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POWER QUALITY COMPENSATION FOR GRID INTERCONNECTED DISTRIBUTION SYSTEM INTERFACING INVERTER WITH (FLC)

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ABSTRACT

This paper presents a proposed schematic of grid interfacing inverter with FLC that compensates power quality problems and also interface Distributed Energy Systems with the electric grid. The grid interfacing inverter can effectively be utilized to perform following functions: 1) transfer of active power acquired from the distributed Energy Systems; 2) supports load reactive power demand; 3) compensate current harmonics at Point of common coupling; and 4) compensation of current unbalance and neutral current in case of 3-phase 4-wire system. The ability of fuzzy logic to handle rough and unpredictable real world data made it suitable for a wide variety of applications, especially, when the models or processes are too complex to be analyzed by classical methods. In this paper fuzzy logic controller is used for controlling the DC capacitor voltage. Simulations using MATLAB / SIMULINK are carried out to verify the performance of the proposed controller. The results show that the proposed controller has fast dynamic response, high accuracy of tracking the DC-voltage reference, and strong robustness to load parameters variation.

KEYWORDS: Fuzzy Logic Controller (FLC), Active Power Filter (APF), Grid Interconnected, Distributed Generation (DG), 4-Leg Inverter

INTRODUCTION

A (ghg) greenhouse gasis any gaseous compound in the atmosphere that is capable of absorbing infrared radiation, thereby trapping and holding heat in the atmosphere. By increasing the heat in the atmosphere, greenhouse gases are responsible for the greenhouse effect, which ultimately leads to warming. Such as carbon dioxide absorb the infrared radiation and trap the heat in the Earth's atmosphere. These greenhouse gases emissions come primarily from the combustion of fossil fuels in energy use. The impact of the traditional fossil fuels in our environment and the fact that these are non-renewable sources, have encouraged the need to find alternative energy sources to the fossil fuel. Therefore, the renewable energy sources have been one of the most important topics of research in the last years. They are constantly replenished and will never run out.

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC.

However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power.

In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system. As a general statement, any deviation from normal of a voltage source (either DC or AC) can be classified as a power quality issue. Power quality issues can be very high-speed events such as voltage impulses / transients, high frequency noise, waveshape faults, voltage swells and sags and total power loss, more than 80 percent of all power quality problems originate within the facility. Common culprits are, Large equipment starting-up or shutting down, Improper wiring and grounding, Overloaded circuits, Harmonics. And less than 20 percent of power problems originate with the utility transmission and distribution system. Lightning strikes, equipment failure, accidents, and weather conditions all adversely affect the utility.

The widespread increase of non-linear loads nowadays, significant amounts of harmonic currents are being injected into power systems. Harmonic currents flow through the power system impedance, causing voltage distortion at the harmonic currents’ frequencies. The distorted voltage waveform causes harmonic currents to be drawn by other loads connected at the point of common coupling (PCC). The existence of current and voltage harmonics in power systems increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipment's.

The harmonic currents and voltages produced by balanced 3-phase non-linear loads such as motor drivers, silicon controlled rectifiers (SCR), large uninterruptible power supplies (UPS) are positive-sequence harmonics (7th, 13th, etc.) and negative-sequence harmonics (5th, 11th, etc.). However, harmonic currents and voltages produced by single phase non-linear loads such as switch-mode power supplies in computer equipment which are connected phase to neutral in a 3-phase 4-wire system are third order zero-sequence harmonics (tripled harmonics—3rd, 9th, 15th, 21st, etc.). These tripled harmonic currents unlike positive and negative-sequence harmonic currents do not cancel but add up arithmetically at the neutral bus. This can result in neutral current that can reach magnitudes as high as 1.73 times the phase current. This effect can require special consideration in the design of an electric system to serve non-linear loads. In addition to the increased line current, different pieces of electrical equipment can suffer effects from harmonics on the power system like hazard of cables and transformers overheating the third harmonic can reduce energy efficiency.

The traditional method of current harmonics reduction involves passive *LC* filters, which are its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. The increased severity of harmonic pollution in power networks has attracted the attention of power electronics and power system engineers to develop dynamic and adjustable solutions to the power quality problems. Such equipment, generally known as active filters (AF’s), Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost. However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. That conventional inverter is called as a "grid interfacing inverter". The inverter is controlled to perform as a multifunction device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously.

The ability of fuzzy logic to handle rough and unpredictable real world data made it suitable for a wide variety of applications, especially, when the models or processes are too complex to be analyzed by classical methods

SYSTEM DESCRIPTION

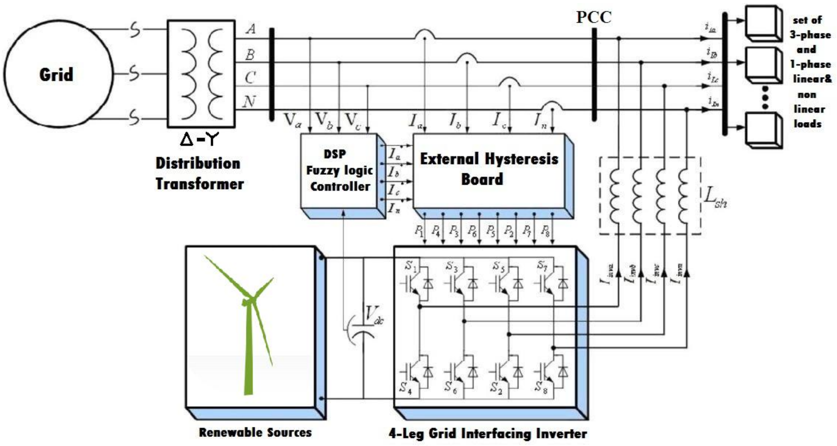


Figure 1: Schematic of Proposed Renewable Based Distributed Generating System

In this paper, it is shown that using an adequate control strategy, with a four-leg four-wire grid interfacing inverter, it is possible to mitigate disturbances like voltage unbalance. The topology of the investigated grid interfacing inverter and its interconnection with the grid is presented in Figure 1. It consists of a four-leg four-wire voltage source inverter. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. In this type of applications, the inverter operates as a current controlled voltage source. Fourth leg is used for neutral connection. The RES may be a DC source or an AC source with rectifier coupled to dc-link. In this paper wind energy is used as a RES, the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs to convert in dc before connecting on dc-link [8]–[10]. The simulink model of wind farm is given in Figure 2. Wind farm generates a variable ac supply, this variable ac supply is converted into dc by connecting a rectifier at output side.

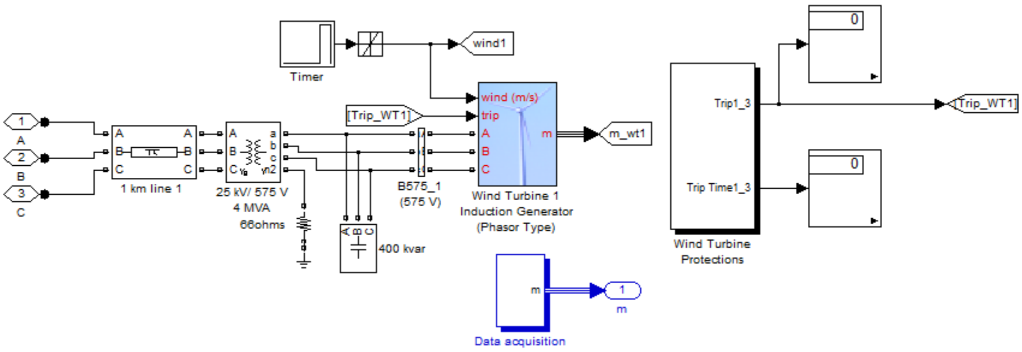


Figure 2: Simulink Diagram of Wind Farm

Control Strategy

The controller requires the three-phase grid current (*Ia,,Ib, Ic*), the three-phase voltage at the PCC (*Va, Vb, Vc*) and the DC-link voltage (*VDC*). As shown in Figure 3, the sinusoidal waveform and the phase of the grid current reference (*Ia*, Ib*, Ic*)* comes from the line voltage thanks to Phase locked loop (PLL).

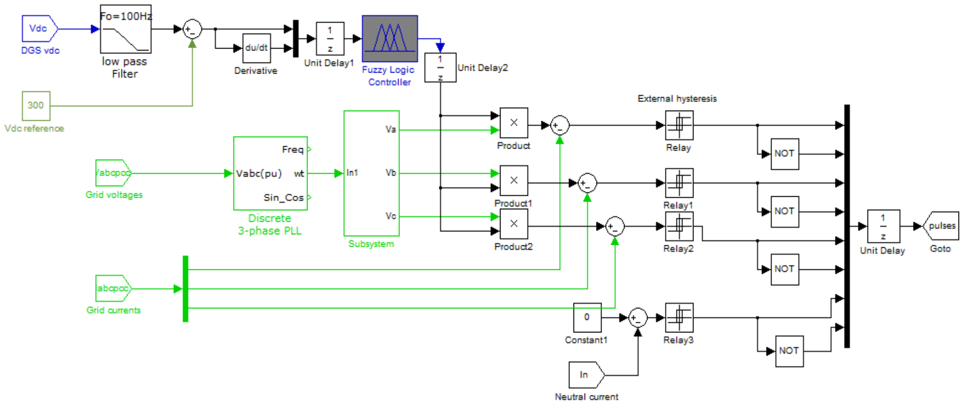


Figure 3: Representation of Grid Interfacing Inverter Control Strategy

$$U_a = \sin(\theta) \tag{1}$$

$$U_b = \sin(\theta - {}^{2\pi}\!/_{3}) \tag{2}$$

$$U_c = \sin(\theta + {}^{2\pi}\!/_{3}) \tag{3}$$

The magnitude I_m of the same current is obtained by passing the error signal between the DC-link voltage (*VDC*) and a reference voltage (V^*_{DC}) through a fuzzy logic controller. Using this magnitude and phase displacement of 120° and 240° respectively, the reference three-phase grid currents $i*_a$, $i*_b$and $i*_c$can be expressed as:

$$I_a{*} = I_m \sin(\theta) \tag{4}$$

$$I_b{*} = I_m \sin(\theta - {}^{2\pi}\!/_{3}) \tag{5}$$

$$I_c{*} = I_m \sin(\theta + {}^{2\pi}\!/_{3}) \tag{6}$$

Fuzzy Logic Controller (FLC)

The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, which in mathematical terms is the derivative of the error denoted as Δε. To solve this problem,[11][12] Fuzzy logic control as it is shown in Figure 4 is proposed.

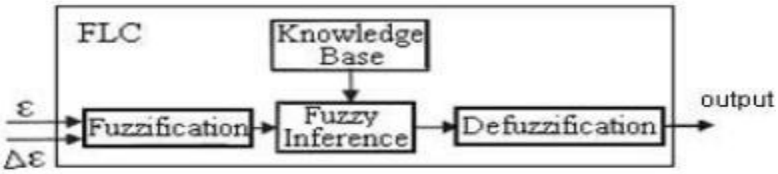


Figure 4: Basic Representation of FLC

The determination of the output control signal, is done in an inference engine with a rule base having if-then rules in the form of "IF ε is .... AND Δε is ...., THEN output is ...." With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of- error Δε. The structure and determination of the rule base is done using trial-and-error methods.

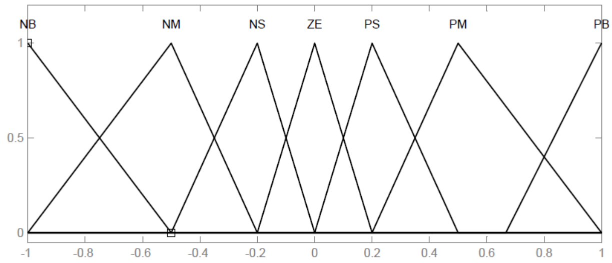


Figure 5: Membership Functions of Input Ɛ

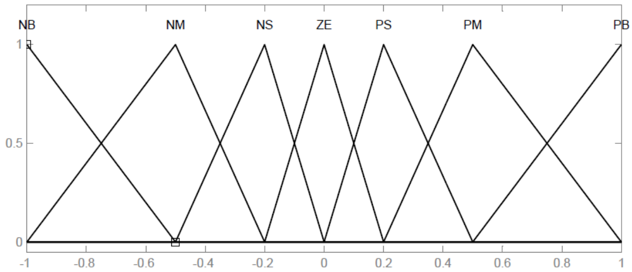


Figure 6: Membership Functions of Input ΔƐ

Table 1: FLC Rule Base

ΔƐ \Ɛ	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PM	NS	ZE	PS	PM	PM	PB	PB

Which is always exists in building a satisfactory fuzzy rule base for controlling a nonlinear system and is also done through experimentation. All the variables' fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). The membership function of inputs is illustrated in figure 5 & 6. The fuzzy control rule is illustrated in the table 1.

Switching Control

As shown in Figure 3, the hysteresis control has been used to keep the controlled current inside a defined band around the references. The status of the switches is determined according to the error. When the current is increasing and the error exceeds a certain positive value, the status of the switches changes and the current begins to decrease until the error reaches a certain negative value. Then, the switches status changes again. Compared with linear controllers, the non-linear ones based on hysteresis strategies allow faster dynamic response and better robustness with respect to the variation of the non-linear load. A drawback [13] [14] of the hysteresis strategies is the switching frequency which is not constant and can generate a large side harmonics band around the switching frequency.

SIMULATION RESULTS

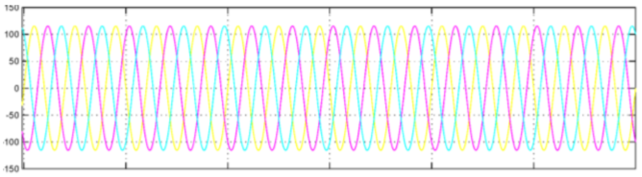
An extensive simulation study is carried out using MATLAB/Simulink in order to verify the proposed control strategy. To achieve balanced sinusoidal grid currents at unity power factor, the 4-leg grid interfacing inverter is actively controlled under varying renewable generating condition. The wave forms of grid voltages, grid currents, unbalanced load current and inverter currents are shown in Figure 7. The corresponding active and reactive of grid (PQ grid), load (PQ load) and inverter (PQ inv) are shown in Figure 8. Positive values of grid active-reactive powers and inverter active-reactive powers imply that these powers flow from grid side towards PCC and from inverter towards PCC, respectively. The active and reactive powers absorbed by the load are denoted by positive signs.

Before t=0.25s, the grid interfacing inverter is not connected to network, hence the grid currents in Figure 7 (b) are same as unbalanced nonlinear load currents Figure 7 (c).

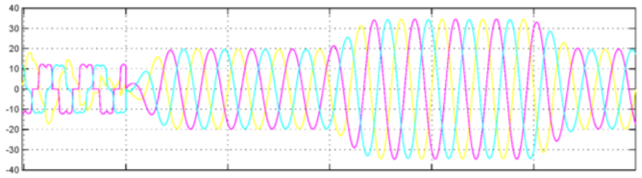
At t=0.25s, the grid interfacing inverter is now connected to network. The grid current starts changing to sinusoidal balanced from unbalanced nonlinear current shown in Figure 7 (b). At this instant active power injected by the inverter from RES. From Figure 8. The load power demand is less than the generated power and the additional power in fed back to the grid. The grid is receiving power from RES after 0.25s and it is indicated by (–ve) sign.

At t=0.35s, considering the load power demand as constant. The power generated from RES is increased to verify the system performance under variable power generation and hence it increases the magnitude of inverter current.

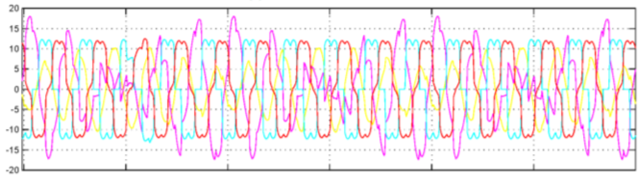
At t=0.45s generation of power from RES is reduced. The active and re-active power flows between the inverter, load and grid during increase and decrease of energy generation from RES can be noticed from Figure 8. Observing Figure 7, 8. It is clear that the fuzzy controller has high accuracy and fast response to load parameter variation.



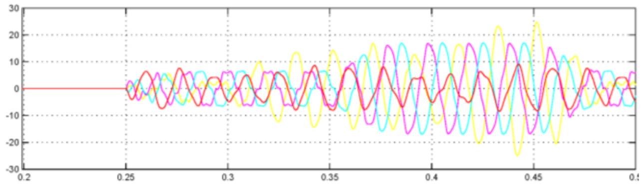
(a). 3-Phase Grid Voltages



(b). 3-Phase Grid Currents

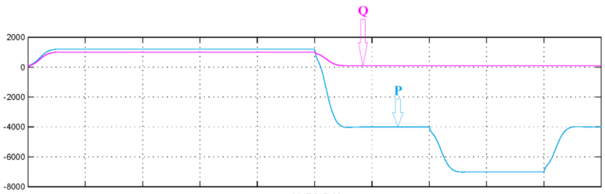


(c). 3-Phase Unbalanced Load Currents

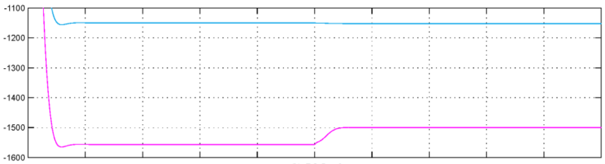


(d). 3-Phase Inverter Currents

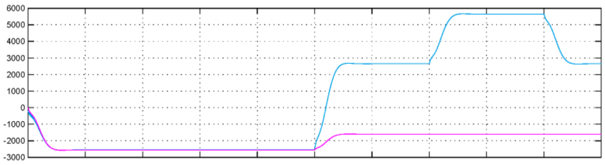
Figure 7: Simulation Results: (a) Grid Voltages, (b) Grid Currents, (c) Load Currents, (d) Inverter Current



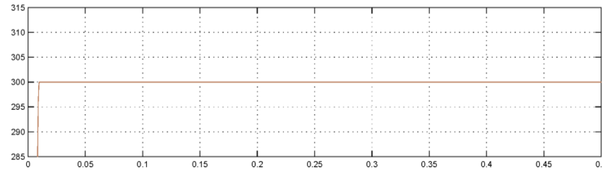
(a). PQ-Grid



(b). PQ-Load



(c). PQ-Inv



(d). DC-Link Voltage

Figure 8: Simulation Results: (a) PQ Grid, (b) PQ Load, (c) PQ Inverter, (d) DC Link Voltage Using Fuzzy Controller

CONCLUSIONS

This paper has presented a novel method to improve the power quality at point of common coupling (PCC) for a 3-phase 4- wire DG system using fuzzy logic control for grid interfacing inverter. The grid interfacing inverter is effectively utilized for power conditioning. This approach eliminates the additional power conditioning equipment to improve power quality at PCC. Simulation results analysis has shown that the proposed controller has fast response, high accuracy of tracking the DC-voltage reference, and strong robustness to load sudden variations. Over PI controller inability to react to abrupt changes in the error signal, and its also has high settling time, high gain which may cause instability.

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