Power Quality Assessment of Perturbed Power System Implementing Fuzzy Logic and Discrete Wavelet Transform

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Abstract: A novel power quality index (PQI) is determined in this paper which helps in determining the power quality under non-sinusoidal condition. Power quality monitoring is important due to exponential growth of non linear loads in electric power system. As non linear loads creates the distortion level in distribution system so it is highly necessary to measure power quality index. The innovative power quality index has been found out by considering three component such as Representative quality factor(RQPF), Detailed pollution factor(DPF), Total harmonic Distortion(THD). When total harmonic distortion of voltage(THD_V) and Total harmonic distortion of current(THD_I) amalgamation occur then THD has been formed using fuzzy inference system. An experimental model has been developed to verify the PQI under different cases by measuring voltage and current both on the source side and utility side . The measured voltage and current are reformulated as wavelet function using discrete wavelet transform (DWT) to calculate referred power quality factors . This new power quality index has been validated through hardware model to justify its importance under different non-sinusoidal conditions.

Keywords : , fuzzy inference system, power quality index, total harmonic distortion wavelet packet transform

I. INTRODUCTION

In last decade distribution system has vital changes as renewable energy system is being integrated to electric grid with various types of non linear loads such as Variable frequency drives, electric furnace[7] etc. As consumer demand is increasing vigorously for power without distortion so power quality is an active research area to explore the ideas to improve power quality. On the basis of power quality electrical consumers are highly anxious in choosing their suppliers In the deregulated market. As all we know product of voltage and current is power , for a better power quality both voltage and current quality are responsible, therefore we need to calculate the power quality by quantifying deviation and distortion which mainly present in electrical voltage and current waveform.

Fuzzy based RQPF is calculated which is an amalgamation of DPF, TEPF and OSCPF.A new PQI is calculated which amalgamates RQPF, Total harmonic distortion and detailed pollution for both purely sinusoidal case and non sinusoidal case with both linear and non linear load[10]. This new power quality index mainly decides which is the best supplier among all in the power market and penalty tariff is being set for those customer who are generating harmonics and proper action has been taken for mitigating the harmonics. The wavelet packet transform(WPT) has been used and a fuzzy wavelet packet power quality Index[7] has been developed and it is also redefined in time frequency domain under non stationary disturbance. This WPT[14] helps to measure the indices properly. For both fundamental and all harmonic signal a innovative method based wavelet packet transform has been used. Fuzzy inference system mainly used to calculate fuzzy wavelet packet transform based power quality index (FWPTPQI) which has a lot many advantageous features such as simplicity, flexibility ,reliability .Non stationary waveform handling is mainly through the wavelet packet transform. This FWPTPQI [8]is significant to power quality mainly and which help in analysing the cost of electric bill in a deregulated market and also it do a fair means of electric bill calculation.

In this paper the author describes a PQI[[9] based on Fast Fourier transform (FFT) which gives accurate result under stationary waveform condition only. Different case studies are considered for both three phase balanced and unbalanced condition. it is shown that the absolute difference in the result in case of wavelet packet transom(WPT) based indices is very small and in case of non stationary waveform when FFT is being used the absolute difference is very large. In a three phase system impact of PQI is identified and quantified with the help of phase crest factor. This node crest factor is mainly represent the wave form in frequency domain. Wavelet Hilbert transform[19]and single side band modulation are used in a new method for calculation of a PQI which is instantaneous.

As location of harmonic generating sources is very much important so the author implement a new algorithm for locating harmonic generating sources[1] in this paper. It is also very important to find out exact location of the dominant harmonic generating sources. Here different case studies have done in a radial distribution system for detecting the location of harmonics and locating the dominant harmonics when multiple harmonic sources are present. A new methodology has been implemented which mainly help for detecting various sources of harmonic in distorted power system, so a new single point strategy has been discussed for detecting the harmonic source upstream and downstream[3] the metering section. An Ideal analytical pyramid process has been developed which has mainly three states such as ideal, actual and possible states. Harmonic pollution[4] on power system has drastically increased as power electronic load demands are increasing day by day so reactive power compensation is a vital task in power system. Worldwide accepted power definition in a single phase circuit with non sinusoidal voltage and current

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are also important for finding out power quality indices. For various categories of electricity consumer the severity level [17]of power quality disturbance is estimated and a new power quality index is calculated depending upon the severity of disturbance and load type. This power quality index improves electricity services. The fuzzy logic is used as a tool to classify power quality problems.

New intelligent system technologies using DSP,AI [5]and machine learning which have some unique advantage in classifying power quality distortion. In this paper the author describes that wavelet can be applied to identify the required amount of balancing capacity by observing the time varying nature of dominant frequency[12] which remain present in power signal and power system generation must match with the load. As there is always a fluctuation between generation and load so to find out the fluctuation pattern wavelet analysis is applied. Here two things are mainly analysed one is Total harmonic distortion and other is K-factor [13] based on DWT . DWT based indices has a lot of advantages over FFT based indices which has been described in this paper.

In this paper a DWT based fuzzy module has been designed to judge power quality under non sinusoidal condition. The new developed power quality index is the combination of Representative Quality Factor(RQPF), Detailed pollution factor(DPF), Total harmonic distortion(THD) and THD module which is the amalgamation of total harmonic distortion of voltage(THD_V) and Total harmonic distortion of current(THD_I) using fuzzy inference system . The authors of the present paper validate the result of new power quality index through both hardware and fuzzy based software implementation.

II. DISCRETE WAVELET BASED POWER COMPONENT [2]

The rms values of voltage (V) and current (I) are given by

$$V = \sqrt{\frac{1}{T}\int_0^T v^2(t)dt} = \sqrt{V_{jo}^2 + \sum_{j\geq jo} V_j^2} \quad (1)$$

$$I = \sqrt{\frac{1}{T}\int_0^T i^2(t)d} = \sqrt{I_{jo}^2 + \sum_{j\geq jo} I_j^2} \quad (2)$$

Here $V_{jo}\, I_{jo}$ mainly represents rms value of the voltage and current of the lowest frequency band and the approximated voltage and current are represented as (V_{app}) and (I_{app}), respectively. $\{V_j\}$, $\{I_j\}$ basically show the rms values of voltage and current of individual frequency band and the wavelet-level which is mostly higher than or equal to the scaling level j_0 and are known as detailed voltage and detailed current and represented i n the form of(V_{det}) and (I_{det}) respectively. The voltage THD (THD_V) which is mainly defined in DWT domain

$$THD_V = \frac{V_{det}}{V_{app}} \quad (3)$$

The current THD which is represented as (THD_I) in DWT domain mainly represented as

$$THD_I = \frac{I_{det}}{I_{app}} = \frac{\sqrt{\sum_{j\geq jo} I_j^2}}{I_{jo}} \quad (4)$$

The active power with approximation known as P_{app} represented as

$$P_{app} = P_{jo}\, \frac{1}{T}\sum_k c'_{j0,k}\; c_{j0,k} \quad (5)$$

The detail active power is given by

$$P_{det} = \sum_{j\geq jo} P_j = \frac{1}{T}\sum_{j\geq jo} d'_{jo,k} d_{jo,k} \quad (6)$$

The discrete wavelet coefficients of voltage and current are $c'_{jo,k}$ and $c_{jo,k}$ respectively, at the scaling level j_0 and k while $d'_{jo,k}$, $d_{jo,k}$ are the voltage and current discrete wavelet coefficients, respectively at any level j other than the scaling level j_0 and sample k.

Total active power (P) is [2]

$$P = P_{app} + P_{det} \quad (7)$$

Approximation apparent power is [2]

$$S_{app} = V_{app}\, I_{app} = V_{jo}\, I_{jo}$$

Current Distortion Power (D_I) is [2]

$$D_I = V_{app} I_{det} = V_{jo}\left(\sqrt{\sum_{j\geq jo} I_j^2}\right) \quad (8)$$

Voltage Distortion Power (D_v) is [2]

$$D_v = V_{det} I_{app} = I_{jo}\left(\sqrt{\sum_{j\geq jo} V_j^2}\right) \quad (9)$$

Detail apparent power is [2]

$$S_{det} = V_{det}\, I_{det} = \left(\sqrt{\sum_{j\geq jo} I_j^2}\right)\left(\sqrt{\sum_{j\geq jo} V_j^2}\right) \quad (10)$$

Detail distortion power [2]

$$D_{det} = \sqrt{S_{det}^2 - P_{det}^2} \quad (11)$$

The total apparent power S is [2]

$$S_N^2 = D_I^2 + D_V^2 + S_{det}^2$$

The detail pollution DP can be defined as the ratio of the non-approximation apparent power S_N to the approximation apparent power S_{app} [2]

$$DP = S_N / S_{app} \quad (12)$$

The displacement power factor [2] is

$$dPF = P_{app} / S_{app} \quad (13)$$

The transmission efficiency power factor [2] is

$$PF = P/S = TEPF \quad (14)$$

The oscillation power factor [2] is

$$PF_{osc} = \frac{P}{\sqrt{P^2 + \frac{1}{2}S^2}} = \frac{PF}{\sqrt{\frac{1}{2} + PF^2}} \quad (15)$$

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Fuzzy based RQPF module [10]:

In this paper the authors have used already established RQPF module [10] which is the combination of DPF,TEPF and PFosc and it is shown in Fig.1. In this module each inputs contain three linguistic variable as poor, medium and good. The output of this module i.e.RQPF have seven number of membership function which are as very low(VL),low(L),medium-low(ML),Medium(M), medium-high(MH), high(H) and very high(VH).

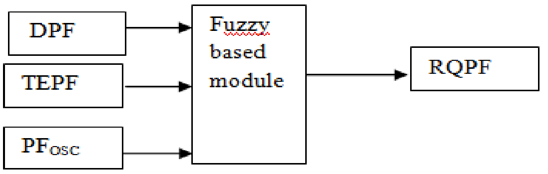

Fig.1: Block diagram of RQPF module

III. FUZZY BASED THD MODULE :

The total harmonic distortion of both the voltage and current signal at the highest approximation level has been considered and normalised. The values of Total harmonic distortion of voltage(THDv) and Total harmonic distortion of current(THD_I) are used in fuzzy module as inputs.They are fuzzified and finally converted to a single value I.e. Total harmonic distortion (THD). Triangular membership functions are used in this module for input and output fuzzification. In both THDv and THD_I module have five number of membership functions which are very-low(VL),low(L),Medium(M),high(H) and very-high(VH) and the output parameter i.e.THD has eight number of membership function such asvery-low(VL),low(L),Low-high(LH),Medium-low(ML), Medium(M),Medium-high(MH),high(H) and very-high(VH). The total module has been shown in Fig. 2 and the membership function of this model is shown in the Fig.3.

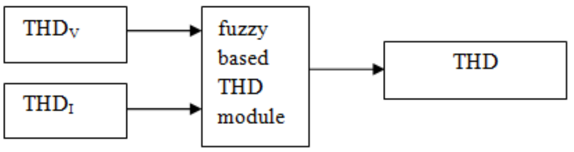

Fig. 2: Block diagram of THD module

Table 1: Different values of THD by considering different input signals

THD_V	THD_I	THD
0.142	0.168	0.128
0.216	0.168	0.134
0.216	0.205	0.14
0.427	0.368	0.349
0.491	0.532	0.561
0.573	0.532	0.647
0.61	0.577	0.7
0.702	0.668	0.776
0.784	0.75	0.859
0.876	0.75	0.877
1	0.841	0.95
1	0.914	0.951
1	0.986	0.966

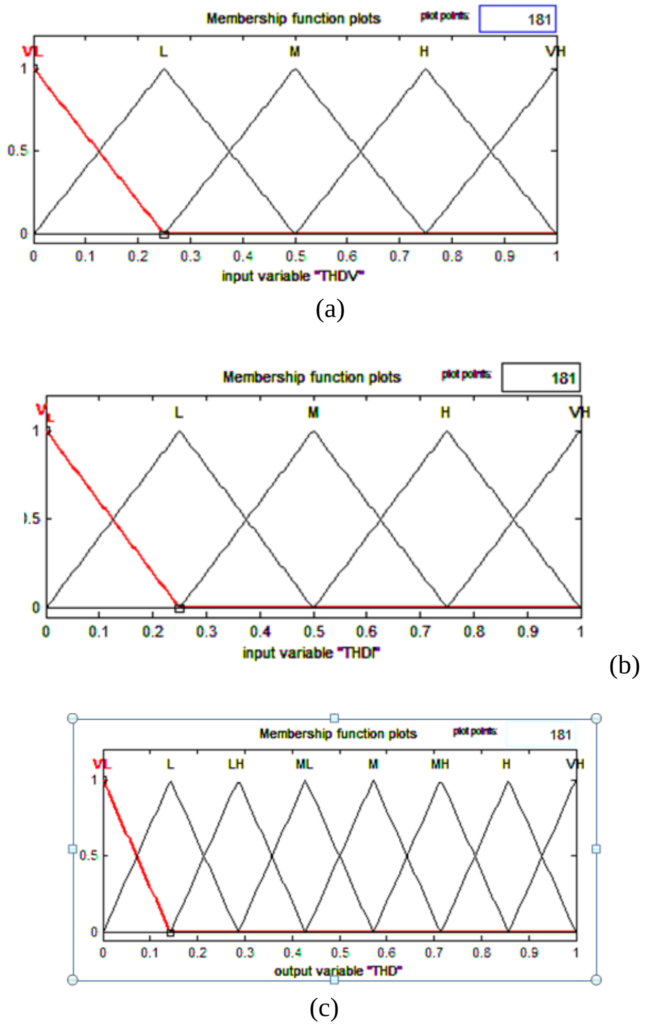

Fig 3:Membership function of THD (a)input variable THD_V (b)input variable THD_I(c)output variable THD

IV. FUZZY SYSTEM IMPLEMENTATION FOR PQI CALCULATION

In this section the authors have used the fuzzy inference system to calculate new power quality index, that will evaluate the quality of power with considering RQPF,DP and THD.A single universal index is calculated by considering above three input and shown in Fig. 4. The membership function of all the inputs are shown in shown in Fig.5 (a) and Fig.5 (b) . In this work the authors have used the same triangular membership function for representation of new PQ index. The output PQI has nine number of membership function as shown in Fig 5(c). The output THD will be acting as input for calculating new power quality index.

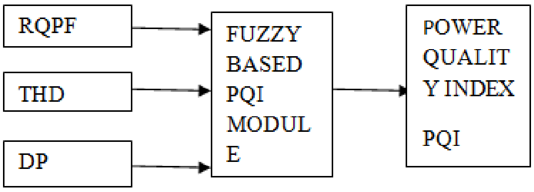

Fig 4: Block diagram representation for new power quality index

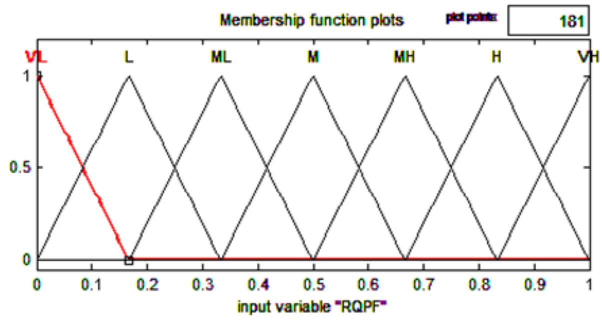

Fig. 5: (a)Membership function of input RQPF

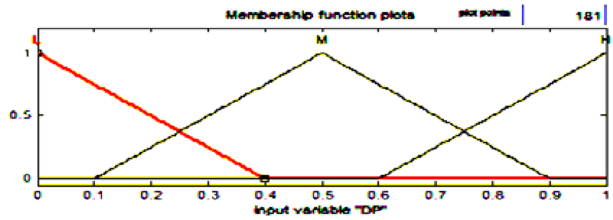

Fig. 5. (b):Membership function of input DP

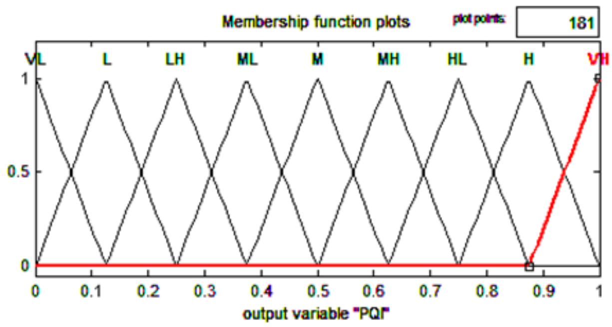

Fig. 5.(c) : Membership function of output PQI

Fig. 5: Membership function plot of Input and output of PQI module

V. A.SIMULATION RESULT FOR NEW POWER QUALITY INDEX:

For getting better accuracy in calculating new power quality index different values of detailed pollution has been considered which means variation of harmonic content in the system. In Table 2 it is reported that variation of PQI index under different conditions i.e. in this table first result shows that when power factor is very high, THD i.e harmonic distortion not present and DP i.e harmonic content is not present then PQI has got maximum value. Then its varying depending on the input signals.

In Table 3 variation of PQI has been shown under different non-sinusoidal conditions. In this case the authors have considered the input signals are contained significant amount of harmonics with varying power factors i.e in case I all the parameters are varying but index has got lowest value i.e. 0.016 when power factor is poor, harmonic pollution (DP) and harmonic distortion (THD) are in maximum value which means maximum non linearity is present in the system . In case II and Case III one of the input has been considered as constant with some value and remaining other two are varying to represent non-sinusoidal conditions. Each case studies are proved that proposed index is very much case sensitive.

VI. CASE STUDY WITH EXPERIMENT

The authors of this paper have used 220V,single phase 0.5 HP,2.6 Amp 1440RPM rating of induction motor as load and a single phase AC to AC converter between the source and the load. The AC to AC converter is a triac based voltage converter .The triac is of BT-139,600V,170 Amp and having 3 pin . In this work voltage and current signal have been captured and processed through discrete wavelet transform to calculate specified power quality components. The experiment conducted is shown in the Fig. 6 and equivalent block diagram has been drawn in Fig 7. In the experimental setup the authors have considered both upstream and down stream side of PCC where voltage and current has been captured for different case studies.

In the above experiment the authors have measured the voltage and the current both on the upstream and downstream side of the PCC. By changing firing angle the voltage and current waveform through a digital storage oscilloscope(DSO) have been recorded . After capturing voltage and current signals, DWT has been applied to calculate required power component by using eq.(1) to (15). These power components are used as a input to the PQI mule in a fuzzy platform.

Case I: In this case the voltage has been measured and also current has been measured on the upstream side of the PCC to represent the voltage and current which shows sinusoidal voltage and non sinusoidal current.The upper graph is the current which is non-sinusoidal and the lower one is the voltage which is sinusoidal i.e. shown in Fig. 8. It is reported in Table 4 that various components of power quality components have been calculated using DWT by varying firing angle of AC to AC converter. This voltage and current signal will helps in measuring the power quality index through DWT based fuzzy module. From the experimental results various power quality components has been calculated such as P_{fosc}, TEPF,DPF,DP,THDv,THD_I.From these value the authors have calculated the RQPF and THD from fuzzy platform. In this Table last column is the proposed index which represent that PQI is very much case sensitive as voltage is sinusoidal THD_V is negligible in comparison to THD_I as the current is non sinusoidal. With increase in current distortion and harmonic pollution the PQI is reducing.

Case II: In this case the voltage and current has been measured on the downstream side of the PCC to represent the voltage non- sinusoidal and current non-sinusoidal.The upper graph is the current which is non-sinusoidal and the lower one is the voltage which is also non-sinusoidal i.e. shown in Fig. 9. It is reported in Table 5 that different power quality components have been calculated using DWT by varying firing angle of AC to AC converter. By following the same procedure the results have been found shown in the Table. In Table 5 last column is the proposed index and in this case also PQI is highly case sensitive as voltage is non-sinusoidal THD_V has got significant values as THD_I . As both voltage current signals are non sinusoidal so resultant THD is significantly high and PQI is comparatively low with respect to Case I. With increase in total harmonic distortion and harmonic pollution the PQI is reducing.

Fig 6.(a): Experimental set up

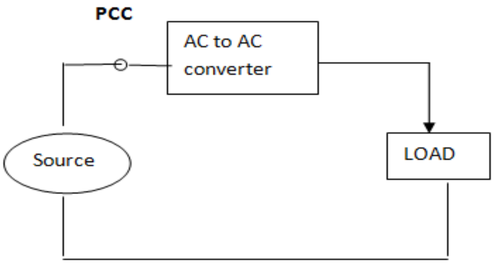

Fig 7: Block diagram of experiment

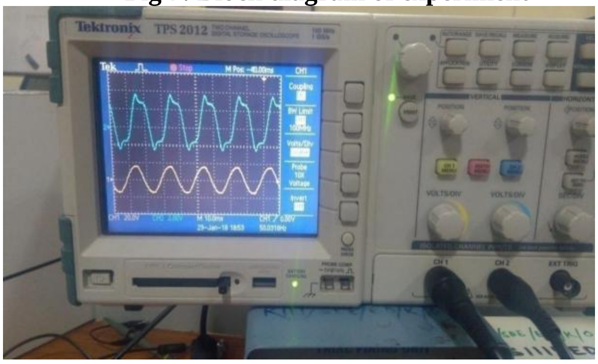

Fig. 8: Current and voltage waveform on source side

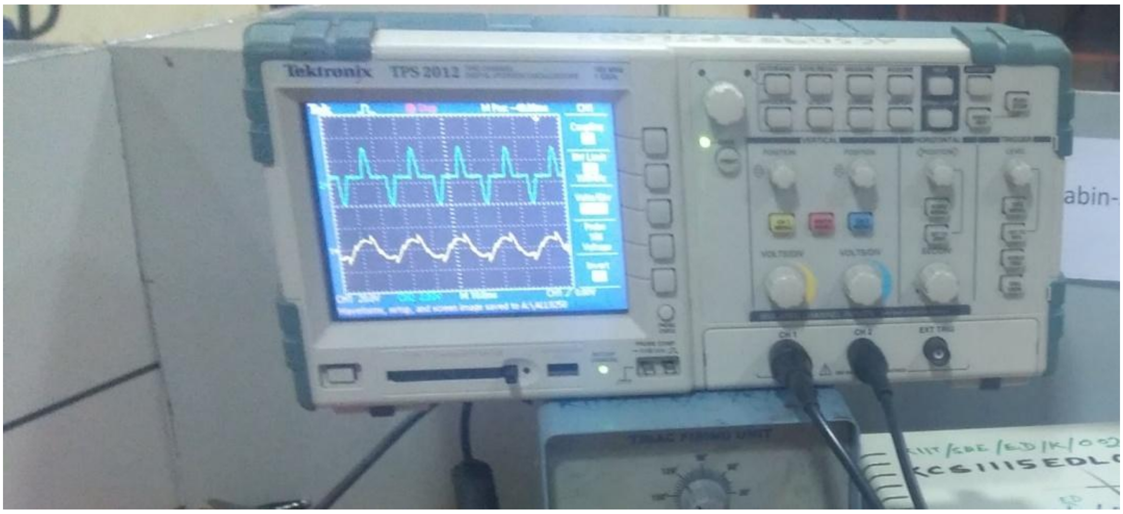

Fig. 9: Current and voltage waveform on load side

Table 1: Different values of THD by considering different input signals

THD_V	THD_I	THD
0.142	0.168	0.128
0.216	0.168	0.134
0.216	0.205	0.14
0.427	0.368	0.349
0.491	0.532	0.561
0.573	0.532	0.647
0.61	0.577	0.7
0.702	0.668	0.776
0.784	0.75	0.859
0.876	0.75	0.877
1	0.841	0.95
1	0.914	0.951
1	0.986	0.966

Table 2: Variation of Power quality Index when only RQPF and THD are varying

RQPF	THD	DP	PQI
1	0	0	0.99
0.488	0.416	0	0.363
0.657	0.512	0	0.488
0.861	0.705	0	0.738

Table 3: variation of Power quality index when all the inputs are varying

Conditions	RQPF	THD	DP	PQI
Case I: Variation of PQI when all the inputs are varying	0.163	0.8	0.87	0.016
	0.331	0.127	0.127	0.284
	0.476	0.319	0.355	0.321
	0.584	0.56	0.367	0.488
	0.777	0.56	0.367	0.562
Case II: Variation of PQI when DP and THD are constant and RQPF is varying	0.0904	0.367	0.199	0.239
	0.355	0.367	0.199	0.303
	0.404	0.367	0.199	0.305
	0.512	0.367	0.199	0.39
	0.717	0.367	0.199	0.5
	0.801	0.367	0.199	0.587
	0.97	0.367	0.199	0.664
Case III: Variation of PQI when RQPF and THD is constant and DP varying	0.97	0.307	0.307	0.62
	0.97	0.307	0.464	0.56
	0.97	0.307	0.572	0.5
	0.97	0.307	0.673	0.451
	0.97	0.307	0.875	0.401

Table IV: Calculation of different power component using DWT when voltage source is sinusoidal

Firing angle(in degree)	Pfosc	TEPF	DPF	RQPF	DP	THD	PQI
120	0.14	0.1	0.1	0.081	0.61	0.693	0.277
90	0.27	0.2	0.2	0.15	0.51	0.622	0.402
60	0.38	0.3	0.3	0.301	0.48	0.42	0.363
30	0.4	0.355	0.355	0.358	0.33	0.36	0.426

Table V :Calculation of RQPF using Fuzzy based RQPF module when voltage is non sinusoidal and current non sinusoidal on load side

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Firing angle(in degree)	P_{fosc}	TEPF	DPF	RQPF	DP	THD	PQI
150	0.39	0.3	0.3	0.301	0.46	0.13	0.33
120	0.51	0.45	0.45	0.5	0.39	0.12	37
90	0.6	0.67	0.67	0.74	0.32	0.09	0.43
60	0.78	0.78	0.77	0.98	0.28	0.07	0.71

VII. FUZZY SYSTEM IMPLEMENTATION FOR PQI CALCULATION

In this section the authors have used the fuzzy inference system to calculate new power quality index, that will evaluate the quality of power with considering RQPF,DP and THD.A single universal index is calculated by considering above three input and shown in Fig. 4. The membership function of all the inputs are shown in shown in Fig.5 (a) and Fig.5 (b) . In this work the authors have used the same triangular membership function for representation of new PQ index. The output PQI has nine number of membership function as shown in Fig 5(c). The output THD will be acting as input for calculating new power quality index.

VIII. CONCLUSION:

In the deregulated market having various power quality parameter with many values has no significance till they are not being represented as a single value. Combination of different power quality indices through fuzzy logic has been implemented which gives a better power quality index that improves the customer satisfaction in deregulated market. The new power quality index contains THD which contain the voltage and current harmonic distortion. A fuzzy based new power quality index has been calculated with three parameter as RQPF,THD and DP. Through experiment it has also been verified for different cases such as voltage sinusoidal and current non sinusoidal, voltage non sinusoidal and current non sinusoidal and voltage and current value has been measured and applied to DWT for calculation of RQPF,DP and THD_V and THD_I. A new PQI has been verified by using fuzzy based PQI module from the experimental data. The index will helps in deciding the penalty for tariff setting for the customers who generates harmonics and also necessary action can taken care to mitigate the harmonics.

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AUTHORS PROFILE

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