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Fuzzy based Non Sinusoidal Power Factor Measurement

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Abstract

Evaluating the Electric Power Quality (EPQ) becomes very important task due to the wide spread use of non linear loads. In a deregulated environment, having different Power Quality Indices (PQIs) with different values has no significance unless they are combined in to a single value that could represent them. In this project, a new Fuzzy based Power Quality Index (FPQI) is introduced that amalgamates the recommended PQIs, such as displacement power factor, transmission efficiency power factor and oscillation power factor. The proposed FPQI is applied to non linear loads with different distortion conditions. It is shown that the new FPQI is expressive and accurately represents the existing power quality indices in all cases and in all situations. Employing the fuzzy systems to deal with imprecision and uncertainties, this index can be used for power quality evaluation, cost effective analysis of PQ mitigation techniques, as well as billing purposes.

Index Terms: Fuzzy logic, fuzzy sets, harmonics, power factor, power quality.

Introduction

In an Electric Power System, the classical definitions of apparent power and power factor hold well as long as the loads are linear and the source voltage waveform is sinusoidal. Increased use of power electronic devices, adjustable speed drives, and other nonlinear loads, causes the voltage and current waveforms to become non sinusoidal and highly distorted. Therefore there is a need for alternative definitions of apparent power and power factor under these conditions. Non sinusoidal Situations has demanded separating the fundamental current and voltage components from the harmonic components in order to calculate the fundamental apparent power and subsequently the displacement power factor. This also allows monitoring the fundamental power content separately from harmonic power content facilitating application of engineering economic techniques, such as power factor correction. Power factor is fundamentally an index of the quality of power that allows a user in a deregulated market to select an electricity provider on the basis of level of quality of the delivered power .As a result, there is a need to evaluate the quality of the power delivered through evaluating a power factor index. Hence a fuzzy-based representative quality power factor (RQPF) is introduced.

Methodology

Power factor is a measure of how efficiently electrical power is consumed. It is an indicator of the health or efficiency of a power distribution system and it impacts operation and utility cost. The active power is defined as the useful power transferred from the source to the load. This is the electric power that performs the useful work. It is what turns on the lights, causes motors to rotate or produces heat in a resistive element. Real power occurs when the current and voltage are sinusoidally varying in phase, peaking and crossing zero at the same time. Real power is measured in watts or kilowatts and billed by the kilowatt-hour. The active power is equal to,

$$P = V_{rms} \,.\, I_{rms} \cos(\varphi) = 1/T \int v(t).i(t)\, dt \qquad (1)$$

Here is T the period of the sinusoidal wave.

The apparent power is defined as the maximal active power that can be transmitted for the given rms value (or magnitude) of the voltage and given rms value (or magnitude) of the current . It can be expressed as,

$$S = Vrms \,.\, Irms \qquad (2)$$

The power factor is then defined as the ratio,

$$PF = P/\,S \qquad (3)$$

In sinusoidal situations, the power factor can be used as a measure of the efficiency of the utilization of the equipment, the efficiency of the power transmission, and the oscillatory character of the power transfer. On the other hand, in non sinusoidal situations, the power factor as defined cannot handle these properties at the same time. Willems proposed separate definitions for the apparent power and the power factor to characterize the power transmission efficiency and the power oscillations. He defined the transmission efficiency power factor as

$$TEPF = P/\,S \qquad (4)$$

Here, P and S are the active and apparent power as defined in (1) and (2). Willems also defined the rms power as the rms value of the instantaneous power which can be shown to be given by

$$S_{rms} = \sqrt{(P^2+½S^2)} \quad (5)$$

In order to evaluate the oscillatory behavior of the transmitted power, Willems defined the oscillating power S_{osc} as the rms value of the oscillating components of the instantaneous power,

$$S_{osc} =(1/\sqrt{2})\ S \quad (6)$$

Therefore, the oscillation power factor is defined as the ratio

$$OSCPF = P/ S_{rms} = P/ \sqrt{(P^2+S^2_{osc})} = TEPF/\sqrt{(½ + TEPF^2)} \quad (7)$$

Note that the maximum value of the oscillation power factor is 0.816 and occurs in case of pure resistive load which explains the unavoidable oscillation even in the sinusoidal situation while the minimum value is zero which occurs in case of the pure reactive element where there is continuous oscillation with zero average or active power. Another important power factor that is useful for monitoring separately the fundamental power from the harmonic power as well as applying many economic engineering techniques such as power factor correction was recommended by the IEEE Working Group in [6]. They recommend the separation of the fundamental power components from the non-fundamental components and hence calculating the fundamental active and fundamental apparent power as

$$P_1 = V_1 . I_1 \cos(\varphi_1),\ \ S_1 = V_1 . I_1 \quad (8)$$

The displacement power factor is defined by the ratio

$$dPF= P_1 / S_1 \quad (9)$$

Fuzzy 3.Base Power Quality Evaluation Modules

Three modules are designed to evaluate the electric PQ via the new single universal index called Fuzzy-Power-Quality-Index (FPQI). The new index ranges from '0' and '1' where value of '0' indicates very poor PQ (minimum value) while a value of '1' indicates very good PQ (maximum value). This module was built using Fuzzy logic toolbox available in Matlab 7.3. The three modules are described detail in this section.

Description of fuzzy RQPF Module in MATLAB

This section explains the fuzzy logic based approach utilized to calculate the fuzzy representative quality power factor (RQPF) which is a single value that represents an amalgamation of the existing power factors DPF, TEPF and OSCPF. Figure.3.1 shows a schematic diagram of the RQPF module. The design procedure is as follows.

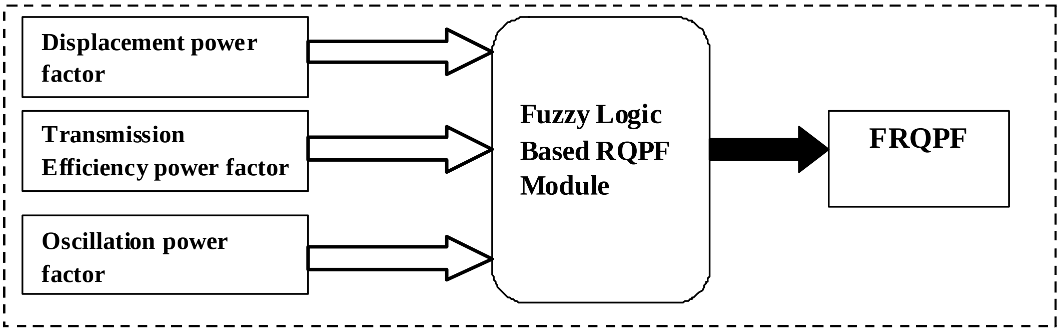

Figure 3.1: A Schematic diagram of the fuzzy representative quality power factor module.

Fuzzy If-Then Rules
We have three inputs each represented by three linguistic variables. Therefore we obtain 27 rules in the FRQPF module. Following are the fuzzy inference rules are used.

If (dPF is L) and (TEPF is L) and (OSCPF is L) then (RQPF is L)

If (dPF is L) and (TEPF is L) and (OSCPF is M), then (RQPF is ML)

If (dPF is L) and (TEPF is L) and (OSCPF is H), then (RQPF is SL)

If (dPF is L) and (TEPF is H) and (OSCPF is H), then (RQPF is SH)

If (dPF is M) and (TEPF is L) and (OSCPF is H), then (RQPF is MH)

If (dPF is H) and (TEPF is M) and (OSCPF is L), then (RQPF is SL)

If (dPF is H) and (TEPF is M) and (OSCPF is M), then (RQPF is M)

If (dPF is H) and (TEPF is M) and (OSCPF is H), then (RQPF is MH)

If (dPF is H) and (TEPF is H) and (OSCPF is L), then (RQPF is M)

If (dPF is H) and (TEPF is M) and (OSCPF is H), then (RQPF is H)

Fuzzy Inference Mechanism (FIM)
Mamdani's fuzzy inference mechanism (FIM) that is used here, is commonly used, in which the implication part is modeled by means of the minimum operator while the aggregation part is processed using the maximum operator.

Output Defuzzification
There are many defuzzification techniques in the literature. We use the center of area (COA) or center of gravity (COG) method. This method returns the center of area under the curve that result from the aggregation process. For given values of the displacement power factor, transmission efficiency power factor, and oscillation power factor, the fuzzy inference system module will calculate the representative quality power factor. Table 1 lists the output of the rule viewer for two cases, an ideal and non ideal case.

Table 1: Rule Viewer Output For Ideal And Non ideal Cases:

Case	DPF Input	TEPF input	OSCPF input	RQPF output
Ideal	1.00	1.00	0.816	1.00
Non Ideal	0.633	0.741	0.585	0.685

Note that, the ideal case corresponds to the sinusoidal linear load while the non ideal case corresponds to any other case than the sinusoidal linear load.

Simulation results

We made use of 230 volts supply and the current and potential transformers for measuring the V_{rms} and $I_{rms.}$ We made use of sample and hold circuits for measuring instantaneous current and voltage. From this we can obtain the COSØ, so that we can obtain TEPF and OSCPF. We made use of low pass filter to measure the fundamental voltage and current in order to obtain DPF. From this three input values using FUZZY LOGIC we found the RQPF.

Comparison of Normal Power factor and RQPF

This involves a pure resistive load results in coinciding values of the displacement power factor and transmission power factor (both value is one), but the oscillation power factor is different because its maximum value is not one, but 0.816. Also fuzzy the representative quality power factor has its maximum value of 0.948 in this case since all of the power factors that it presents are at their maximum value. But the normal power factor will give a UNITY POWER FACTOR.

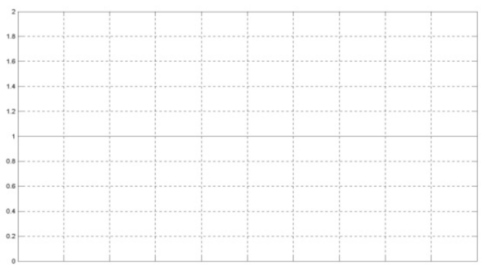
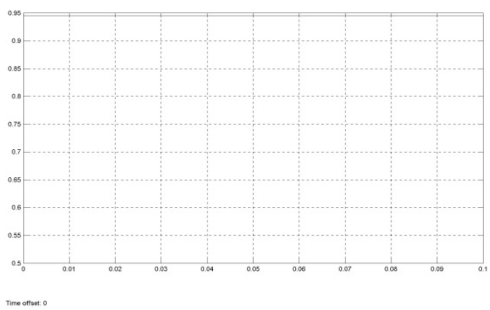

Figure 4.1: comparison of NPF and RQPF

Linear load supplied from sinusoidal source

Figure 4.2 shows a circuit consisting of linear load supplied from a sinusoidal source f=50Hz through a line having an impedance of 5+j5Ω. The source voltage has the rms voltage of 230 volts. The load voltage and the load current are used to calculate the displacement power factor, oscillation power factor, transmission power factor. Next using the proposed fuzzy based representative quality power factor module, the value of the representative quality power factor is obtained. Six cases are considered and their results under sinusoidal linear load are analyzed. The values for these cases are chosen to represent different values of power factors.

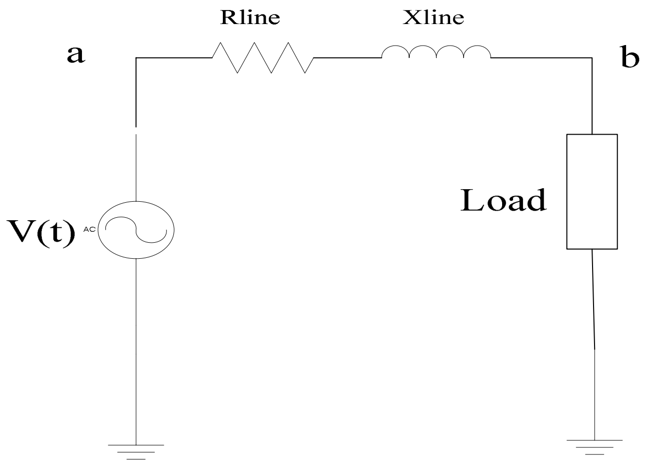

Figure 4.1: Linear loads supplied from sinusoidal or non sinusoidal source

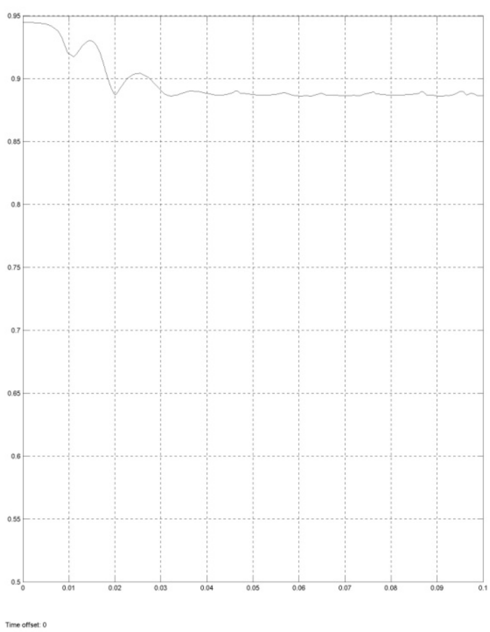

Figure 4.3: simulation output of linear load and sinusoidal case

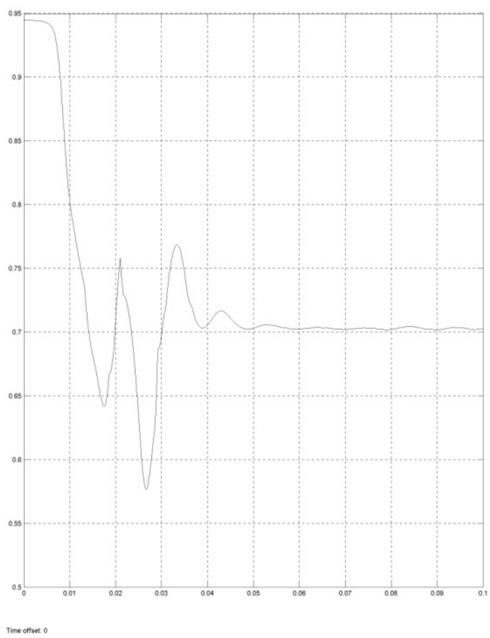

Figure 4.4: simulation output of non linear load and non sinusoidal case

Table 4.1: simulation output results for all the cases

LOADS	CASES	RQPF
1+j0	SL	0.948
	SNL	0.768
	NSL	0.925
	NSNL	0.944
0+j20	SL	0.05
	SNL	0.05
	NSL	0.05
	NSNL	0.05
0-j5	SL	0.049
	SNL	0.049
	NSL	0.051
	NSNL	0.051
20+j20	SL	0.751
	SNL	0.714
	NSL	0.685
	NSNL	0.701
20+113j	SL	0.283
	SNL	0.391
	NSL	0.251
	NSNL	0.288
20-j20	SL	0.690
	SNL	0.682
	NSL	0.758
	NSNL	0.714

Description of fuzzy FRQPF module in DSPACE

Linear load supplied from a sinusoidal source

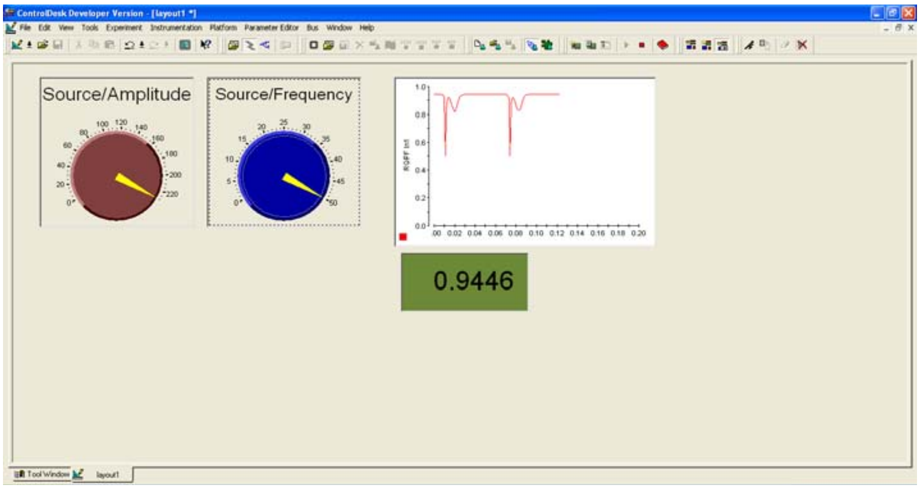

Figure 5.1: simulation output under linear load and sinusoidal condition

In the dSPACE kit we kept the voltage source for 230 V and the frequency parameter is set for the nominal value as 50 Hz. The output values for the various loads are tabulated in the table 6.1.

Non linear load supplied from non sinusoidal source

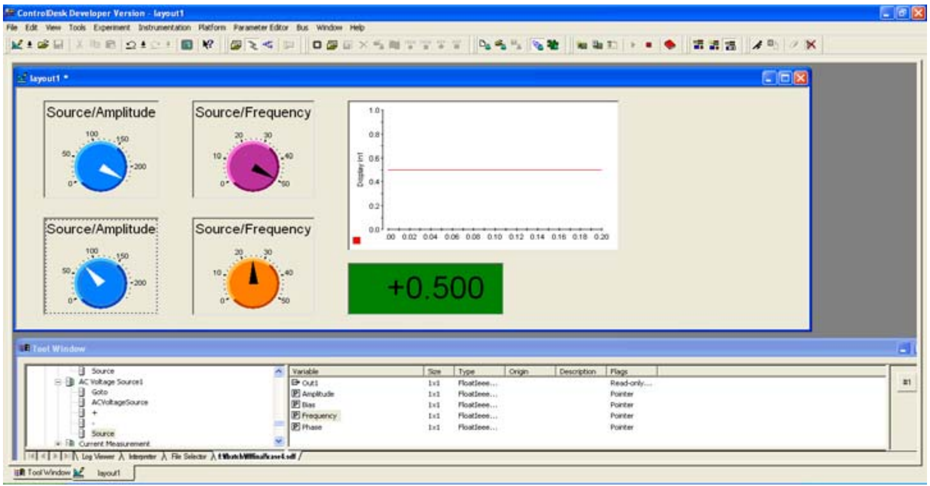

Figure 5.2: Simulation output under Non linear load and Non sinusoidal condition.

This is the case most likely to be encountered in practice. The load is non linear and the source is non sinusoidal. There is no coincidence between the displacement power factor values and the power factor values which indicates the presence of oscillating power. The useful power transmitted to load is less than the generated one in all loading conditions.

The results obtained reveal that the representative quality power factor expresses and successfully discriminates between these situations since its value does not exceed unity, situation. The fuzzy RQPF module can represent an essential module for evaluating and amalgamating the three power factors. The FRQPF proposed can be effective in making a cost- effective analysis for applying the power factor correction devices and power quality mitigation techniques.

Conclusion

In this project, a new fuzzy – based PQ index (FPQI) is developed through the amalgamation of displacement power factor, transmission power factor, oscillation power factor. The use of fuzzy system helps handling the uncertainties that arise in the electric power system due to the dynamic variation of its operation.

The RQPF characterize the degree of electric power system utilizations by a single index while carrying all of the characteristics of the three power factors that it represents. The result obtained indicates that, amalgamating the PQIs into the single index provides accurate, qualitative and quantitative measure of the power quality. The proposed FPQI would facilitate in ranking and evaluating the power quality indices under different cases where the stand-alone power quality indices are either not accurate or not enough. Based on this fact, the new index could be helpful in,

- Determining which PQ mitigation technique should be used.
- Deciding which supplier is the best among other suppliers during deregulation.
- Accurately evaluating the impact of DGs or renewable energy sources when being integrated with the electric grid.
- Charging customers fairly based on the disturbance that they cause to the electric power network.

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