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# Power Quality & Unified Compensator using Distributed Generation Intelligent & Islanding Detection

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## ABSTRACT

*A new proposal for the placement, integration, and control of unified power quality conditioner (UPQC) in distributed generation (DG)-based grid connected/autonomous microgrid/micro generation (μG) system has been presented here. The DG converters (with storage) and the shunt part of the UPQC Active Power Filter (APFsh) is placed at the Point of Common Coupling (PCC). The series part of the UPQC (APFse) 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 μG−IR. The advantages of the proposed UPQC μG−IR over the normal UPQC are to compensate voltage interruption in addition to voltage sag/swell, harmonic and reactive power compensation in the interconnected mode. During the interconnected and islanded mode, DG converter with storage will supply the active power only and the shunt part of the UPQC will compensates the reactive and harmonic power of the load. It also offers the DG converter to remain connected during the voltage disturbance including phase jump.*

***KEYWORDS:*** *Distributed generation (DG), intelligent islanding detection (Is), micro grid, power quality, smart grid, unified power quality compensator (UPQC).*

## I. INTRODUCTION

The challenging issues of a successful integration of unified power quality conditioner (UPQC) 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 nonnative 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, anew 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, communication process between theUPQC µG and go system is mentioned in [4]. In this paper, the control technique of the presented UPQC µG in [4] 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. Hence, it is termed as UPQC µG−IR. The benefits offered byte 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 nonnative Reactive and Harmonic Power (QH) power of the load.
3. Both in the interconnected and islanded modes, the µGprovides only the active power to the load. Therefore, it can reduce the control complexity of the DG converters.
4. Islanding detection and reconnection technique is introduced in the proposed UPQC as a secondary control. A communication between the UPQC and go is also provided in the secondary control. The DG converters may not require having islanding detection and reconnection features in their control system.
5. The system can even work in the presence of a phase jump/difference (within limit) between the grid and µG.
6. Thus, the UPQCµG−IR will have the total control of the islanding detection and reconnection for a seamless operation of µG with a high-quality power service.

## II. RELATED WORK

### 2.1 Power Quality

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: 'Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

*Power Quality Problems*

For the purpose of this article, we shall define power quality problems as:

'Any power problem that results in failure or disoperation of customer equipment manifests itself as an economic burden to the user, or produces negative impacts on the environment.'

When applied to the container crane industry, the power issues which degrade power quality include:

- Power Factor
- Harmonic Distortion
- Voltage Transients
- Voltage Sags or Dips
- Voltage Swells

The AC and DC variable speed drives utilized on board container cranes are significant contributors to total harmonic current and voltage distortion. Whereas SCR phase control creates the desirable average power factor, DC SCR drives operate at less than this. In addition, line notching occurs when SCR's commutate, creating transient peak recovery voltages that can be 3 to 4 times the nominal line voltage depending upon the system impedance and the size of the drives. The frequency and severity of these power system disturbances varies with the speed of the drive. Harmonic current injection by AC and DC drives will be highest when the drives are operating at slow speeds. Power factor will be lowest when DC drives are operating at slow speeds or during initial acceleration and deceleration periods, increasing to its maximum value when the SCR's are fazed on to produce rated or base speed. Above base speed, the power factor essentially remains constant. Unfortunately, container cranes can spend considerable time at low speeds as the operator attempts to spot and land containers. Poor power factor places a greater kava demand burden on the utility or engine-alternator power source. Low power factor loads can also affect the voltage stability which can ultimately result in detrimental effects on the Life of sensitive electronic equipment or even intermittent malfunction. Voltage transients created by DC drive SCR line notching, AC drive voltage chopping, and high frequency harmonic voltages and currents are all significant sources of noise and disturbance to sensitive electronic equipment

It has been our experience that end users often do not associate power quality problems with Container cranes, either because they are totally unaware of such issues or there was no economic Consequence if power quality was not addressed. Before the advent of solid-state power supplies, Power factor was reasonable, and harmonic current injection was minimal. Not until the crane Population multiplied, power demands per crane increased, and static power conversion became the way of life, did power quality issues begin to emerge. Even as harmonic distortion and power Factor issues surfaced, no one was really prepared. Even today, crane builders and electrical drive System vendors avoid the issue during competitive bidding for new cranes. Rather than focus unawareness and understanding of the potential issues, the power quality issue is intentionally or unintentionally ignored. Power quality problem solutions are available. Although the solutions are not free, in most cases, they do represent a good return on investment. However, if power quality is not specified, it most likely will not be delivered.

## III. IMPLEMENTATION

### 3.1 Controller Design

The block diagram of the proposed UPQC$\mu$G–IR controllers shown in Fig. 4. It has the same basic functionality as theUPQC controller except for the additional islanding detection and reconnection capabilities. A communication channel (signals transfer) between the proposed UPQC$\mu$G–IR and the$\mu$G 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 [13]. Level 1 deal with the primary control of the UPQC to perform their basic functions in the interconnected and the islanded mode [14].

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 (APFse) control; 3) shunt part (APFsh) control;4) intelligent islanding detection (IsD); and 5) synchronization and reconnection (SynRec). As the is and Syn Recfeatures are new in UPQC, therefore, these have been described in details.

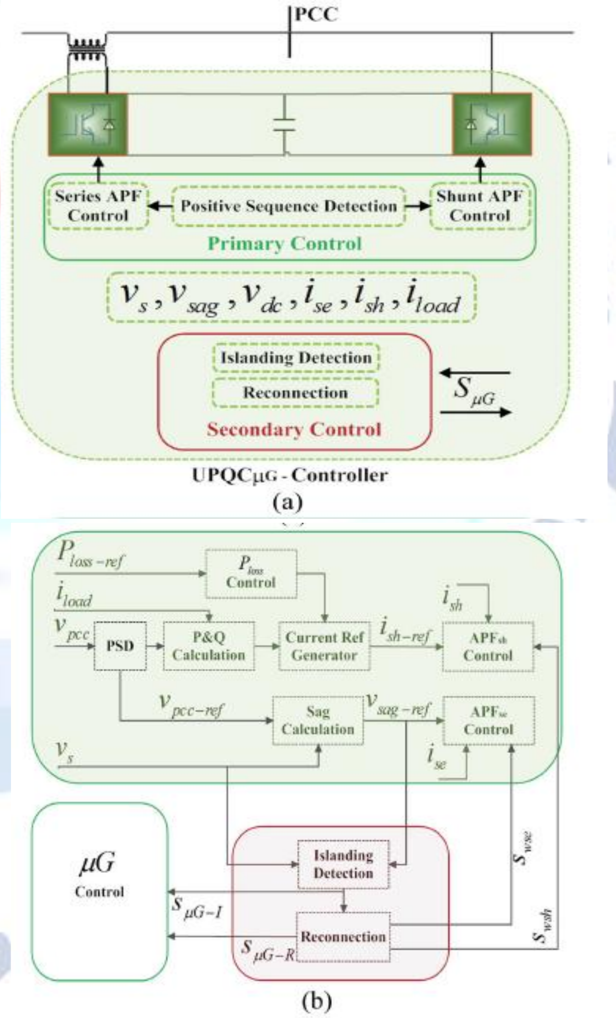


***Fig. 4. Block diagram of the UPQCμG–IR. (a) Controller. (b) Controlalgorithm.***

*A. Intelligent Islanding Detection*

Considering the future trends toward the smart-grid and 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 the $\mu$G system. In that case, the placement of APFsein the proposed integration method of the system plays an important role by extending the operational flexibility of theDG converter in the $\mu$G 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

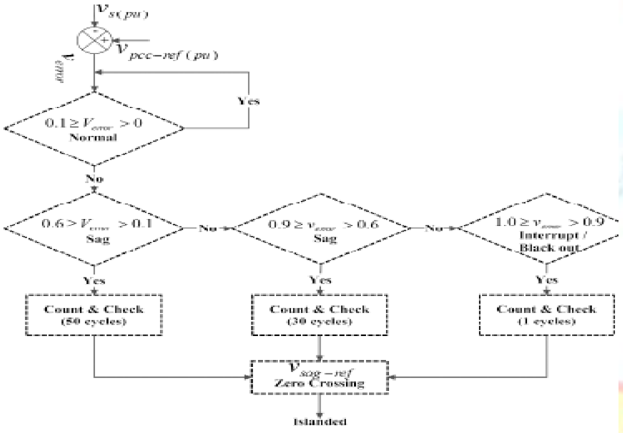


Fig. 5. Algorithm for IsD method in UPQC$_{\mu G-IR}$.

Detection is delayed in the case of hierarchical control [15].Therefore, seamless voltage transfer control between the grid connected and isolated controlled modes is very important [16]–[17]. Both indirect and direct current control techniques are proposed in [2] and [15]–[19] to mitigate the voltage transients in transition mode, but these then increase the control complexity of the $\mu$G converters.

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 maximum duration of 30 cycles [20]. Therefore, based on the islanding detection requirement and sag/swell/interrupt compensation, islanding is detected and a signal *Sag−I*, as shown in Fig. 4(b), is also generated in the proposed UPQC $\mu$G−IRto 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 detection technique or even can be removed formal the DG converters in a $\mu$G 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 *V*pcc-ref (pu) and *V*s (pu) is *V*error. This error is then compared with the preset values (0.1–0.9) and a waiting period (user defined *n* cycles) issued to determine the sag/interrupt/islanding condition. In this example: 1) if *V*error is less than or equal to 0.6, then 60%sag will be compensated for up to 50 cycles; 2) if *V*error is in between 0.6 and 0.9, then compensation will be for 30 cycles; and 3) otherwise (if *V*error ≥ 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 *V*error 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 in [16], an additional module named ICA is connected to an existing $\mu$G with number of current sources. The ICA module acts as voltage source to fix the voltage and frequency in islanding mode and able to guarantee seamless connection/disconnection of the $\mu$G 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 $\mu$G, 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 no detection zone (NDZ) increases with the number fop inverters, since they are not able to distinguish between the external grid 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 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.

### *B. Synchronization and Reconnection*

Once the grid system is restored, the *g*o may be reconnected to the main grid and return to its pre disturbance condition. A smooth reconnection can be achieved when the difference between the voltage magnitude, phase, and frequency of the two buses are minimized or close to zero. The seamless reconnection also depends on the accuracy and performance of the synchronization methods [21]–[22]. In case of UPQC $\mu$G−IR, reconnection is performed by the APFse.In addition, due to the control of sag/swell by the APFse, this UPQC $\mu$G−IR has the advantage of reconnection even in case of phase jump/difference (up to a certain limit) between the voltage of the utility and at the PCC. This obviously increases the operational flexibility of the *g*o system with high-power quality. The phase difference limit depends on the rating of the APFse and the level of *V*sag-max required for compensation. This limit can be calculated using (1) and Fig. 2. It is also discussed in [6]. Assuming that the possible *V*sag-max= *V*s = *V*pcc, the

$\theta_{\text{sag-max}}$ can be found as

$$\theta_{\text{sag-max}} = \cos\left[(\theta_s - \theta_{\text{pcc}})\right]^{-1} = 1/2 = 60^\circ. \quad (13)$$

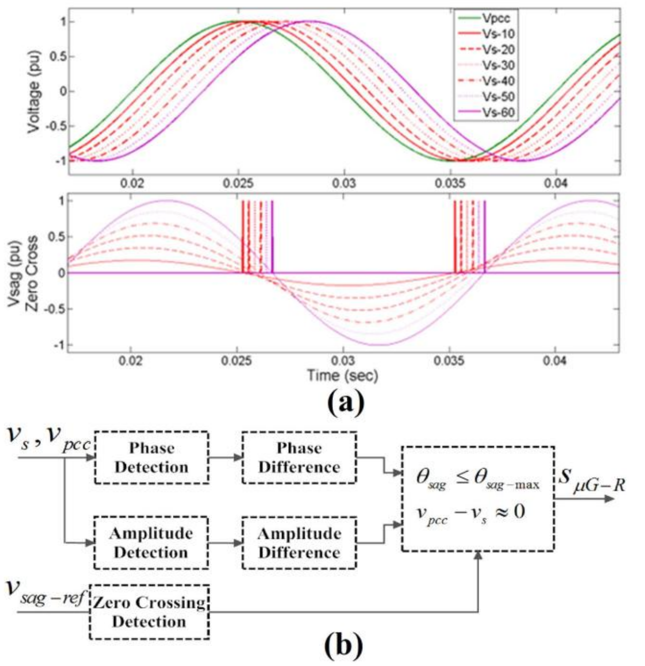


***Fig. 6. (a) Position of Vs and Vpcc for different phase differences to measure TheVsag and Vsag-ref. (b) SynRec.***

The relation for the phase difference and magnitude between*'s, V*pcc, and *V*sag are also shown in Fig. 6(a). It also shows the zero-crossing point of the *V*sag-ref depending upon the phase. This zero-crossing detection also indicates the point at which the instantaneous voltage difference between the utility and the PCC becomes zero. Detection of this zero-crossing point and activation of the switches S2 and S3, as shown in Fig. 1, at the same time are the key control of this reconnection method for seamless transfer from the off-grid to the on-grid conditionals well as changing the controller of the DG inverter from voltage to current control mode.

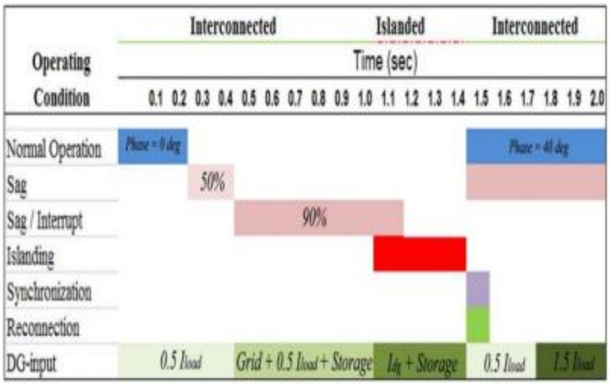
The reconnection method is shown in Fig. 6(b). Conditions for reconnection are set as: 1) assuming the phase difference between the utility grid and DG unit should be within *θ*sag-max; 2) instantaneous value of the two bus voltages becomes equal; and 3) these should occur at the zero-crossing condition. Once the utility supply is available after a blackout, a synchronization pulse (generated in reconnection process) is enabled to start synchronization. A simple logic sequence is then created, based on the condition shown in Fig. 6(b), to generate the active pulse for S2 and S3 to return the system in the interconnected mode.

At the same time *S*$\mu$G−*R*, asshown in Fig. 4(b) is also transferred to the $\mu$G system for reconnection.The other advantage is that, IsD and SynRec methods have been carried out as a secondary control in Level 2, i.e., these can also be added in conventional UPQC system as an additional block to convert it to UPQC $\mu$G−IR. It is to be noted that the proposed UPQC $\mu$G−IR will be helpful to meet the required advanced grid integration features as mentioned in [7].

## IV. EXPERIMENTAL WORK

A 3-phase, 3-wire active distribution network (230 VL−N) with the proposed UPQC µG−IR and µG, as shown inFig.1, has been developed in the MATLAB using RT-LAB (real time simulation) tools to observe the performance in the real-time environment. The system is then tested in software-in-loop (SIL), i.e., both the controller and plant are simulated and controlled with the help of real-time communication through external AD/DA cards with appropriate time delay, which is termed as the hardware synchronization mode. Fig.7 shows the real-time simulation structure in a SIL configuration used to develop the real-time environment by OPAL-RT.

*Table I: Timeline of The Operating Conditions*



| Operating Condition | Interconnected | | | | | | | | | | Islanded | | | | | Interconnected | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time (sec) | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 |
| Normal Operation | Phase = 0 deg | | | | | | | | | | | | | | | Phase = 40 deg | | | | |
| Sag | | | | 50% | | | | | | | | | | | | ▨ | | | | |
| Sag / Interrupt | | | | | | 90% | | | | | | | | | | | | | | |
| Islanding | | | | | | | | | | | 🟥 | | | | | | | | | |
| Synchronization | | | | | | | | | | | | | | | | 🟪 | | | | |
| Reconnection | | | | | | | | | | | | | | | | 🟩 | | | | |
| DG-input | 0.5 $I_{load}$ | | | | | Grid + 0.5 $I_{load}$ + Storage | | | | | $I_{dg}$ + Storage | | | | | 0.5 $I_{load}$ | | | 1.5 $I_{load}$ | |

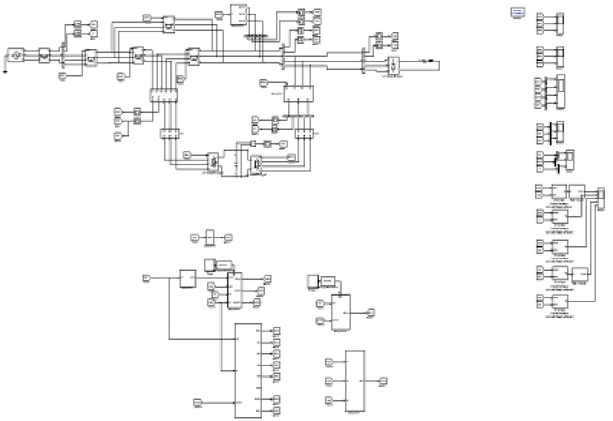


***Fig.12. Mat lab model for proposed method***

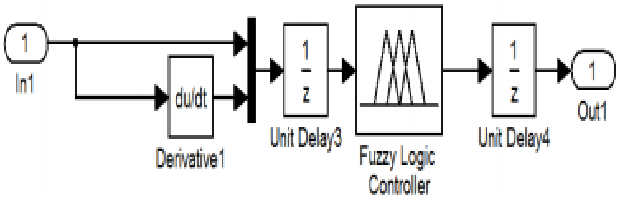
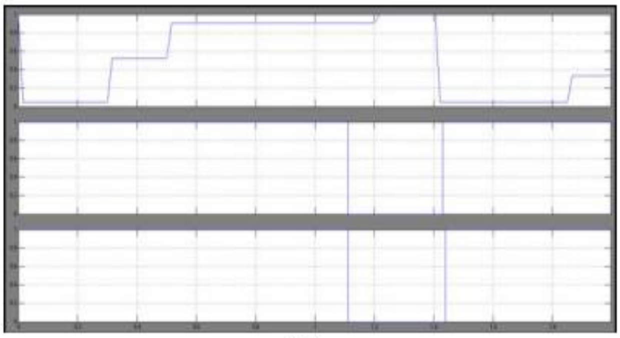
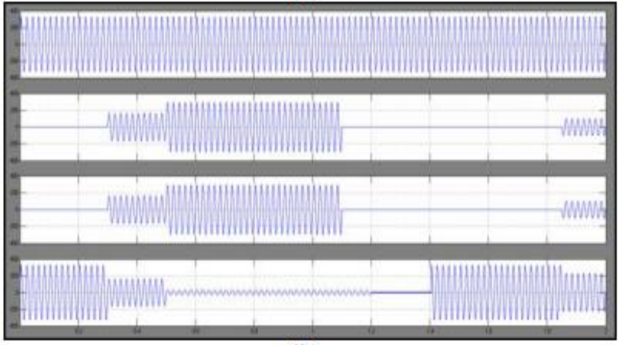


***Fig.13. Fuzzy logic controller***



(a)



(b)

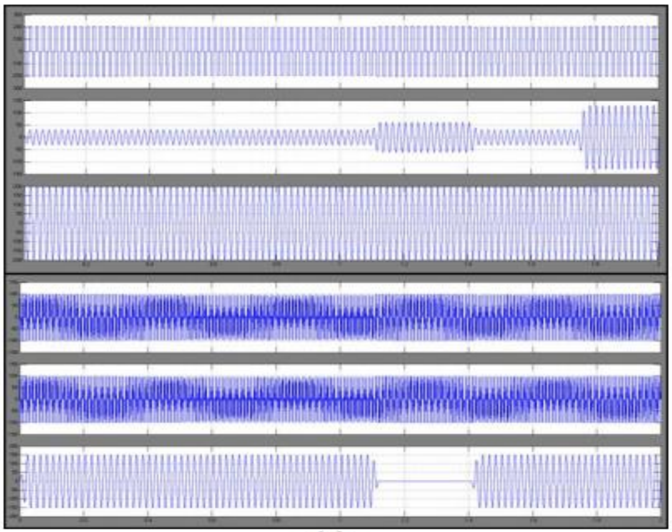


***Fig. 14. (a) Switching positions during theoperation. (b) Voltage and (c) current waveforms atdifferent conditions and positions in the network.***

## V. CONCLUSION

This paper describes a powerful control and integration technique of the proposed UPQC µG−IR in the grid connected condition. The real-time performance with off-line simulation has been obtained using MATLAB and RT-LAB in real-time simulator by OPAL-RT. The results show hat the UPQC µG−IR can compensate the voltage and current disturbance at the PCC during the interconnected mode. Performances also observed in bidirectional power flow condition. In islanded mode, the DG converters only supply the active power. Therefore, the DG converters do not need to be disconnected or change their control strategy to keep the µG operating in any time with any condition. Islanding detection and seamless reconnection technique by the UPQC µG−IR and 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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