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on

The actual current is forced to track the sine reference within the hysteresis band by back and forth (or bang-bang) switching of the upper and lower switches. The inverter then essentially becomes a current source with peak-to-peak current ripple, which is controlled within the hysteresis band, which makes the source current to be sinusoidal.

The switching logic is realized by three hysteresis controllers, one for each phase (figure.3). The hysteresis PWM current control, also known as "bang-bang "control, is done in the three phases separately. Each controller determines the switching -state of one inverter half-bridge in such a way that the corresponding current is maintained within a hysteresis band

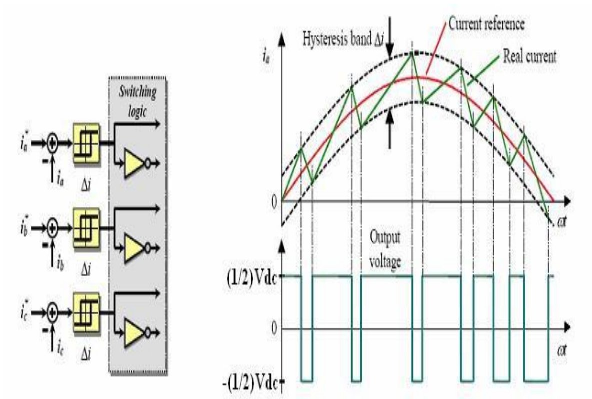

Fig. 5 Hysteresis PWM Current Control and Switching Logic

C. FUZZY LOGIC CONTROLLER (FLC)

The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, which in mathematical terms is the derivative of the error denoted as Δε[7]. To solve this problem, Fuzzy logic control as it is shown in Fig 6 is proposed.

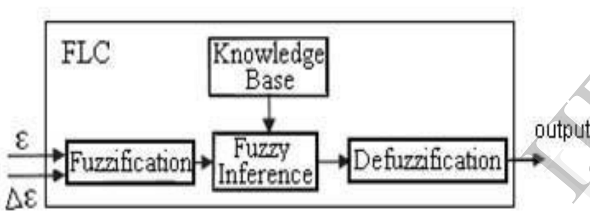

Fig.6.Basic represent at ion of FLC

The determination of the output control signal, is done in an inference engine with a rule base having if-then rules in the form of

"IF ε is .... AND Δε is ...., THEN output is ...."

With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of-error Δε. The structure and determination of the rule base is done using trial-and-error methods and is also done through experimentation

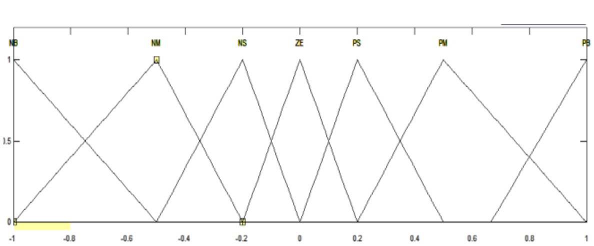

Fig.7 Membership functions of input Ɛ

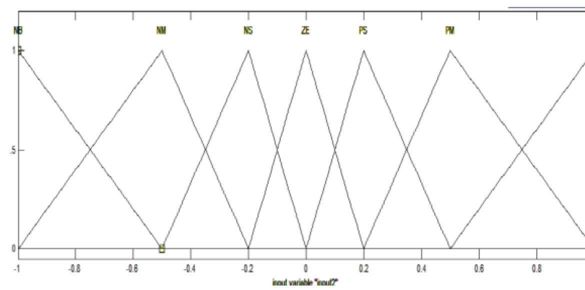

Fig.8.Membership functions of input ΔƐ

V. SIMULATION MODELS

The simulation was performed on the MATLAB/ SIMULINK package. Simulink is a software package for modelling, simulating and analyzing dynamic systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., having different parts that are sampled or updated at different rates.In this the simulink models of the shunt active filter with hysteresis current controller are given along with simulation results.

A. Modelling of power circuit

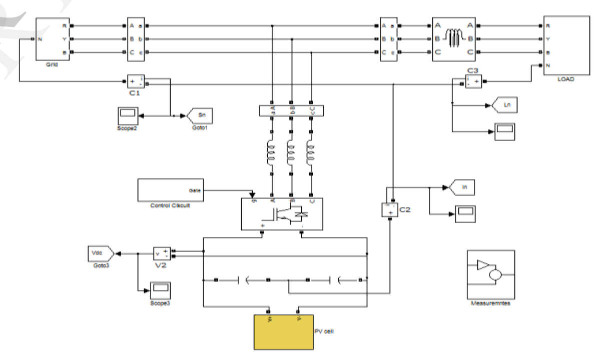

Fig.9-Matlab/Simulink model of grid connected active power conditioner using PV-cell

B. Modelling of Hysteresis Current Control

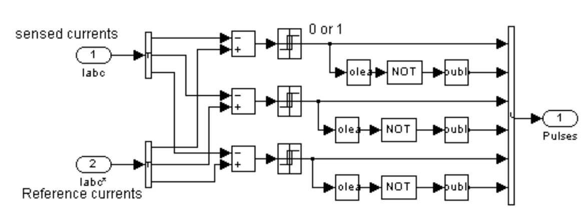

Fig.10-The Simulink Model for Hysteresis Current Controller subsystem

C. Modelling of Fuzzy Current Control

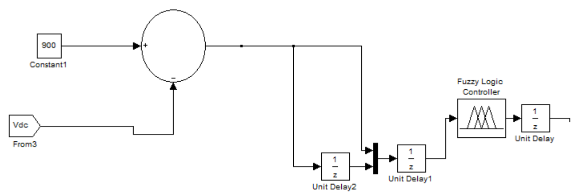

Fig.11- The Simulink Model for Fuzzy Current Controller subsystem

V1.SIMULATION RESULTS

An extensive simulation study is carried out using MATLAB/Simulink in order to verify the proposed control strategy.To achieve balanced sinusoidal grid currents at unity power factor, the 3-leg grid interfacing inverter is actively controlled using renewable energy source.

The simulation results are grouped and presented according to the following power quality indicators: THD(Total Harmonic Distortion),power factor and unbalanced load.

A. Harmonics compensation

During this case study, the APC is investigated using a three-phase diode bridge rectifier with a 60Ω resistor in series with a 0.1mH inductor at the DC side.

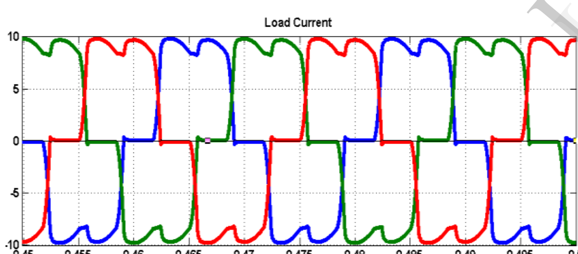

Fig.9- shows the nonlinear load current

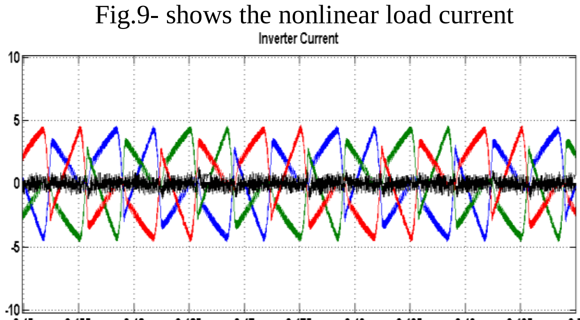

Fig. 8-shows the APC side current

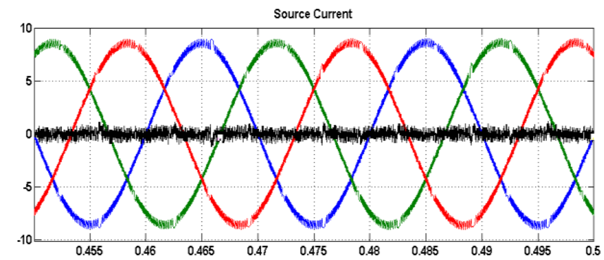

Fig.9- shows the source side current

Fig.7,8,9 shows the currents at the PCC. As can be seen, most of the current required by the load is injected by the APC and the balance comes from the microgrid, The current absorbed by the rectifier is not sinusoidal and has a THD of 27.13%. The frequency noise that can be observed on the APC current waveforms is due to the switching of the IGBTs.

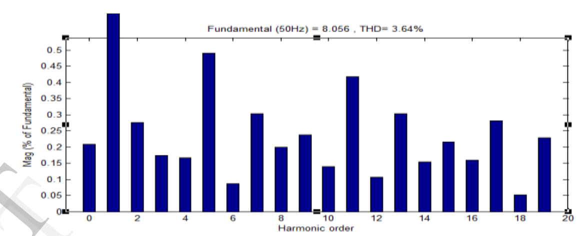

Fig.10-THD of Source current as 3.64%

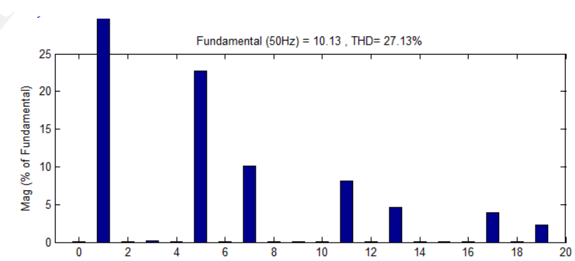

Fig.11- THD of load current as 27.13%

The proposed control strategy allows the current on the microgrid side to be sinusoidal with a THD of about 3%. In the same, it can be seen the THD of the load current(28%) .

B. Power factor correction

The second case study shows the effectiveness of the APC to compensate the power factor.

The power faction can be controlled with the capacitor banks, but this is the manual operation. In distorted conditions the results are power and also the capacitor life is shorter. So maintenance cost also high.

For this case study, the load is composed by a three-phase inductor in series with a three-phase resistor and requires about 3KW active power and 4kVAR reactive power.

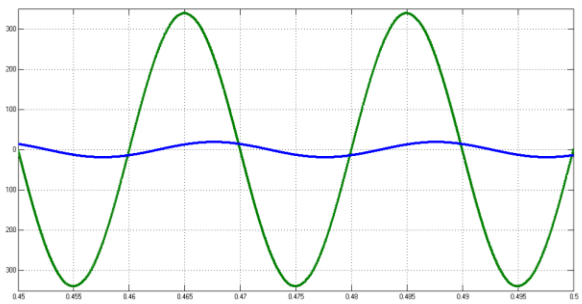

Fig.12- Before Compensation

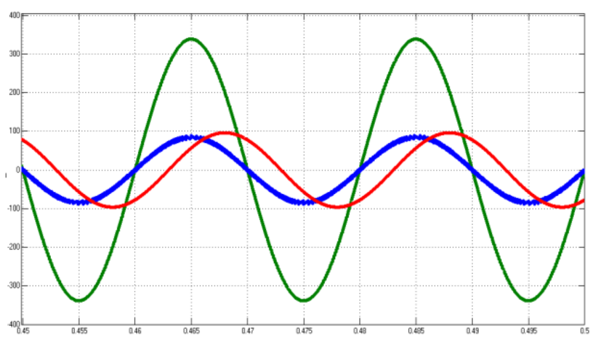

Fig.13- After Compensation

Fig.13 illustrates the load current, the microgrid side current and the supply voltage respectively at the PCC of phase-a. As shown in fig.12 the measured power factor between the load current and the supply voltage is 0.58. Thanks to the proposed control strategy, the APC is able to impose a unity power factor between the microgrid side currents and the supply voltage. The phase of the microgrid side currents is inverted relatively to the phase of supply voltages at the PCC because the power injected by the APC exceeds the power required by the load. Consequently, the surplus renewable energy is injected into the microgrid.

C. Unbalanced load

When several single-phase loads are unequally distributed on a distribution system, the fluctuating power required from each of these loads can cause unbalanced voltage in a weak power system. Under unbalanced conditions, the distribution system will incur more losses and heating effects and will be less stable.

For this case study, the APC is used to compensate the unbalance induced by a resistive three-phase load.

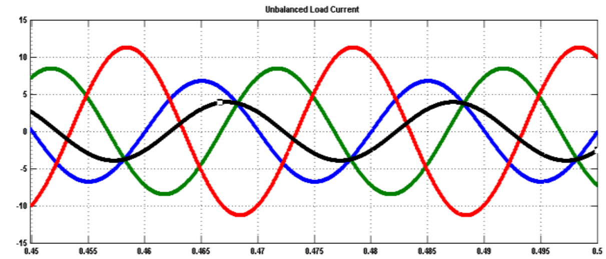

Fig.12- shows Grid connected unbalanced load

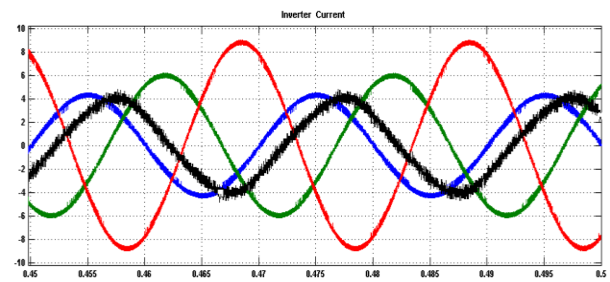

Fig.13- shows Inverter side current

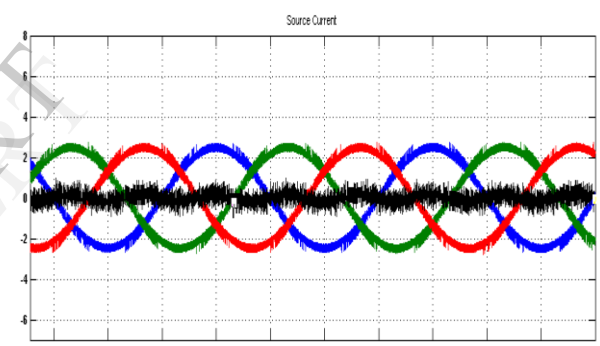

Fig.14- shows source side current

The phase a, b ,c are connect with 50Ω, 40Ω , 30Ω are connected respectively. As shown in the previous section, the investigated APC is controlled such that the microgrid current required by the load is sinusoidal and balanced. Consequently, the voltage in this point is also balanced.

Using the APC equipped with the proposed controller, the degree of the negative sequence unbalance is lower than 0.8%. It must be Noticed that international standards admit unbalances lower than 2%.

D. System response using Fuzzy controller

Due to the fast response of the fuzzy controller, the system will respond faster. By using the fuzzy controller APF starts compensating at 0.02s.

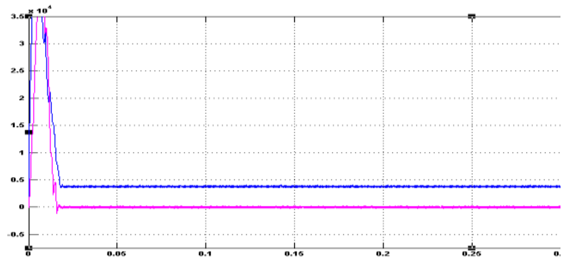

Fig.15 Active and Reactive power response using Fuzzy controller.

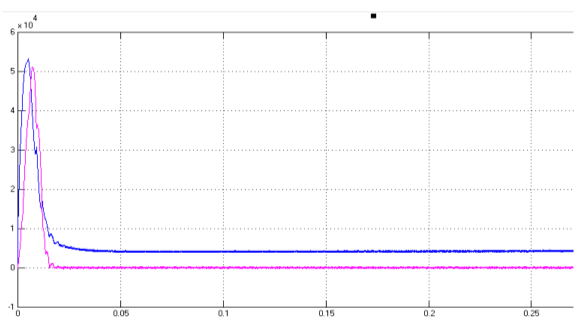

Fig.16 Active and reactive power response using PI controller

It can be conclude that the system will come to steady state using PI controller is 0.04s and 0.02s for Fuzzy controller. This is the benefit of using Fuzzy controller

V11.Conclusions

In this paper, an APC used to improve power quality in microgrids based on renewable energy has been presented. The APC is controlled using an innovative control strategy allowing the line current at the point of common coupling to be balanced and sinusoidal even when the load is unbalanced.

This approach presents the following advantages:

- The control system is simpler, because only three sinusoidal waveforms have to be generated for the reference currents.
- These sinusoidal waveforms to control the current are generated in phase with the main supply, allowing unity power-factor operation.
- The control of the three-phase line current enables the three-phase voltage balance at the PCC, allowing excellent regulation characteristics.
- Using the fuzzy logic controller the performance of APC is increased

Different case studies have been investigated with the APC simulated in the Matlab SymPowerSystem

V111.References

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