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Analysis of Fuzzy Logic Based Interline Unified Power Quality Conditioner for Grid Voltage Regulation of Critical Load Bus

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ABSTRACT

This paper focuses on an innovative topology of FACTS device, namely UPQC whose nomenclature is interline UPQC (IUPQC). The new topology of iUPQC includes all previous topology functionalities, including the voltage regulation at the load-side bus, and now providing also voltage regulation at the grid-side bus, like a STATCOM to the grid. The new equipment is only a mere extension of the existing FACTS device features like Distributed Static Compensator which does not limit to better voltage regulation at the gird side as well as load side bus. In iUPQC; Series Active Filter (SAF) works as a current source and Parallel Active Filter (PAF) works as a voltage source and due to these there is a high and low impedances occurs which is indirectly compensates the harmonics and disturbances of the grid voltage and load current and also impedance path is low harmonic at load current. The main difference between these compensators is the sort of source emulated by the series and shunt power converters. The structure, control and capability of the IUPQC are discussed in this paper with the fuzzy logic controller. The efficiency of the proposed configuration has been verified through simulation studies using MATLAB/ Simulink.

KEYWORDS: *iUPQC, Micro-grids, Power quality, static STATCOM, Fuzzy Logic*

I. INTRODUCTION

Electric power quality may be defined as a measure of how well electric power service can be utilized by customers. Power Quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a mis-operation of end user equipment. To compensate harmonics conventional Passive Filters are used for specific number of harmonics. To compress total harmonic content Active Power Filters are used. For all types of **Power Quality solutions at the distribution system voltage level DFACTS** also called as Custom Power Devices are introduced to improve Power Quality.

In contrast, power-electronics-driven loads generally require ideal sinusoidal supply voltage in order to function properly, whereas they are the most responsible ones for abnormal harmonic currents level in the distribution system. In this scenario, devices that can mitigate these drawbacks have been developed over the years. Some of the solutions involve a flexible compensator, known as the unified power quality conditioner (UPQC).

The STATCOM has been used widely in transmission networks to regulate the voltage by means of dynamic reactive power compensation. 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 micro-grids.

II. Custom Power Devices

A Custom power device provides "wide area" power quality protection: that is to say a single device can protect all of a plant's critical loads, rather than protecting a single load like a UPS product. The Custom Power products are appropriate for large energy sensitive to the quality of electricity supply. Custom Power is a technology driven product and service solution which embraces a family of devices which will provide power quality functions at distribution voltages. It has been made possible by the now widespread availability of cost effective high power solid state switches such as GTO's and IGBT's. The rapid response of these devices enables them to operate in real time, providing continuous and dynamic control of the supply including: sub-cycle transfer of critical loads, voltage and reactive power regulation, harmonic mitigation and elimination of voltage sags. Custom Power embraces a family of devices, which together make up a toolbox to provide power quality solutions at the distribution system voltage level. There are three principle elements to the Custom Power concept, these are:

- Dynamic Voltage Restorer (DVR)
- Distribution Static Compensator (D-STATCOM)
- Unified Power Quality Conditioner (UPQC)

All Custom devices are capable of providing a number of power quality functions which can be employed selectively or simultaneously. Two of the devices - D-STATCOM and the DVR share a similar architecture. Both are based on the voltage source inverter and the basic anatomy of the device. DVR is connected in series with the line where as DSTATCOM is in shunt with the line across the load. Using a converter, the devices appear as fully synchronous sources which are capable of absorbing and injecting reactive power on an electricity system at distribution voltages. UPQC is another Custom Power Device having both series and shunt connected Active Power Filters common coupled at the DC side of the both converters. Using an inverter, the devices appear as fully synchronous sources which are capable of absorbing and injecting reactive power on an electricity system at distribution voltages.

The basic operation principle of the DVR is to inject an appropriate voltage in series with the supply through injection transformer whenever voltage sag or voltage swell is detected. In addition to voltage sags and swells compensation, DVR can also perform other tasks such as harmonic compensation and Power Factor correction. Compared to the other Custom Power devices, the DVR clearly provides the best economic solution for its size and capabilities.

The basic operation principle of the DSTATCOM is to inject an appropriate current in parallel with the supply. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes like, voltage regulation and compensation of reactive power, correction of power factor and elimination of current harmonics.

III. Interline Unified Power Quality Conditioner (IUPQC)

The IUPQC shown in Fig.1 below consists of two VSCs (VSC- 1 and VSC-2) that are connected back to back through a common energy storage dc capacitor. Let us assume that the VSC-1 is connected in shunt to Feeder-1 while the VSC-2 is connected in series with Feeder-2. Each of the two VSCs is realized by three H-bridge inverters. In its structure, each switch represents a power semiconductor device (e.g., IGBT) and an anti-parallel diode. All the inverters are supplied from a common single dc capacitor dc and each inverter has a transformer connected at its output. The complete structure of a three-phase IUPQC with two such VSCs is shown in figure. The secondary (distribution) sides of the shunt-connected transformers (VSC-1) are connected in star with the neutral point being connected to the load neutral. The secondary winding of the series-connected transformers (VSC-2) are directly connected in series with the bus B-2 and load L-2. The ac filter capacitors Cf and Ck are also connected in each phase to prevent the flow of the harmonic currents generated due to switching. The six inverters of the IUPQC are controlled independently. The switching action is obtained using output feedback control. An IUPQC connected to a distribution system is shown in the figure. In this figure, the feeder impedances are denoted by the pairs (Rs1, Ls1) and (Rs2, Ls2). It can be seen that the two feeders supply the loads L-1 and L-2. The load L-1 is assumed to have two separate components—an unbalanced part (L-11) and a non-linear part (L-12). The currents drawn by these two loads are denoted by il1 and il2, respectively. We further assume that the load L-2 is a sensitive load that requires uninterrupted and regulated voltage. The shunt VSC (VSC-1) is connected to bus B-1 at the end of Feeder-1, while the series VSC (VSC-2) is connected at bus B-2 at the end of Feeder-2. The voltages of buses B-1 and B-2 and across the sensitive load terminal are denoted by Vt1, Vt2, and Vl2, respectively.

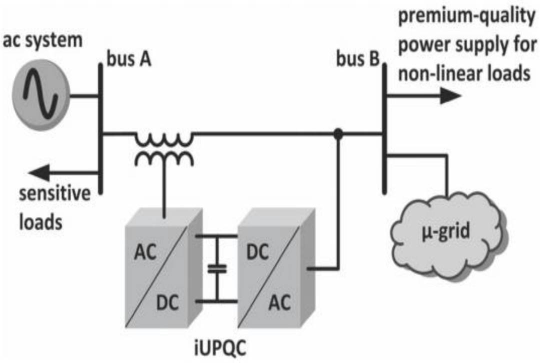

Fig.1: Electrical System with two buses.

Modified IUPQC:

The modified iUPQC serves as an intertie between the buses A and B. Moreover, the micro-grid connected to the bus B could be a complex system comprising distributed generation, energy management system, and other control systems.

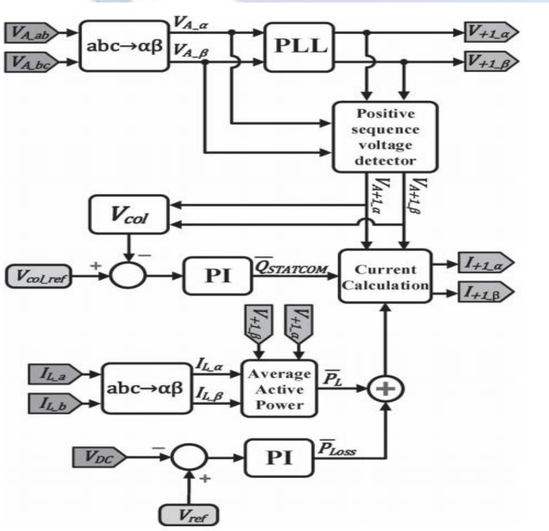

Figure.2: Improved iUPQC controller

The iUPQC hardware and the measured units of a three-phase three-wire system are used in the controller. Figure 3 bus B (*iL*), and the voltage *VDC* 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 simply employed, or be improved further so as to deal better with voltage and current imbalance and harmonics. The voltage at bus B is imposed by the shunt converter. Therefore, 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 whose amplitude is equal to 1 P.U. In the iUPQC approach as presented, the voltage reference of the shunt-converter can be either the PLL outputs or the fundamental positive-sequence component *VA*+1 of the grid voltage. The use of *VA*+1 in the controller is to minimize the power that is circulating through the series and the shunt converters, under normal operation, while the amplitude of the grid voltage is kept within an acceptable range of magnitude. However, this is not the case here, in the modified iUPQC controller, since the grid voltage will also be regulated by the modified iUPQC. In other words, both buses will be regulated independently so that their reference values can be tracked.

Fuzzy Logic Controller:

FLC determined by the set of linguistic rules. The mathematical modeling is not required in fuzzy controller due to the conversion of numerical variable into linguistic variables. FLC consists of three part:

a. Fuzzification
b. Interference engine
c. De-Fuzzification.

The fuzzy controller is characterized as; for each input and output there are seven fuzzy sets. For simplicity a membership functions is Triangular. Fuzzification is using continuous universe of discourse. Implication is using Mamdani's "min" operator. De-Fuzzification is using the "height" method. FLC block diagram as shown in figure 3.

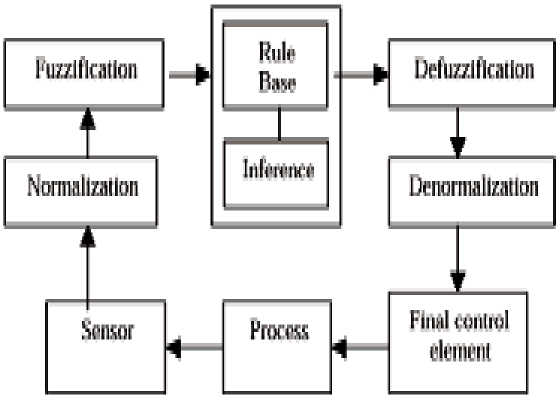

Figure.3: Fuzzy Logic-Controller

In this system the input scaling factor is between -1 and +1 has design. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset is shown in fig4.

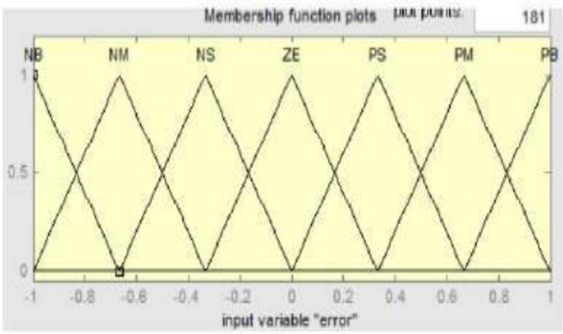

Figure.4: Membership function

e / Δe	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table 1: iUPQC Parameters

In under abnormal conditions performance of DVR connected to a single feeder system is investigated with PI and FLC controllers. Here, with IUPQC system operated with PI is investigated first for abnormal and dangerous conditions like sags, swells, harmonics, symmetrical and asymmetrical faults. Then the same IUPQC system with Mamdani based FLC is investigated for above faulty conditions. Using MATLAB/Simulink software the IUPQC connected

IV. Simulation Results

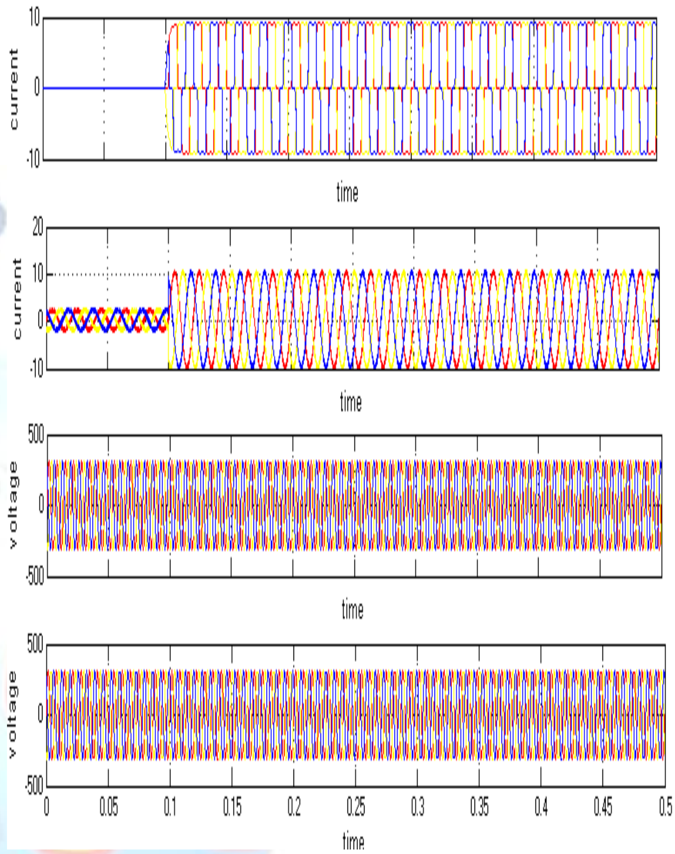

Fig.5: Load current, grid current, load voltage, grid voltage for iUPQC response using PI controller

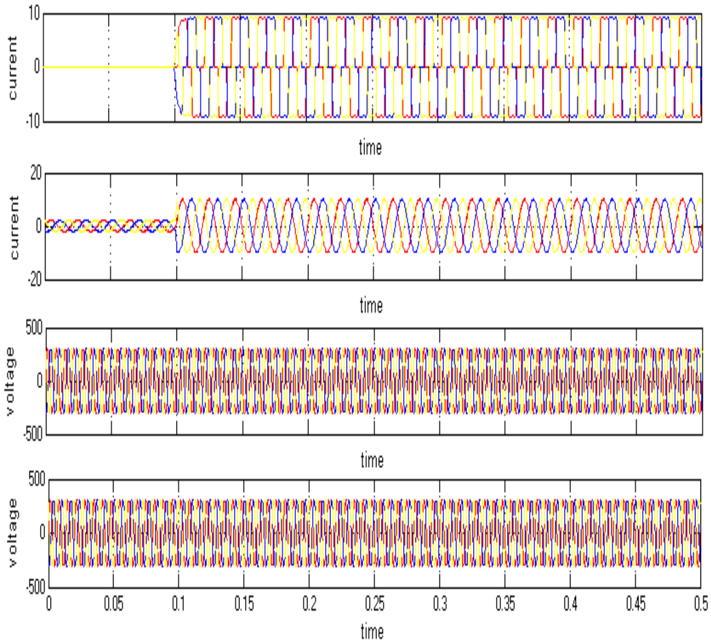

Fig.6: Load current, grid current, load voltage, grid voltage for iUPQC response using fuzzy logic controller

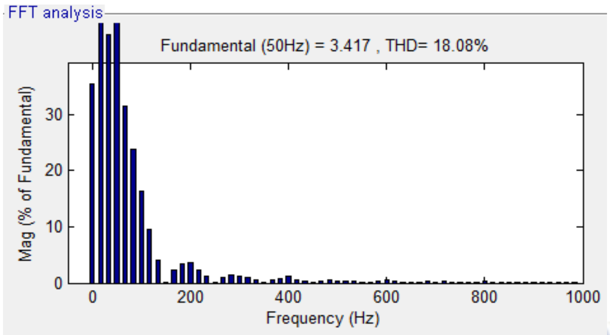

Fig.7: THD without using controller

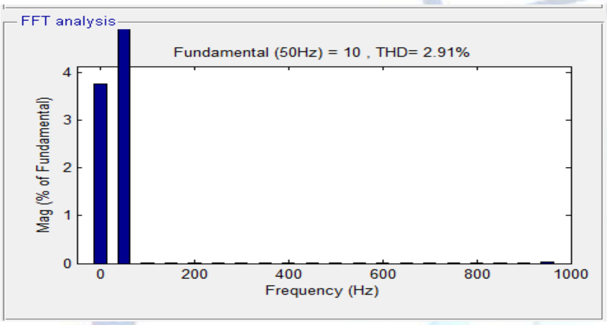

Fig.8: THD using PI controller

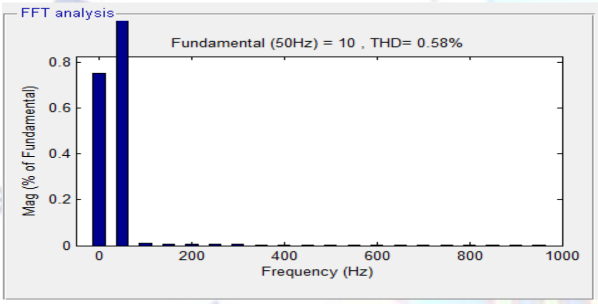

Fig.9: THD using fuzzy logic controller

Comparison Table:
Type of the Controller THD in %:

Type of the Controller	THD in %
Without controller	18.08
PI controller	2.91
Fuzzy Logic controller	0.58

V. Conclusion

The simulation of non-linear load with iUPQC is successfully accomplished using PI controller and Fuzzy logic controllers. The fuzzy logic controller gives better response with THD of (0.58) % in the grid current compared to THD of (2.91) % in the case of PI controller and also the THD of (18.08) % without controller in the grid current. In the future analysis another controller can be used such as Neuro-fuzzy for better performance.

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