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Power Quality Improvement in Distributed Generation Resources using UPQC

Farid Hosein-Zdeh *, Ashakn Edrisian *[‡], Majid Reza Naseh *

** Department of Electrical Engineering, Sciences & Researches branch of Islamic Azad University, Birjand, Iran

(hzhz.fd91@yahoo.com, Ashkan_edrisian@yahoo.com, naseh@iaubir.ac.ir)

[‡] Corresponding Author; Ashkan Edrisian, Postal address, Tel: +98 585 722 2301,

Ashkan_Edrisian@yahoo.com

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Abstract- This paper examines the involved factors in creation of harmonics which have direct effects on the power quality issues specially, on three-wire systems. One of the main causes of harmonic distortion is the non-linear loads. Bearing in mind that Consistent with the consumer sector, the production sector can also be harmful in presence of unbalanced and Harmonic power supplies. In this study, a distributed generation (DG) case study to observe and evaluate of the impact of non-linear loads and also induction generators (IG) with power electronic interfaces – specially in wind turbine-based DGs are modeled, as the main sources of harmonics. In order to eliminate the harmonic generated in supply and demand sections of power system, UPQC is used, and the results of simulations demonstrate the reliefs of UPQC in rebate of non-linear loads and unbalanced power resources effectives.

Keyword Harmonics Distortion; Power Quality; UPQC; Distributed Generation (DG).

1. Introduction

Nowadays, one of the major concerns of experts is production, transmission and distribution of energy in an appropriate and high quality manner. It's why that the issue of power quality improvement has become a pervasive topic in research studies. One of the main factors that undermine the power quality is harmonic distortion which this generated harmonic can be injected either from production zone or consumption zone of energy. Among the factors of harmonic can mention to the increase the use of non-linear distributed devices in grid with limited nominal values, non-linear loads with continuous and random changes and also, widespread sets of power electronic component-based static converters with limited nominal values. Today, many types of converters that are used in generators and transformers are injecting the harmonics into the utility [1]. Hence, study on the output of wind power plant due to production of harmonics by its power electronic converters is important [2]. Since the distributed generations with enjoying renewable energies, especially wind energy, have great advantages in terms of environmental and economic, utilization of wind power plant based distributed generation can't be ignored. In this paper a single unit of distributed generation based on wind turbine generators (WTG) has been modeled and interface converter of WTG acts as a source of harmonic generation. Using nonlinear loads as consumers the production and harmonic injection in addition to the supply side, in the demand side of the power system will also be possible, and ultimately UPQC is used as a practical solution on power quality improvement. The circumstance of connection of UPQC to DGs is considered in [3], and UPQC in tow different manners has utilized. Once is connected to DG unit through DC link in series and investigated the results in case an error has occurred. Four-wire system has employed in connecting to the UPQC in [4], which has investigated controlling strategies in order to reduce the total harmonic distortion (THD) amounts of voltage and current onto $THD_V=2.47$, $THD_i=4.36$ respectively. Due to impact of neutral wire in the four-wire systems, controller systems will become more complex and the results in comparison with three-wire systems (similar to what was done in this study) would be worse. Neoteric controlling strategies to reduction of harmonic is given in [5].

In the first part of this study the issues related to the generation of harmonics and nonlinear loads have been investigated, and in the second part, the role of DGs in reducing power quality has been explained briefly. In the third section the UPQC equalizer has been studied. Finally, the simulation results have been presented in MATLAB/Simulink software and the final conclusion is stated.

2. The Production Factors of Harmonic

The one of the most important factors that lowers the power quality is presence of harmonics in the power system. Indeed, the harmonic distortion and imbalance influence not only the phase components of system and electrical power, but the neutral point of voltage and current is affected too [6]. Considering to characteristics and widespread changes of in whole terms of electrical networks, including development of power electronic devices and high-capacity nonlinear load-demands, the injected harmonics into the power system have had an increase [7, 8]. Nonlinear loads with regard to their high-level THD, cause damage to the system [8]. The some nonlinear loads that have highlighted contribution on harmonic generation include electric arc furnaces, inverters, DC convertors, electric drives and other small sets of nonlinear loads [9]. Nowadays, harmonic generation and injection is not only of consumer zone but some suppliers of the grid such as wind farms are the one of harmonic production factors, because of the induction generator operations. The electrical converters which are used in induction generators are the main source of manufacture of harmonic distortions. Fig. 1 indicates a representing block diagram of voltage harmonics.

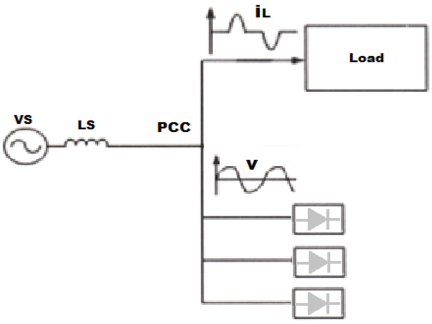

Fig. 1. The block diagram of voltage harmonics.

3. Distributed Generation

The DGs based on wind and solar energies because of their advantages such as ensuring system stability, voltage regulation, economic generation and environmental factors, today's have taken the pulse of electricity markets [10, 11].

The recent research in solar and wind- based DG systems are covering various aspects such as network connectivity issues, controlling the inverter/ converter to achieve maximum power production, stability problems, evaluation of the impacts of power system and etc. [11, 12]. Besides of inverse power problem which can be caused to flow the current in the opposite direction from the main network [10, 13], DGs by using switching technologies are being used increasingly by electrical institutions. And hence lead to the overall increase in THD of distribution networks.

The effect of harmonic distortion after adding DG is a major problem in the use of electricity. The most of DGs like fuel cells, micro turbines and wind turbines can only be connected through power electronics equipment to power systems [14].

4. Unified Power Quality Conditioner (UPQC)

Actually the UPQC is the one of most flexible devices on the new concept of equalization that can provide harmonic compensation [15].

4.1. Principles

The UPQC consists of a combination of series and shunt active filters for simultaneous voltage and current compensation requirements [15]. In fact, the main task of series component is isolation of harmonic between distribution and sub-distribution. Also it has capability of equalization of filter, unbalanced, harmonic voltage adjustment at the connection point to the network.

The shunt component is used to reduce problems due to the consumer, and its main tasks are absorption of harmonic currents, reactive power compensation, voltage adjustment of the DC link and compensating the negative sequence. Generally, the performance of UPQC depends on controlling the shunt and series components.

4.2. Control Functions

The block diagram of UPQC controller is illustrated in Fig. 2.

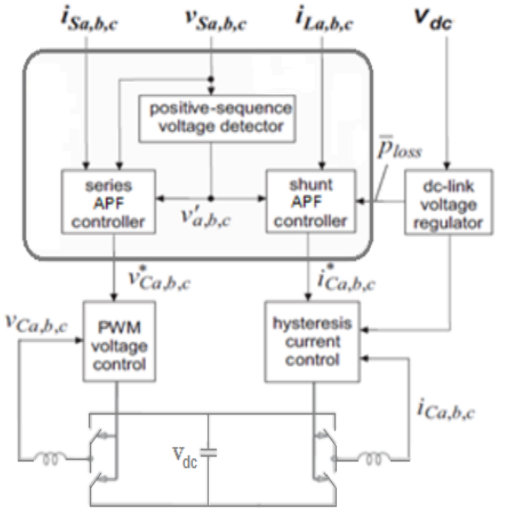

Fig. 2. Block diagram of controller.

As you can be saw in Fig. 2, $V'_{a,b,c}$ are the main components of positive sequences of voltage. And the inputs of series part controller are $i_{S\,a,b,c}$, $V_{S\,a,b,c}$. The voltage of DC link is named V_{dc}, the voltages and currents of stabilizer are $V_{C\,a,b,c}$, $i_{C\,a,b,c}$ respectively. By using the matrix conversion of Clark $V'_{\alpha,\beta}$ and $i'_{\alpha,\beta}$ will be obtained

$$\begin{bmatrix} V'_\alpha \\ V'_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V'_a \\ V'_b \\ V'_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2}$$

Using the above results the real and imaginary components of power can be calculated by (3) to (6) equations:

$$\mathrm{P} = \mathrm{V}'_\alpha \mathrm{i}_\alpha + \mathrm{V}'_\beta \mathrm{i}_\beta \tag{3}$$

$$q = V'_\beta i_\alpha - V'_\alpha i_\beta \tag{4}$$

$$P = \bar{P} + \tilde{P} \tag{5}$$

$$q = \bar{q} + \tilde{q} \tag{6}$$

In the above relations, $\bar{P}$ and $\bar{q}$ are constant components of power and can calculated by (7) to (8) equations:

$$\bar{P} = \sum_{n=1}^{\infty} 3V_{+n} I_{+n} \cos(\varphi_{+n} - \delta_{+n}) + \sum_{n=1}^{\infty} 3V_{-n} I_{-n} \cos(\varphi_{-n} - \delta_{-n}) \tag{7}$$

$$\bar{q} = \sum_{n=1}^{\infty} 3V_{+n} I_{+n} \sin(\varphi_{+n} - \delta_{+n}) + \sum_{n=1}^{\infty} -3V_{-n} I_{-n} \cos(\varphi_{-n} - \delta_{-n}) \tag{8}$$

And also, $\tilde{P}$ and $\tilde{q}$ are calculated by following equations as the swinging components of power:

$$\tilde{P} = \Bigg\{ \sum_{\substack{m=1 \\ m \neq n}}^{\infty} + \Big[\sum_{n=1}^{\infty} 3V_{+m} I_{+n}\, cos\big((\omega_m - \omega_n)t + \varphi_{+m} - \delta_{+n}\big) \Big] + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \Big[\sum_{n=1}^{\infty} 3V_{-m} I_{-n}\, cos\big((\omega_m - \omega_n)t + \varphi_{-m} + \delta_{-n}\big) \Big] + \sum_{m=1}^{\infty} \Big[\sum_{n=1}^{\infty} -3V_{+m} I_{-n}\, cos\big((\omega_m + \omega_n)t + \varphi_{+m} + \delta_{-n}\big) \Big] + \sum_{m=1}^{\infty} \Big[\sum_{n=1}^{\infty} -3V_{-m} I_{+n}\, cos\big((\omega_m + \omega_n)t + \varphi_{-m} + \delta_{+n}\big) \Big] \Bigg\} \tag{9}$$

$$\tilde{q} = \Bigg\{ \sum_{\substack{m=1 \\ m \neq n}}^{\infty} + \Big[\sum_{n=1}^{\infty} 3V_{+m} I_{+n}\, sin\big((\omega_m - \omega_n)t + \varphi_{+m} - \delta_{+n}\big) \Big] + \sum_{\substack{m=1 \\ m \neq n}}^{\infty} \Big[\sum_{n=1}^{\infty} -3V_{-m} I_{-n}\, sin\big((\omega_m - \omega_n)t + \varphi_{-m} - \delta_{-n}\big) \Big] + \sum_{m=1}^{\infty} \Big[\sum_{n=1}^{\infty} -3V_{+m} I_{-n}\, sin\big((\omega_m + \omega_n)t + \varphi_{+m} + \varphi_{-n}\big) \Big] + \sum_{m=1}^{\infty} \Big[\sum_{n=1}^{\infty} 3V_{-m} I_{+n}\, sin\big((\omega_m + \omega_n)t + \varphi_{-m} + \delta_{+n}\big) \Big] \Bigg\} \tag{10}$$

Should be noted that the regulator of DC voltage determines the signal of $\bar{p}_{loss}$. The signal of $\bar{p}_{loss}$ will cause that the active filter in an attempt to eliminate the voltage variations, absorbs or injects the positive sequence power. In other words, the shunt active filter that produces a mean of negative sequence power, must absorbs the same value of positive sequence power from power system in order to fix the DC voltage. For this reason, signal of $\bar{p}_{loss}$ is very important for balancing of energy in the active filter.

5. Simulation Results

All simulations in this study have been conducted in MATLAB/Simulink software. Initially, the system is simulated in ideal conditions that connected to balanced supplier in line-line voltage 380^{V} and frequency 50^{Hz}, according to Fig. 3 . In this case, any harmonic of the load and the power supply is not emitted.

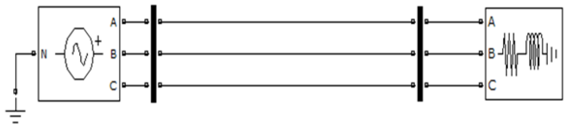

Fig. 3. The initial state of the network with linear load and balanced supplier.

The current and voltage waveforms are presented in Fig. 4 and 5, ideally. As can be seen, there is no distortion in current and voltage. In other words, in this case THD=0 and the load which is consumer of fixed current and voltage, is fed by a balanced source.

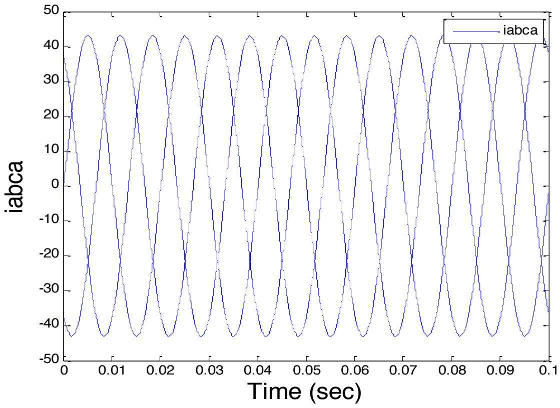

Fig. 4. Current waveform ideally.

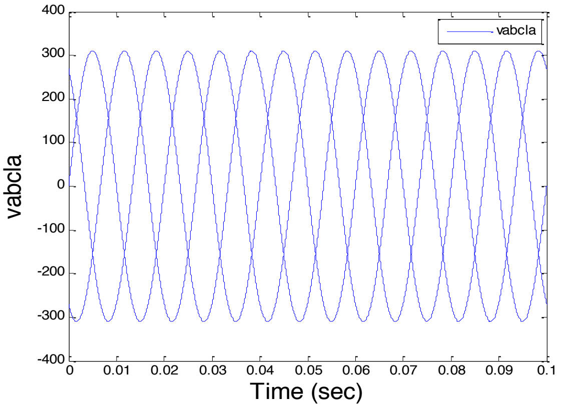

Fig. 5. Voltage waveform ideally.

In continuation of the simulation process, with placement of a nonlinear load with effective capacity of $S{=}21.45^{\mathrm{Kw}} + j\ 12.43^{\mathrm{KVar}}$ instead of linear load, and using a wind farm consisting of 6 units wind turbine with capacity of 1.5^{Mw}, equipped to doubly-fed induction generator (DFIG) with electronic interface (total capacity 9^{Mw}), adverse condition of power quality that can be affected by harmonic injecting of production and consumption zones, is simulated. The Fig. 6 and 7 indicate harmonic waveforms of voltage and current, respectively.

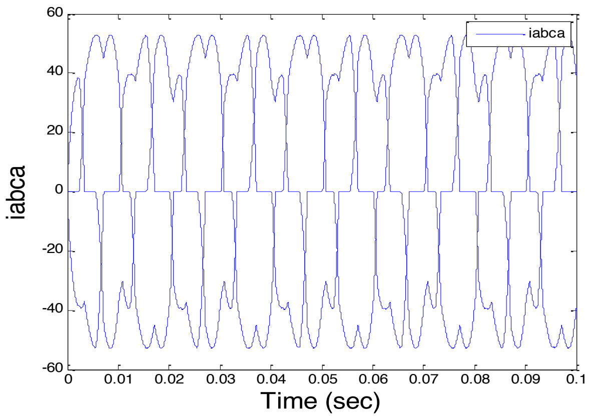

Fig. 6. Current waveform in the presence of harmonic sources.

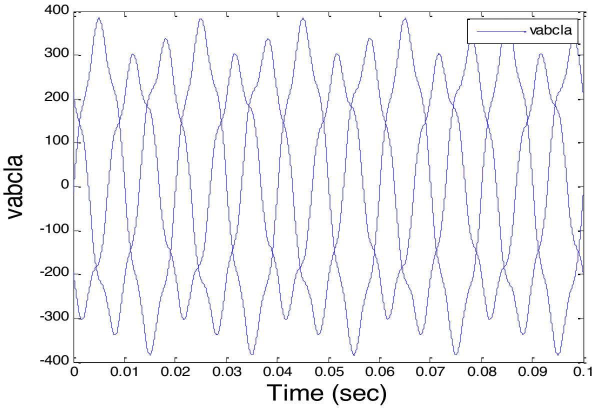

Fig. 7. Voltage waveform in the presence of harmonic sources.

Under this conditions, the rate of THD for current and voltage is $THD_i = 8.99$ and $THD_v = 18.01$, respectively. In fact, the system in this situation of power quality, confronts sthenic problems and can't continue to operate normally. That is because of, the disturbance within the system, will cause serious problems to the network. What will cause serious problems to the network is such a disturbance within the system. Nonlinear load model used in this study is an induction furnace that is indicated in Fig. 8. This induction furnace injects harmonic currents into the network and causes reactive power increment.

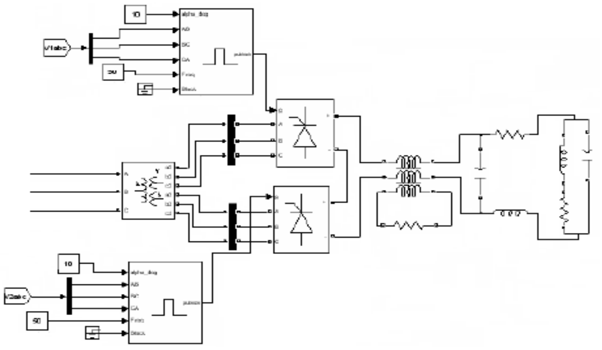

Fig. 8. The model of Induction Furnace

Fig. 9 shows the structure of the proposed system in presence of wind farm, nonlinear load and UPQC. As previously noted, the series part of UPQC is connected to wind farm bus and is responsible of reduction of voltage disturbances that caused by wind farm. The voltage of capacitor is controlled at DC voltage regulator and signal of $\bar{p}_{loss}$ is generated. The voltage waveform of DC link has been shown in Fig. 10 . The effect of harmonic distortion after connecting the DGs to power system is a major problem in the use of electricity. Most of GDs such as solar cells, micro turbines, wind turbines and etc. can only be connected to utility through power electronic equipment [14]. The corrected waveforms of current and voltage are visible in Fig. 11 and 12, respectively.

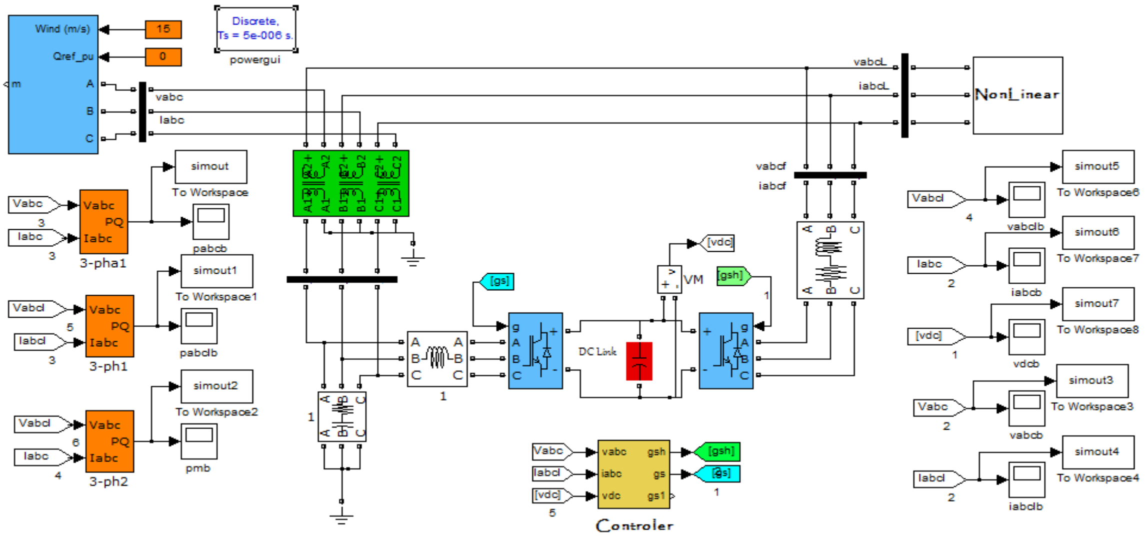

Fig. 9. Block diagram of the main grid with unbalanced-harmonic power supply and nonlinear load and connection of UPQC.

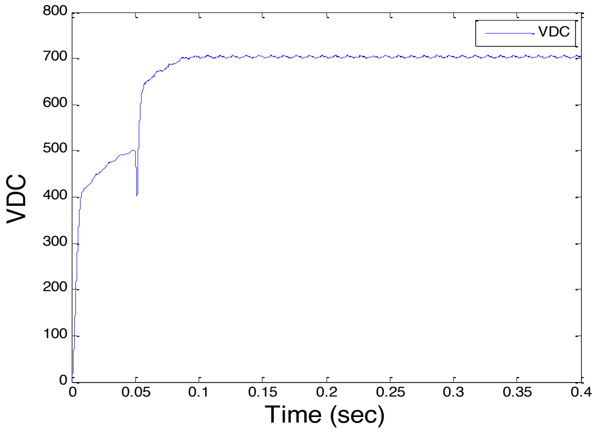

Fig. 10. The voltage waveform of DC link.

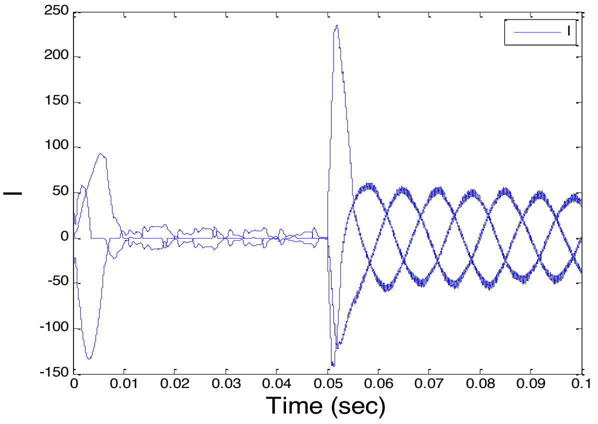

Fig. 11. The current waveform of power Supplier.

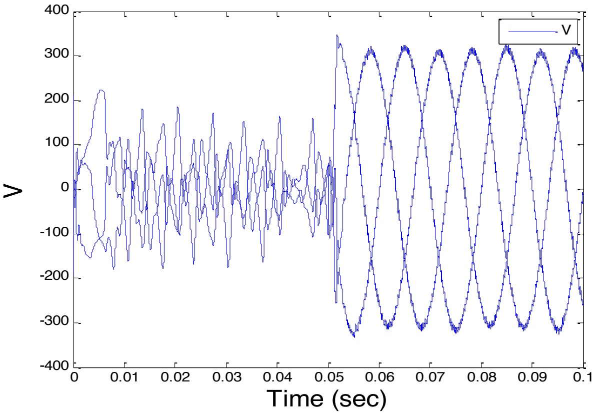

Fig. 12. The voltage waveform of load.

According to tow recent figures, with entering UPQC to circuit at the moment of 0.05s, harmonic pollution of current and even voltage unbalancing have reduced strongly, and is closed to sinusoidal waveform. After entering UPQC, the THD of current and voltage will fall to 4.03 and 1.01, respectively, that reflects the positive impact of UPQC to improvement of the power quality.

6. Conclusion

In this paper, at first an ideal system along with a nonlinear load and unbalanced-power supply (DFIG-based wind farm) connected to system is simulated in absence of stabilizer, and the waveforms were displayed in order to observe the difference of the presence impact of linear load against presence of nonlinear load.

Then an influenced system by the nonlinear load and unbalanced-power supply was simulated. Eventually the harmonics were removed, as possible as could be done. In the initial conditions (ideal system) THD of current and voltage was $THD_{i,V} = 0$, and in the connected system to nonlinear load and wind farm the THD level of current and voltage proliferated to $THD_i = 18.01$ and $THD_V = 8.99$, respectively, which ultimately could lessen the amount of THD to $THD_i = 4.03$ and $THD_V = 1.01$ by using UPQC.

Only one type of power supply in form of wind farm was studied in this work, as the creation factor of harmonic distortion. Hence, increasing the number of harmonic resources with take into consideration variable distance between power suppliers and nonlinear loads, and also utilization of multi-layer UPQC for better compensation could be a framework for future studies.

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