Fuzzy System for the Detection of Power Quality Performance on Induction Motor

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***Summary*: Sensitive equipment and non-linear loads are now more common in both the industrial/commercial sectors and the domestic environment. Because of this a heightened awareness of power quality is developing amongst electricity users. Therefore, power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. This article presents the fuzzy system to determine the power quality. The performance of three-phase induction motor is observed for different power quality conditions in laboratory. The power quality is in terms of voltage is intentionally disturbed by means of three-phase motor alternator set and chopper circuit. It is observed that the fuzzy system is able to make correct diagnosis of power quality. It is also observed that as the power quality become poor, the motor efficiency decreases, causing significant rise in power input to meet the rated load demand, and thereby rise in electric bill.**

Keywords:
power quality (PQ)
fuzzy logic
induction motor
efficiency

1. INTRODUCTION

Electric power quality (*PQ*) has captured considerable attention from utility companies as well as their customers. The major reason for growing concerns are the continued proliferation of sensitive equipment and the increasing applications of power electronics devices which results in power supply degradation. *PQ* has recently acquired intensified interest due to wide spread use of microprocessor based devices and controllers in large number of complicated industrial process. The proper diagnosis of *PQ* problems requires a high level of engineering expertise. The increased requirements on supervision, control and performance in modern power systems make power quality monitoring a common practice for utilities. With the growth of the number of monitors installed in the system, the amount of data collecting is growing and making individual inspection of all wave shapes no longer an option.

Several tools were presented for the detection and classification of *PQ* events. In [1], *PQ* monitoring is explained in terms of disturbances, and in [2] it is explained in terms of underlying events. Signal analysis tools are used for detection and mostly consist of spectral domain analysis and wavelets [3, 4]. Voltage imbalance effect on the induction motor is mentioned in [5]. In [6] expert system application used for the classification of power system events. The survey in [7] cites the work for *PQ* applications using artificial intelligence and advanced mathematical tools. Adaptive neural-fuzzy tool is implemented in [8] for the analysis and diagnosis of *PQ*. In [9] *PQ* events were classified using optimal time frequency response. *PQ* event detection and classification methods explained in [10] using higher order cumulants and quadratic classifiers. Fuzzy logic and adaptive neural fuzzy inference system have proved ability in the area of fault detection [11, 12]. In this article fuzzy logic approach is applied and the software program is developed in DSP TMS 320 LF2812 for the determination of power quality input.

In general, the main *PQ* issue can be identified as, voltage variation, voltage imbalance, voltage fluctuations, low frequency, transients, interruptions, harmonic distortions, etc. The consequences of one or more of the above non-ideal conditions may cause thermal effects, life

expectancy reduction, dielectric strength and misoperation of different equipments. Furthermore, the *PQ* can have direct economic impact on technical as well as financial aspects by means of increase in power consumption and in electric bill. In this paper, the *PQ* is verified in a laboratory on 3 hp, 415 volts, 3 phase induction motor at constant load condition. The power input to the motor under performance is intently affected by a Motor-Alternator set and harmonic distortion added by three-phase chopper. This affects the *PQ* by implementing change in voltage, frequency as well as by adding harmonic distortion. It is observed from experimentation that, as the *PQ* becomes poor and poor, the motor efficiency reduces.

2. FUZZY LOGIC APPROACH FOR THE DETERMINATION OF *PQ*

The input supply voltage signals of each phase have potential to contain information related to *PQ*. The most suitable measurements for the diagnosis of *PQ* under consideration in terms of easy accessibility, reliability and sensitivity, are the input supply voltage. The voltage amplitudes, frequency and associated harmonics in terms of FFT are monitored by the system. In this study, the source power supply is provided by three phase Motor – Alternator Set and Chopper circuit. By means of this it is possible to disturb the power quality in terms of voltage, frequency and harmonics distortion.

As stated, the *PQ* can be deduced by observing the supply voltage amplitudes, frequency and harmonic distortions. Interpretation of result is difficult as relationship between *PQ* and the supply voltage amplitudes, frequency and harmonic distortions are vague. Therefore, using fuzzy logic, numerical data are represented as linguistic information. In our study, the supply voltage amplitudes, frequency and harmonic distortions in terms of Fast Fourier Transform (FFT) are considered as the input variable to the fuzzy system. The *PQ* is chosen as the output variable. All the system inputs and outputs are defined using fuzzy set theory:

$$\left.\begin{array}{l} V_r = \left\{\mu_{V_r}\left(v_{rj}\right)/\, v_{rj} \in V_r\right\} \\ V_y = \left\{\mu_{V_y}\left(v_{yj}\right)/\, v_{yj} \in V_y\right\} \\ V_b = \left\{\mu_{V_b}\left(v_{bj}\right)/\, v_{bj} \in V_b\right\} \\ F = \left\{\mu_f\left(f_j\right)/\, f_j \in F\right\} \\ H = \left\{\mu_H\left(h_j\right)/\, h_j \in H\right\} \end{array}\right\} \quad (1)$$

$$PQ = \left\{\mu_{PQ}\left(pq_j\right)/\, pq_j \in PQ\right\} \quad (2)$$

where v_{rj}, v_{yj}, v_{bj}, f_j, h_j and pq_j are the elements of the discrete universe of discourse V_r, V_y, V_b, F, H and PQ respectively, and $\mu_V(v_{rj})$, $\mu_V(v_{yj})$, $\mu_V(v_{bj})$, $\mu_f(f_j)$, $\mu_H(h_j)$ and $\mu_{PQ}(pq_j)$ are the corresponding membership functions respectively. The universe of discourse represents the operating range of the inputs. The voltage variation for all the phases between 0.94 pu to 1.06 pu consider as normal voltage. The voltages below 0.94 pu and above 1.06 pu considered as under voltage and over voltage respectively. If the voltages of each phase differ below 0.94 pu and above 1.06 pu, the condition is treated as imbalance voltage condition. The frequency deviation between 0.97 pu and 1.03 pu considered as normal frequency and below 0.97 pu considered as under frequency conditions. The most common measure of distortion in *PQ* is due to total harmonic distortion (THD). THD applies to both current and voltage and is defined as the rms value odd harmonics divided by the rms value of fundamental, and then multiplied by 100%. THD of current varies from a few percent to more than 100%. THD of voltage is usually less than 5%. Voltage THD below 5% are widely considered to be acceptable, but values above 10% are definitely unacceptable and will cause problems for sensitive equipment and load [13]. Voltage THD within 0.1 pu is considered as low harmonic distortion, where as above 0.1 pu is considered as high harmonic distortion.

Basic tools of fuzzy logic are linguistic variables. Their values are words or sentences in a natural or artificial language, providing a means of systematic manipulation of vague and imprecise concepts. For instance, the term set *T* (*PQ*) , interpreting power quality, *PQ*, as linguistic variable could be:

$$T(PQ) = \{Good, Fair, Poor\} \quad (3)$$

where each term in *T* (*PQ*) is characterized by a fuzzy subset, in a universe of discourse *PQ*. Similarly, the input variables V_r, V_y, V_b, F, and H are interpreted as linguistic variables, with:

$$\left.\begin{array}{l} T(V) = \{Normal, Under, Over\} \\ T(F) = \{Normal, Under\} \\ T(H) = \{Low, High\} \end{array}\right\} \quad (4)$$

where, $V = V_r$, V_y and V_b respectively.

Fuzzy rules and membership functions are constructed by observing the data set. For the measurements related to three-phase supply voltages, frequency and harmonics more insight data set is needed. Therefore, the membership functions will be generated as normal, under and over for voltages, normal and under for frequency and low and high for the total harmonic distortions. For the measurements related to power quality, it is only necessary to know if the *PQ* is good, fair, poor or extremely poor. The sugeno [14] type fuzzy inference system is used having five inputs and one output. The five inputs are three phase voltages (V_r, V_y, V_b), frequency (*F*) and voltage THD (*H*). The output of the system is *PQ*. The optimized membership functions for the inputs of this problem are shown in Figure 1. Once, the form of the initial membership functions has been determined,

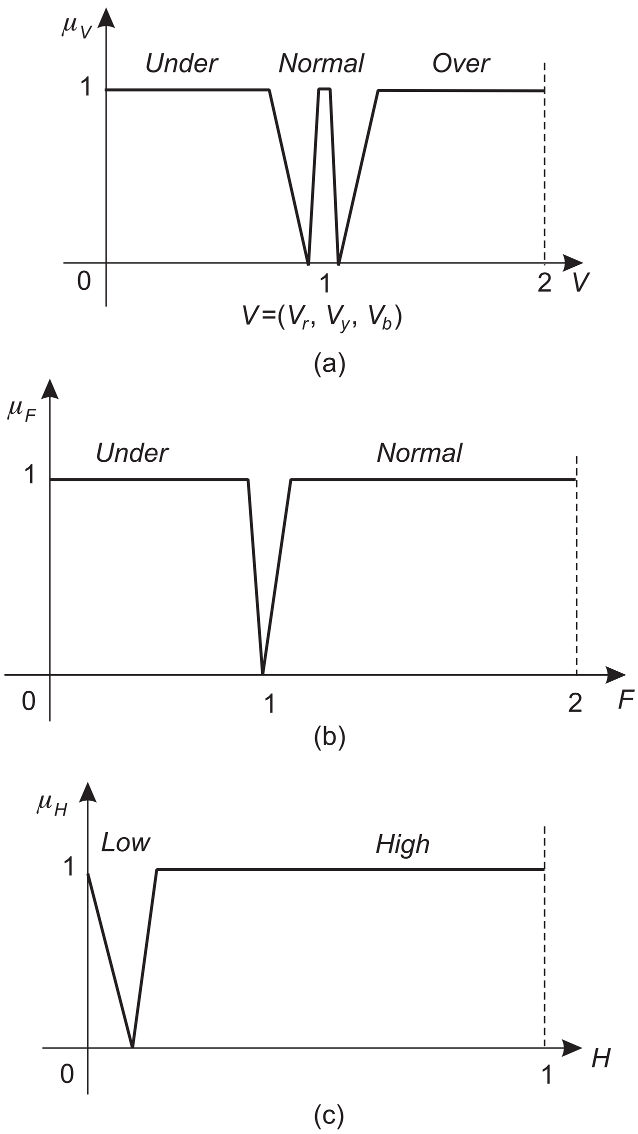


Fig. 1. Fuzzy membership functions for (a) Input supply voltages, (b) frequency and, (c) Total harmonics distortions (THD) volts

Table 1. Samples of fuzzy rules for the determination of power quality

1. If (Vr is N) and (Vy is N) and (Vb is N) and (F is N) and (H is L) then (PQ is G) (1)
2. If (Vr is U) and (Vy is U) and (Vb is U) and (F is N) and (H is L) then (PQ is F) (1)
3. If (Vr is O) and (Vy is O) and (Vb is O) and (F is N) and (H is L) then (PQ is F) (1)
4. If (Vr is N) and (Vy is U) and (Vb is O) and (F is N) and (H is L) then (PQ is F) (1)
5. If (Vr is N) and (Vy is N) and (Vb is N) and (F is U) and (H is L) then (PQ is F) (1)
6. If (Vr is U) and (Vy is U) and (Vb is U) and (F is U) and (H is L) then (PQ is P) (1)
7. If (Vr is O) and (Vy is O) and (Vb is O) and (F is U) and (H is L) then (PQ is F) (1)
8. If (Vr is N) and (Vy is U) and (Vb is O) and (F is U) and (H is L) then (PQ is F) (1)
9. If (Vr is N) and (Vy is N) and (Vb is N) and (F is N) and (H is H) then (PQ is F) (1)
10. If (Vr is U) and (Vy is U) and (Vb is U) and (F is N) and (H is H) then (PQ is P) (1)
11. If (Vr is N) and (Vy is U) and (Vb is O) and (F is N) and (H is H) then (PQ is F) (1)
12. If (Vr is N) and (Vy is N) and (Vb is N) and (F is U) and (H is H) then (PQ is F) (1)
13. If (Vr is U) and (Vy is U) and (Vb is U) and (F is U) and (H is H) then (PQ is P) (1)
14. If (Vr is N) and (Vy is U) and (Vb is O) and (F is U) and (H is H) then (PQ is P) (1)

the fuzzy *if – then* rules can be derived. These rules have been optimized so as to cover all the fourteen cases related to power quality. Samples of fuzzy rules are depicted in Table 1.

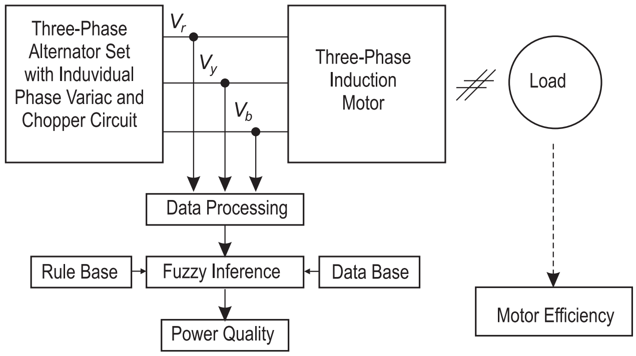


Fig. 2. Schematic view of the experimental setup

3. EXPERIMENTAL PROCESS AND RESULTS

The experimental setup is illustrated in Figure 2. It consists of three-phase, 3 hp, induction motor, supplied by an alternator. The excitation of the alternator is adjusted in such a fashion that, it can provide normal voltage, under voltage and over voltage conditions. However, the imbalance voltage condition is created by three individual units of variac connected in each phase.

The frequency of the supply can be varied changing speed of the motor coupled to alternator. It is possible to distort the waveform by chopping it with the chopper circuit. In this way, voltage THD of 14% is produced. The motor under performance is of three-phase, 3 hp, 415 volts, 4 poles, 50 Hz Δ connected, squirrel cage induction motor. The motor is coupled with DC generator and it provides constant rated load.

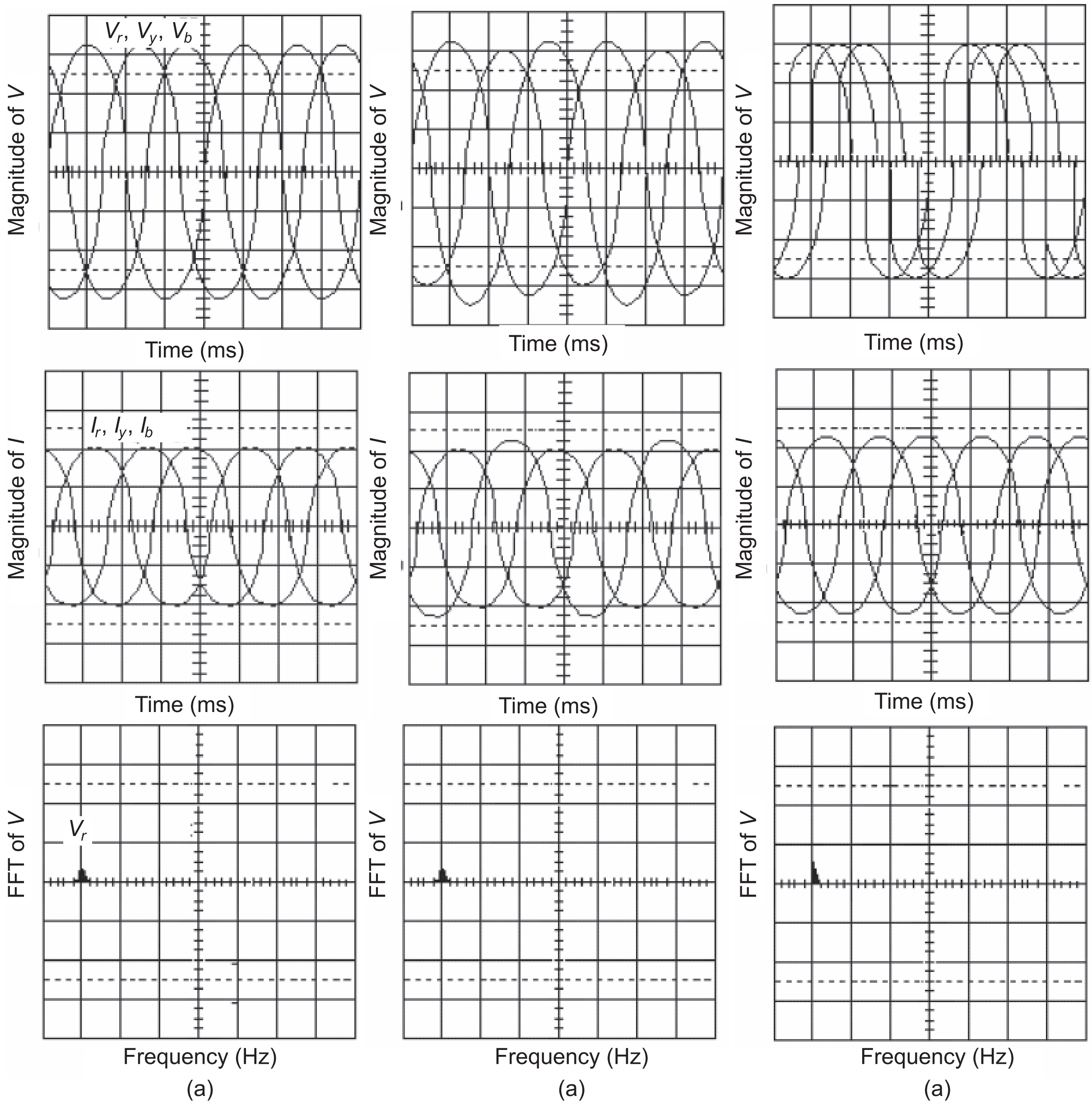
A detailed description of the 14 *PQ* operational cases that will be considered in the analysis is listed in Table 2. The power quality is intently made poor and poor by means of a Motor-Alternator set and three-phase chopper circuit. This is achieved by varying voltages, frequency and adding harmonic distortion. The multistage diagnosis of the *PQ* using fuzzy logic will be centered on these operational modes only.

Figure 3 depicts the few samples waveforms and their corresponding FFTs of above explained cases. Fuzzy inference diagrams for case 1, case 5, and case 14 are illustrated in Fig. 4 (a), 4 (b) and 4(c) respectively. In this figure, the indication of $PQ = 1$, $PQ = 0.5$ and $PQ = 0$ means power quality is good, fair and poor respectively. It is observed from the results that the proposed fuzzy logic approach is capable of highly accurate diagnosis. It is observed that as the *PQ* become poor and poor, the motor efficiency decreases. The results indicating the impact of *PQ* on motor efficiency and the corresponding fuzzy diagnosis of all the 14 cases are illustrated in Table 2. By examining the results, the following conclusions could be reached.

1. Fuzzy Logic approach has its unique advantages and these are applicable for diagnosis of power quality.
2. The specialty of this research work is that the Motor Alternator Set and Chopper circuit are used for creating the disturbance in power quality.
3. It is observed from the performance results that the fuzzy logic approach diagnosis accuracy is up to 94%.
4. It is observed that with the degradation of *PQ*, the motor efficiency reduces. To meet the rated load requirement, motor draw more power at the input and it effects in increase in electric bill.

Table 2. Different cases of *PQ* and their analysis.

Case No.	Input Voltage volts			frequency (f) [Hz]	% THD volts	Motor Efficiency	Fuzzy logic diagnosis accuracy
	V_r	V_y	V_b				
1	415	415	415	50	2	81.70%	100.00%
2	373	373	373	50	2	78.41%	100.00%
3	457	457	457	50	2	79.13%	100.00%
4	415	373	457	50	2	78.97%	98.43%
5	415	415	415	48	2	74.83%	99.02%
6	373	373	373	48	2	73.19%	99.02%
7	457	457	457	48	2	75.79%	99.02%
8	415	373	457	48	2	75.22%	97.48%
9	415	415	415	50	14	78.53%	96.38%
10	373	373	373	50	14	76.29%	95.63%
11	415	373	457	50	14	75.01%	95.16%
12	415	415	415	48	14	73.81%	96.91%
13	373	373	373	48	14	71.22%	95.47%
14	415	373	457	48	14	73.09%	94.51%



Scale: Voltage 100 volts/div, current 2.5 Amp. /div and frequency 10 ms/div.

Fig. 3. Voltage / current waveforms and corresponding FFT of *r* phase voltages (a) Normal voltage, normal frequency and less harmonic distortion, (b)Imbalance voltage, normal frequency and less harmonic distortion, (c) Imbalance voltage, normal frequency and 14 % harmonic distortion

4. CONCLUSION

This paper presents fuzzy logic approach for the determination of *PQ*. The main objective is to distinguish the *PQ* and study its effect on the performance of three-phase induction motor. The *PQ* is intently made poor by means of a programmable inverter. The variation in voltages, frequency as well as addition of harmonics distortion is possible by it. The diagnosis accuracy of fuzzy system to determine the *PQ* is found up to 94%. It is observed that with the degradation of *PQ*, the motor efficiency get reduced and there is a considerable rise in motor intake current. The additional motor intakes not only affect the motor performance but it also cause rise in electric bill.

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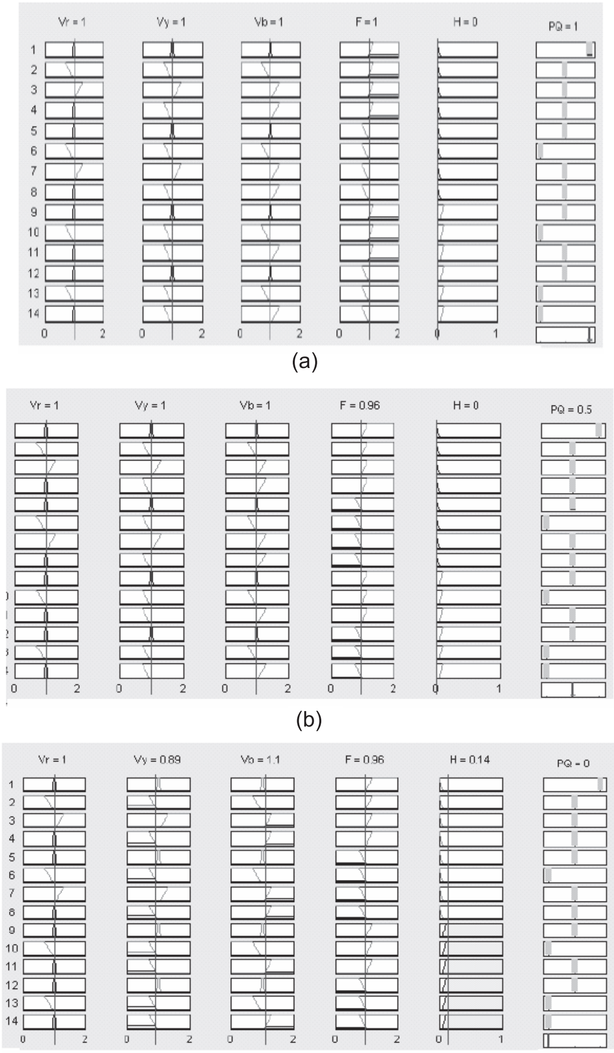

(a)

(b)

(c)

Fig. 4. Fuzzy inference diagram for (a) case 1, (b) case 5 and (c) Case 14

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