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POWER QUALITY IMPROVEMENT WITH FUZZY LOGIC BASED IPQC OF MICRO GRID FOR HYBRID RENEWABLE APPLICATIONS

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ABSTRACT

This paper presents a fuzzy logic controller based on integrated power quality controller (IPQC) for micro-grid is used to mitigate power quality problems when it is applied for PV/Wind renewable energy system. The unusual requirements of micro grid power quality, such as the harmonic high penetration, frequent voltage fluctuation and over current phenomenon, when wind energy is connected to the grid voltage sag, swells, harmonics, flicker etc and bidirectional power flow and small capacity. The IPQC is an effective custom power solution, which consists of two back to back connect IGBT based voltage sourced bi-directional converters with a common DC bus to mitigate power quality problems. A hybrid energy system, or hybrid power, usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

Renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and micro turbines being integrated into the power-grid in the form of distributed generation (DG). A fuzzy logic control scheme is proposed for the controlling operation of IPQC. FLC controller provides right performance for the faultless control over IPQC. The system performance will analyzed by using MATLAB/SIMULINK software

Keywords- *Power Quality, IPQC,DG, power control, renewable energy sources (RES's), Voltage Sourced Bi-Directional Converters.(VSBDC).*

I. INTRODUCTION

Distributed power generation [1] has been emerged as a promising option to meet the growing customer needs for electric power with an emphasis on reliability and environmentally friendly renewable energy. In this context, in order to maximize the operational efficiency of the distributed energy resources (DERs) and take full advantage of distributed power generation, as an effective means of integrating DERs into the traditional power grid, micro grid is presented, which can enhance the local customer power supply reliability and system performance, reduce the impact on large power grid, and minimize the system losses. Micro grid has good environmental and economical benefits and has attracted more and more attentions of power researchers. However, the power quality problem of micro grid [2] is much more serious than that of the traditional grid because of the intermittency and randomness of DERs, the high penetration betweenconventional grid and micro grid, the diversity of DERs, load, energy conversion unit, storage, and operating state. Micro grid power quality [3] [4]has the following unique features compared with the conventional power grid.

1. Background harmonic of DERs and harmonic high penetration are more serious than those of the traditional grid. The traditional grid has less system background harmonic, and the harmonic is mainly from the nonlinear load. However, in micro grid, in addition to the nonlinear load, DERs and energy storage converter system access to micro grid may also generate harmonics.
2. Bidirectional power flow control is much more challenging. Traditional distribution network is with the features of "passive network" and "one-way power flow," whereas the micro grid is with the features of "active network" and "bidirectional power flow."
3. Voltage fluctuation and sag often happen in micro grid. In micro grid, except the voltage fluctuation and sags from the load change, most kinds of DERs, which are intermittent and random, will cause significant voltage fluctuations in distribution network.

4. The overvoltage and over current phenomena are more frequent. In general, micro grid is comparatively small in capacity, and the effect of load fluctuation on micro grid is more than that on the traditional power grid. In addition to this, control mode switching of many converters connecting in parallel to bulbar and the seamless state transition may produce overvoltage and over current.
5. So far, relevant research studies on micro grid power quality controllers can be sorted into two types: uni-functional controllers and multifunctional controllers. Uni-functional power quality controllers aim at a specific power quality issue in micro grid. However, these multifunctional power quality controllers do not take into account all of the above mentioned features of micro grid.

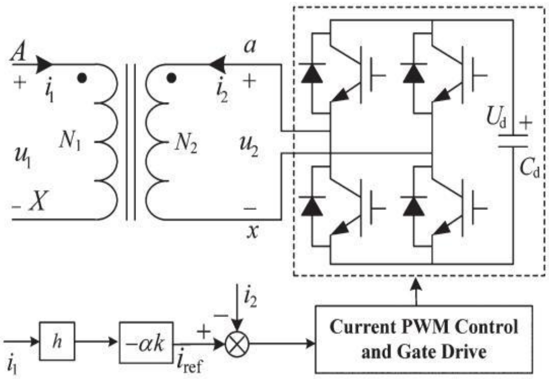

Fig 1 System configuration of the novel variable reactor

To date, there is less research on integrated power quality controller (IPQC) particularly suitable for micro grid with the above mentioned features. In addition, the micro grid capacity is comparatively small, and it is not cost effective to install various types of power quality controller. In order to solve these problems, a novel variable reactor based on magnetic flux control is first proposed. In order to cater for the peculiar requirements of micro grid of harmonic high penetration, frequent voltage fluctuation and over current phenomenon, and bidirectional power flow and small capacity, a novel IPQC suitable for micro grid is proposed based on the novel variable reactor. The IPQC is characterized by mitigating the harmonic penetration, controlling the bidirectional power flow, limiting the fault current and compensating the voltage fluctuation, and being a variable reactor. Finally, experimental results are provided to validate the analyses.

II. SYSTEM DESCRIPTION

The novel IPQC can be installed in series and parallel in micro grid or point of common coupling (PCC). For simplicity, the IPQC is installed in PCC. Fig 3.8 shows the three-phase detailed system configuration of the IPQC with transformer andinverter. $U_s$and$L_s$represent the source voltage and impedance of conventional power supply, respectively. The passive filters, which have the function of absorbing the harmonics, are shunted in both sides. The primary winding of a transformer is inserted in series between the conventional power utility and the micro-grid, whereas the secondary winding is connected withal voltage-source PWMconverter. $U_{dc}$is the voltage of the dc side of theinverter. The micro grid contains a harmonic load, a photo voltaic cell system, a battery storage system, and a normal load. The proposed IPQC has the following functions.

Power flow control

When the power flow control and the fault current limiter are concern, only the fundamental is taken into account. In terms of the preceding analysis, the primary winding exhibits adjustable impedance$Z_{L1} + (1 - \alpha)Z_{Lm}$.
With the change in coefficient α, the equivalent impedance of the primary winding can be achieved, which is shown in Table I. Therefore, when the primary winding is connected in series in circuit, it can be applied to control the power flow between the conventional power utility and the micro grid or the internal power flow of the micro grid. The schematic of power flow control is shown in Fig 3.9 when the novel variable reactor is connected in series

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between the sending and receiving ends. Suppose that theequivalent impedance $Z_1 + (1 - \alpha) Z_m$ of the variablereactorisR+jX.

$$UmCos\varphi = Us\cos(\varphi - \delta) + RI$$

$$Umsin\varphi = Us\sin(\varphi - \delta) + XI$$

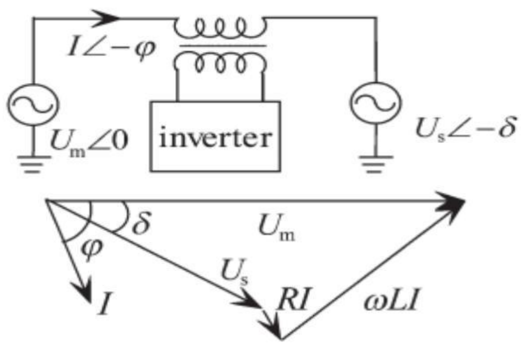

Fig 2 Power flow control principle and its vector diagram

$$Um(Um - Uscos\delta) = PR + QX$$
$$Us\sin\delta = PX - QR$$

The active and reactive power from U_m to U_s are $P = \frac{Um}{R^2+X^2}[R(Um - Us\cos\delta) + XUs\sin\delta]$

$$Q = \frac{Um}{R^2+X^2}[-RU_s\sin\delta + X(U_m - U_s\cos\delta)]$$

In the power system with high voltage level, the inductive reactance component of the transmission line is much more than the resistance component of the transmission line, $P = \frac{U_s U_m}{X}\sin\delta \quad Q = \frac{U_m}{X}(U_m - U_s\cos\delta)$

In micro grid with low voltage level, when the resistance component of the transmission line is much more than the inductive reactance component of the transmission line can be expressed as

$$P = \frac{U_s U_m}{X}\sin\delta \qquad Q = \frac{U_m}{X}(U_m - U_s\cos\delta)$$

.

In terms of above equation,, there is a striking difference in power flow control and voltage regulation between micro grid and conventional power grid.

Fault current limiter

When the terminal *AX* is connected in series in circuit, in the normal operation state, the coefficient α can be controlled as$\alpha = 1 + Z_1/Z_m$,and the equivalent impedance of the primary winding *AX* is zero. Hence, the series transformer does nothave any influence on the power system normaloperation. The maximum system currentI_{max} of the three phases is obtained by a current-detecting circuit and compared with a reference current. In case of a short-circuit fault, maximum system current I_{max} reaches the reference current, the coefficient α can be controlled between −1 and 1 in terms of the requirement of fault current, and the equivalent impedance of the primary winding *AX* is controlledbetween $Z_1 + Z_m$ and Z_1 to limit the system current to a desired value.

Voltage compensation

In order to compensate the voltage fluctuation, the primary winding of the transformer is connected in series between the power electric utility and the load. When the load voltage is higher than the desired voltage, the coefficient α can be controlled between 0 and $1 + Z_1/Z_m$, and the primary winding exhibits inductive impedance. When the load voltage is lower than the desired voltage, the coefficient α is controlled more than $1 + Z_1/Z_m$, and the primary winding exhibits capacitive impedance. Therefore, the load voltage can be controlled as a stable voltage.

Harmonic isolation

The preceding function of power flow control, fault current limiter, and voltage compensation is concerned with the fundamental. If there exits harmonic in the power utility, the primary current contains the fundamental current and *n*th order harmonic currents, that is to say, $i_1 = i_1^{(1)} + \sum i_1^{(n)}$ The fundamental component $i_1^{(1)}$ rather than harmonic is detected from the primary winding current *i*1 and functions as a reference signal. A voltage source inverter is applied to track the fundamental reference signal $i_1^{(1)}$ to produce a fundamental compensation current $i_2^{(1)}$, which has the same frequency as $i_1^{(1)}$. $i_2^{(1)}$ is inversely in phase injected to the secondary winding *ax*.

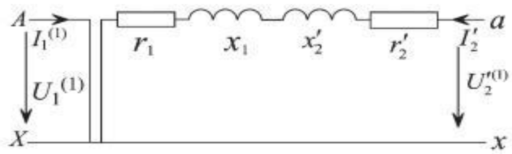

Fig 3 Fundamental equivalent circuit

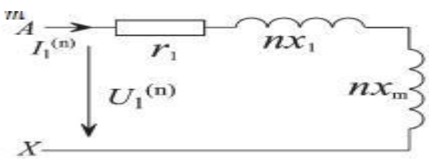

Fig 4 Harmonic equivalent circuit.

When α = 1 + [illegible], the fundamental equivalent impedance of primary winding *AX* is zero, which is shown in Fig 3. Meanwhile, for the *n*th-order harmonic, since only a fundamental current is injected to the secondary winding of-the transformer, i_2 does not include any order harmonic current other than the fundamental current, which means that the transformer is open circuit to harmonic current. Therefore, the equivalent *n*th-order harmonics shown in Fig. 4. Then, the harmonic equivalent impedance of the transformer is

$$Z_{AX}^{(n)} = (r_1 + Jn\,x_1) + Jnx_m \approx n\,Z_m^{(1)}$$

From the primary winding, the series transformer exhibits very low impedance at the fundamental and simultaneously exhibits high impedance to harmonics to act as a "harmonic isolator."Then, the harmonic currents are forced to flow into the passive *LC* filter branches in both sides.

III. GRID FORMER CONVERTER IPQC

When integrating the preceding functions of variable reactor, power flow control, fault current limiter, voltage compensation, and harmonic isolation, a novel IPQC can be achieved. For fundamental and harmonic, the primary winding of the series transformer exhibits the impedance of [illegible] respectively. That is to say, the primary winding of the series transformer exhibits adjustable impedance, which plays the role of power flow control, fault current limiter, and voltage compensation to fundamental. Meanwhile, the primary winding of the seriestransformer exhibits high impedance $n\,Z_m^{(1)}$ to harmonic which can greately improve to harmonics and really acts as a harmonic isolator. Therefore, it can mitigate the harmonic high penetration.

To compensate the power quality problems, a modern active harmonic power filters[7] are been used and they are small in size . the active filters are slightly low in cost and operating losses, when compared to passive . Active power filters conscious for power conditioning are also referred to as "active power line conditioners,""active power quality conditioners," "improved power quality conditioners (IPQCs),"[8]

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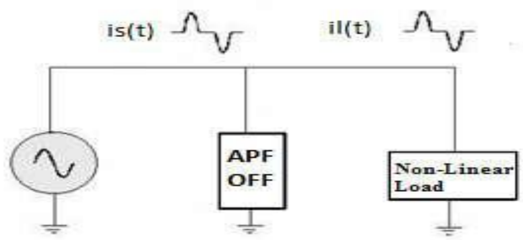

Fig 5 When IPQC is off

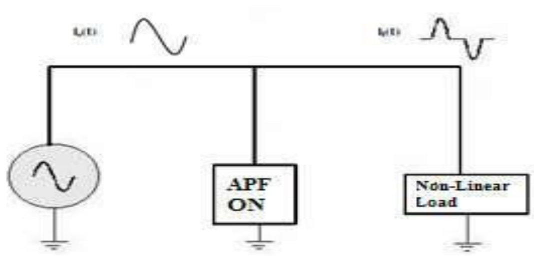

Fig 6 when IPQC is on

In a modern electrical distribution system, there has been a rapid usage of nonlinear loads, such as power electronic apparatus like power supplies, rectifier equipment, and other domestic appliances, and adjustable speed drives (ASD), etc. As the number of these loads may increases in day to day life, harmful harmonics currents generated by these loads may become very considerable. These harmful harmonics can cause to a variety of different power quality problems including the distorted voltagewaveforms, malfunction in system protection, equipment overheating, excessive neutral currents, inaccurate power flow metering, light flicker etc. It may goes to efficiency reduction by drawing reactive current component from the distribution network. In order to overcome these problems, active power filters (APFs, named as IPQC) have been developed.

In an integrated power quality controller (IPQC) the capacitor Z7 is connected to a photo voltaic system along with the wind energy. Here these two energy sources will start injecting the supply voltage to the line through a three phase circuit breaker. The breaker will turn on and turn off which is based on transition time .By adding, non linear load (power electronics devices) at load side the power quality disturbances will increase, in order to reduce that disturbances IPQC will be used. The dc supply of the inverter is taken from renewable energy sources (PV & wind) the output voltage of PV and wind energy system are given to the capacitor Z7.The PV and wind energy sources will start injecting the supply into the line only when transition time is above 0.2 and it will take off the occurred disturbances which are due to placing of non linearload[10][11]. The IPQC system will not operate when the transition time is less than 0.2.This transition time will be changed in a three phase circuit breaker[12].

Design of Fuzzy Logic Controller:
Fuzzy logic (FL) controller is one of the most successful operations of fuzzy set theory; its major features are the use of linguistic variables rather than numerical variables. This control technique relies on human capability to understand the systems behavior and is based on quality control rules. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.

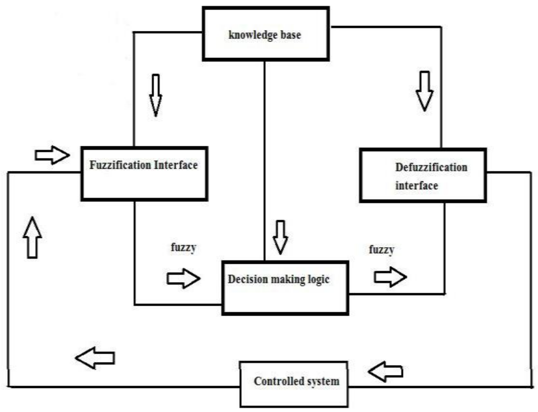

Fig 6 Basic Structure of FL Controller

FLC are formed by simple rule based on "*If xand y then z*". These rules are defined by taking helpfrom person's experience and knowledge about the system behavior. The performance of the system is improved by the correct combinations of these rules.

Each of the rules defines one membership which is the function of FLC.

The general structure of an FLC is represented in Figure 6 and comprises of four principal components: A Fuzzyfication interface which converts input data into suitable linguistic values.

1) A Knowledge Base which consists of a data base with the necessary linguistic definitions and control rule set.
2) A Decision Making Logic which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions and
3) A Defuzzyfication interface which yields a non fuzzy control action from an inferred fuzzy control action.

Need of Fuzzy Controller:

PI controller across the dc-link does not compensate the switching transients during switching period, in order to avoid the disadvantage of PI controller; PI controller is replaced with the fuzzy controller. Fuzzy controller gives dynamic performance for different types of loads than PI controller. It also decreases the notches in the o/p voltage during the transient conditions, gives better filtering performance

Fuzzy Logic Rules

The existent of this dissertation is to manipulate the output voltage of the converter. The change in error and error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are designed to divide d into seven groups; NL: Negative Large, NM: Negative Medium, NS: Negative Small, ZO: Zero Area, PS: Positive small, PM: Positive Medium and PL: Positive Large and its parameter. These fuzzy control rules for error and change of error can be referred that is shown in below table 1.

Table 1 Rules for Fuzzy Logic Controller

$e/\Delta e$	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	EZ	NM	NS	EZ	PS	PM	PL

IV. SIMULATION RESULTS

Control strategy for fuzzy logic controller

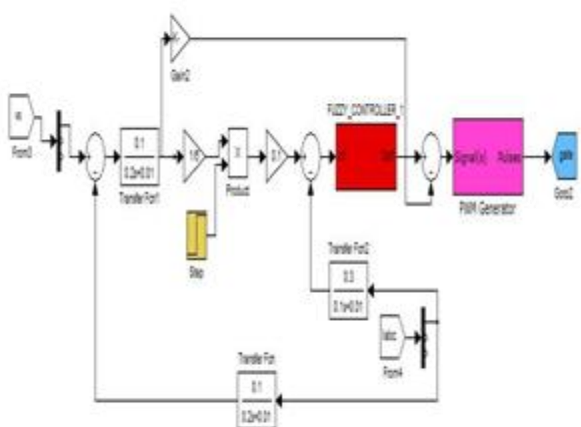

Fig 7 Control Strategy for Fuzzy Logic Controller

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Simulink diagram for fuzzy logic controller based ipqc

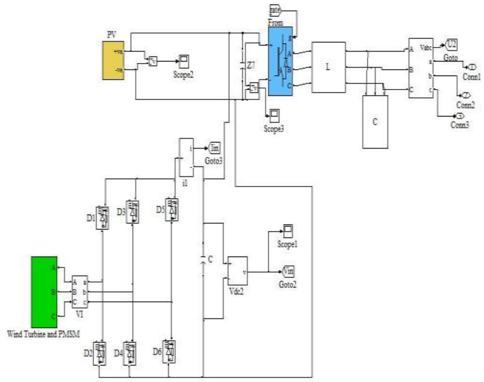

Fig 8 IPQC design for Fuzzy Logic Controller with PV and Wind energy sources

Voltage waveform fuzzy logic controller based ipqc

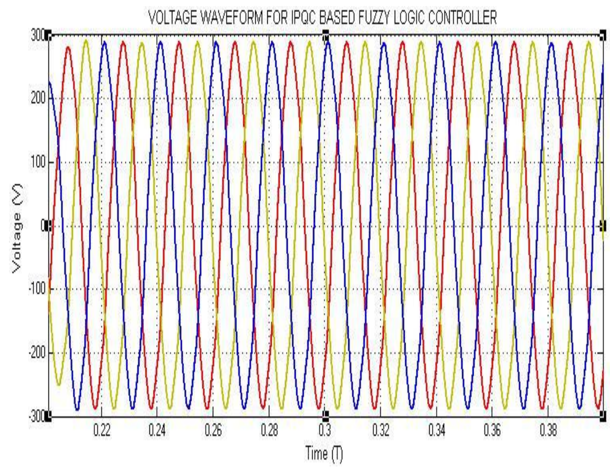

Fig 9 Voltage waveform Fuzzy Logic Controller based IPQC

Current waveform fuzzy logic controller based ipqc

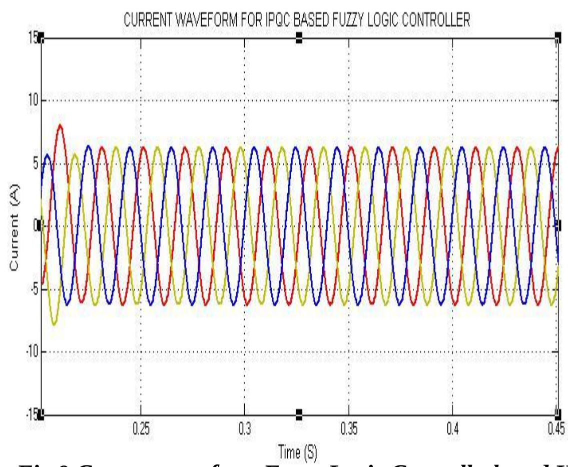

Fig 9 Current waveform Fuzzy Logic Controllerbased IPQC

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THD measurement for fuzzy logiccontroller with ipqc

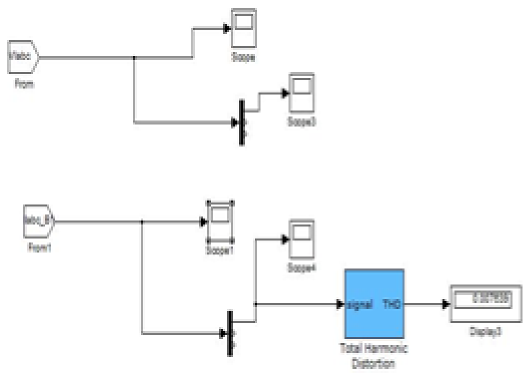

Fig 10 THD for Fuzzy Logic Controller with IPQC

FFT analysis for fuzzy logiccontroller with ipqc

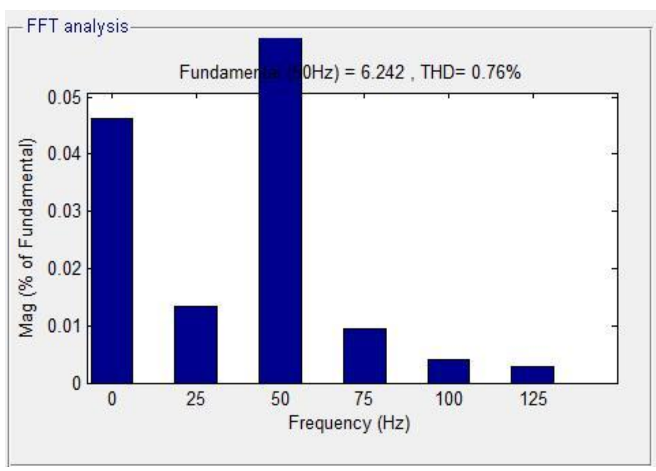

Fig 11 FFT analysis for Fuzzy Logic Controllerwith IPQC

Table 4.1 for THD calculation with and withoutIPQC

S.No	Order of the Harmonic	Harmonic frequency (Hz)	Without IPQC %	IPQC with PI Controller %	IPQC with Fuzzy Logic Controller %
1	1	50	18.51	2.20	0.76
2	3	150	0	0	0
3	5	250	16.66	2.13	0.74
4	7	350	7.09	0.54	0.18
5	11	550	2.27	0.07	0.02
6	13	650	1.71	0.03	0.01

Total harmonic distortion THD calculation:At 50Hz frequency with fuzzy logic controller

$$THD = \left(\frac{\sqrt{i_2^2 + i_3^2 + i_4^2 + i_5^2 + i_6^2 + \cdots i_n^2}}{i_1} \right) \qquad THD = \frac{\sqrt{6.5047301947}}{4.413}$$

$$THD = \frac{2.55043725566}{4.413}$$

$$THD = 0.577937$$

As per the simulation results the total THD at 50 Hz is 0.76, by manual calculations THD =0.57.

V. CONCLUSION

This paper has presented a Power Quality Improvement with fuzzy logic based IPQC of Micro-grid for hybrid Renewable Applications, Before start using the active filter a large amount of source current consists of harmonic current in it, this is due to the usage of passive filter. To overcome the effect of the harmonic current in the passive filter, the active filter is proposed to improve the filtering performance.

The fuzzy logic control scheme is proposed to control the operation of IPQC, the operation consists of back to back IGBT connected voltage source bi directional converter to mitigate the problem of power quality. By this arrangement it improves micro-grid power quality, such as the harmonic high penetration, frequent voltage fluctuation and over current phenomenon. In addition to that Hybrid Renewable energy sources like (wind energy and photo voltaic etc) are connected to the grid voltage to improve harmonics and flicker etc. Hybrid Renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and micro turbines being integrated into the power grid in the form of distributed generation (DG) to improve the power quality of a micro grid. In this project the comparison results of using IPQC are obtained for both PI and fuzzy logic controller, by using fuzzy logic controllerthe system performance has been improved than PI controller. Total harmonic distortion in fuzzy logic controller is very less when compared to the PI controller.

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