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Power Quality Enhancement in Residential Small Grids Through Power Factor Correction Stages Using Fuzzy Based Pi-Controller

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ABSTRACT

The proliferation of non-linear loads and the increasing penetration of Distributed Energy Resources (DER) in Medium-Voltage (MV) and Low Voltage (LV) distribution grids, make it more difficult to maintain the power quality levels in residential electrical grids, especially in the case of weak grids. Most household appliances contain a conventional Power Factor Corrector (PFC) rectifier, which maximizes the load Power Factor (PF) but does not contribute to the regulation of the voltage Total Harmonic Distortion (THDV) in residential electrical grids. This manuscript proposes a modification for PFC controllers by adapting the operation mode depending on the measured THDV. As a result, the PFCs operate either in a low current Total Harmonic Distortion (THDI) mode or in the conventional resistor emulator mode and contribute to the regulation of the THDV and the PF at the distribution feeders.

KEY WORDS: Power Quality, Active Power Filter, Fuzzy Controller and Smart appliances.

1. INTRODUCTION:

In order to ensure efficient and proper operation of the grid-connected equipment, such as generators, loads, and storage systems, harmonic limits are specified by international standards and grid codes for AC electrical networks. There are restrictions on individual harmonics as well as current Total Harmonic Distortion (THDI) and current Total Demand Distortion in IEEE 519- 2014, a recommended practise and requirements for harmonic control in electric power systems [1]. (TDD). If highly nonlinear loads are connected, the recommended THDV limits in electrical distribution feeder tap points will likely be exceeded due to the strong relationship between voltage and current harmonic distortion levels [2]. In weak or critical electrical power systems, exceeding voltage or current harmonic limitations affects overall efficiency and may result in critical problems (EPS).

Harmonic distortion causes induction motor heating [3], insulation accelerated ageing [4], and harmonic resonances in capacitors for compensating reactive power, among other things. Medical equipment could be harmed by harmonic distortion [3] and distribution transformers in residential areas could be overloaded, which would hasten their ageing [8]. Residential loads, particularly at 3rd, 11th, and 13th harmonics, contribute to an increase in THDV via increasing voltage harmonic distortion [9]. Local or wide-area mitigation measures reduce harmonics' impact on residents' quality of life. DER active front-ends, which operate as adjustable harmonic impedances or include active power filter features, use local ones on the load or Distributed Energy Resource (DER) side. Coordination of local solutions, such as allocating compensation priorities to DERs, is used in wide-area mitigation methods. Droop-based technique, adjustment of the equivalent admittance or deployment of distributed low- power equipment for current harmonic filtering all help to improve the THDV's performance. Increasing the PF and reducing the impact of voltage disturbances on household appliances is made easier with the addition of mitigation equipment at the distribution feeder level, such as hybrid active power filters.

On the other side, active filters require high power converter ratings and are relatively expensive for large-scale systems. Particularly for high-power nonlinear systems, hybrid filters effectively reduce the limitations of both passive and active filter approaches while also offering affordable harmonic compensation. Active and hybrid filters have been improved through the use of numerous control techniques, such as instantaneous reactive power theory, synchronous rotating reference frames, sliding-mode controllers, neural network techniques, nonlinear control feedforward control, Lyapunov function-based control, and others. Several filter topologies for reducing harmonics and reactive power have been recorded in the literature when used in a multi-converter conditioner architecture made by an active conditioner working in tandem with a hybrid conditioner. The hybrid conditioner combines a low-rated active power filter with one or more passive filters connected in series (APF).

2. PROPOSED CONTROLLER POWER QUALITY OF RESIDENTIAL GRIDS:

The proposed PQE PFC consists of a conventional PFC stage with an enhanced digital controller, which adjusts the operation mode to maximize the PF while contributing to reduce the THDV at the PCC. The proposed controller modification is shown in Figure 1, where the local THDV measurement is employed to adjust the PFC operation mode. For analysis purposes, as depicted in Fig. 1, the Low-Voltage (LV) residential grid and household appliances are modeled through their Thevenin and Norton equivalents respectively. In an individual residential house is modeled by its equivalent impedance and a current source, representing the linear and non-linear loads respectively. Considering that most of the Conventional Household Appliances (CHA) are connected to the grid through unidirectional AC/DC converters, the house impedance is approximated by a pure resistor, RCHA, and a current source, corresponding to the sum of N − 1 current harmonics.

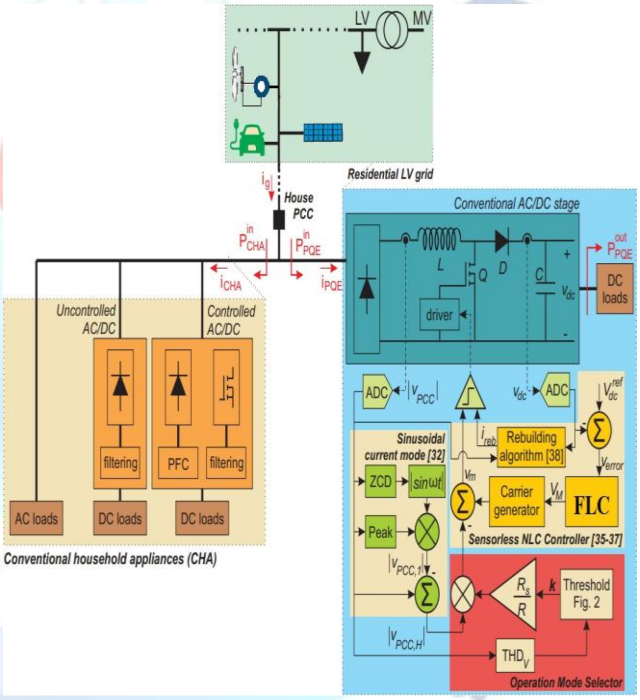


Figure 1: Residential LV grid with household appliances feed through conventional AC/DC stages (without the proposed operation mode selector) and the proposed PQE controller

PF at the PCC with the PQE PFC controller in both operation modes:

The PQE PFC in home appliances can improve the PF at the PCC, as this subsection shall demonstrate. The PF is assessed using the IEEE Std. 1459 [39] specification and both operation modes are taken into account (k = 1 and k = 0). Figure 1 shows the following:

$$PF = \frac{P^{in}_{PQE} + P^{in}_{CHA}}{V_{PCC} I_g} = \frac{P^{out}_{PQE} + \frac{V^2_{PCC,1}(1+THD_V^2)}{R_{CHA}} + P_{harm}}{\sqrt{V^2_{PCC,1}(1+THD_V^2)}\sqrt{I_g^2}}$$

$$\text{and } P_{harm} = \sum_{n \neq 1}^{M} V_{PCC,n} I'_{CHA,n} \cos\theta_n,$$

in where Pin CHA represents the CHA's active power, and Pharm represents the active power transferred by harmonic current components as a result of the traditional load nonlinearities and the PCC voltage harmonic distortion. Kirchhoff's Current Law (KCL) at the PCC can be used to calculate the total current of all household appliances (ig) in the home. and then using (10) to get the squared root of the whole household appliance current:

$$\begin{aligned} i_g(t) &= i_{PQE}(t) + i_{CHA}(t) \\ &= i'_{PQE}(t) + i'_{CHA}(t) + \frac{R_{eq}+R_{CHA}}{R_{eq}R_{CHA}} v_{PCC}(t) \end{aligned}$$

3. FUZZY LOGIC CONTROLLER

The main objective of this controller is to enhance the stability and robustness of the control performance against set point changes and load disturbances. The parameters of the traditional controller are altered by the fuzzy system in this way. A straightforward upper-level intelligent controller and a lower-level classical controller make up the hybrid control framework. While the lower-level controller should give the solutions to a specific scenario, the upper-level controller provides a method to the system's primary objective. A traditional PI controller is used for the bottom level of the proposed control structure, while the upper level uses a rule-based mamdani-type fuzzy controller. A mathematical system entirely based on fuzzy logic is called a fuzzy control system. The fuzzy rules are used directly by fuzzy controllers. Conditional statements that describe the relationship between all fuzzy variables are known as fuzzy rules. The fuzzy controller's logic is capable of handling ideas that cannot be represented as true or false. A block diagram of a fuzzy logic controller is illustrated in the image below.

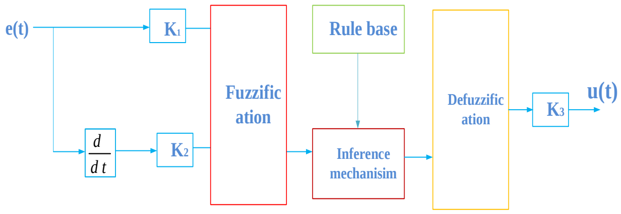
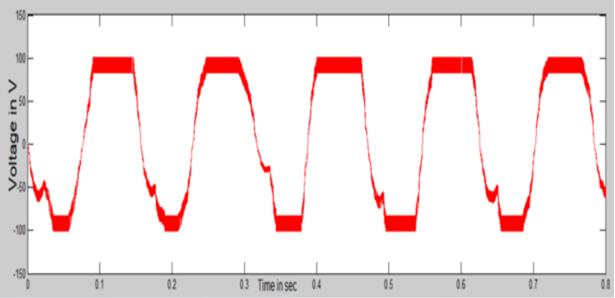


Figure 2: Fuzzy Logic Controller

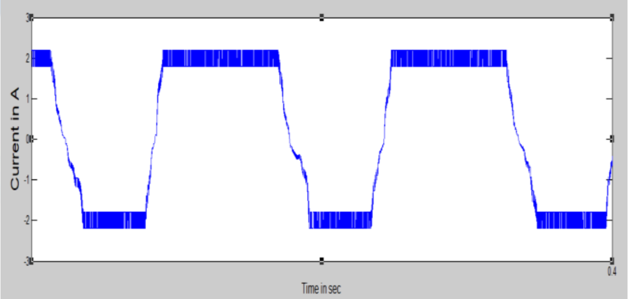
A function that converts items from a domain of interest to the set's membership value defines the fuzzy set. This type of function is known as a membership function and is typically identified by the Greek letter "." In order to design FIS, Figure 2, illustrates the selection of a number of inputs and outputs in the form of membership functions.

4. SIMULATION RESULTS:

Voltage, frequency, and power input measurements have been performed on the Converter at a distortion level of 12 percent when connected to 330 W and 800 W power sources. The Fuzzy PFC's voltage and current waveforms are the resistor emulator and sinusoidal current mode voltage and current waveforms, respectively, at 50 Hz. The current waveform in resistor emulator mode is shown in Fig. 1. The additional voltage generated by the resistor emulator, known as Zg, causes current harmonics to form at the power factor correction (PFC) component. When using sinusoidal current, the THDI and THDV drop by 11.5 percent and 4.2 percent, respectively, to 0.04 percent and 1.14 percent. Fuzzy PFC active power has to be increased to make up for the fact that in both operating modes the fundamental input current is equal to the active power of the current harmonics (350 W).



(a)



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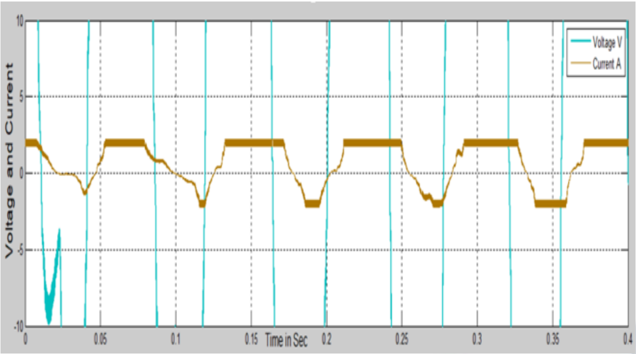

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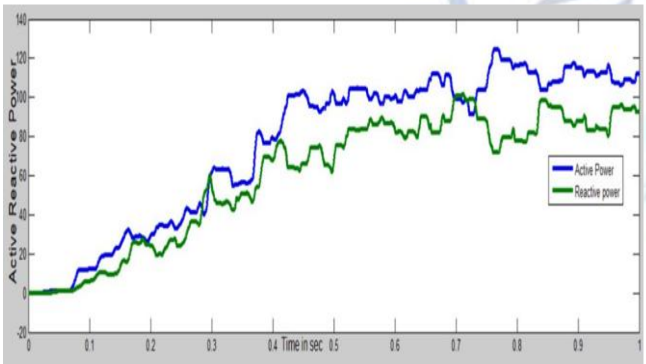
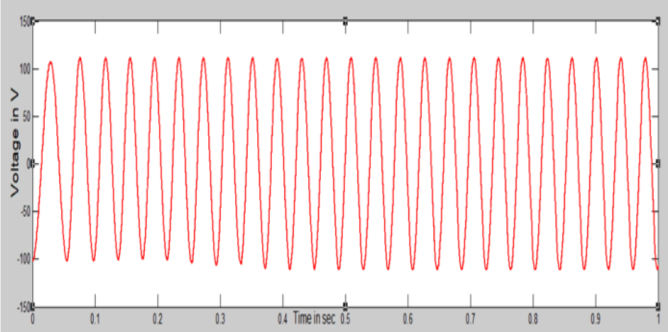


(d)

Figure 3: Simulation result for PI Controller (a) Voltage (b) Current (c) Power Factor correction (d) Active & Reactive Powers



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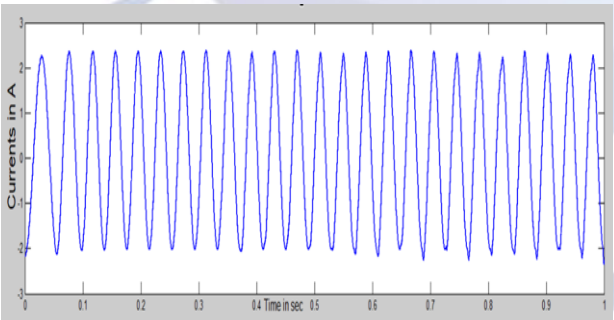

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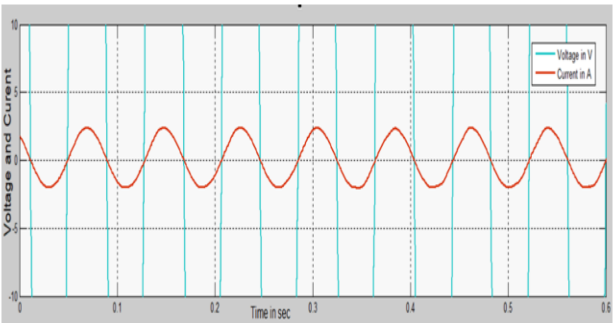

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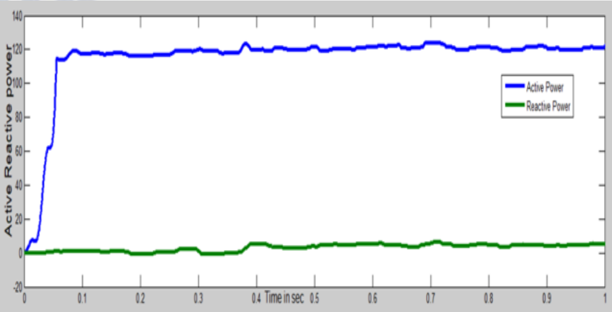

(d)

Figure 4: Simulation result for Fuzzy Controller (a) Voltage (b) Current (c) Power Factor correction (d) Active & Reactive Powers

When comparing the voltage waveform in Fig4.(a) to that in Fig3, there are no THDs visible. (a) The PI controller's voltage waveform. Figure 4(b) compares the current waveform of 2A in the system to figure 3 and shows no deviations or ripples (b) As shown in Fig. 4(c), the Power Factor Correction of Voltage and Currents is controlled by the FLC controller, whereas in Fig. 3(c), Voltage and Currents are variations in angle (cos). Figure 4(c) displays the Power Factor Correction of Voltage and Currents of the System. Figure 4(d) depicts the system's Active and Reactive power; it was distinct and balanced in comparison to Figure 3. (d).

Table 1. THDs of the Voltage and Currents of the grid.

Controller	Voltage THD%	Current THD%	Power Factor
PI	4.2%	3.4%	0.97
Fuzzy	1.14%	0.07%	0.99

5. CONCLUSION

Home appliances connected to the grid via PFC stages have had their impact on electrical power quality examined under various THDV scenarios. Sinusoidal current consumption has a better PF at the PCC under certain conditions than resistor emulator behaviour, which is usually thought to be optimum for PFC stages. To impress sinusoidal input current despite input voltage distortion, NLC controllers use PFC stages to modify their carrier signal. The NLC with excellent noise immunity is implemented using line current estimation with no contact with the power stage. The digital version of the non-linear controller is suitable for defining the carrier and for including further distortion reduction in accordance with the application. Nonlinear loads in home appliances can have a negative impact on residential electrical networks, which can be mitigated by using the PQE controller. The digital controller's operating mode can be independently altered using only the locally measured THDV and no further circuitry. Convenient behaviour can be chosen by the user or detected using a THDV threshold (either resistor emulator or pure sinusoidal current). The PQE controller's sinusoidal current and resistive emulator modes are both feasible with large THDV (above 5%), according to the results of the experiments.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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