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POWER QUALITY ENHANCEMENT OF DISTRIBUTED GENERATION BY USING UPQC WITH FUZZY LOGIC CONTROLLER

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Abstract- This work deals with Islanding and Seamless Reconnection for microgrid using fuzzy based UPQC. Mainly Power Quality is a function of power factor so the use of non-linear and low power factor loads these nonlinear loads draw non-linear current and degrade electric power quality. In this project a powerful control and integration technique of the proposed UPQC in a distributed generation (DG)-based grid connected micro generation (μG) system is presented. The control technique of the presented UPQCμG is enhanced by implementing an intelligent islanding and novel reconnection technique with reduced number of switches that will ensure seamless operation of the μG without interruption. The shunt part of the UPQC Active Power Filter is placed at the Point of Common Coupling (PCC) and series part of the UPQC is connected before the PCC and in series with the grid. The dc link can also be integrated with the storage system. An intelligent islanding detection and reconnection technique (IR)are introduced in the UPQC as a secondary control. Hence, it is termed as $UPQC_{\mu G-IR}$. The advantages of the proposed $UPQC_{\mu G-IR}$ over the normal UPQC are to compensate voltage interruption in addition to voltage sag/swell, harmonic, and reactive power compensation in the inter connected mode. During the inter connected and islanded mode, DG converter with storage will supply the active power only and the shunt part of the UPQC will compensate the reactive and harmonic power of the load. It also offers the DG converter to remain connected during the voltage disturbance including phase jump. The simulation results are presented by using Matlab/simulink software.

Index Terms— Distributed generation (DG), intelligent islanding detection (IsD), microgrid, power quality, smart grid, Unified power quality compensator (UPQC), fuzzy logic controller.

I. INTRODUCTION

The issues of a successful integration of unified power quality conditioner (UPQC) along with fuzzy logic controller in a distributed generation (DG)-based grid connected micro generation (μG) system are primarily: 1) control complexity for active power transfer; 2) ability to compensate non-active power during the islanded mode; and 3) difficulty in the capacity enhancement in a modular way [1]. For a seamless power transfer between the grid-connected operation and islanded mode, various operational changes are involved, such as switching between the current and voltage control mode, robustness against the islanding detection and reconnection delays, and so on [2], [3]. Clearly, these further increase the control complexity of the µG systems. To extend the operational flexibility and to improve the power quality in grid connected µG systems, a new placement and integration technique of UPQC have been proposed in [4], which is termed as UPQC µG. In the UPQC µG integrated distributed system, µG system (with storage) and shunt part of the UPQC are placed at the Point of Common Coupling (PCC).The series part of the UPQC is placed before the PCC and in series with the grid. The dc link is also connected to the storage, if present. To maintain the operation in islanded mode and reconnection through the UPQC and fuzzy, communication process between the UPQC µG and µG system is mentioned in [5].In this paper, the control technique of the presented UPQC µG and fuzzy logic controller in[6] is enhanced by implementing an intelligent islanding and novel reconnection technique with reduced number of switches that will ensure seamless operation of the µG without interruption [7].Hence, it is termed as UPQC µG−IR. The benefits offered by the proposed UPQC µG−IR over the conventional UPQC are as follows.

1) It can compensate voltage interruption/sag/swell and non-active current in the interconnected mode. Therefore, the DG converter can still be connected to the system during these distorted conditions. Thus, it enhances the operational flexibility of the DG converters/µG system to a great extent, which is further elaborated in later section.

2) Shunt part of the UPQC Active Power Filter (APFsh) can maintain connection during the islanded mode and also compensates the non active Reactive and Harmonic Power (QH) power of the load.

3) Both in the interconnected and islanded modes, the µG provides only the active power to the load. Therefore, it can reduce the control complexity of the DG converters.

4) Islanding detection and reconnection technique are introduced in the proposed UPQC as asecondary control. A communication between the UPQC and µG is also provided in the secondary control. The DG converters may not require to have islanding detection and reconnection features in their control system [8-12].

II WORKING PRINCIPLE

The integration technique of the proposed $UPQC_{\mu G-IR}$ to a grid connected and DG integrated µG system is shown inFig. 1(a). S2 and S3 are the breaker switches that are usedto island and reconnect the µG system to the grid as directedby the secondary control of the $UPQC_{\mu G-IR}$. The workingprinciple during the interconnected and islanded mode for thisconfiguration is shown in Fig.1 (b) and (c). The operation of $UPQC_{\mu G-IR}$ can be divided into two modes.

A. Interconnected Mode

In this mode, as shown in Fig. 1(b), the following holds:

1) The DG source delivers only the fundamental activepower to the grid, storage, and load;

2) The APFsh compensates the reactive and harmonic (QH)power of the nonlinear load to keep the Total HarmonicDistortion at the PCC within the IEEE standard limit;

3) Voltage sag/swell/interruption can be compensated bythe active power from the grid/storage through the APFse,t. The DG converter does not sense any kindof voltage

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disturbance at the PCC and hence remainsconnected in any condition;

4) If the voltage interruption/black out occurs, UPQC sendsa signal within a preset time to the DG converter to beislanded.

B. Islanded Mode

In this case, as shown in Fig. 1(c), the following holds:

1) The APFse is disconnected during the grid failure and DGconverter remains connected to maintain the voltage atPCC;

2) The APFsh still compensates the nonactive power of the nonlinear load to provide or maintain undistorted currentat PCC for other linear loads (if any);

3) Therefore, DG converter (with storage) delivers only theactive power and hence does not need to be disconnectedfrom the system;

4) The APFse is reconnected once the grid power isavailable.

From Fig.1(a)–(c), it is clear that the UPQCμG−IR requirestwo switches compared with four, as required for UPQCμG in [4]. A detail of the switching mechanism is discussed inthe controller design section.

III. DESIGN ISSUES AND RATING SELECTION

The fundamental frequency representation of the system isshown in Fig. 1(d) and the voltage and current relations arederived in (1) and (2). According to the working principle, theAPFse is able to work during voltage interruption/sag/swellup to a certain level before it is islanded. The APFsh always compensates QH power of the load. Therefore, design andrating selection for the APFse, APFsh, and series transformertogether with the sizing of dc link capacitor are very important.

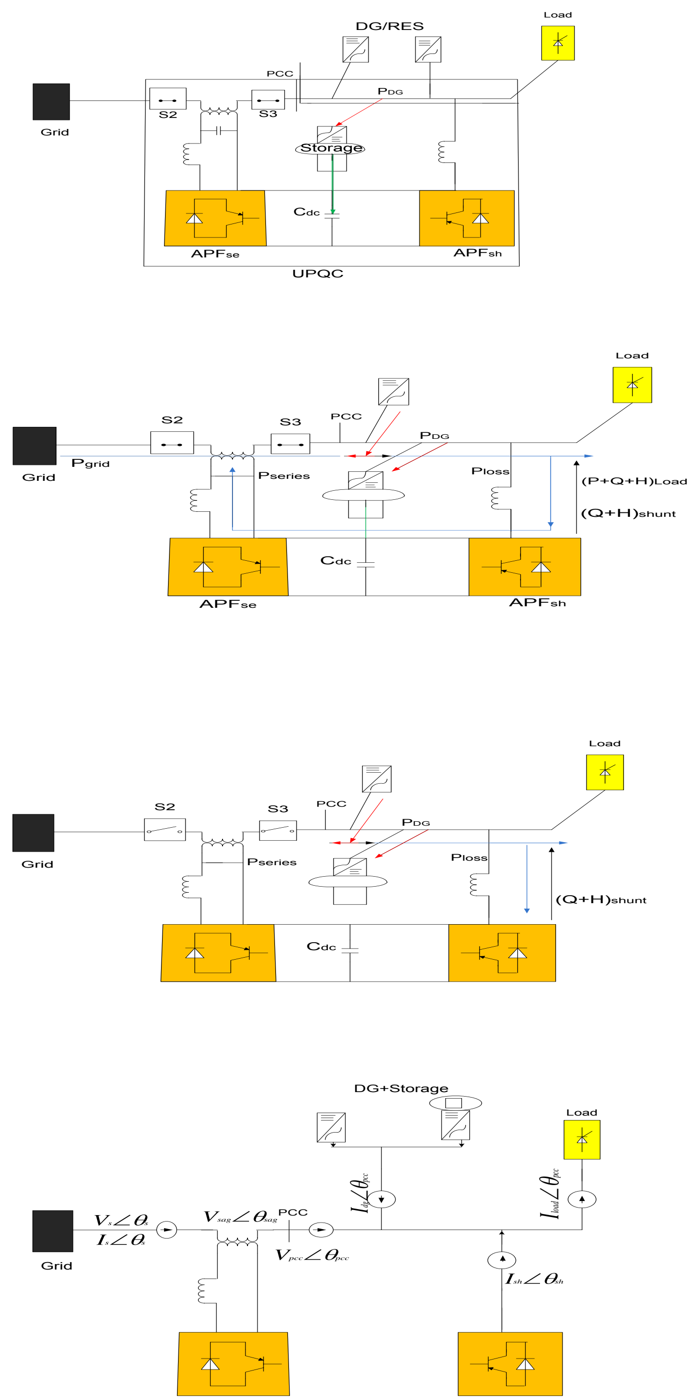

Fig.1. (a) Integration technique of the UPQCμG−IR. Working principle in(b) interconnected mode, (c) islanded mode, and (d) fundamental frequencyrepresentation.

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These are discussed in the following section:

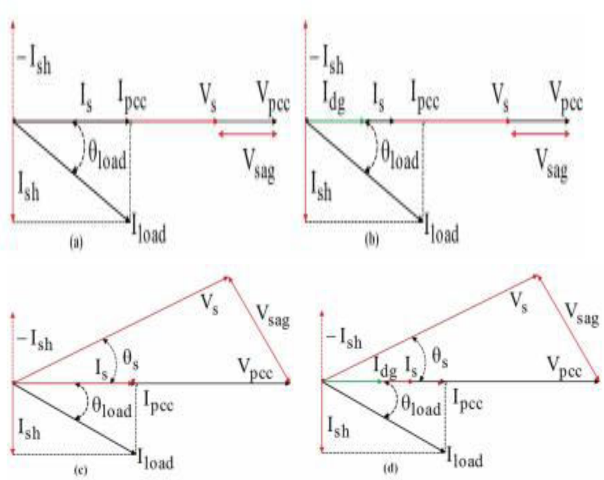
$$V_{\text{pcc}} \angle \theta_{\text{pcc}} = V_s \angle \theta_s + V_{\text{sag}} \angle \theta_{\text{sag}} \quad (1)$$

$$I_{\text{load}} \angle \theta_{\text{load}} = I_s \angle \theta_s + I_{\text{dg}} \angle \theta_{\text{pcc}} + I_{\text{sh}} \angle \theta_{\text{sh}} \quad (2)$$

Under any condition assume that $V_{pcc} = V_{dg} = V_{load}$ andθ_{pcc}= 0°. The phasor diagrams of the proposed system indifferent conditions are shown in Fig.2.

A. Shunt Part of U P QC µG−I R (APFsh)

It is shown in Fig.2 that for any condition, APFsh compensates the non-fundamental current of the load by injecting Ishin quadrature to Vpcc. When voltage sag appears in the supplyside, APFse compensates the sag by injecting the requiredvoltage to maintain the constant voltage and zero-phase atPCC. To complete the task, APFsh draws additional currentfrom the source, to supply power to the APFse. The increased source current *I's*still remains in phase to the Vpcc. But thischanges the magnitude and phase angle of the compensating current, Ish as an additional active component of current (x) is added to the shunt compensator current now, as shown in Fig.2(e).



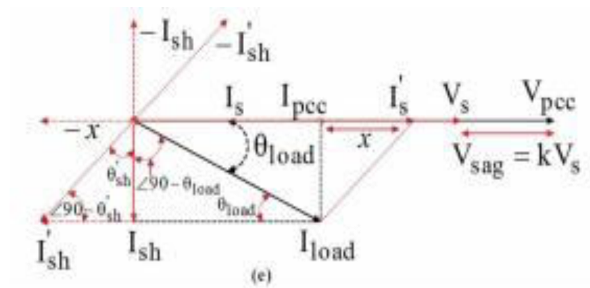


Fig.2. Phasor diagram of UPQCμG−IR when (a) no DG andθs =θpcc, (b) with DG and θs =θpcc, (c) no DG and θs ≠θpcc, (d) with DG and θs ≠θpcc, and (e) in-phase voltage compensation mode.

In this case

$$I_s' = I_{\text{pcc}} + I_{\text{sh}}' \sin(\theta_{\text{sh}}') \quad (3)$$

$$I_{\text{sh}}' = I_{\text{sh}} / \cos(\theta_{\text{sh}}') \quad (4)$$

This ultimately increases the current at PCC and thus creates a VA loading impact on the APFsh, which is also observed in [6].

B. Series Part of UPQCµG−IR (APFse)

The APFse always appears in series with the grid. In the proposed integration technique when no energy is available from the DG unit and shunt the APF compensates the reactive and harmonic part of the load current, the active fundamental part of the load current (I_{loadfp}) flows through the APFse. Therefore, the APFse must have at least the same current rating as the active load fundamental requirement

$$I_{\text{APF}_{\text{se,min}}} = I_{\text{loadfp}} \quad (5)$$

From Fig.2(c) and (d), the general equation for voltage sag compensation by the APFse can be written as

$$V_{sag} = \sqrt{V_s^2 + V_{pcc}^2 - 2V_s V_{pcc} \text{Cos}(\theta_s - \theta_{pcc})} \quad (6)$$

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The voltage rating of the APFse should be equal to the highest value of the injected sag voltage, thus

$$V_{APF_{se,rated}} = V_{sag,max} = kV_{load,rated} \quad (7)$$

Assume k is the fraction of Vs that appears as a voltage sag

$$V_{sag} = kV_s = kV_{load} \text{ and } k < 1$$

Therefore, the VA rating of the APFse, can be calculated as

$$S_{APF_{se,rated}} = I_{APF_{se,rated}} V_{APF_{se,rated}} = kP_{loadf,rated} \quad (8)$$

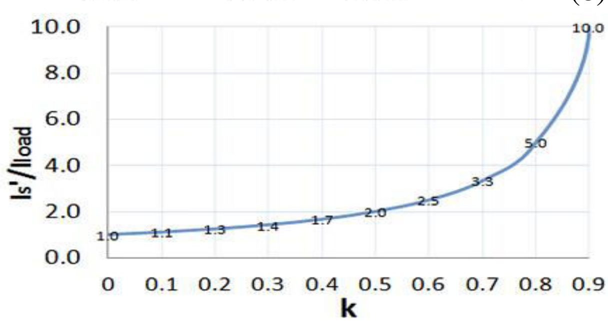

Fig.3. Relation between source current, load current, andkfor voltage sag compensation.

From Fig.2, the active power transfer through the APFse can be calculated for the case when Idg=0

$$P_{APF_{se}} = P_{loadf}\left[\frac{kV_s}{V_{load}}\cos(\theta_s - \theta_{pcc})\right] \quad (9)$$

Under stable and in-phase operating conditions, assume that $\theta_s = \theta_{pcc} = 0$

$$P_{APF_{se}} = \frac{kP_{loadf}V_s}{V_{load}} \quad (10)$$

Therefore, during voltage sag compensation, the source current that is transferred through the series transformer of the APFse, as shown in Fig.2(e), can be calculated as

$$I_s' = \frac{P_{loadf}}{(1-k)V_s} = \frac{1}{(1-k)} I_{loadfp} \quad (11)$$

Thus, the size and VA rating of the series transformer depends on the amount of sag to be compensated. Fig.3. shows how the source current increases with the value of k. Based on (6)–(11), and for a given value of k, there can be of multiple solutions for Vsag, I's, and P_{APFse}. Control strategies are based on the minimization of the energy exchange during compensation or by reducing the voltage rating [5]–[11].The voltage rating of the APFse is an important design parameter, as it determines some other characteristics, such as the compensating range, the need to include (and size of) energy storage devices, and the overall size of the series transformer. In addition, losses tend to increase if the voltage rating of the A_{PFse} is increased. Therefore, the voltage injection capability should be chosen as low as necessary to reduce equipment cost and standby losses.

C. DC Link Capacitor

According to the working principle, the APFse should be able to work during a high-sag/swell condition and even in the case of interruption (depending on the interruption time) before it goes to the islanded mode. At this stage, the dc link capacitor should be able: 1) to maintain the dc voltage with minimal ripple in the steady state; 2) to serve as an energy storage element to supply the nonactive power of the load as a compensation; and 3) to supply the active power difference between the load and source during the sag/swell or interruption period. For a specific system, it is better to consider the higher value of C_{dc} so that it can handle all of the above conditions. It also helps to get a better transient response and lower the steady-state

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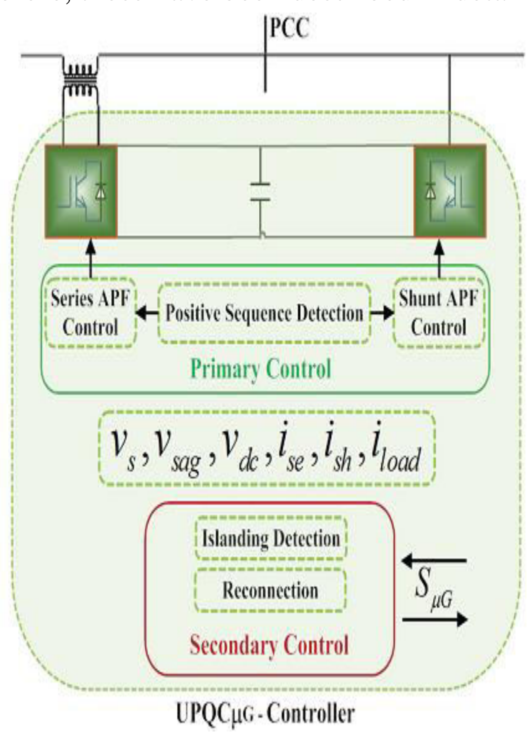
ripples. According to the calculation in [12], for the proposed system, the required capacitor size will be

$$C_{dc} = \frac{2S_{load} \, . \, n \, . \, T}{4 \, . \, c \, . \, V_{dc}^2} \quad (12)$$

Where S_{load} is the total VA rating of the load, n is the number of cycles to perform the task, T is the time period, and c is the percentage of Vdc.It indicates that the size of the capacitor can be adjusted by the selection of cycles (n) for which the APFse will compensate. One of the purposes of the proposed integration technique of the $UPQC_{\mu G-IR}$ is to maintain smooth power supply during sag /swell/ interruption and extend the flexibility of the DG converters operation during interconnected and islanded modes. For the supply continuity, DG storage system has also been introduced. Therefore, a dc link connection between the capacitor and the DG storage has been proposed for the system. It will help to reduce the size of the capacitor and provide power during the sag/interrupt condition. Therefore, the source current will maintain the required load current active component and the additional current will be provided by the DG converters and storage. Thus, it will ultimately help to reduce the rating of the APFse converter.

IV. CONTROLLER DESIGN

The block diagram of the proposed UPQCμG−IR controller is shown in Fig.4. It has the same basic functionality as the UPQC controller except for the additional islanding detection and reconnection capabilities. A communication channel (signals transfer) between the proposed $UPQC_{\mu G-IR}$ and the μG is also required for the smooth operation. These signals generation are based on the sag/swell/interrupt/supply failure conditions. This task is performed in Level 2 (secondary control) of the hierarchical control. Level 1 deals with the primary control of the UPQC to perform their basic functions in the interconnected and the islanded mode. The overall integration technique and control strategy are to improve the power quality during interconnected and islanded modes. This involves detecting islanding and reconnection that ensures the DG converter remains connected and supply active power to the load. This reduces the control complexity of the converter as well as the power failure possibility in the islanded mode. The five main elements of the proposed $UPQC_{\mu G-IR}$ controller are: 1) positive sequence detection; 2) series part (APF_{se}) control; 3) shunt part (APF_{sh}) control; 4) intelligent islanding detection (IsD); and 5) synchronization and reconnection (SynRec). As the IsD and SynRec features are new in UPQC, therefore, these have been described in details.



(a)

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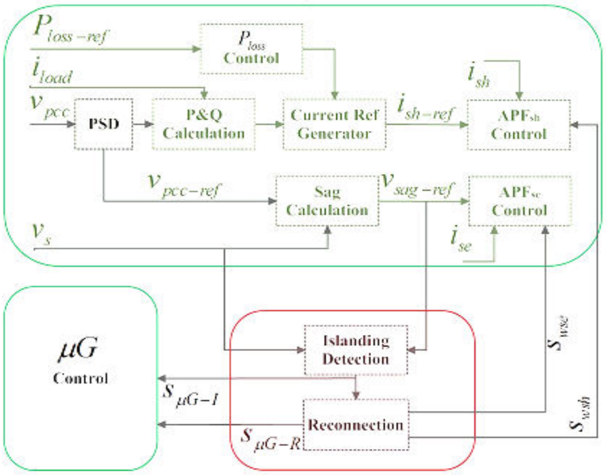

(b)

Fig.4. Block diagram of the UPQCμG−IR. (a) Controller. (b) Control algorithm.

A. Intelligent Islanding Detection

Considering the future trends toward the smart-grid and μG operation in connection with the distribution grid, the capability of: 1) maintaining connection during grid fault condition; 2) automatically detecting the islanded condition; and 3) reconnecting after the grid fault are the most important features of theμG system. In that case, the placement of APFse in the proposed integration method of the system plays an important role by extending the operational flexibility of the DG converter in the μG system.In addition to the islanding detection, changing the control strategy from current to voltage control may result in serious voltage deviations and it becomes severe when the islanding detection is delayed in the case of hierarchical control.Therefore, seamless voltage transfer control between the grid connected and isolated controlled modes is very important. Both indirect and direct current control techniques are proposed in [2] to mitigate the voltage transients in transition mode, but these then increase the control complexity of the μG converters.

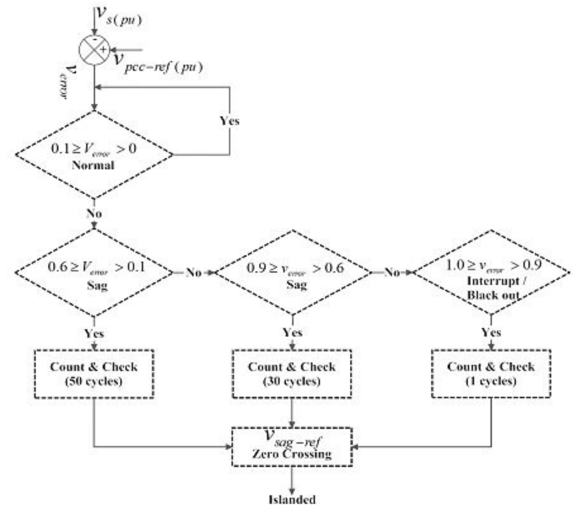

Fig.5. Algorithm for IsD method in UPQC$_{\mu G-IR}$.

In the case of power quality problems, it is reported that more than 95% of voltage sags can be compensated by injecting a voltage of up to 60% of the nominal voltage, with a maximum duration of 30 cycles. Therefore, based on the islanding detection requirement and sag/swell/interrupt compensation, islanding is detected and a signal SμG−I, as shown in Fig.4(b), is also generated in the proposed UPQCμG−IR to transfer it to the DG converters. As the APIn the case of power quality problems, it is reported that more than 95% of voltage sags can be compensated by injecting a voltage of up to 60% of the nominal voltage, with a maximum duration of 30 cycle. Therefore, based on the islanding detection requirement and sag/swell/interrupt compensation, islanding is detected and a signal SμG−I,as shown in Fig.4(b), is also generated in the proposed UPQC$_{\mu G-IR}$ to transfer it to the DG converters. As the APFse takes the responsibility for compensating voltage sag/ swell/ unbalance disturbances (depending on the controller), IsD algorithm in the proposed UPQC$_{\mu G-IR}$ can be simple yet quite flexible. On the other hand, it will help to reduce the complexity of islanding

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detection technique or even can be removed from all the DG converters in a µG system.Fse takes the responsibility for compensating voltage sag/swell/unbalance disturbances (depending on the controller), IsD algorithm in the proposed $UPQC_{\mu G-IR}$ can be simple yet quite flexible. On the other hand, it will help to reduce the complexity of islanding detection technique or even can be removed from all the DG converters in a µG system.Fig.5 shows a simple algorithm (with example) that has been used to detect the islanding condition to operate the UPQC in islanded mode. The voltage at PCC is taken as the reference and it is always in phase with the source and the DG converters, the difference between the Vpcc-ref (pu) and Vs (pu) is Verror. This error is then compared with the preset values (0.1–0.9) and a waiting period (user defined n cycles) is used to determine the sag/interrupt/islanding condition. In this example: 1) if Verror is less than or equal to 0.6, then 60% sag will be compensated for up to 50 cycles; 2) if Verror is in between 0.6 and 0.9, then compensation will be for 30 cycles; and 3) otherwise (ifVerror≥0.9) it will be interrupt/black out for islanding after 1 cycle.This signal generation method is simple and can be adjusted for any time length and Verror condition. Thus, the intelligence can be achieved by introducing the operational flexibility of time and control of sag/interrupt compensation before islanding. As the seamless voltage transfer from grid connected to isolated mode is one of the critical tasks in transition period, the transfer is completed at the zero-crossing position of the APFse. Therefore, no voltage fluctuation or abrupt conditions occur.It is to be noted that, this is the first time the algorithm and islanding techniques are introduced in the control part of the UPQC, which are intelligent and flexible in operation. According to Fig.1, the proper control and operation of the switches are very important for intelligent islanding and seamless reconnection. In that case, this paper presents a topology that represents a step forward compared with the use of intelligent connection agents (ICA) as presented, an additional module named ICA is connected to an existing µG with a number of current sources. The ICA module acts as voltage source to fix the voltage and frequency in islanding mode and is able to guarantee seamless connection/disconnection of the µG from the main grid. The $UPQC_{\mu G-IR}$ presented in this paper is not only able to perform these seamless transitions, but also improve the power quality with some operational flexibility. In addition, the UPQC having a series element (APFse) can perform the role of voltage source of the µG, and easily PCC voltage observation-based anti-islanding algorithm can be implemented, as shown in Fig.5. Notice that using conventional equipment, e.g., in grid connected PV systems, the non-detection zone (NDZ) increases with the number of PV inverters, since they are not able to distinguish between the external grids or other PV inverters output voltage, thus may remain connected for a dangerously long time. With the proposed UPQC control strategy, we can add it in an existing PV plant, and this unit will be the only one responsible of the voltage support and islanding detection, thus being more effective and reducing drastically the NDZ.

V. FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties

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of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to power system [5]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of compensator.

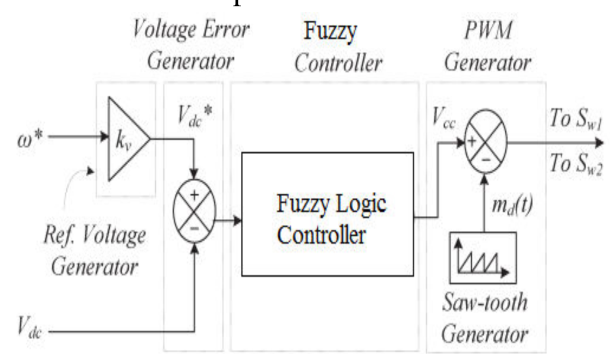

Fig. 6. Fuzzy logic Control of the PFC BL-CSC converter feeding BLDC Motor Drive.

The basic scheme of a fuzzy logic controller is shown in Fig 7 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

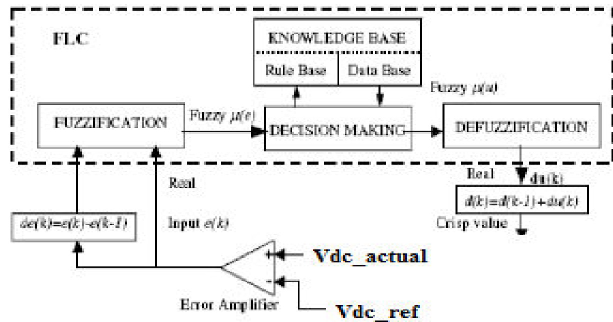

Fig.7.Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter.

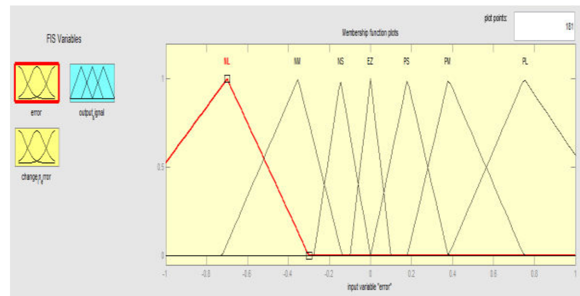

Fig.8. Membership functions for error.

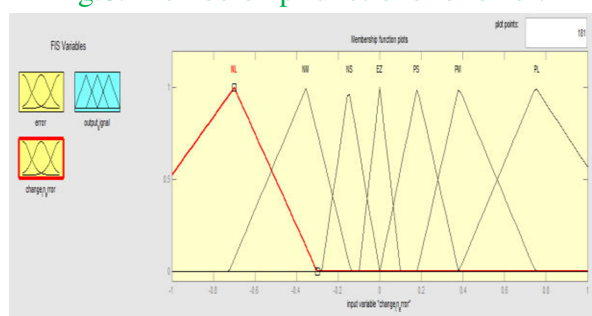

Fig.9. Membership functions for change_in_error.

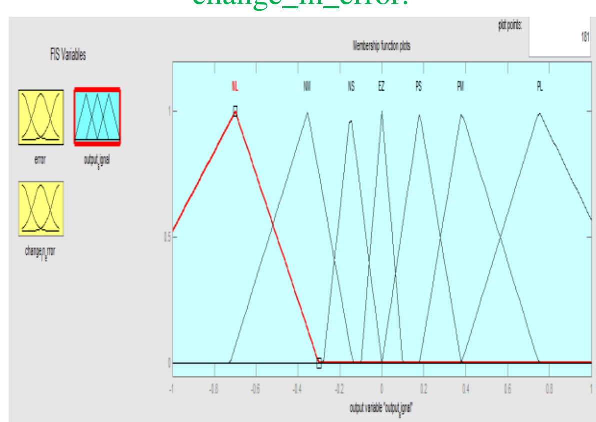

Fig.10. Membership functions for Output. Table rules for error and change of error.

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Error / Change error	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	NL
NM	NL	NL	NL	NM	NS	EZ	NM
NS	NL	NL	NM	NS	EZ	PS	NS
EZ	NL	NM	NS	EZ	PS	PM	EZ
PS	NM	NS	EZ	PS	PM	PL	PS
PM	NS	EZ	PS	PM	PL	PL	PM
PL	EZ	PS	PM	PL	PL	PL	PL

VI. MATLAB/SIMULATION RESULTS

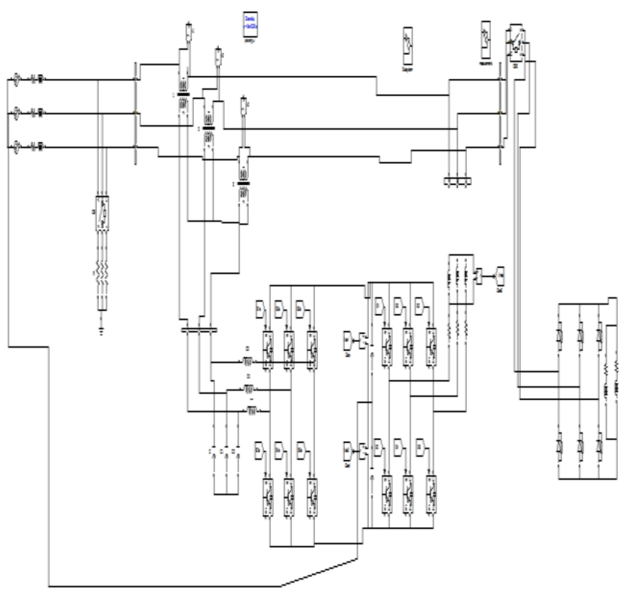

Fig.11.Matlab/Simulation model of without UPQC.

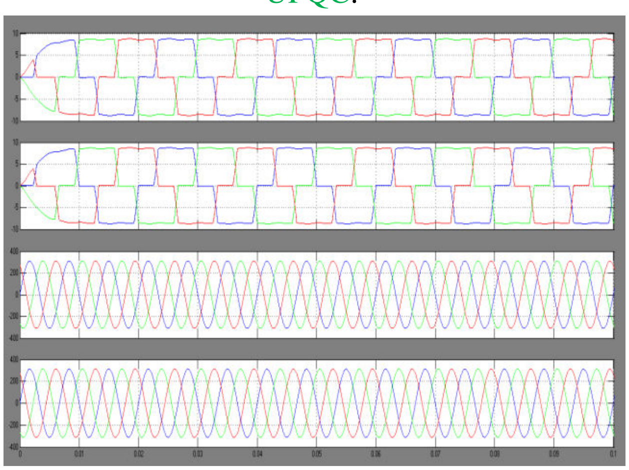

fig.12 Source & Load currents and voltages

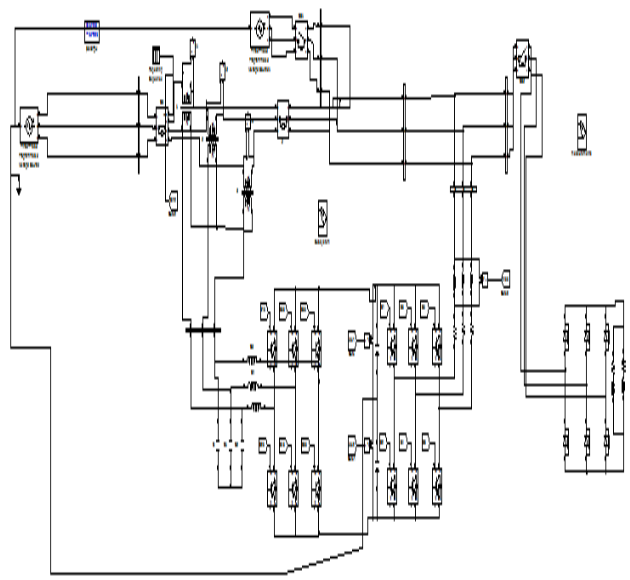

Fig.11.Matlab/Simulation model of Integration technique of the UPQCμG−IR.

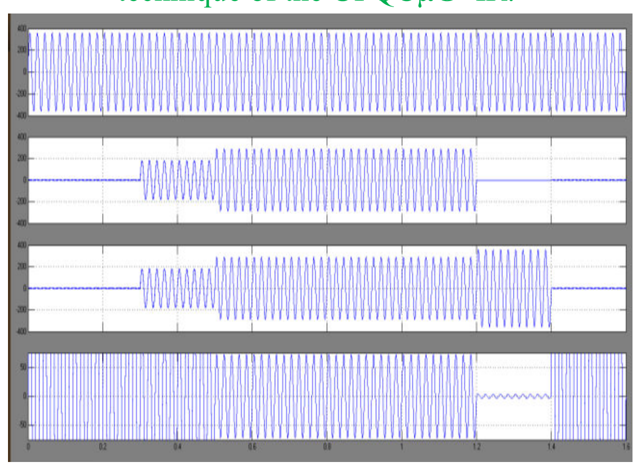

Fig.12.Voltage waveforms at different conditions and positions in the network.

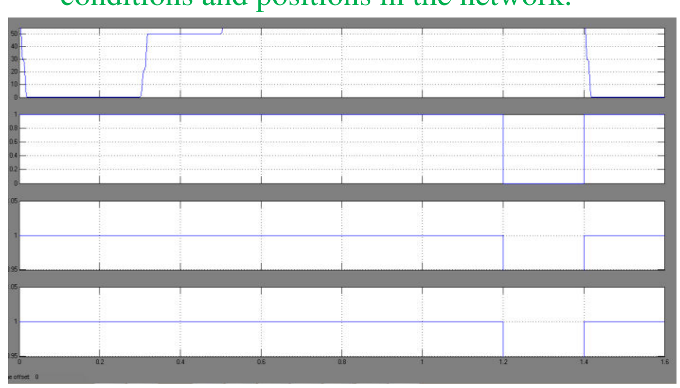

Fig. 13. Switching positions during the operation.

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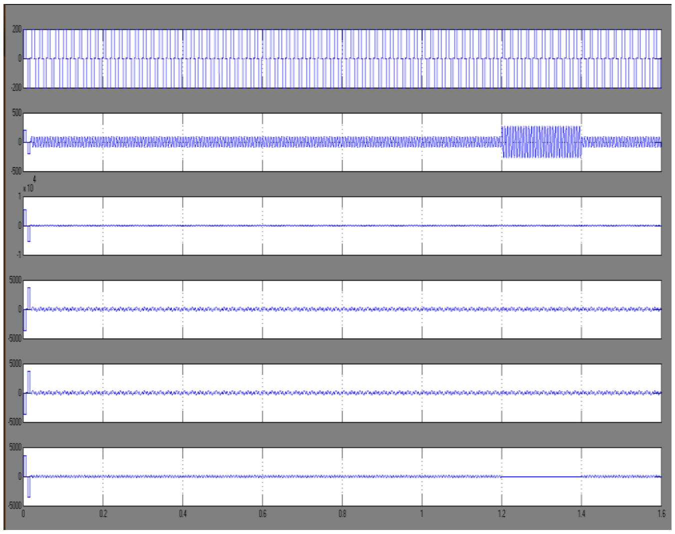

Fig.14.Current waveforms at different conditions and positions in the network.

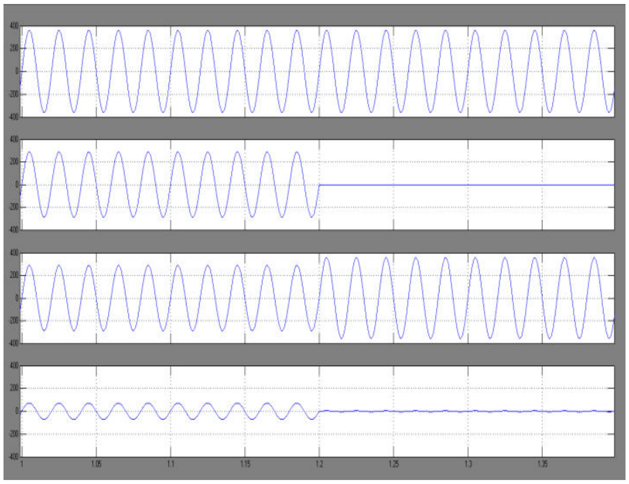

Fig.15.APFse.

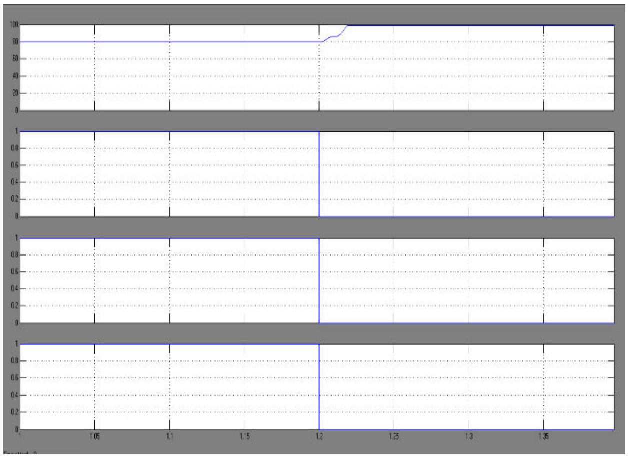

Fig. 16. Performance of Switching (S2 and S3 are open).

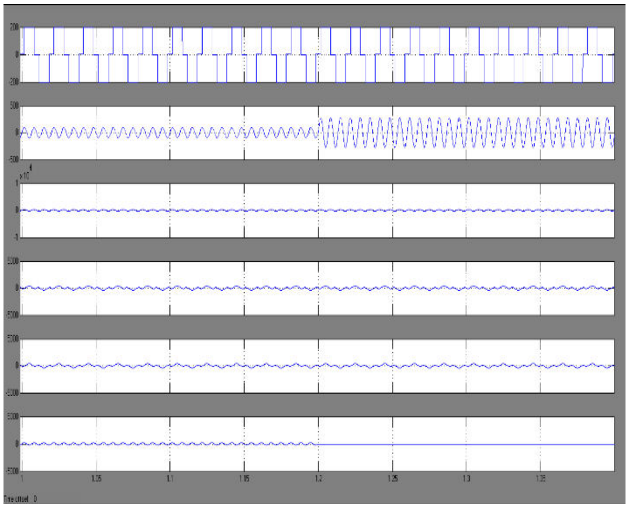

Fig.17.APFsh during islanded mode.

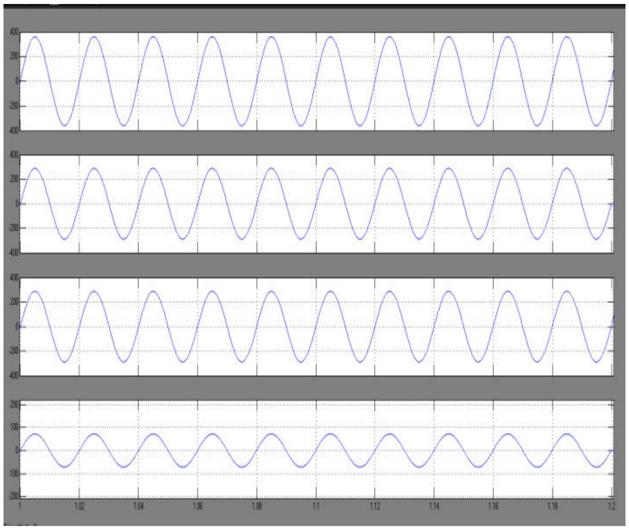

Fig.18.APFse (S3 is closed).

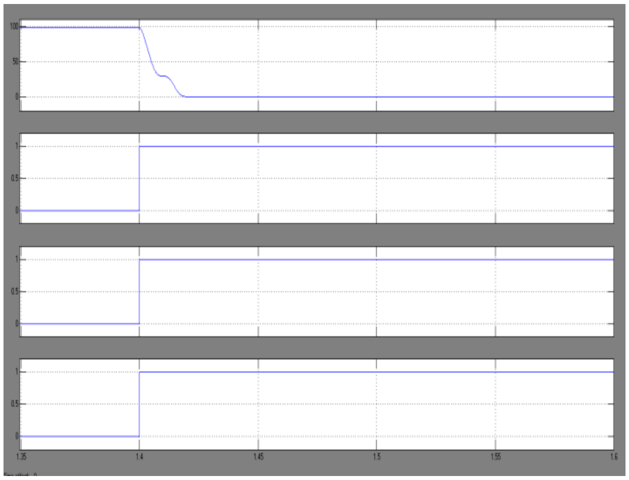

Fig.19.Switching (S2 and S3 instances are shown).

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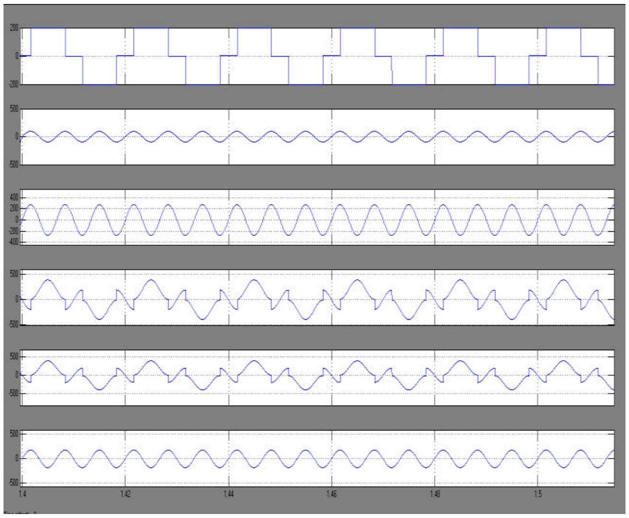

Fig.20.APFsh (S2 is closed as shown in switching diagram).

With Fuzzy logic controller

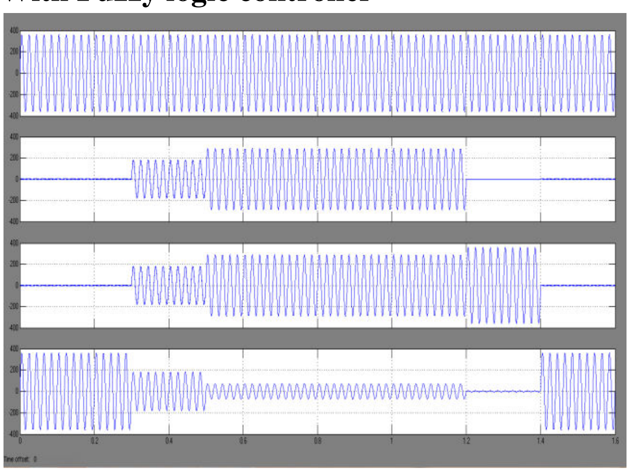

Fig.12.Voltage waveforms at different conditions and positions in the network.

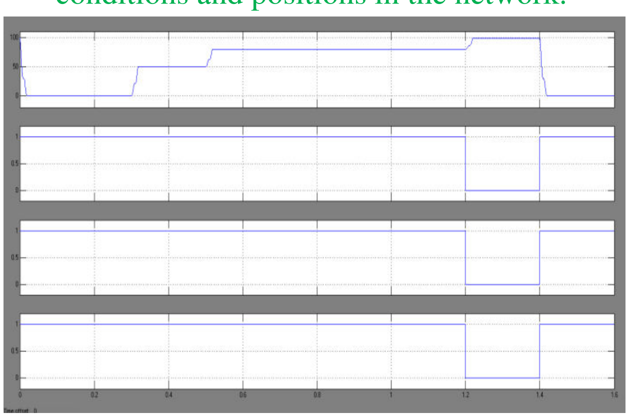

Fig. 13. Switching positions during the operation.

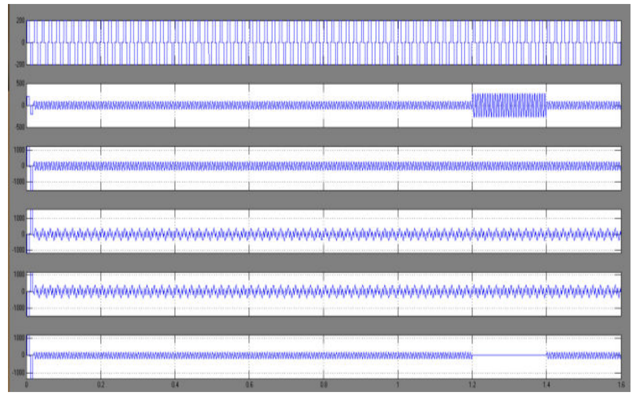

Fig.14.Current waveforms at different conditions and positions in the network.

V.CONCLUSION

This paper describes a control and integration of islanding and reconnection technique of the proposed UPQCmicro grid-IR in the grid connected micro grid condition. The performance with off-line simulation has been obtained. The results show that the UPQCmicrogrid-IR can compensate the voltage and current disturbance at the Point of Common Coupling during the interconnected mode. In islanded mode, the DG converters only supply the active power. This paper describes a powerful control and integration technique of the proposed UPQCμG−IR in the grid connected μG condition using fuzzy logic controller. The real-time performance with off-line simulation has been obtained using MATLAB and RT-LAB in real-time simulator by OPAL-RT. The dynamic change with bidirectional power flow are validated in real-time for a DG integrated μG System without compromising on power quality.

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