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A NOVEL IMPROVED UPQC CONTROLLER TO PROVIDE ADDITIONAL GRID VOLTAGE REGULATION AS A STATCOM FOR NON-LINEAR LOADS

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Abstract: This paper introduces an enhanced controller for the double topology of the brought together power quality conditioner (iUPQC) expanding its pertinence in control quality remuneration, and additionally in microgrid applications. By utilizing this controller, past the customary UPQC control quality highlights, including voltage list/swell pay, the iUPQC will likewise give responsive power support to manage the heap transport voltage as well as the voltage at the matrix side transport. As it were, the iUPQC will act as a static synchronous compensator (STATCOM) at the matrix side, while giving likewise the regular UPQC pay at the heap or microgrid side. Test comes about are given to confirm the new usefulness of the gear.

Keywords: iUPQC, Microgrid, Topology, Functionality, Equipment.

I. INTRODUCTION

The present power conveyance framework is typically designed as a three-stage three-wire or four-wire structure highlighting a power-restrict voltage source with critical source impedance, and a collection of different sorts of burdens. In a perfect world, the framework ought to give an adjusted and unadulterated sinusoidal three-stage voltage of consistent adequacy to the heaps; and the heaps should draw a current from the line with solidarity control factor, zero sounds, and adjusted stages. To four-wire frameworks, no unreasonable impartial current should exist. Thus, the most extreme power limit and effectiveness of the vitality conveyance are accomplished, least irritation to different apparatuses is guaranteed, and safe operation is justified. In any case, with a quick expanding number of utilizations of industry gadgets associated with the dissemination frameworks today, including nonlinear, exchanging, receptive, single-stage and uneven three-stage stacks, an unpredictable issue of energy quality developed described by the voltage and current sounds, unbalances, low Power Factor (PF). As of late dynamic strategies for control quality control have turned out to be more appealing contrasted with uninvolved ones due with their quick reaction, littler size, and higher execution. For instance, Static VAR Compensator (SVC) have been accounted for to enhance the power factor; Power Factor Corrector (PFC) and Active Power Filters (APF) have the capacity of current sounds concealment and power factor rectification; some dynamic circuits were produced to repay uneven streams and additionally confine the nonpartisan current. All in all, parallel-associated converters can enhance the present quality while the arrangement associated controllers embedded between the heap and the supply, enhance the voltage quality. For voltage and current quality control, both arrangement and shunt converters are essential, which is known as Unified Power Quality Conditioner (UPQC) and have been dissected in this postulation. UPQC was exhibited amid 1998. Such arrangement can make up for various power quality marvels, for example, lists, swells, voltage awkwardness, flash, music and receptive streams. UPQC more often than not comprises of two voltage-source converters having the same capacitive DC connect. One of the converters is a dynamic rectifier (AR) or shunt dynamic channel while other is an arrangement dynamic channel (SF). Likewise, at the purpose of the heap association, uninvolved channel banks are associated. In UPQC the arrangement dynamic power channel kills supply voltage glint/unevenness from the heap terminal voltage and powers a current shunt inactive channel to retain all the present sounds delivered by a nonlinear load. The shunt dynamic channel performs dc connect voltage control, consequently prompting a critical diminishment of limit of dc interface capacitor. This class talks about different power quality issues and arrangements with an accentuation on the UPQC.

II. CUSTOM POWER DEVICES

Initially for the improvement of power quality or reliability of the system FACTS devices like static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), interline power flow controller (IPFC), and unified power flow controller (UPFC) etc are introduced. These FACTS devices are designed for the transmission system. But now a day as more attention is on the distribution system for the improvement of power quality, these devices are modified and known as custom power devices. The term ―custom power‖ describes the value-added power that electric utilities will offer to their customers. The value addition involves the application of high power electronic controllers to distribution systems, at the supply end of industrial, commercial consumers. The main custom power devices which are used in distribution system for power quality improvement are distribution static synchronous compensator (DSTATCOM), dynamic voltage Restorer (DVR), active filter (AF), unified power quality conditioner (UPQC) etc. N.G Hingorani was the first to propose FACTS controllers for improving PQ. He termed them as Custom Power Devices CPD). These are based on VSC and are of 3 types given below.

- Shunt connected Distribution STATCOM (DSTATCOM)
- Series connected Dynamic Voltage Restorer (DVR)
- Combined shunt and series, Unified Power Quality Conditioner (UPQC).

The DVR is similar to SSSC while UPQC is similar to UPFC. In spite of the similarities, the control techniques are quite different for improving PQ. A major difference involves the injection of harmonic currents and voltages to separate the source from the load. A DVR can work as a harmonic isolator to prevent the harmonics in the source voltage reaching the load in addition to balancing the voltages and providing voltage regulation. A UPQC can be considered as the combination of DSTATCOM and DVR. A DSTATCOM is utilized to eliminate the harmonics from the source currents and also balance them in addition to providing reactive power compensation to improve power factor or regulate the load bus voltage. Several power providers have installed custom power devices for mitigating power quality problems. In particular, three major power quality devices (PQDs)—an advanced static VAR compensator, a dynamic voltage restorer, and a high-speed transfer switch are used these days. Over the past ten years, advanced power electronic devices have been the center of various research studies, installation projects, and development technologies. By custom power devices, we refer to power electronic static controllers used for power quality development on distribution systems rated 1 through 38 kV. This interest in the usage of power quality devices (PQDs) arises from the need of mounting power quality levels to meet the everyday growing sensitivity of consumer needs and expectations. Power quality levels, if not achieved, can cause costly downtimes and customer dissatisfaction. According to contingency planning research company's annual study, downtime caused by power disturbances results in major financial losses. In order to face these new needs, advanced power electronic devices have developed over the last years. Their performance has been demonstrated at medium distribution levels, and most are available as commercial products.

A. Need of Custom Power Devices

Power quality is one of major concerns in the present era. Distribution system locates the end of power system and is connected to the customer directly, so the reliability of power supply mainly depends on distribution system. It has become important, especially, with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure of end use equipments. The electrical distribution network failures account for about 90% of the average customer interruptions. As the customer's demand for the reliability of power supply is increasing day by day, so the reliability of the distribution system has to be increased. One of the major problems dealt here is the power sag. Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the distribution system, have numerous nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supplies is lost. This ends up producing many power quality problems. While power disturbances occur on all electrical systems, the sensitivity of today's sophisticated electronic devices makes them more disposed to the quality of power supply. For some sensitive devices, a temporary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valuable components. To solve this problem, custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance.

B. Configurations

The compensating type custom power devices can be classified on the basis of different topologies and the number of phases. For power quality improvement the voltage source inverter (VSI) bridge structure is generally used for the development of custom power devices, while the use of current source inverter (CSI) is less reported. The topology can be shunt (DSTATCOM), series (DVR), or a combination of both (UPQC).

C. Converter Based Classification

For the development of compensating type custom power devices the VSI is used usually, because of self-supporting dc voltage bus with a large dc capacitor, while the use of CSI is less reported. The current source inverter topology finds it application for the development of active filters, DSTATCOM and UPQC. The voltage source inverter topology is popular because it can be expandable to multilevel, multi-step and chain converters to enhance the performance with lower switching frequency and increased power handling capacity. In addition to this, this topology can exchange a considerable amount of real power with energy storage devices in place of the dc capacitor.

1.Topology Based Classification

Compensating type custom power devices can be classified based on the topology used as shunt (DSTATCOM), series (DVR) and combination of both series and shunt (UPQC). DSTATCOM is most widely used for power factor correction, to eliminate current based distortion and load balancing, when connected at the load terminals. DVR can perform voltage regulation when connected to a distribution bus.

2. DSTATCOM

A DSTATCOM is a custom power device which is utilized to eliminate the harmonics from the source currents and also balance them in addition to providing reactive power compensation to improve power factor or regulate the load bus voltage.

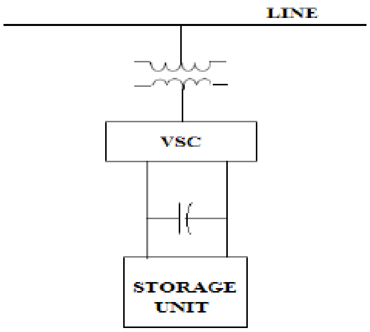

Fig.1. Distribution Shunt Connected STATCOM

3. DVR (Dynamic Voltage Restorer)

A DVR is a custom power device which can work as a harmonic isolator to prevent the harmonics in the source voltage reaching the load in addition to balancing the voltages and providing voltage regulation.

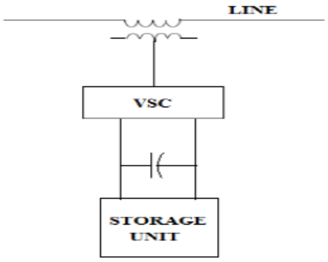

Fig.2. Series Connected Dynamic Voltage Restorer

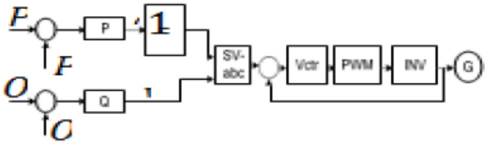

Fig.3. Real and Reactive Power Control through Voltage Regulation in Grid-Connected Mode

In grid connected mode, the main target for the inverter control is to control the power injected into the grid. The power command can be generated by the micro-grid management system or the maximum power tracking system. When the reactive power command is zero, the output current and voltage are in phase with each other, the unity power factor is obtained. Generally, there are two ways to control the power: through output voltage regulation; through output current regulation.

4.UPQC(Unified Power Quality Conditioner)

A UPQC is also a custom power device which can be considered as the combination of DSTATCOM and DVR.

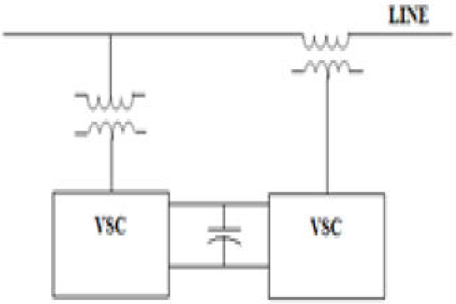

Fig.4. Unified Power Quality Conditioner

D. Supply System Based Classification

This classification of compensating devices is based on the supply and/or the load system having single-phase (two wire) and three-phase (three-wire or four-wire) systems. There are many nonlinear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase nonlinear loads are without neutral, such as ASD's, fed from three-wire supply systems. There are many nonlinear single-phase loads distributed on four-wire three-phase supply systems, such as computers, commercial lighting, etc. Hence, compensating devices may also be classified accordingly as two-wire, three wire, and four-wire types.

E. Benefits with the Application of Custom Power Devices.

The custom power devices such as DVR, DSTATCOM, UPQC, etc are used to increase the reliability of the distribution system by providing voltage support at critical buses in the system (with series connected controllers) and regulate power flow in critical lines (with shunt connected controllers like DSTATCOM. Both voltage and power flow are controlled by the combined series and shunt controller which is known as UPQC. As we know that the power electronic control is quite fast and this enables regulation both under steady state and dynamic conditions as compared to other controllers when the system is subjected to disturbances. The benefits due to custom power devices are listed below.

- The power flow in critical lines can be improved as the operating margins can be reduced by fast controllability.

- The power carrying capacity of lines can be increased to values up to the thermal limits by imposed by current carrying capacity of the conductors).
- The transient stability limit is improved thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.
- They contribute to best possible system operation by improving voltage profile and reducing power losses.
- The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations.
- FACTS controllers such as TCSC can counter the problem of Sub synchronous Resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal power stations (with turbo generators).
- The problem of voltage fluctuations and in particular, dynamic over voltages can be overcome by these controllers.
- The problem of starting voltage dip in case of industrial loads like induction motor can also be reduced by these devices.

F. Unified Power Quality Conditioner (UPQC) A Unified Power Quality Conditioner (UPQC) is relatively a new member of the custom power device family. It is a comprehensive custom power device, with integrated shunt and series active filters. The cost of the device, which is higher than other custom power/FACTS devices, because of twin inverter structure and control complexity, will have to be justified by exploring new areas of application where the cost of saving power quality events outweighs the initial cost of installation. Distributed generation (such as wind generation) is one field where the UPQC can find its potential application. There has been a considerable increase in the power generation from wind farms. This has created the necessity for wind farms connectivity with the grid during power system faults, voltage sags and frequency variations. The application of active filters/custom power devices in the field of wind generation to provide reactive power compensation, additional fault ride through capability and to maintain Power Quality (PQ) at the point of common coupling is gaining popularity. Wind generation like other forms of distributed generation often relies on power electronics technology for flexible interconnection to the power grid. The application of power electronics in wind generation has resulted in improved power quality and increased energy capture. The rapid development in power electronics, which has resulted in high kVA rating of the devices and low price per kVA, encourages the application of such devices at distribution level. This work focuses on development of a laboratory prototype of a UPQC, and investigation of its application for the flexible grid integration of fixed and variable speed wind generators through dynamic simulation studies.A DSP based fully digital controller and interfacing hardware has been developed for a 24 kVA (12 kVA-shunt compensator and 12 kVA-series compensator) laboratory prototype of UPQC. The modular control approach facilitates the operation of the device either as individual series or shunt compensator or as a UPQC. Different laboratory tests have been carried out to demonstrate the effectiveness of developed control schemes. A simulation-based analysis is carried out to investigate the suitability of application of a UPQC to achieve Irish grid code compliance of a 2 MW Fixed Speed Induction Generator (FSIG). The rating requirement of the UPQC for the wind generation application has been investigated. A general principle is proposed to choose the practical and economical rating of the UPQC for this type of application. A concept of UPQC integrated Wind Generator (UPQC-WG) has been proposed. The UPQC-WG is a doubly fed induction machine with converters integrated in the stator and rotor circuits and is capable of adjustable speed operation. The operation of UPQC-WG under sub and super-synchronous speed range has been demonstrated. The Irish grid code compliance of the same has been demonstrated with a detailed dynamic simulation.

1. Research Motivations and Objectives

Generators driven by renewable sources such as wind that are connected to the power system at distribution level rely on a healthy power grid for proper operation. Some PQ events like voltage sag which can occur due to any fault occurring upstream of the Point of Common Coupling (PCC) can lead to mal-function and hence disconnection of these distributed generators. The disconnection of such small scale generators can lead to a deficiency in generation capacity and possibly system instability. This potential problem becomes more significant as more such generators are connected at a distribution level. Therefore, the existing grid codes for renewable sources such as wind have been revised and disconnection of generation during certain17 PQ events is to be avoided. Grid integration of this type of generation requires some special measures to be taken to achieve grid code compliance and for better operational reliability. The challenges posed by modern power systems and the search for better PQ has attracted more and more researchers into this field. Technologies such as Flexible AC Transmission Systems devices (FACTS) and custom power devices emerged as a result of continuous improvement of PQ. FACTS devices are applied in transmission level for reactive power compensation and power flow control. Therefore they improve the reliability and quality of power transmission systems. The application of power electronics to power distribution system for the benefit of a customer or group of customers is categorized under generic name-custom power devices. Though both FACTS and custom power devices are power electronics based compensators their control and operational philosophy is different. Since FACTS devices are applied in power transmission level their power ratings are higher and switching frequency is

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lower than custom power devices applied in distribution systems. FACTS devices are assumed to work under balanced sinusoidal conditions. The application of power electronics devices in the field of wind generation to provide reactive power compensation, additional fault ride through capability and to maintain PQ at the PCC is gaining popularity. A Unified Power Quality Conditioner (UPQC) is an up-to-date PQ conditioning device of the custom power device family [7-9]. The concept being relatively new is still being researched. It is speculated that this will be a universal solution to all power quality issues because of its voltage and current compensating capability. This research work focuses on the development of a laboratory prototype of a UPQC for application to problems of power quality in electrical networks. These problems

2. Unified Power Quality Conditioner-Control and New Areas of Application

A Unified Power Quality Conditioner (UPQC) is a relatively new member of the custom power device family. It is a combination of shunt and series compensators. The concept of UPQC was first introduced in 1996 by authors of [7,8]. It is speculated that almost any Power Quality (PQ) issues can be tackled with this device. Generally PQ problems arise either because of supply voltage distortion or because of load current distortion. Since a UPQC has both series and shunt compensators, it can handle supply voltage and load current problems simultaneously when installed at the point of common coupling. It can protect sensitive loads from power quality events arising from the utility side and at the same time can stop the disturbance being injected in to the utility from load side. This chapter explores the structure, different control techniques and potential new applications of the UPQC.

G. The Structure and Working Principle Of a UPQC

The UPQC is a power electronics based compensator which works on the principle of active filtering. It is a combination of Shunt (SHUC) and Series (SERC) Compensators, cascaded via a DC link capacitor. Based on the position of the SHUC and the SERC two configurations of a UPQC are possible. Schematic diagrams of the two configurations are presented in Figure 2.1 and Fig.4. Each compensator of the UPQC consists of an IGBT based full bridge inverter, which may be operated in a22 voltage or a current controlled mode depending on the control scheme. Inverter I (Series Compensator, SERC) is connected in series with the supply voltage through a low pass LC filter and a transformer. Inverter II (Shunt Compensator, SHUC) is connected in parallel to the load through a smoothing link inductor.The SERC operates as a controlled voltage source and compensates for any voltage disturbance in the network. The SHUC operates as a controlled current source and compensates for reactive or harmonic elements in the load. It also acts as a real power path and maintains the DC link voltage at a constant value by charging the DC link capacitor continuously The SHUC responsible for reactive power and load current harmonic compensation is place closer to the load side in right shunt configuration of the UPQC.

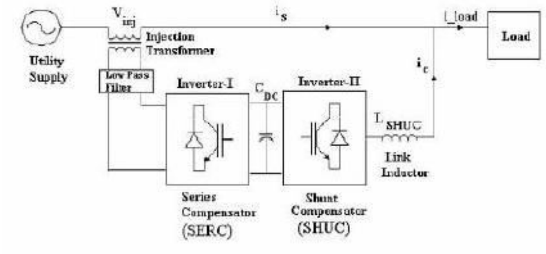

Fig.5. Right Shunt UPQC

The left shunt configuration can be achieved by swapping the position of the SHUC and the SERC (Figure 2.2). The majority of the work reported on a UPQC is on application of the right shunt UPQC, as its characteristics are more favorable than those of the left shunt UPQC in typical applications when the SHUC has to compensate for load reactive power and harmonics and the SERC has to compensate for voltage disturbances from the source side [9]. When the application of UPQC is considered for a distribution system as in [10], where UPQC has to cater for two different loads, one of which is voltage sensitive and the other generates harmonics, the left shunt configuration of UPQC is preferred

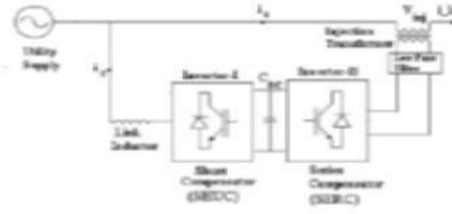

Fig.6. Left Shunt UPQC Configuration

H. Applications of UPQC

Due to the power conditioning capability of the UPQC, it can find numerous applications in the modern power systems. It is worth exploring the new areas of application of this versatile device. P. Li et al in [5] have designed a customer quality control center as a part of a flexible distribution system. Different users can choose different quality of electricity in this system. The key part of the customer quality control center is a UPQC, which assures high quality power to important users. Correa J.M. et al in [6] report the application of a UPQC in a high frequency AC micro-grid.31 The micro-grid consists of small generators with local loads. The UPQC, when connected at the high frequency common bus, compensates for reactive power, load current harmonics and voltage distortions.

III. PROPOSED SYSTEM

In order to clarify the applicability of the improved iUPQC controller, Fig. 1 depicts an electrical system with two buses in spotlight, i.e., bus A and bus B. Bus A is a critical bus of the power system that supplies sensitive loads and serves as point of coupling of a microgrid. Bus B is a bus of the microgrid, where nonlinear loads are connected, which requires premium-quality power supply. The voltages at buses A and B must be regulated, in order to properly supply the sensitive loads and the nonlinear loads. The effects caused by the harmonic currents drawn by the nonlinear loads should be mitigated, avoiding harmonic voltage propagation to bus A. The use of a STATCOM to guarantee the voltage regulation at bus A is not enough because the harmonic currents drawn by the nonlinear loads are not mitigated. On the other hand, a UPQC or an iUPQC between bus A and bus B can compensate the harmonic currents of the nonlinear loads and compensate the voltage at bus B, in terms of voltage harmonics, unbalance, and sag/swell. Nevertheless, this is still not enough to guarantee the voltage regulation at bus A. Hence, to achieve all the desired goals, a STATCOM at bus A and a UPQC (or an iUPQC) between buses A and B should be employed. However, the costs of this solution would be unreasonably high. An attractive solution would be the use of a modified iUPQC controller to provide also reactive power support to bus A, in addition to all those functionalities of this equipment, as presented in and . Note that themodified iUPQC serves as an intertie between buses A and B.Moreover, the microgrid connected to the bus B could be a complex system comprising distributed generation, energy management system, and other control systems involving microgrid, as well as smart grid concepts .

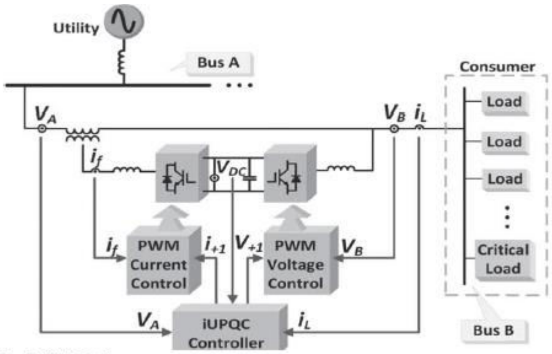

Fig.7. iUPQC

In summary, the modified iUPQC can provide the following functionalities:

- smart‖ circuit breaker as an intertie between the grid and the microgrid;
- energy and power flow control between the grid and the microgrid (imposed by a tertiary control layer for the microgrid);
- reactive power support at bus A of the power system;
- voltage/frequency support at bus B of the microgrid;
- harmonic voltage and current isolation between bus A and bus B (simultaneous grid-voltage and load-current active filtering capability);
- voltage and current imbalance compensation.

The functionalities (d)–(f) previously listed were extensively explained and verified through simulations and experimental analysis [14]–[18], whereas the functionality (c) comprises the original contribution of the present work. Fig. 2 depicts, in detail, the connections and measurements of the iUPQC between bus A and bus B. According to the conventional iUPQC controller, the shunt converter imposes a controlled sinusoidal voltage at bus B, which corresponds to the aforementioned functionality (d). As a result, the shunt converter has no further degree of freedom in terms of compensating active- or reactive-power variables to expand its functionality. On the other hand, the series converter of a conventional iUPQC uses only an active-power control variable *p*, in order to synthesize a fundamental sinusoidal current drawn from bus A, corresponding to the active power demanded by bus B. If the dc link of the iUPQC has no large energy storage system or even no energy source, the control variable *p* also serves as an additional active-power reference to the series converter to keep the energy inside the dc link of the iUPQC balanced. In this case, the losses in the iUPQC and the active power supplied by the shunt converter must be quickly compensated in the form of an additional active power injected by the series converter into the bus B. The iUPQC can serve as: a) ―smart‖ circuit breaker and as b) power flow controller between the grid and the microgrid only if the compensating active- and reactive-power references

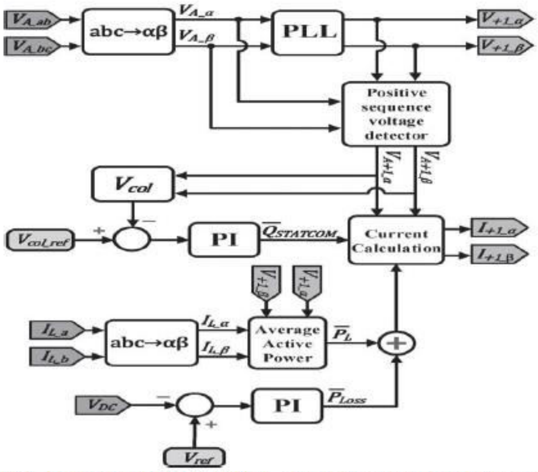

Fig.8. Novel Iupqc Controller. of the Series Converter Can Be Set Arbitrarily.

In this case, it is necessary to provide an energy source (or large energy storage) associated to the dc link of the iUPQC.The last degree of freedom is represented by a reactive-power control variable *q* for the series converter of the iUPQC. In this way, the iUPQC will provide reactive-power compensation like a STATCOM to the bus A of the grid. As it will be confirmed, this functionality can be added into the controller without degrading all other functionalities of the iUPQC. Amplitude and frequency. Consequently, the signals sent to the PWM controller are the phase-locked loop (PLL) outputs with amplitude equal to 1 p.u. There are many possible PLL algorithms, which could be used in this case, as verified in [29]–[33]. In the original iUPQC approach as presented in [14], the shunt-converter voltage reference can be either the PLL outputs or the fundamental positive-sequence component *VA*+1 of the grid voltage

$$\begin{bmatrix} V_{A\_\alpha} \\ V_{A\_\beta} \end{bmatrix} = \begin{bmatrix} 1 & 1/2 \\ 0 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{A\_ab} \\ V_{A\_bc} \end{bmatrix} \qquad (1)$$

The use of *VA*+1 in the controller is useful to minimize the circulating power through the series and shunt converters, under normal operation, while the amplitude of the grid voltage is within an acceptable range of magnitude. However, this is not the case here, in the modified iUPQC controller, since now the grid voltage will be also regulated by the modified iUPQC. In other words, both buses will be regulated independently to track their reference values. The series converter synthesizes the current drawn from the grid bus (bus A). In the original approach of iUPQC, this current is calculated through the average active power requiredby the loads *PL* plus the power *P*Loss. The load active power can be estimated by

$$PL = V{+}1\_\alpha \cdot iL\_\alpha + V{+}1\_\beta \cdot iL\_\beta \qquad (2)$$

where *iL_α*, *iL_β* are the load currents, and *V*+1_*α*, *V*+1_*β* are the voltage references for the shunt converter. A low-pass filter is used to obtain the average active power (*PL*). The losses in the power converters and the circulating power to provide energy balance inside the iUPQC are calculated indirectly from the measurement of the dc-link voltage. In other words, the power signal *P*Loss is determined by a proportional–integral (PI) controller (PI block in Fig. 3), by comparing the measured dc voltage *V*DC with its reference value. The additional control loop to provide voltage regulation like a STATCOM at the grid bus is represented by the control signal

*Q*STATCOM in Fig. 3. This control signal is obtained through a PI controller, in which the input variable is the error between the reference value and the actual aggregate voltage of the grid bus, given by The sum of the power signals *PL* and *P*Loss composes the active-power control variable for the series converter of the iUPQC (*p*) described in Section II. Likewise, *Q*STATCOM is the reactive-power control variable *q*. Thus, the current references *i*+1*α* and *i*+1*β* of the series converter are determined by

$$\begin{bmatrix} i_{+1\_\alpha} \\ i_{+1\_\beta} \end{bmatrix} = \frac{1}{V^2_{A+1\_\alpha} + V^2_{A+1\_\beta}} \begin{bmatrix} V_{A+1\_\alpha} & V_{A+1\_\beta} \\ V_{A+1\_\beta} & -V_{A+1\_\alpha} \end{bmatrix} \times \begin{bmatrix} P_L + P_{Loss} \\ Q_{STATCOM} \end{bmatrix}. \tag{3}$$

A. Power Flow in Steady State

The following procedure, based on the average power flow, is useful for estimating the power ratings of the iUPQC converters.

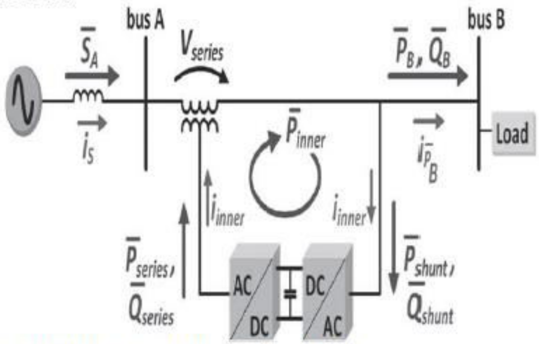

Fig.9. iUPQC Power Flow in Steady-State

For combined series–shunt power conditioners, such as the UPQC and the iUPQC, only the voltage sag/swell disturbance and the power factor (PF) compensation of the load produce a circulating average power through the power conditioners [34], [35]. According to Fig. 4, the compensation of a voltage sag/swell disturbance at bus B causes a positive sequence voltage at the coupling transformer (*V*series _= 0), since *VA* _= *VB*. Moreover, *V*series and *iPB* in the coupling transformer leads to a circulating active power *P*inner in the iUPQC. Additionally, the compensation of the load PF increases the current supplied by the shunt converter. The following analysis is valid for an iUPQC acting like a conventional UPQC or including the extra compensation like a STATCOM. First, the circulating power will be calculated when the iUPQC is operating just like a conventional UPQC. Afterward, the equations will include the STATCOM functionality to the grid bus A. In both cases, it will be assumed that the iUPQC controller is able to force the shunt converter of the iUPQC to generate fundamental voltage always in phase with the grid voltage at bus A. For simplicity, the losses in the iUPQC will be neglected. For the first case, the following average powers in steady state can be determined:

$$\begin{aligned} \overline{S}_A &= \overline{P}_B \\ \overline{Q}_{shunt} &= -\overline{Q}_B \\ \overline{Q}_{series} &= \overline{Q}_A = 0 \text{ var} \\ \overline{P}_{series} &= \overline{P}_{shunt} \end{aligned} \tag{4}$$

where *SA* and *QA* are the apparent and reactive power injected in the bus A; *PB* and *QB* are the active and reactive power injected in the bus B; *P*shunt and *Q*shunt are the active and reactive power drained by the shunt converter; *P*series and *Q*series are the active and reactive power supplied by the series converter, respectively. Equations (5) and (8) are derived from the constraint of keeping unitary the PF at bus A. In this case, the current passing through the series converter is responsible only for supplying the load active power, that is, it is in phase (or counterphase) with the voltages *VA* and *VB*. Thus, (7) can be stated. Consequently, the coherence of the power flow is ensured through (8). If a voltage sag or swell occurs, *P*series and *P*shunt will not be zero, and thus, an inner-loop current (*i*inner) will appear. The series and shunt converters and the aforementioned circulating active power (*P*inner) flow inside the equipment. It is convenient convenient to define the following sag/swell factor. Considering *VN* as the nominal voltage

$$k_{sag/swell} = \frac{|V_A|}{|V_N|} = \frac{V_A}{V_N}. \quad (5)$$

$$\sqrt{3} \cdot k_{sag/swell} \cdot V_N \cdot i_S = \sqrt{3} \cdot V_N \cdot i_{P_B}$$

$$i_S = \frac{i_{P_B}}{k_{sag/swell}} = i_{P_B} + i_{inner} \quad (6)$$

$$i_{inner} = \left| i_{P_B} \left(\frac{1}{K_{sag/swell} - 1} \right) \right|. \quad (7)$$

The circulating power is given by

$$P_{inner} = P_{series} = P_{shunt} = 3(V_B - V_A)(i_{P_B} + i_{inner}). \quad (8)$$

From (7) and (8) it follows that

$$P_{inner} = 3(V_N - V_A) \left(\frac{P_B}{3V_N} \frac{1}{k_{sag/swell}} \right) \quad (9)$$

$$P_{inner} = P_{series} = P_{shunt} = \frac{1 - K_{sag/swell}}{k_{sag/swell}} P_B. \quad (10)$$

Thus, (10) demonstrates that *P*inner depends on the active power of the load and the sag/swell voltage disturbance. In order to verify the effect on the power rate of the series and shunt converters, a full load system *SB* = *_B* = 1p.u. with PF ranging from 0 to 1 was considered. It was also considered the sag/swell voltage disturbance at bus A ranging *k*sag/swell from 0.5 to 1.5. In this way, the power rating of the series and shunt converters are obtained through (6)–(8) and (10). Fig. 9 depicts the apparent power of the series and shunt power converters. In these figures, the *k*sag/swell-axis and the PF-axis are used to evaluate the power flow in the series and shunt power converters according to the sag/swell voltage disturbance and the load power consumption, respectively. The power flow in the series converter indicates that a high power is required in case of sag voltage disturbance with high active power load consumption. In this situation, an increased *P*inner arises and high rated power converters are necessary to ensure the disturbance compensation.

IV. SIMULATION RESULTS

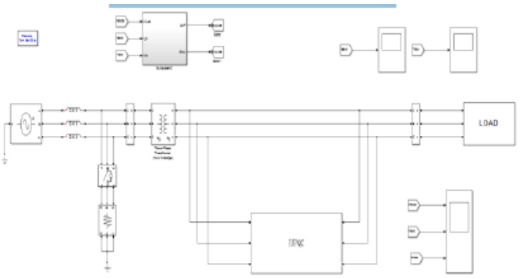

Fig.10. Simulation Model of Modified iUPQC Configuration.

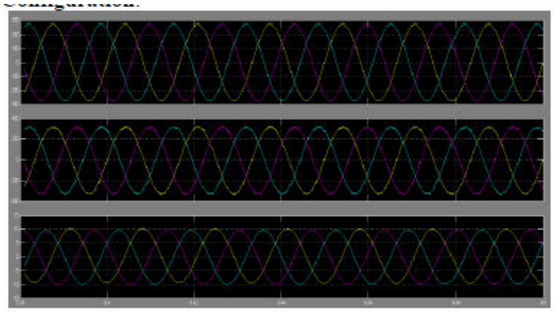

Fig.11. Simulation Result iUPQC Response at No Load Condition: (a) Grid Voltages *VA*, (b) Load Voltages *VB*, and (c) Grid Currents.

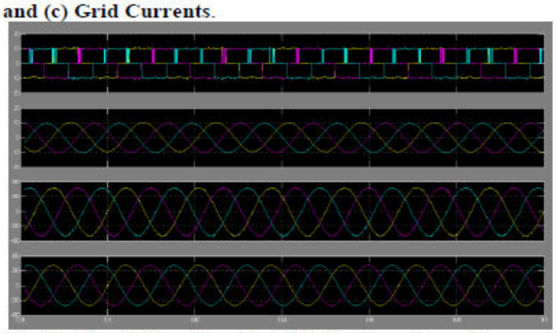

Fig.12. Simulation Results iUPQC Transitory Response During the Connection of a Threephasediode Rectifier: (a) Load Currents, (b) Grid Currents, (c) Load Voltages and (d) Grid Voltages

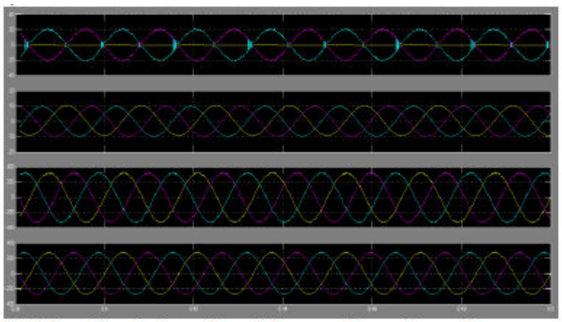

Fig.13. Simulation Resultiupqc Transitory Response During the Connection of a Twophase Diode Rectifier: (a) Load Currents, (b) Source Currents, (c) Load Voltages, and (d) Source Voltages.

V.CONCLUSION AND FUTURE SCOPE

In this paper, a new configuration for simultaneous compensation of voltage and current in adjacent feeders has been proposed. The new configuration is named multiconverter unified power-quality conditioner (MC-UPQC). Compared to a conventional UPQC, the proposed topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell, and interruption in two-feeder systems. The idea can be theoretically extended to multibus/multifeeder systems by adding more series VSCs. The performance of the MC-UPQC is evaluated under various disturbance conditions and it is shown that the proposed MC-UPQC offers the following advantages:

- power transfer between two adjacent feeders for sag/swell and interruption compensation;
- compensation for interruptions without the need for a battery storage system and, consequently, without storage capacity limitation;
- sharing power compensation capabilities between two adjacent feeders which are not connected.

The power quality issues and its consequences on the consumer and electric utility are presented. The operation of the control system developed for the UPQC in MATLAB/SIMULINK for maintaining the power quality is to be simulated. It has a capability to cancel out the harmonic parts of the load current. It maintains the source voltage and current in-phase and support the reactive power demand Further investigation can be done on shunt active power filter and robust control can be studied by designing a prototype model to demonstrate the simulation results for both balanced and unbalanced non-linear loads under distorted source voltage conditions.

VI. REFERENCES

[1]K. Karanki, G. Geddada, M. K. Mishra, and B. K. Kumar, ―A modified three-phase four-wire UPQC topology with reduced DC-link voltage rating,‖ *IEEE Trans. Ind. Electron.*, vol. 60, no. 9, pp. 3555–3566, Sep. 2013.

[2]V. Khadkikar and A. Chandra, ―A new control philosophy for a unified power quality conditioner (UPQC) to coordinate load-reactive power demand between shunt and series inverters,‖ *IEEE Trans. Power Del.*, vol. 23, no. 4, pp. 2522–2534, Oct. 2008.

[3]K. H. Kwan, P. L. So, and Y. C. Chu, ―An output regulation-based unified power quality conditioner with Kalman filters,‖ *IEEE Trans. Ind. Electron.*, vol. 59, no. 11, pp. 4248–4262, Nov. 2012.

[4]A. Mokhtatpour and H. A. Shayanfar, ―Power quality compensation as well as power flow control using of unified power

quality conditioner,‖ in *Proc. APPEEC*, 2011, pp. 1–4.

[5]J. A. Munoz *et al.*, ―Design of a discrete-time linear control strategy for a multicell UPQC,‖ *IEEE Trans. Ind. Electron.*, vol. 59, no. 10, pp. 3797– 3807, Oct. 2012.

[6]V. Khadkikar and A. Chandra, ―UPQC-S: A novel concept of simultaneous voltage sag/swell and load reactive power compensations utilizing series inverter of UPQC,‖ *IEEE Trans. Power Electron.*, vol. 26, no. 9, pp. 2414–2425, Sep. 2011.

[7]V. Khadkikar, ―Enhancing electric power quality using UPQC: A comprehensive overview,‖ *IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2284–2297, May 2012.

[8]L. G. B. Rolim, ―Custom power interfaces for renewable energy sources,‖ in *Proc. IEEE ISIE*, 2007, pp. 2673–2678.

[9]N. Voraphonpiput and S. Chatratana, ―STATCOM analysis and controller design for power system voltage regulation,‖ in *Proc. IEEE/PES Transmiss. Distrib. Conf. Exhib.—Asia Pac.*, 2005, pp. 1–6.

[10]J. J. Sanchez-Gasca, N. W. Miller, E. V. Larsen, A. Edris, and D. A. Bradshaw, ―Potential benefits of STATCOM application to improve generation station performance,‖ in *Proc. IEEE/PES Transmiss. Distrib. Conf. Expo.*, 2001, vol. 2, pp. 1123–1128.

[11]A. P. Jayam, N. K. Ardeshna, and B. H. Chowdhury, ―Application of STATCOM for improved reliability of power grid containing a wind turbine,‖ in *Proc. IEEE Power Energy Soc. Gen. Meet.—Convers. Del. Elect. Energy 21st Century*, 2008, pp. 1–7.

[12]C. A Sepulveda, J. A Munoz, J. R. Espinoza, M. E. Figueroa, and P. E. Melin, ―All-on-chip dq-frame based D-STATCOM control implementation in a low-cost FPGA,‖ *IEEE Trans. Ind. Electron.*, vol. 60, no. 2, pp. 659–669, Feb. 2013.

[13]B. Singh and S. R. Arya, ―Back-propagation control algorithm for power quality improvement using DSTATCOM,‖ *IEEE Trans. Ind. Electron.*, vol. 61, no. 3, pp. 1204–1212, Mar. 2014.

[14]M. Aredes and R. M. Fernandes, ―A dual topology of unified power quality conditioner: The iUPQC,‖ in *Proc. EPE Conf. Appl.*, 2009, pp. 1–10.

[15]M. Aredes and R. M. Fernandes, ―A unified power quality conditioner with voltage sag/swell compensation capability,‖ in *Proc. COBEP*, 2009, pp. 218–224.

[16]B. W. Franca and M. Aredes, ―Comparisons between the UPQC and its dual topology (iUPQC) in dynamic response and steady-state,‖ in *Proc. 37th IEEE IECON*, 2011, pp. 1232–1237.

[17]B. W. Franca, L. G. B. Rolim, and M. Aredes, ―Frequency switching analysis of an iUPQC with hardware-in-the-loop development tool,‖ in *Proc. 14th EPE Conf. Appl.*, 2011, pp. 1–6.

[18]B.W. Franca, L. F. da Silva, and M. Aredes, ―Comparison between alphabeta and DQ-PI controller applied to IUPQC operation,‖ in *Proc. COBEP*, 2011, pp. 306–311.

[19]R. J. Millnitz dos Santos, M. Mezaroba, and J. C. da Cunha, ―A dual unified power

quality conditioner using a simplified control technique,‖ in *Proc. COBEP*, 2011, pp. 486–493.

[20]Y. Tang *et al.*, ―Generalized design of high performance shunt active power filter with output LCL filter,‖ *IEEE Trans. Ind. Electron.*, vol. 59, no. 3, pp. 1443–1452, Mar. 2012.

[21]H. Akagi, E. Watanabe, and M. Aredes, *Instantaneous Power Theory and Applications to Power Conditioning*. New York, NY, USA:Wiley-IEEE Press, 2007.

[22]J. M. Guerrero, P. C. Loh, T.-L. Lee, and M. Chandorkar, ―Advanced control architectures for intelligent microgrids—Part II: Power quality, energy storage, and AC/DC microgrids,‖ *IEEE Trans. Ind. Electron.*, vol. 60, no. 4, pp. 1263–1270, Apr. 2013.

[23]S. R. Bowes and S. Grewal, ―Novel harmonic elimination PWM control strategies for three-phase PWM inverters using space vector techniques,‖ *Proc. Inst. Elect. Eng.—Elect. Power Appl.*, vol. 146, no. 5, pp. 495–514, Sep. 1999.

[24]M. Liserre, R. Teodorescu, and F. Blaabjerg, ―Multiple harmonics control for three-phase grid converter systems with the use of PI-RES current controller in a rotating frame,‖ *IEEE Trans. Power Electron.*, vol. 21, no. 3, pp. 836–841, May 2006.

[25]R. Teodorescu, F. Blaabjerg, U. Borup, and M. Liserre, ―A new control structure for grid-connected LCL PV inverters with zero steady-state error and selective harmonic compensation,‖ in *Proc. 19th Annu. APEC Expo.*, 2004, vol. 1, pp. 580–586.

[26]X. Yuan, W. Merk, H. Stemmler, and J. Allmeling, ―Stationary-frame generalized integrators for current control of active power filters with zero steady-state error for current harmonics of concern under unbalanced and distorted operating conditions,‖ *IEEE Trans. Ind. Appl.*, vol. 38, no. 2, pp. 523–532, Mar./Apr. 2002.

[27]D. N. Zmood and D. G. Holmes, ―Stationary frame current regulation of PWM inverters with zero steady-state error,‖ *IEEE Trans. Power Electron.*, vol. 18, no. 3, pp. 814–822, May 2003.

[28]D. N. Zmood, D. G. Holmes, and G. H. Bode, ―Frequency-domain analysis of three-phase linear current regulators,‖ *IEEE Trans. Ind. Appl.*, vol. 37, no. 2, pp. 601–610, Mar./Apr. 2001.

[29]M. Ciobotaru, R. Teodorescu, and F. Blaabjerg, ―A new-single PLL structure based on second order generalized integrator,‖ in *Proc. 37th IEEE PESC*, Jeju, Island, Korea, 2006, pp. 1–6.

[30]D. R. Costa, Jr., L. G. B. Rolim, and M. Aredes, ―Analysis and software implementation of a robust synchronizing circuit based on pq theory,‖ *IEEE Trans. Ind. Electron.*, vol. 53, no. 6, pp. 1919–1926, Dec. 2006.

[31]M.K. Ghartemani, ―A novel three-phase magnitude-phase-locked loop system,‖ *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 53, no. 8, pp. 1798–1802, Aug. 2006.

[32]M. S. Padua, S. M. Deckmann, G. S. Sperandio, F. P. Marafao, and D. Colon, ―Comparative analysis of synchronization algorithms based on PLL, RDFT and Kalman filter,‖ in *Proc. IEEE ISIE*, Jun. 2007, pp. 964–970.

[33]J. A. Moor Neto, L. Lovisolo, B. W. França, and M. Aredes, ―Robust positive-sequence detector algorithm,‖ in *Proc. 35th IEEE IECON*, Nov. 2009, pp. 788–793.

[34]V. Khadkikar, A. Chandra, A. O. Barry, and T. D. Nguyen, ―Steady state power flow analysis of unified power quality conditioner (UPQC),‖ in *Proc. ICIECA*, 2005, pp. 1–6.