Improvement of Power Quality Using a Hybrid UPQC with Distributed Generator

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ABSTRACT: This paper proposed a reduced rating star- connected transformer based unified power quality conditioner with distributed generator for power quality improvement. This work comprises of a three phase three wire UPQC, star connected transformer and LC filter. This hybrid approach significantly improves the performance of UPQC under unbalance source voltage condition. The UPQC adopted to compensate current and voltage-quality problems of sensitive loads and suppressing the load current harmonics under distorted supply conditions. The dc link control strategy is based on the fuzzy-logic controller. The proposed solution has analyzed and described, and a model of a 500-kVA grid is considered. The extensive simulation results have carried out in MATLAB/Simulink environment power system blockset toolboxes. From the results it has shown that hybrid UPQC with DG achieves superior capability of mitigating the effects of voltage sag/swell and suppressing the load current harmonics, phase current harmonics and neutral current under distorted supply conditions. To validate the results produced by the proposed method, it is compared with the conventional UPQC method and better results obtained from the hybrid approach.

KEYWOEDS: Hybrid Unified Power Quality Conditioner, Fuzzy Logic Controller, Neutral current, Distributed Generator

I. INTRODUCTION

Electricity is utmost important for today's fast growing world. The electricity consumption and demand rises randomly due to increase in manufacturing industrial load, domestics load and other loads. On behalf of the load forecasting the new power sector also installed to meet the load demand and future demand. However, some power losses occur during the transmission and distribution system. The conventional source like coal and nuclear is widely used in the electricity production, that source pollutes the environment severely. As well as, to prevent the increases of pollution by installing renewable energy sources in distribution network as Distributed Generator (DG). The DG is the small amount of power deliver to the distribution system such as diesel generator or other source. In this work the DG is used with solar and/or wind energy.

The DG plays a vital role during the peak load period or load exceeds the generation. However, DG also compensates the power quality problem to a great extent. Power quality problems have been resolved in past using shunt passive or active filter. Lately, several solutions have been suggested and the recent developments in FACTS and power devices have opened new opportunities to apply power electronics based solutions to power system problems. The use of power devices is the topic of current research and Unified Power Quality Conditioner (UPQC) is one of the most popular solutions used nowadays. The UPQC as classified in literature as simultaneous control device to control the active power and reactive power and it protects the sensitive load from major disturbances [1]. The major disturbances occur in the distribution side are harmonics, voltage sags/swell, excessive neutral current. The UPQC comprises of combined operation of Static Synchronous Compensator (STATCOM) and Dynamic Voltage Restorer (DVR) [2]. The STATCOM is compensating the reactive power and harmonics in the load side and DVR mitigates the voltage sags/swell in the source side. From this proposed method the major disturbances are reduced and also the control voltage sag originating from the supply side [6].The reduced rating star connected transformer is minimum volt-ampere rating transformer which connected in parallel to the load and a LC filter is connected between the neutral of the star connected transformer. The reduced rating star connected transformer with LC filter based UPQC coupled with DG has been proposed in this paper.

The star connected transformer is only for compensating the phase current harmonics and the LC

filter suppressing the neutral current, from this approach with UPQC is hybrid UPQC [7], [8].The application of star connected transformer for reduction of neutral current has an advantage due to less complexity over the conventional method [9]. The DG is connected in between the dc link of the UPQC. The wind and/or solar energy source of 10 MW power is connected as DG. This wind energy DG is suitable for the wind source location however the wind source is not available the solar energy is used as DG [10], [11]. The Fuzzy Logic Controller (FLC) is used in the shunt converter controller of the UPQC in conventional method [12], [13], the hybrid UPQC consisting of FLC in series converter controller. The result obtained from the hybrid approach clearly shown that power quality of the distribution system is increased from that of the conventional method [14]. The simulation of the proposed method has been carried out by MATLAB software. The results are compared with DG and without DG and also compared from the source side and load side it shown that new scheme has been compensates the disturbances on both side with superior capability.

II .CONFIGURATION OF HYBRID UPQC

The proposed methodology comprises of the reduced rating star connected transformer based UPQC coupled with DG. The three phase source is taken from the 500 kVA grid. The series converter is connect through the series reactor from the line similarly through the shunt reactor is shunt converter. The series and shunt converter is linked with common DC link and capacitor. The proposed UPQC model is shown in Fig 1.

The DG is connected in the DC link of this UPQC. The series converter control strategy is based on the
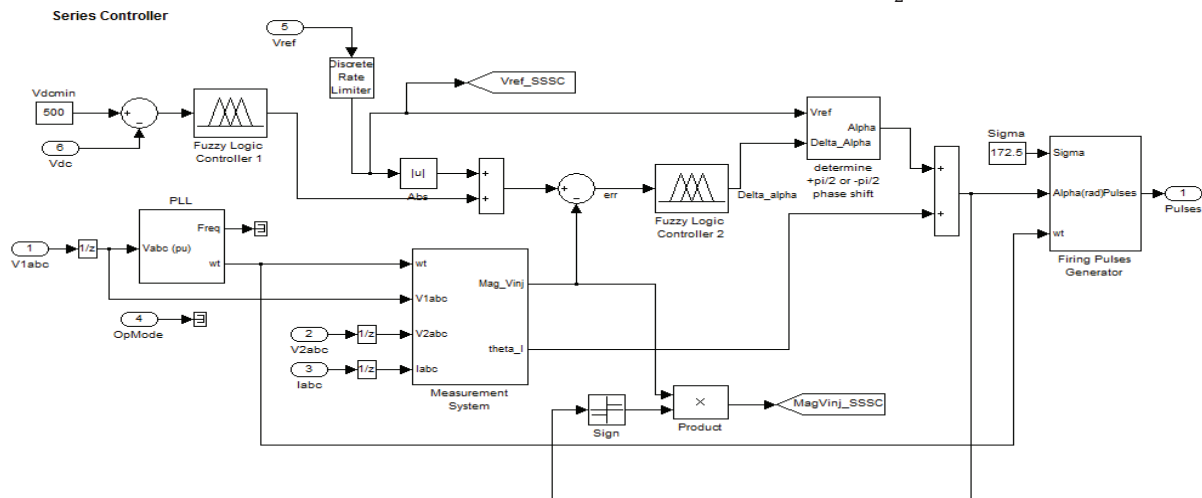
FLC.T he line current (I_L) to compensate the voltage sags/swell for the series converter as in (1).
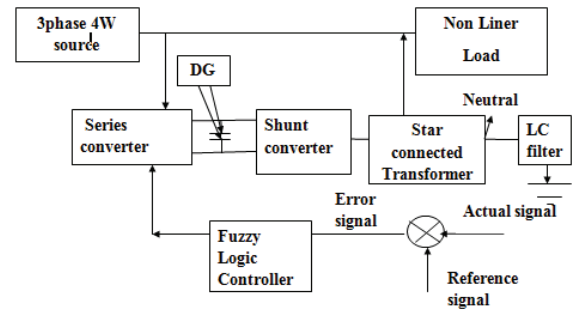

Fig.1. Proposed UPQC model

$$I_L = \frac{2v \sin \delta/2}{X} + \frac{V_c}{X} \qquad (1)$$

The power flow in the line is used for the series converter modeling and it is expressed as in (2)

$$P = VI_L \cos(\delta/2) \qquad (2)$$

Where

V is the magnitude of voltage δ is the angular Difference of the line

X is the series reactance of the transmission Line

The power balance equation is used for shunt converter modeling and it is expressed as in (3)

$$V_{dc}I_{dc} = \frac{3}{2}(E_{sR}I_{sR} + E_{sI}I_{sI}) \qquad (3)$$

Fig.2. FLC based series converter controller

Where
V_{dc} is the voltage value of DC link
I_{dc} is the current Value of DC link
E_{sI} is the power injected in the shunt converter
E_{sR} is the power injected in the shunt reactance
I_{sI} is the magnitude of shunt current
I_{sR} is the magnitude of shunt reactance current

The common DC link modeling is based on the shunt converter DC side circuit as in (4)

$$\frac{dv_{dc}}{d} = \frac{-1}{c_s} \left(I_{dc} + \frac{V_{dc}}{R_p}\right) \tag{4}$$

Where
c_s is the capacitor value of DC link
I_{dc} is the current value of DC link
V_{dc} is the voltage value in the DC link
R_p is the resistance in the circuit

The UPQC is connected with reduced rating star connected transformer. The neutral of the star connected transformer is connected with LC filter and its remains to earth. This hybrid approach reduces the phase current harmonics and compensates the neutral current. During the peak load and load exceeds generation from main source, the DG provide desired power to compensate and quality of power to the end users. The disturbance is made by the programmable voltage source then the result obtained with and without UPQC and DG is analyzed in source side as well as the load side.

A. Series Converter Control

The various disturbances like switching operation and other faults occur in the distribution system causes voltage sags and swell. It affects the consumer equipment severely. The series converter compensates the voltage sag and swells in the distribution network. The fuzzy logic controller based series converter controller is shown in Fig 2.

The DC link measured voltage is compared with the reference voltage by comparator. The error signal obtained from the comparator is processed with FLC 1.The actual value of voltage in phase a, b, c is processed with the magnitude of the injected voltage in series converters. This output value is compared with output of FLC 1 by comparator. The amplitude of voltage is used for reference current calculation. The amplitude of the voltage computed from the three phase sensed value voltage as expressed as in (5).

$$v_{sm} = \left[\frac{2}{3} \left(v_{sa}{}^2 + v_{sb}{}^2 + v_{sc}{}^2 \right) \right]^{\frac{1}{2}} \tag{5}$$

Where
v_{sm} is the amplitude of supply voltage.
v_{sa}, v_{sb}, v_{sc}, are the three phase supply voltage.

The error signal from that comparator is again processed in the FLC 2. The output of FLC 2 is given to PWM. Depending on the firing signals from PWM the series converters compensate the voltage sags and swell. The compensation of voltage sag/swell is based on reference value of injected voltage. The reference value of the injected voltage is depends on the specification of the system. The reference values of injected voltage are expressed as in (6), (7), (8).

$$v_{ia} = \sqrt{2}\ v_{inj} \sin\left(\omega t + \delta_{inj}\right) \tag{6}$$

$$v_{ib} = \sqrt{2}\ v_{inj} \sin\left(\omega t + 2\frac{\Pi}{3} + \delta_{inj}\right) \tag{7}$$

$$v_{ic} = \sqrt{2}\ v_{inj} \sin\left(\omega t - 2\frac{\Pi}{3} + \delta_{inj}\right) \tag{8}$$

Where
$$v_{inj} = v_s\ -\ v_l \tag{9}$$

v_s – supply voltage, v_l – load voltage,
v_{ia}, v_{ib}, and v_{ic} are three phase reference Voltage,
δ_{inj} is the phase of the injected voltage,
ωt is constant.

B. Shunt Converter Control

Due to increasing in nonlinear load and power electronic equipment in distribution systems causes harmonics. This harmonics and is compensate by the shunt converter. The dc link voltage is sensed and compared with reference voltage. The error signal is processed and it considered as the magnitude of the three phase supply current references. The reference current is calculated by using the unit vector in phase, with the actual supply voltage the three phase unit vector in phase is derived as in (10).

$$u_{sa} = \frac{v_{sa}}{v_{sm}}, u_{sb} = \frac{v_{sb}}{v_{sm}}, u_{sc} = \frac{v_{sc}}{v_{sm}} \tag{10}$$

Where
v_{sm} is the amplitude of supply voltage.
v_{sa}, v_{sb}, v_{sc}, are the three phase supply voltage.
u_{sa}, u_{sb}, u_{sc} are the multiplication of three phase Unit current vectors.

The three phase shunt current for compensation of harmonics as expressed as in (11)

$$I_{sha} = \frac{V_{ia}}{Z_{sh}} \; ; \quad I_{shb} = \frac{V_{ib}}{Z_{sh}}; \quad I_{shc} = \frac{V_{ic}}{Z_{sh}} \; ; \qquad (11)$$

Where

$I_{sha}, I_{shb}, I_{shc},$ is the shunt current in phase a,b,c.

$V_{ia}, V_{ib}, V_{ic},$ is injected voltage in phase a,b,c.

Z_{sh} is impedance of the transformer.

The multiplication of magnitude with unit current vectors obtained from three phase reference supply current. This reference current is compared with actual supply current, and then the error value is obtained. The error signal obtained is converted in to PWM signals. Depending on the PWM signal obtained the shunt converter compensates the harmonic and reactive power in the distribution system.

III.   Fuzzy Logic Controller

The sensed DC link voltage value is input of the FLC. The voltage value is converted in to fuzzy value by fuzzification method. In this fuzzification method the input values is converted in to linguistic value, which may be viewed as labels of fuzzy sets. In fuzzy control system, the measurement of the input signal is interpreted as a fuzzy singleton.
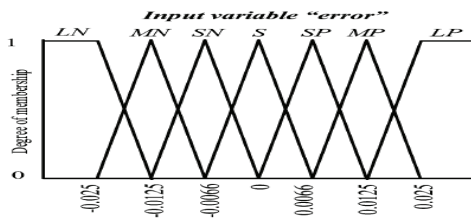
Fig.3.Fuzzification Input voltage variable 1

Here mamdani type fuzzification is used. In mamdani type fuzzy inference system, both the input and output linguistic variables will take fuzzy variables as values. The input variable of fuzzification is shown in Fig 3,4 and output variable of defuzzificationis shown in Fig 5.The membership function of a fuzzy set is a generalization of the indicator function in classical sets. Fuzzy variables are defined by membership function and characterized by shapes, position and width or whole overlap. The triangular membership is used in the controller.
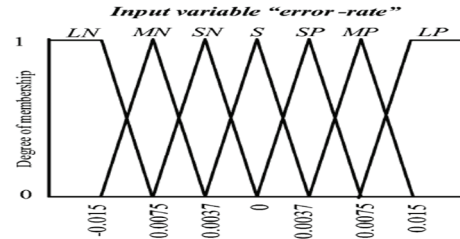
Fig.4. Fuzzification input voltage variable 2

The fuzzy rule base assemblies plant information and apply the human control expertise to the given problem. The Rule base was formed using a 7*7 matrix. Centroid of area method is used for defuzzification method to obtain the crisp value from the fuzzy value.
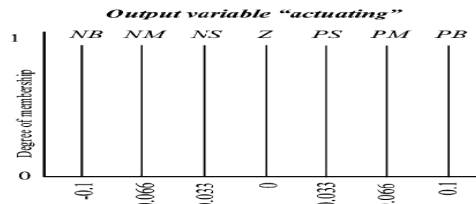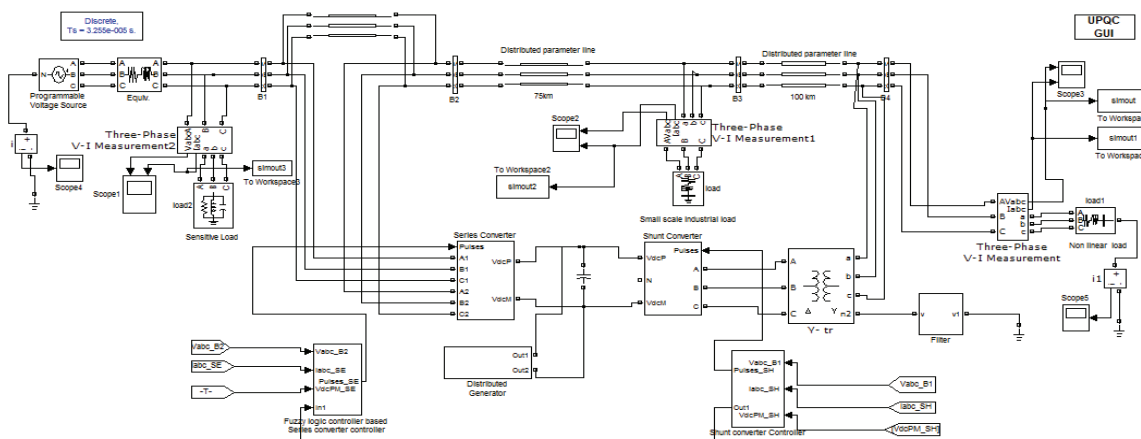
Fig.5.Defuzzification Output Voltage Variable

Fig.6. Matlab Simulink Model of the Hybrid UPQC

Table 1
System Parameters

System Input Quantity	3φ Supply voltage	415V (Ph-Ph)
	Frequency	50 Hz
	Line Impedance	0.004Ω + j0.016Ω
LC Filter	Filter inductance (L_f)	8mH
	Filter Capacitor (C_f)	36 μF
DC link	Capacitor	1100 μF
Non linear load	Load Impedance	40Ω+j10Ω
Reduced Rating Transformer	Star connected Transformer	20kVA

The simulation diagram is shown in Fig 6. The design of UPQC is based on the parameter specification of the distribution system. The 500 KVA grid is considered in the system. The 5th, 7th and 11th order harmonics are created in this scheme. The reduced rating star connected transformer is connected with the UPQC. In this scheme the sensitive load is connected in near to the series converter side, where as the industrial and domestics loads are connected in near to the shunt converter side. The system parameter from the above table as consists of three phase source with line impedance are based on the distance of distributed parameter line are taken. The DC link capacitor is based on the voltage circulation in the DC link. The minimum volt-ampere star connected transformer is connected on the load side.

IV   Results and Discussion

The UPQC has simulated using the proposed hybrid UPQC with DG. The source voltage waveform before and after connecting the UPQC are analyzed. It noticed that the source voltage is distorted before connecting the UPQC and it becomes sinusoidal after connecting the UPQC.

The voltage waveform on source side without UPQC is shown in Fig 7 and with UPQC is shown in Fig 8. It has clearly shown that the voltage sag and swell present in the waveform is compensated after connecting the UPQC. The voltage sags and swell present in the load side are also reduced, due to source side compensation.
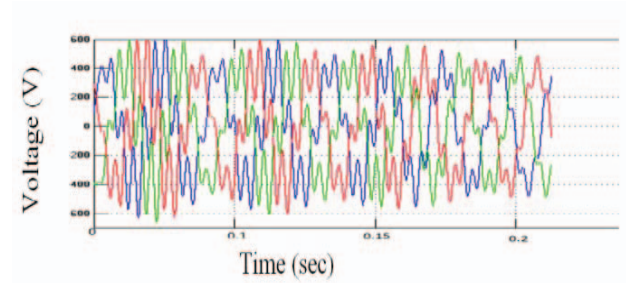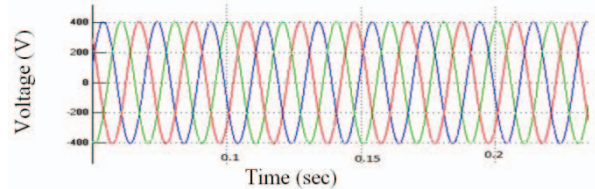

Fig.7. Voltage waveform without UPQC

Fig.8. Voltage waveform with UPQC

The current waveform obtain from the load side contains harmonics on before connecting the UPQC as in Fig 9 and after connecting the UPQC as in Fig 10. It shown that high order harmonics present in waveform is reduced after connecting the UPQC.
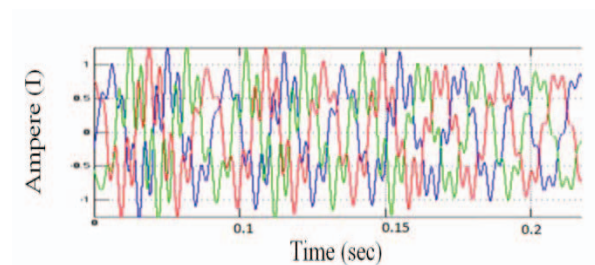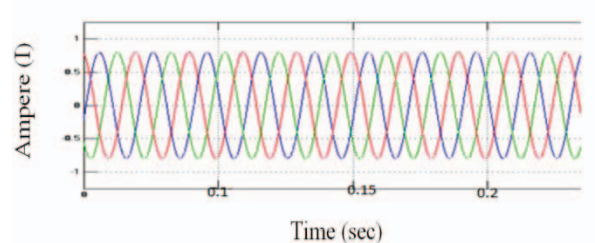

Fig.9. Current waveform without UPQC

Fig.10. Current waveform with UPQC

The harmonic distortion in the system is analyzed in source side as well as the load side. The THD in the load side before connecting the UPQC is 38.83% as in Fig 11 and after connecting the UPQC with DG as wind is 2.88% is shown in Fig 12.However the THD in the source side before connecting the UPQC is 30.89% as in Fig 13and after connecting UPQC with DG is 2.54% as in Fig14. It has clearly shown without DG the THD is 3.21% in load side as in Fig

15. The results are also taken from with DG as wind and/ or solar is shown in Fig 16 and 17. The THD with DG as solar and DG as hybrid energy is shown in Fig 20 and 21. The result obtained from the conventional method in load side before connecting UPQC is shown in Fig 18 and after connecting UPQC with DG as wind is shown in 19. The conventional method THD with DG as solar and DG as hybrid is shown in Fig 22 and 23.
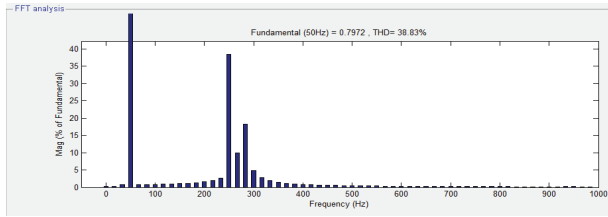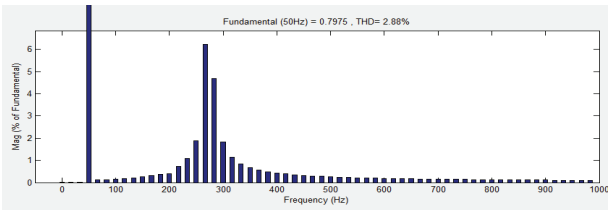

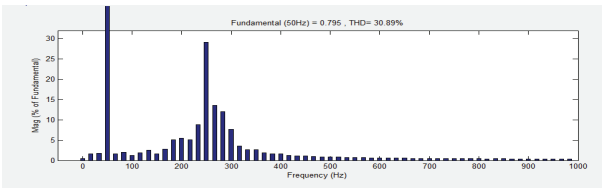Fig.11. THD without UPQC in load side

Fig.12. THD with UPQC and wind energy as DG in load side

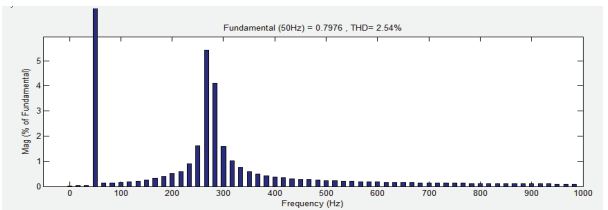Fig.13. THD without UPQC in source side
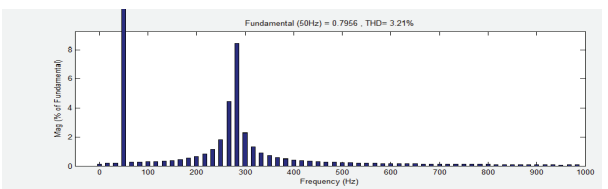

Fig.14. THD with UPQC in source side

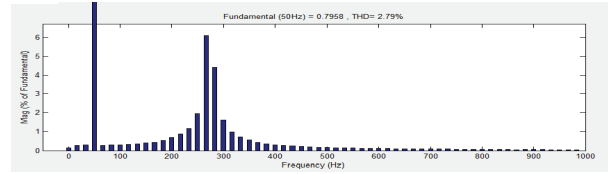Fig.15. THD without DG in load side

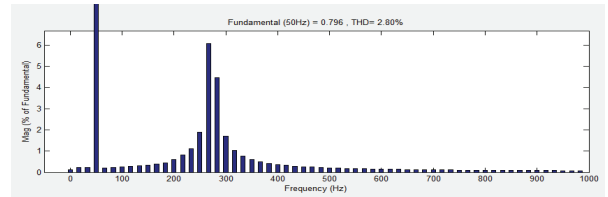Fig.16. THD with solar energy as DG in load side

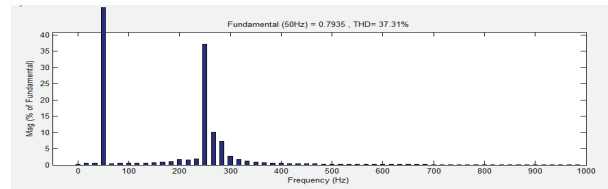Fig.17. THD with solar and wind energy as DG in load side

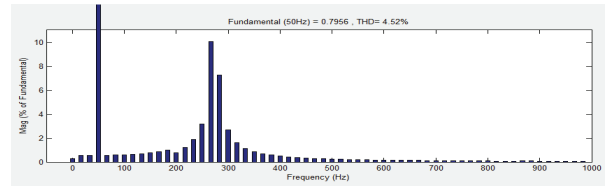Fig.18. THD without conventional UPQC in load side

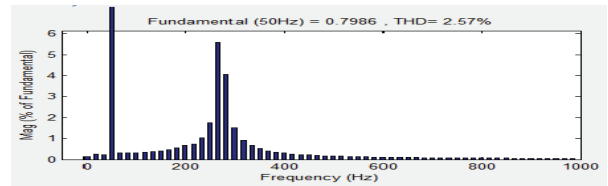Fig.19. THD with conventional UPQC in load side

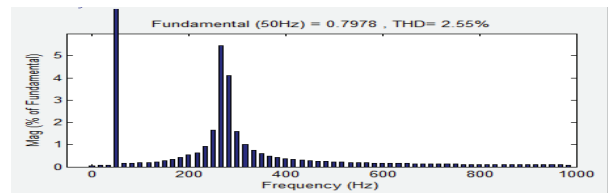Fig.20. THD with DG as solar in source side

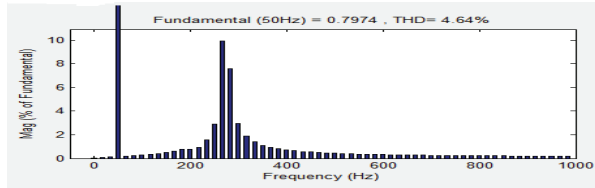Fig.21. THD with DG as solar and wind energy in source side

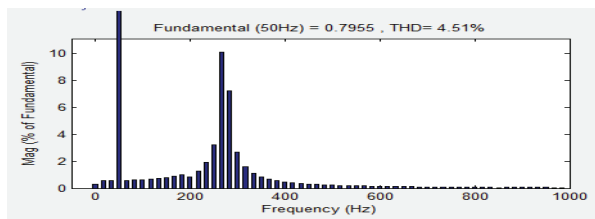Fig.22. THD with solar as DG in load side(conventional method)

Fig.23. THD with solar and wind as DG in load side (conventional method)

Table 2
Results Comparison

Location	Without UPQC	With UPQC DG as wind	With UPQC DG as solar	With UPQC Combined Wind and solar as DG
THD In Source side	30.83%	2.54%	2.57%	2.55%
THD In Load side	38.83%	2.88%	2.79%	2.80%
THD In Load side Without star connected transformer (Conventional) Method)	37.31%	4.52%	4.64%	4.51%
Neutral Current In Source Side	124.6 A (Without Star Connected)	0.18 A	0.19A	0.18A
Neutral Current In Load Side	56.3 A	56.2 A	56.3A	56.3A

The above table has shown the results comparison. It clearly noticed that compared to load side the source side THD is low. From the origin place of the harmonics that is in load side the THD content is high. The neutral current on the source side is 124.6 A (rms) and 56.3 A (rms) on the load side. When star connected transformer is connected then the source neutral current becomes almost zero and the load neutral current remains the same. The THD value of the proposed method is low when it is compared with conventional method. The THD value also analyzed with wind and/or solar energy as DG. The better THD is obtained from the solar energy as DG from that of the wind energy. When comparing to with and without DG, with the DG better THD value obtained.

V.   Conclusion

This paper presents a reduced rating star connected hybrid UPQC in distribution systems for simultaneous compensation of load current harmonics, voltage sag/swell and source neutral current. The star connected transformer has an advantage of using minimum volt-ampere rating and consequently, the cores are economical to build and occupy low space. The performance of proposed UPQC has been investigated through extensive simulation studies. From these studies it is observed that the proposed scheme completely compensated the source current harmonics, load current harmonics, voltage sag/swell and neutral current.

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