

Enhancement of IUPQC Controller performance for Induction drive

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Abstract - This paper presents a dual topology of unified power quality conditioner (IUPQC) with improved controller for induction drives and grid voltage regulation. By using this controller, beyond the conventional UPQC power quality features, including voltage sag/swell compensation, the IUPQC will also provide reactive power support to regulate not only the load-bus voltage but also the voltage at the grid-side bus. In other words, the IUPQC will work as a static synchronous compensator (STATCOM) at the grid side, while providing also the conventional UPQC compensations at the load (Induction Drives). This proposed IUPQC simulated in MATLAB/SIMULINK.

Index Terms - Static Synchronous Compensator (STATCOM), Unified Power Quality Conditioner (UPQC), Total Harmonic Distortion (THD).

I. INTRODUCTION

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Reactive power plays a vital role on the security and stability of power system, therefore, the reactive power compensation device has a very wide range of application in power system. In recent years, technology of power electronics, especially flexible alternating current transmission system (FACTS), has a rapid development. As a part of FACTS, STATCOM has good performances of slightly capacity, high efficiency, fast dynamic response, good control stability and so on, and it has gradually become one of the representative techniques in the field of reactive power compensation [1]-[4]. The power circuit of a UPQC consists of a combination of a shunt active filter and a series active filter connected in a back-to-back configuration. This combination allows the simultaneous compensation of the load current and the supply voltage, so that the compensated current drawn from the grid and the compensated supply voltage delivered to the load are kept balanced and sinusoidal. The dual topology of the UPQC, i.e., the IUPQC, was presented in [9]-[10], where the shunt active filter behaves as an ac-voltage source and the series one as an ac-current source, both at the fundamental frequency. This is a key point to better design the control gains, as well as to optimize the *LCL* filter of the power converters, which allows improving significantly the overall performance of the compensator [8].

Nowadays, the STATCOM is largely used for voltage regulation [9], whereas the UPQC and the IUPQC have been selected as solution for more specific applications. Moreover, these last ones are used only in particular cases, where their relatively high costs are justified by the power quality improvement it can provide, which would be unfeasible by using conventional solutions. By joining the extra functionality like a STATCOM in the IUPQC device, a wider scenario of applications can be reached, particularly in case of distributed generation in smart grids and as the coupling device in grid-tied microgrids. The performance of the IUPQC and the UPQC was compared when working as UPQCs. The main difference between these compensators is the sort of source emulated by the series and shunt power converters. In the UPQC approach, the series converter is controlled as a non sinusoidal voltage source and the shunt one as a non-sinusoidal current source. Hence, in real time, the UPQC controller has to determine and synthesize accurately the harmonic voltage and current to be compensated. On the other hand, in the IUPQC approach, the series converter behaves as a controlled sinusoidal current source and the shunt converter as a controlled sinusoidal voltage source. This means that it is not necessary to determine the harmonic voltage and current to be compensated, since the harmonic voltages appear naturally across the series current source and the harmonic currents flow naturally into the shunt voltage source.

This paper proposes an improved controller, which expands the IUPQC functionalities. This improved version of IUPQC controller includes all functionalities including the voltage regulation at the under the large induction drive and now providing also voltage regulation at the grid-side bus, like a STATCOM to the grid. Experimental results are provided to validate the new controller design.

II. EQUIPMENT APPLICABILITY

In order to clarify the applicability of the improved IUPQC controller, Fig. 1 (a) 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 micro-grid. Bus B is a bus of the micro-grid, 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 [9]. Note that the modified 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 [11].

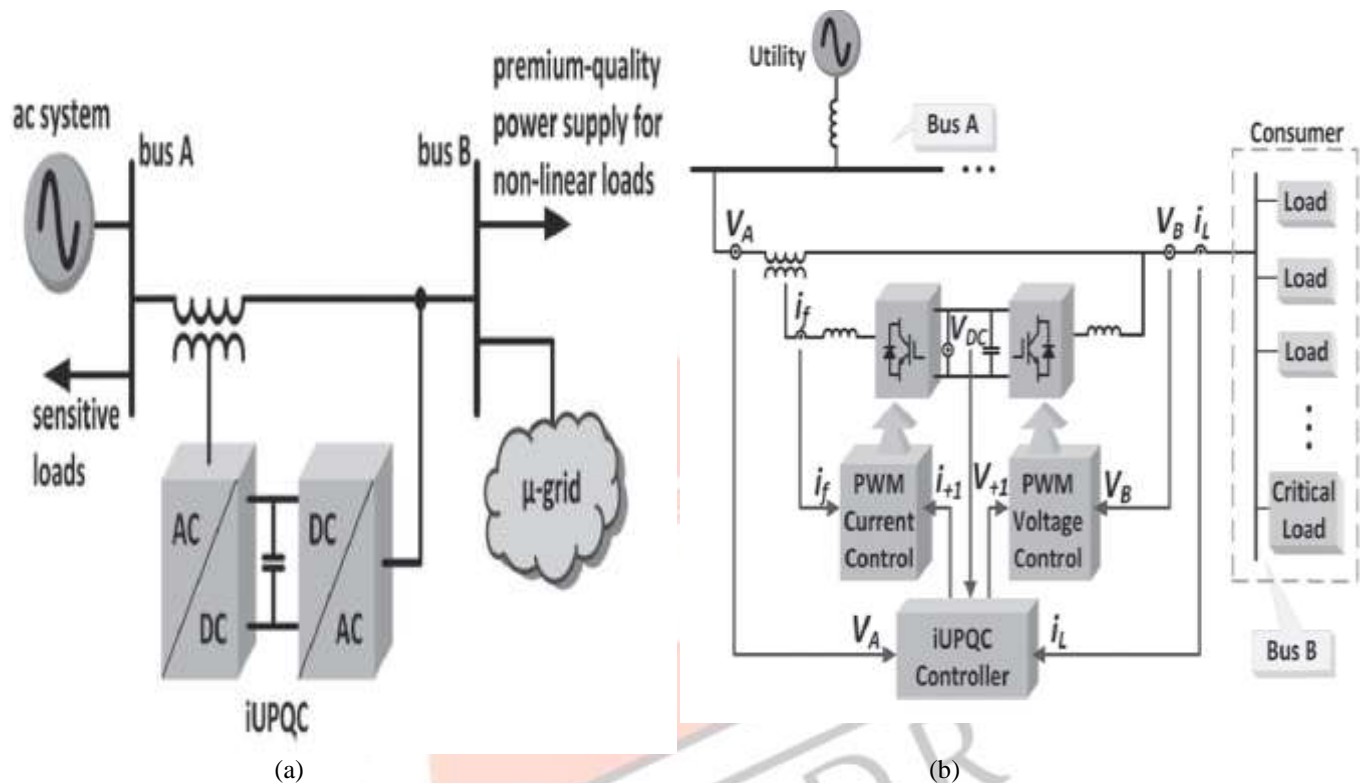


Fig.1. (a) Example of applicability of IUPQC; (b) Modified IUPQC configuration.

Fig. 1(b). 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.

Induction Drive

In recent years the control of high-performance induction motor drives for general industry applications and production automation has received widespread research interests. Induction machine modeling has continuously attracted the attention of researchers not only because such machines are made and used in largest numbers but also due to their varied modes of operation both under steady and dynamic states. Traditionally, DC motors were the work horses for the Adjustable Speed Drives (ASDs) due to their excellent speed and torque response. But, they have the inherent disadvantage of commutator and mechanical brushes, which undergo wear and tear with the passage of time. In most cases, AC motors are preferred to DC motors, in particular, an induction motor due to its low cost, low maintenance, lower weight, higher efficiency, improved ruggedness and reliability. All these features make the use of induction motors a mandatory in many areas of industrial applications. As shown in figure.2, the advancement in Power electronics and semiconductor technology has triggered the development of high power and high speed semiconductor devices in order to achieve a smooth, continuous and low total harmonics distortion (THD).

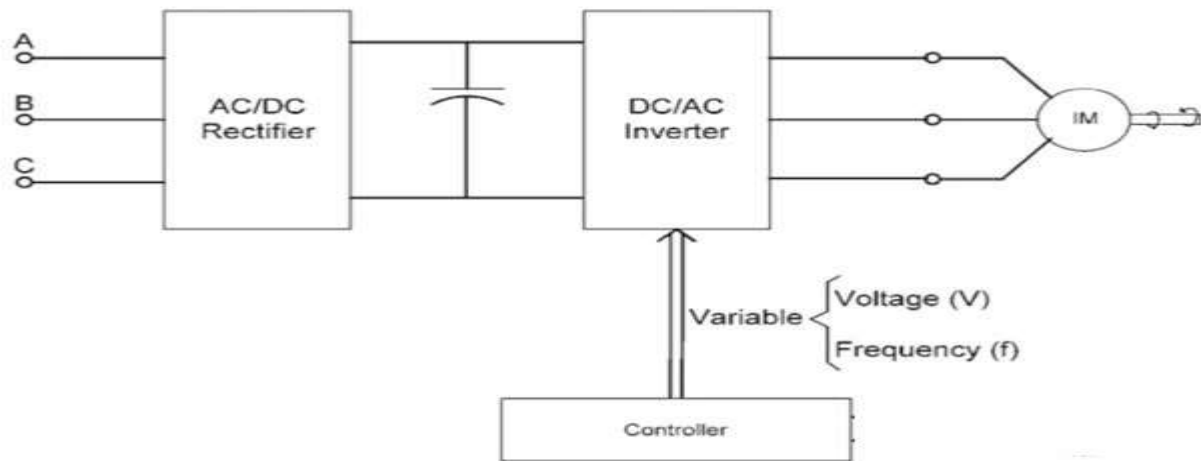


Fig. 2. Block Diagram of Induction drive.

III. IUPQC CONTROLLER

Fig. 1 (b) depicts the IUPQC hardware and the measured units of a three-phase three-wire system that are used in the controller. Fig. 2 shows the proposed controller. The controller inputs are the voltages at buses A and B, the current demanded by bus B (i_L), and the voltage DC of the common dc link. The outputs are the shunt-voltage reference and the series-current reference to the pulse width modulation (PWM) controllers. The voltage and current PWM controllers can be as simple as those employed or be improved further to better deal with voltage and current imbalance and harmonics. First, the simplified Clark transformation is applied to the measured variables. As example of this transformation, the grid voltage in the $\alpha\beta$ -reference frame can be calculated as

$$\begin{bmatrix} V_{A_ \alpha} \\ V_{A_ \beta} \end{bmatrix} = \begin{bmatrix} 1 & 1/2 \\ 0 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{A_ ab} \\ V_{A_ bc} \end{bmatrix}. \quad (1)$$

The shunt converter imposes the voltage at bus B. Thus, it is necessary to synthesize sinusoidal voltages with nominal 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. In the original IUPQC approach as presented in [11], the shunt-converter voltage reference can be the PLL outputs or the fundamental positive-sequence component V_{A+1} of the grid voltage (bus A in Fig. 1(b)). The use of V_{A+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 required by the loads P_L plus the power P_{Loss} . The load active power can be estimated by

$$P_L = V_{+1_ \alpha} \cdot i_{L_ \alpha} + V_{+1_ \beta} \cdot i_{L_ \beta} \quad (2)$$

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. 2), 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. 2. 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

$$V_{col} = \sqrt{V_{A+1_ \alpha}^2 + V_{A+1_ \beta}^2}. \quad (3)$$

The sum of the power signals P_L and P_{Loss} composes the active-power control variable for the series converter of the IUPQC (p). Likewise, $Q_{STATCOM}$ is the reactive-power control variable q . Thus, the current references $i_{+1\alpha}$ and $i_{+1\beta}$ of the series converter are determined by

$$\begin{bmatrix} i_{+1_ \alpha} \\ i_{+1_ \beta} \end{bmatrix} = \frac{1}{V_{A+1_ \alpha}^2 + V_{A+1_ \beta}^2} \begin{bmatrix} V_{A+1_ \alpha} & V_{A+1_ \beta} \\ V_{A+1_ \beta} & -V_{A+1_ \alpha} \end{bmatrix} \times \begin{bmatrix} \overline{P}_L + \overline{P}_{Loss} \\ \overline{Q}_{STATCOM} \end{bmatrix}. \quad (4)$$

Power flow in study state

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

condition. According to Fig. 4, the compensation of a voltage sag/swell disturbance at bus B causes a positive sequence voltage at the coupling transformer ($V_{\text{series}} \neq 0$), since $V_A \neq V_B$. Moreover, V_{series} and i_{PB} 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.

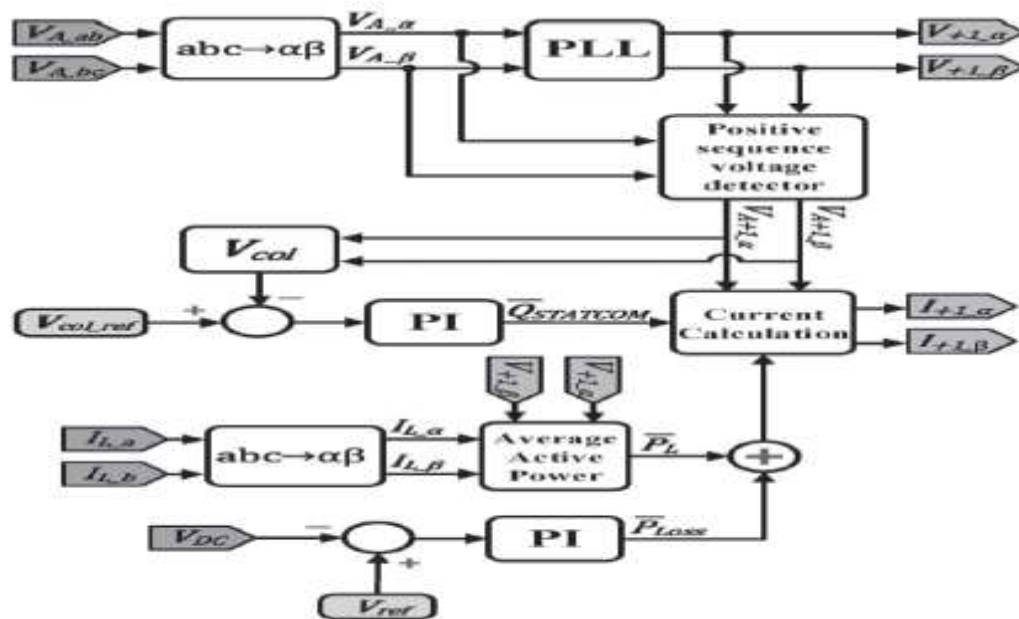


Fig.3. Novel IUPQC control.

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.

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

If the IUPQC performs all original UPQC functionalities together with the STATCOM functionality, the voltage at bus A is also regulated with the same phase and magnitude, that is, $V_A = V_B = V_N$, and then, the positive sequence of the voltage at the coupling transformer is zero ($V_{\text{series}} = 0$). Thus, in steady state, the power flow is determined by

$$\begin{aligned}\bar{S}_A &= \bar{P}_B + \bar{Q}_{\text{STATCOM}} \\ \bar{Q}_{\text{STATCOM}} + \bar{Q}_{\text{series}} &= \bar{Q}_{\text{shunt}} + \bar{Q}_B \\ \bar{Q}_{\text{series}} &= 0 \text{ var} \\ \bar{P}_{\text{series}} &= \bar{P}_{\text{inner}} = 0 \text{ W}\end{aligned}$$

Where S_A and Q_A are the apparent and reactive power injected in the bus A; P_B and Q_B 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. Where Q_{STATCOM} is the reactive power that provides voltage regulation at bus A. Ideally, the STATCOM functionality mitigates the inner-loop active power flow (P_{inner}), and the power flow in the series converter is zero. Consequently, if the series converter is properly designed along with the coupling transformer to synthesize the controlled currents I_{+1_a} and I_{+1_b} , as shown in Fig. 3, then a lower power converter can be employed.

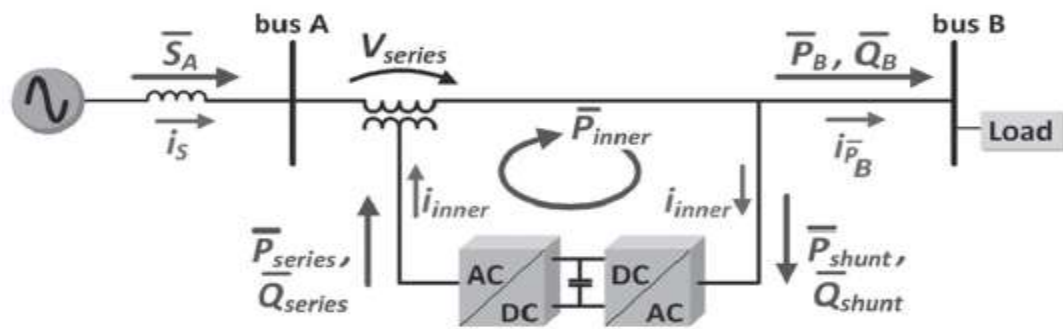


Fig.4. IUPQC power flow in steady state.

IV. SIMULATION RESULTS

The improved IUPQC controller, as shown in fig.3, was verified in MATLAB/SIMULINK. This proposed IUPQC model as shown in fig.5 and fig.6.

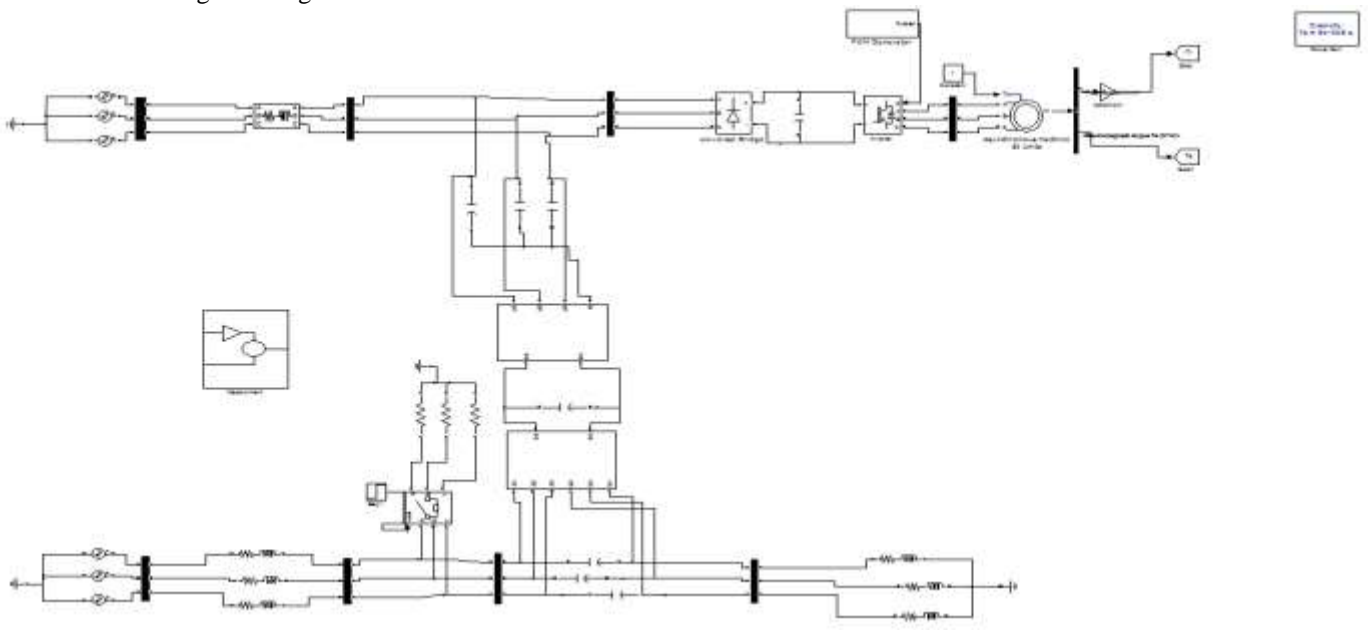


Fig.5. Simulation model diagram of proposed IUPQC controller with induction Drive.

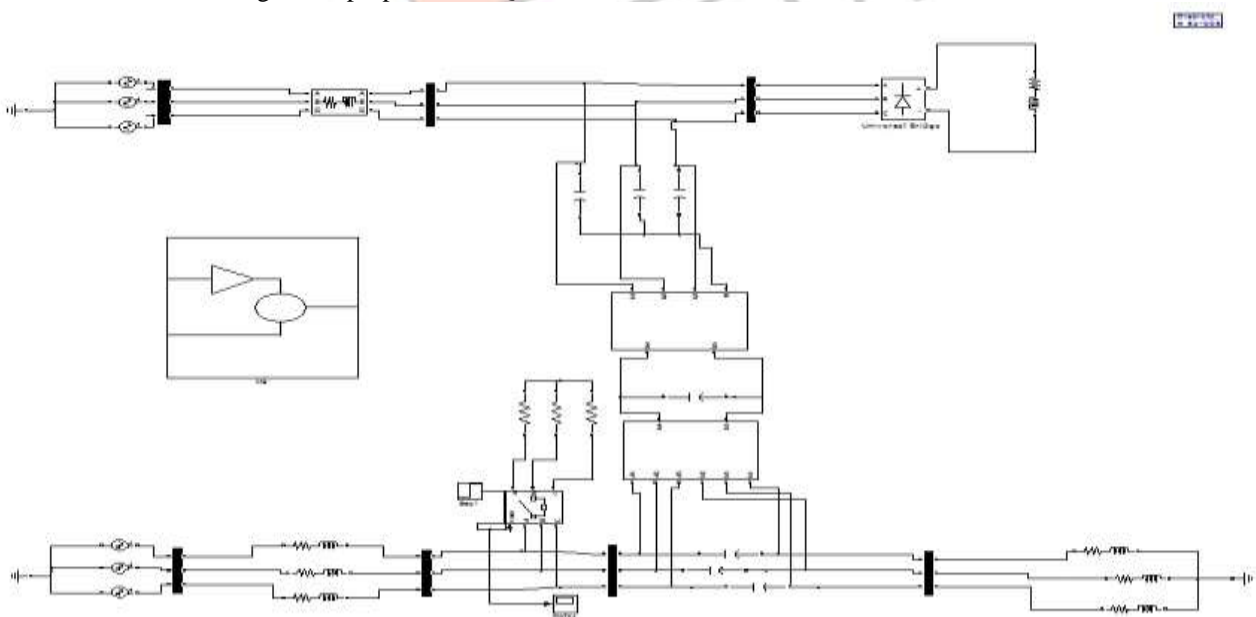


Fig.6. Simulation model Diagram of Proposed IUPQC controller with Diode Rectifier.

The experimental case was carried out to verify the IUPQC performance during the connection of a nonlinear load with the IUPQC already in operation. The load is a three phase diode rectifier with a series RL load at the dc link. In Fig. 7, it is possible to verify that the IUPQC is able to regulate the voltages at both sides of the IUPQC, simultaneously. The circuit breaker S_{Sag} is permanently closed. In this way, the voltage-sag disturbance is increased due to the load connection.

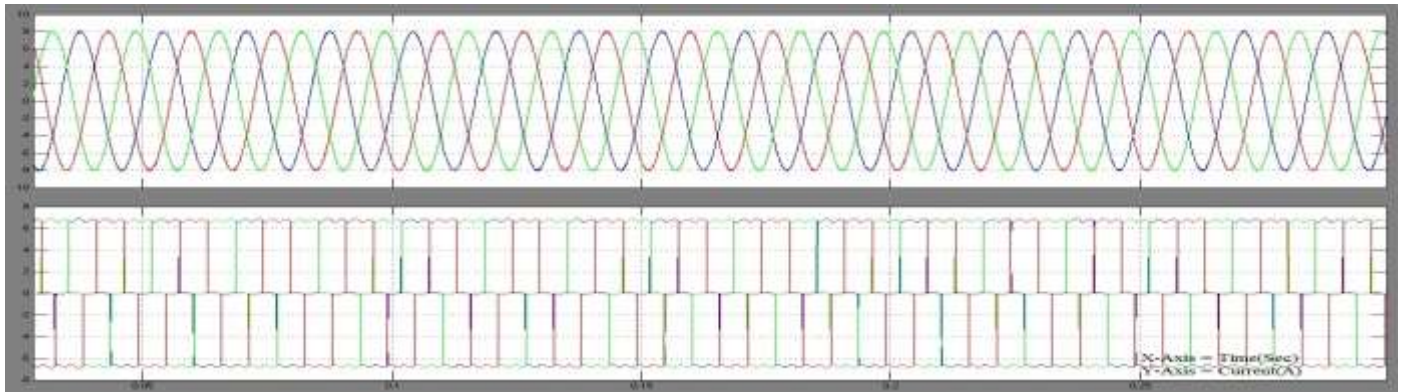


Fig.7. IUPQC response during the connection of a three phase diode rectifier: (a) Grid current, (b) load current.

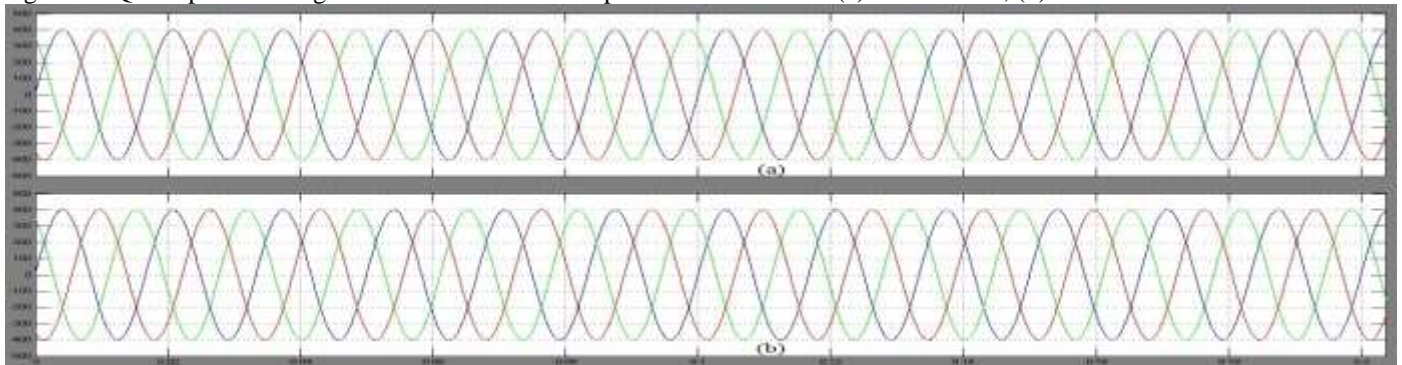


Fig.8. IUPQC response during the connection of a three phase diode rectifier: (a) Grid voltage, (b) load voltage.

In fig.7, IUPQC compensate the load current to almost sinusoidal wave at grid side current. The voltages are still regulated, and the currents drawn from bus A are almost sinusoidal. Hence, the IUPQC can perform all the power-quality compensations, as mentioned before, including the grid-voltage regulation. It is important to highlight that the grid-voltage regulation is also achieved by means of the improved IUPQC controller.

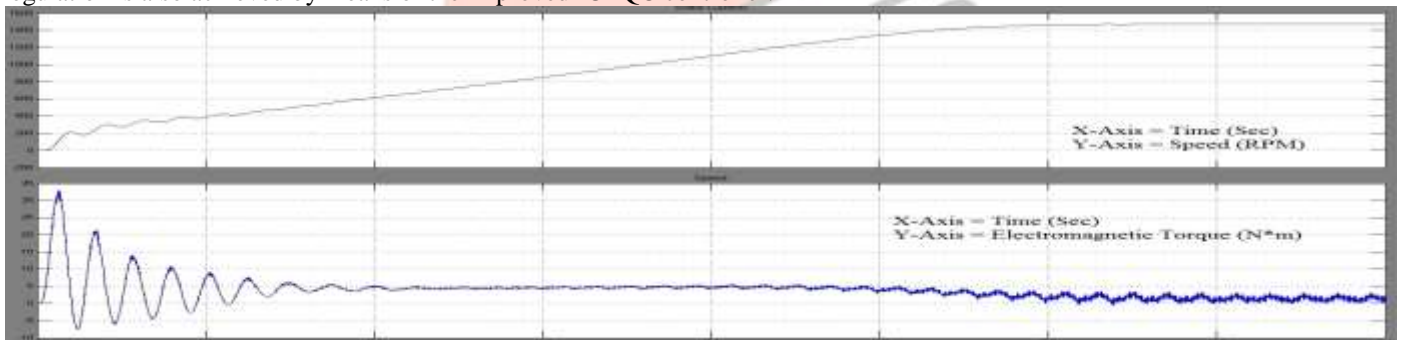


Fig.9. IUPQC controller applied to Induction Drive performance: (a) Speed (RPM), (b) Electromagnetic Torque (N*m).

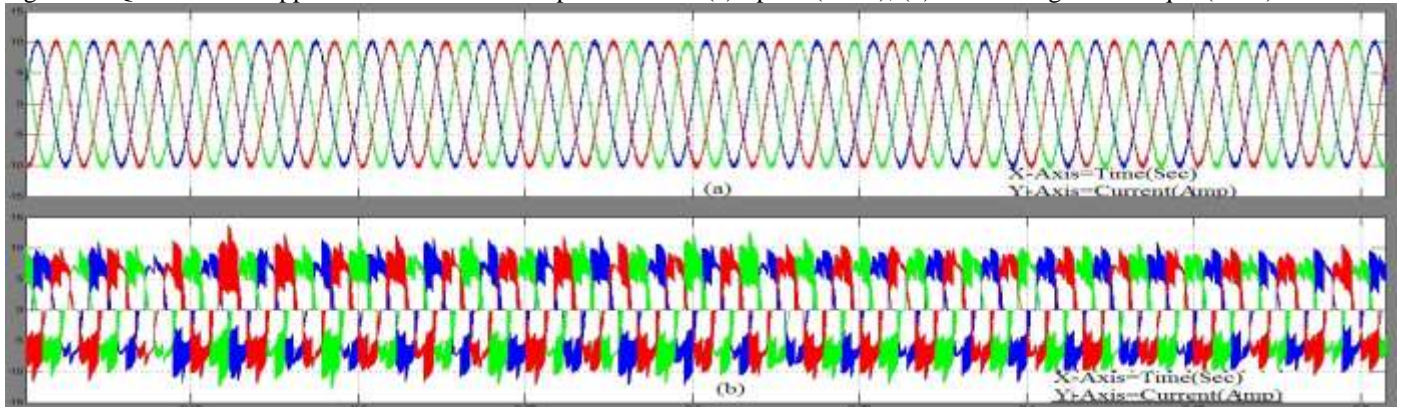


Fig.10. IUPQC controller applied to Induction Drive performance: (a)Grid Current, (b) Load current.

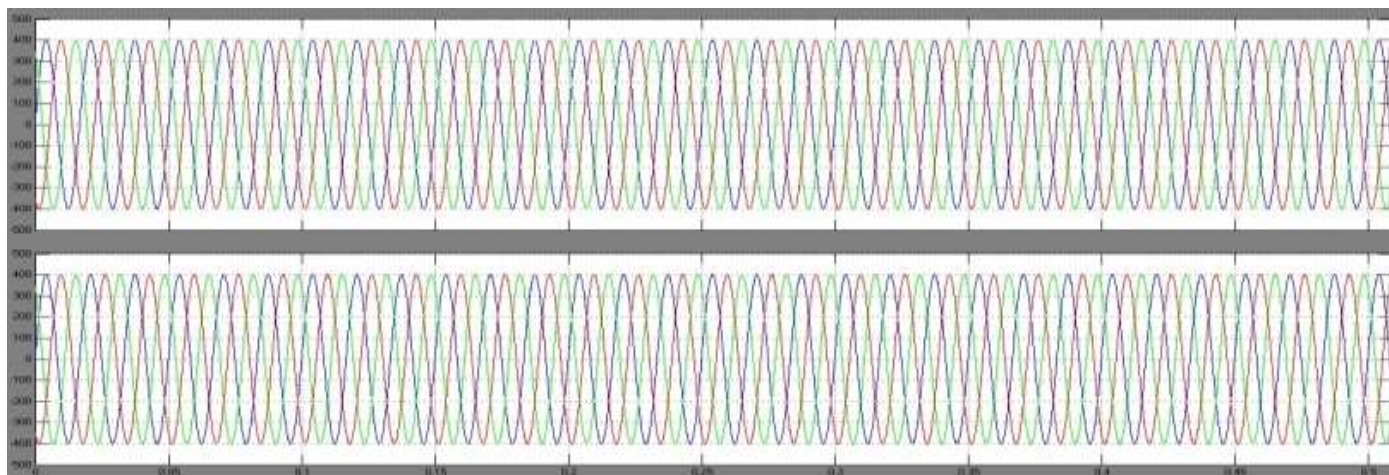


Fig.11. IUPQC controller applied to Induction Drive performance Grid voltage and load voltage.

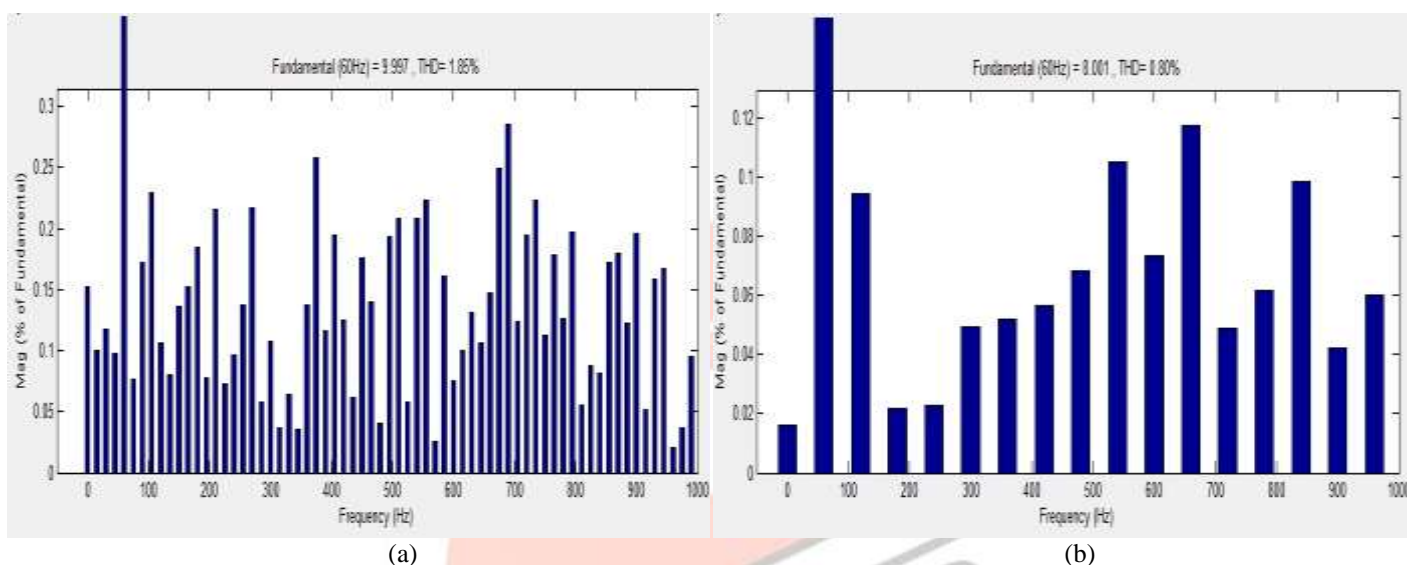


Fig.12. Grid Current THD% under (a) Induction drive load, (b) Diode rectifier load.

Fig.8. depicts the IUPQC controller performance under Induction Drive speed and electromagnetic torque, these running characteristic shows the performance of IUPQC controller. Induction motor is best illustration of reactive power consumption. Because the rotor field always lags behind the stator field, the induction machine always "consumes" reactive power, regardless of whether it is operating as a generator or a motor. A source of excitation current for magnetizing flux (reactive power) for the stator is still required, to induce rotor current. When induction motor operated which draws the disturbed current due to non-linear circuit as shown in fig.10 (b). The dynamic performance of IUPQC has verified with the induction drive. In this case also IUPQC provide better grid current. However, percentage total harmonic distortion (THD) is very low (1.80%) in grid current as shown in fig.12 (a). Fig.12 (b) showed the THD% of grid current under diode rectifier load.

V. CONCLUSION

The simulation results verified the improved IUPQC goals. The grid-voltage regulation was achieved with non linear load, as well as when supplying a three-phase induction drive. These results have demonstrated a suitable performance of voltage regulation at both sides of the IUPQC, even while compensating harmonic current and voltage imbalances. In the improved IUPQC controller, the currents synthesized by the series converter are determined by the average active power of the load and the active power to provide the dc-link voltage regulation, together with an average reactive power to regulate the grid-bus voltage. In this manner, in addition to all the power-quality compensation features of a conventional UPQC or an IUPQC, this improved controller also mimics a STATCOM to the grid bus. This new feature enhances the applicability of the IUPQC and provides new solutions in future scenarios involving large induction drive industries and microgrids, including distributed generation and energy storage systems to better deal with the inherent variability of renewable resources such as solar and wind power.

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