

IMPACT OF THE VOLTAGE HARMONIC SEQUENCE ON THE POWER QUALITY BASED ON UPQC

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Abstract: *This study proposes a combined operation of the Unified Power Quality Conditioner (UPQC) with wind power generation system. The proposed system consists of a series inverter, a shunt inverter and an induction generator connected to a weak distribution power grid. The proposed system can compensate voltage sag and swell, voltage interruption, harmonics, and reactive power. We have studied the impact of the double disturbances which concern sag and sequence of the harmonic voltage on the power quality.*

Key words: *UPQC, power quality, distributed network, Wind Turbine.*

1. Introduction

Today, the situation of distribution networks of the electrical energy become critical due to the extensive use of power electronic equipments. That could cause a great distortion at the point of common coupling (PCC)[1]. This proliferation of non-linear loads, such as rectifiers, and DC/AC converters, has arbitrary increased the THD values of both voltage and current. harmonics are the main interest of the quality in the industry. Many solutions of harmonic filtering are studied in this field. As an improved solution, active filters [2, 3] and hybrid filters [4, 5] are developed. In addition to complex and expensive control circuit, they provide partial voltage or current compensation to improve power quality. One of the most attractive structures of energy conditioner is the two back-to-back connected DC/AC fully controlled converters. In this case, depending on the control scheme, the converters may have different compensation functions [6, 7]. For example, they can function as active series and shunt filters to compensate simultaneously load current harmonics and supply voltage fluctuations. Unified Power Quality Conditioner (UPQC) is one of the custom power devices, it is the powerful tool to settle the power quality problems. UPQC [8, 9] is a hybrid topology of series and shunt active filter with a

common DC link capacitor. UPQC has two components, a series compensator and a shunt compensator. The series compensator of UPQC is used to mitigate voltage sag, voltage distortions and shunt compensator compensates for harmonic current to specifically protect highly sensitive loads at the PCC. The shunt filter effectively reduces the source current harmonics and provides reactive power compensation while the series filter ensures a distortion free, balanced and regulated voltage at PCC. UPQC is capable of compensating in steady state as well as in dynamic conditions. The performance of UPQC depends on the control algorithm used. Different algorithms such as dq0 transformation [10], synchronous reference frame theory [11], unit vector template generation [12] and Icos algorithm [13] to generate reference signals for voltage and current compensation are developed.

In this paper we propose and analyze a compensation strategy using an UPQC. For the case of Wind Energy Generation System (WEGS) connected to a weak distribution power grid. The UPQC is controlled to regulate the WEGS terminal voltage and to mitigate voltage fluctuation at the point of common coupling caused by system load changes and pulsating wind generator power respectively. The voltage regulator at wind generator power terminal is conducted using the UPQC series converter by voltage injection in phase with PCC voltage.

On the other hand, the shunt converter is used to filter the wind system generator power to prevent voltage fluctuations, requiring active and reactive power handling capability. The sharing of active power between converters is managed through the common DC link. Simulations were carried out to demonstrate the effectiveness of the proposed compensation approach.

The proposed scheme has been evaluated and tested using matlab/simulink. The main objective of this

paper is the study of the impact of the sag and sequence of the harmonic voltage on the power quality.

2. System Description and Modeling

The configuration of UPQC with WECS proposed in this study as shown in Fig. 1. In the diagram, there are main parts in proposed system: wind turbine, induction generator, maximum power point tracking which controls the turbine torque output. PWM converter, shunt inverter and series inverter of UPQC. The modeling of each section is discussed separately and then the overall model is investigated.

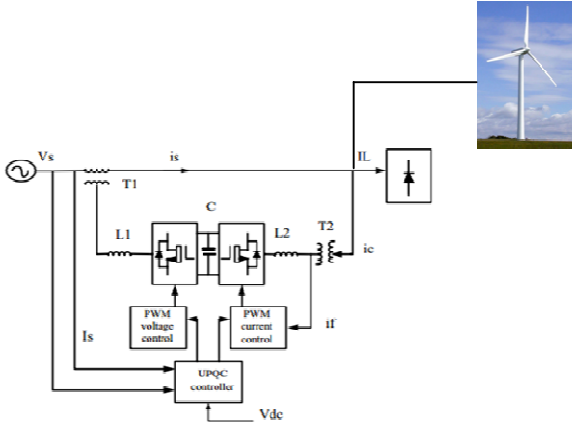


Fig. 1. Configuration of proposed UPQC with WECS

2.1 Modeling of WECS

A wind turbine is a power extracting device. Thus, the performance of a wind turbine is primarily characterized by the manner in which the main indicator – power – varies with wind speed. Besides that, other indicators like torque and thrust are important when the performances of a wind turbine are assessed. The function of the wind power module is transformed into mechanical energy by means of a wind turbine whose rotation is transmitted to the generator by means of a mechanical drive train [14, 15].

The mechanical power captured by a wind turbine in the steady state is given by[16] :

$$P = \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot C_p(\lambda, \beta) \cdot v^3 \quad (1)$$

where ρ is the air density in kg/m^3 , R is the turbine radius in m , v is the wind speed in m/sec and C_p is the aerodynamic power coefficient, usually provided as a set of curves gives information about the power efficiency of a wind turbine. C_p depends on two factors : β , the blade pitch angle and the tip speed ratio

λ which is defined as[17] :

$$\lambda = \frac{\Omega_r \cdot R}{v} \quad (2)$$

Where Ω_r denotes the turbine rotor speed in rad/sec.

The power coefficient, C_p is defined as[18] :

$$C_p(\lambda, \beta) = c_1 \cdot \left(c_2 \cdot \frac{1}{\lambda} - c_3 \cdot \beta - c_4 \right) \cdot e^{-\frac{c_5}{\lambda}} + c_6 \cdot \lambda \quad (3)$$

Where

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08 \cdot \beta} - \frac{0.035}{1 + \beta^3}$$

and coefficients $c_1=0.5176$, $c_2=116$, $c_3=0.4$, $c_4=5$, $c_5=21$, and $c_6=0.0068$. The power coefficient is nonlinear, and it depends upon turbine blade aerodynamics and it can be represented as a function of tip speed ratio λ . The optimum value of λ corresponds to maximum of C_p from the power coefficient_tip speed ratio curve.

Figure 2 shows the power coefficient with respect to tip speed ratio. It is observed that the maximum power coefficient value $C_{p_{max}}(\lambda, \beta) = 0.48$ for $\lambda = 8.12$ and for $\beta = 0^\circ$. This particular value of λ_{opt} results in optimal efficiency point where maximum power is captured from wind by the turbine.

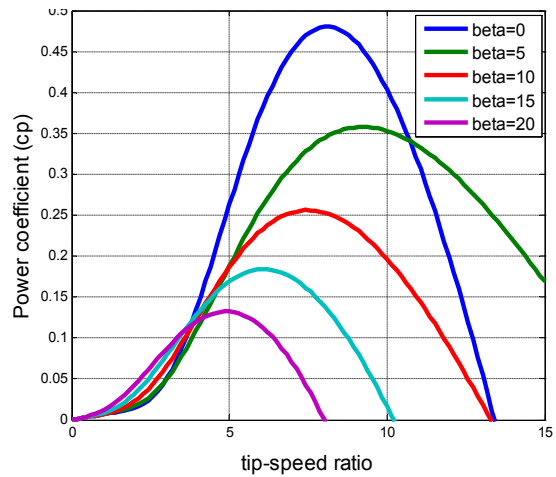


Fig. 2. Power coefficient factor versus tip-speed ratio for various pitch angles.

Figure 3 above shows wind turbine power characteristics used for this study with the turbine input power plotted against the rotor speed of the turbine. The turbine mechanical power as function of turbine

speed is displayed for wind speeds ranging from 5 m/s to 12 m/s. Here it can be observed that maximum power (active) is achieved through optimal wind speeds and not at high wind velocity. The wind turbine does not operate when the wind speed is less than the minimum speed because the captured wind energy is not enough to compensate the losses and operation cost.

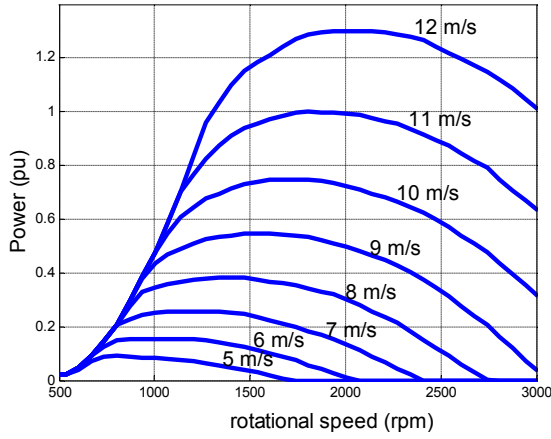


Fig. 3. Wind turbine power characteristics

2.2 Modeling of UPQC

Fig. 4 shows an equivalent circuit of UPQC installed on the common bus, where v_s is the voltage at the power supply; v_{sr} is the series- active filter compensating voltage and v_l is the load voltage, i_{sh} is the shunt- active power filter (APF) compensating current and v_{sr} [19].

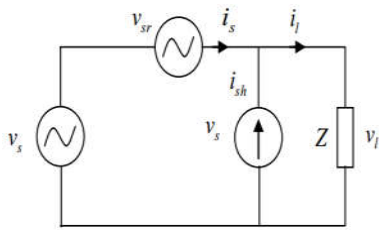


Fig. 4. Equivalent circuit of a basic UPQC

Due to the voltage distortion, the system may contain negative phase sequence and harmonic components. In general, the source voltage in Fig. 4 can be expressed as:

$$v_l = v_s + v_{sr} \quad (4)$$

To obtain a balance sinusoidal load voltage with fixed amplitude V , the output voltages of the series-APF should be given by;

$$v_{sr} = (V - V_{1P}) \sin(\omega t + \theta_{1P}) - V_{1n}(t) - \sum_{k=2}^{\infty} v_{rk}(t) \quad (5)$$

where,

V_{1P} : Positive sequence voltage amplitude fundamental frequency

θ_{1P} : Initial phase of voltage for positive sequence

V_{1n} : Negative sequence component

The shunt-APF acts as a controlled current source and its output components should include harmonic, reactive and negative-sequence components in order to compensate these quantities in the load current. When the output current of shunt-APF i_{sh} is kept to be equal to the component of the load as given the following equation[20]:

$$i_l = I_{1P} \cos(\omega t + \theta_{1P}) \sin \phi_{1P} - i_{1n} - \sum_{k=2}^{\infty} i_{1k} \quad (6)$$

$$\theta_{1P} = \phi_{1P} - \theta_{1P} \quad (7)$$

where,

ϕ_{1P} : Initial phase of current for positive sequence

As seen from the above equations that the harmonic, reactive and negative sequence current is not flowing into the power source. Therefore, the terminal source current is harmonic-free sinusoid and has the same phase angle as the phase voltage at the load terminal

$$\begin{aligned} i_s &= i_l - i_{sh} \\ &= \sin(\omega t - \theta_{1P}) \cos \theta_{1P} \end{aligned} \quad (8)$$

2.3 DC voltage controller

In compensation process, the DC side voltage will be changed because UPQC compensates the active power and the losses of switches, etc. If the DC voltage is not the same as the rating value, the output voltage of the series active filter will not be equal to the compensation value and the compensation would not be corrected [20]. It is the same with the shunt active filter. A PI-Controller is used in DC voltage regulator. It realizes a slower feedback control loop that is useful to correct the compensation errors that arise during transients. The DC current is added to the reference current to calculate the compensation currents. The DC voltage regulator shown in Fig. 5 is used to generate a control signal to keep the voltage in a constant stage and this is forcing the shunt active filter to draw additional active current from the network.

The PI-controller can be expressed as,

$$G(S) = k_p + \frac{k_i}{S} \quad (9)$$

In simulation, the values of k_p and k_i are set as $k_p=4.5766$ and $k_i=616.1911(\text{sec})$

$G(S)$: Transfer function of the PI-controller
 k_p : Proportional gain of the PI-controller
 k_i : Integral gain of the PI-controller
 S : Complex Laplace variable

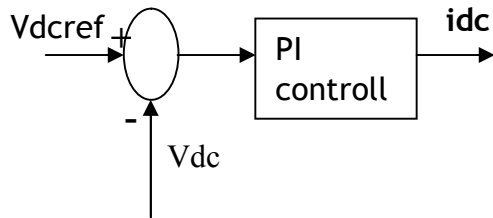


Fig. 5. The DC voltage regulator

3. Results

The simulation of the system has been carried out using MATLAB/Simulink. Table 1 shows the Parameters of the simulated system.

To see the impact of the voltage harmonic sequence, four simulations for the four different cases of harmonic are taken into consideration. In effect, the simulation is destined for a constant wind of 10 m/s.

Table:1
System parameters

Three phase Source	
220V, 50Hz	
Rs, Ls	0.1Ω, 0.2 mH
UPQC	
Vdc	735.6V
Cdc	34.7mF
Unbalanced Linear Load	
Ra, La	40Ω, 10-5H
Rb, Lb	10Ω, 10-5H
Rc, Lc	13Ω, 10-5H
Non Linear Load	
P_active, P_reactive	8000W, 500VA
Passive filter	
Nominal reactive power (var)	200VA
Tuning frequency	250Hz
Quality factor	10
WEGS	
S_n	275KVA

V_n	380V
F	50HZ
R_s	0.016p.u
L_s	0.06p.u
R_r	0.015p.u
L_r	0.06p.u
L_m	3.5p.u
P	2

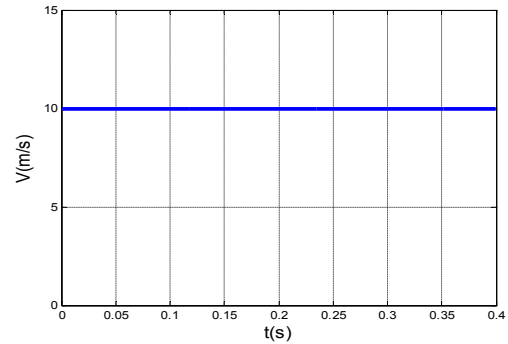


Fig. 6. The speed of the wind

Case 1: Balanced sinusoidal voltage source with a voltage sag occurs at 0.15s-0.25s of 30% without harmonic.

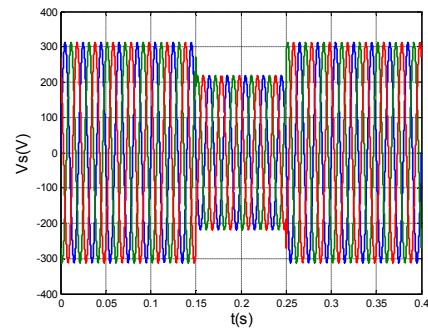


Fig. 7. Source voltage

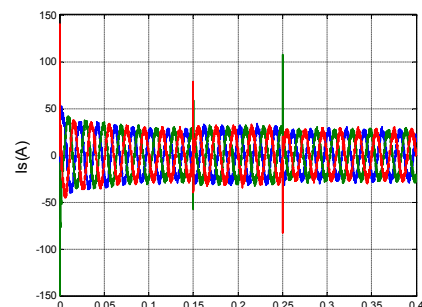


Fig. 8. Source current

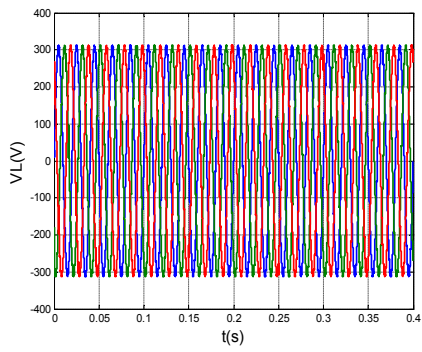


Fig. 9. Load voltage

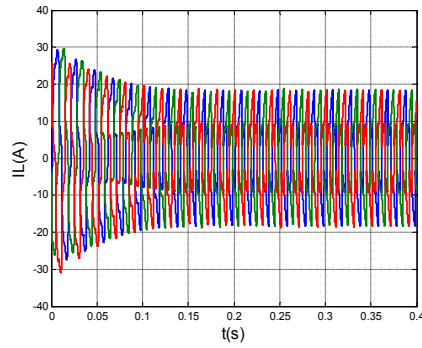


Fig. 10. Load current

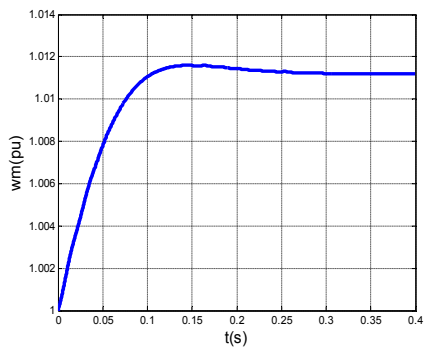


Fig. 11. Rotor speed

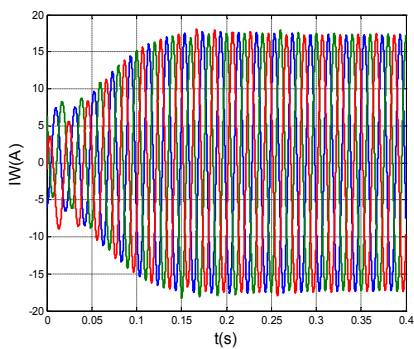


Fig. 12. Current wind

Case 2 : Balanced sinusoidal voltage source with a voltage sag occurs at 0.15s-0.25s of 30% and with harmonic voltage at 0.2s-0.32s where is:

- Fifth harmonic: ordre5; amplitude=0.2pu; phase=+35°; sequence=0
- Seventh harmonic: ordre7; amplitude=0.3pu; phase=-25°; sequence=2

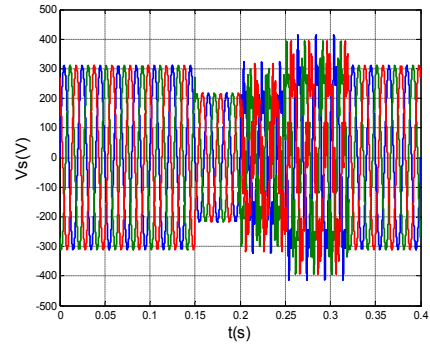


Fig. 13. Source voltage

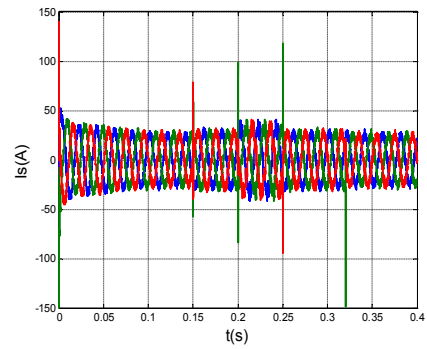


Fig. 14. Source current

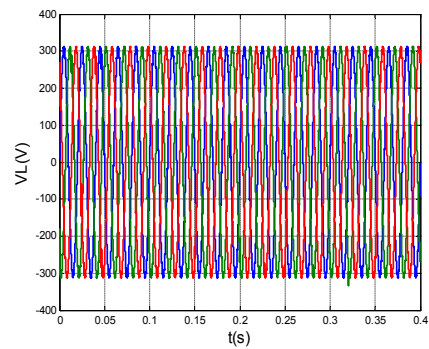


Fig. 15. Load voltage

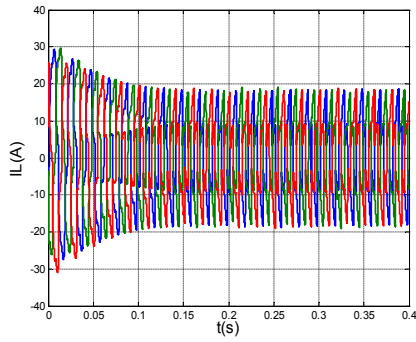


Fig. 16. Load current

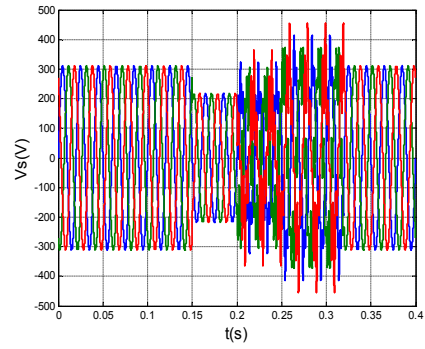


Fig. 19. Source voltage

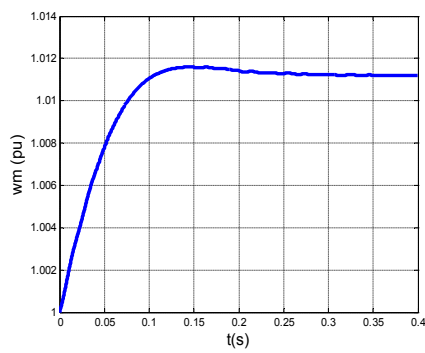


Fig. 17. Rotor speed

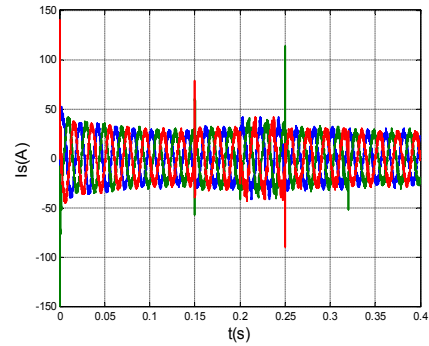


Fig. 20. Source current

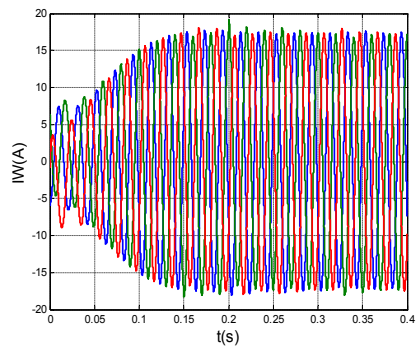


Fig. 18. Current wind

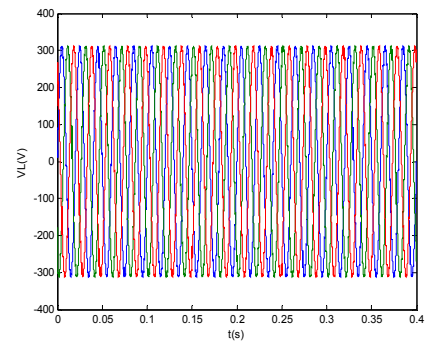


Fig. 21. Load voltage

Case 3 : balanced sinusoidal voltage source with a voltage sag occurs at 0.15s-0.25s of 30% and with harmonic voltage occurs at 0.2s-0.32s where is:

- Fifth harmonic: ordre5; amplitude=0.2pu; phase=+35°; sequence=1
- Seventh harmonic: ordre7; amplitude=0.3pu; phase=-25°; sequence=2

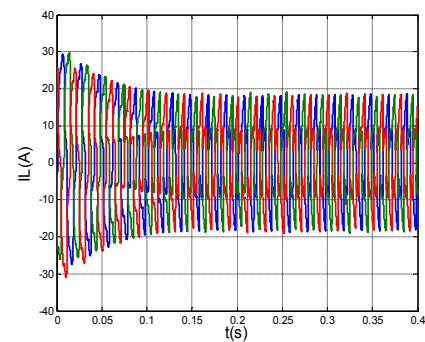


Fig. 22. Load current

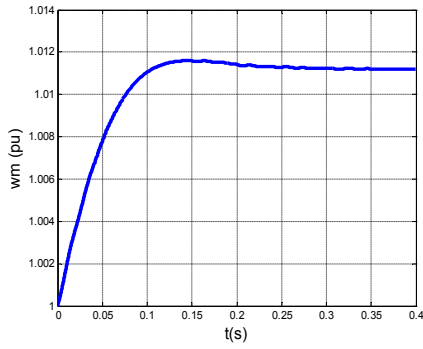


Fig. 23. Rotor speed

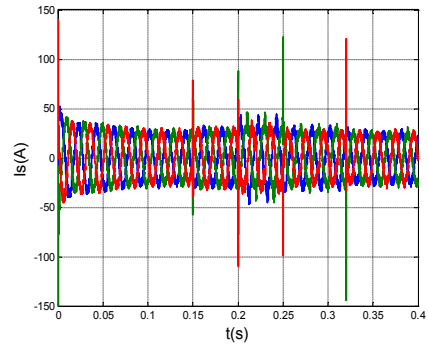


Fig. 26. Source current

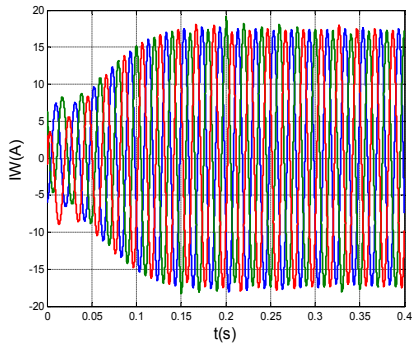


Fig. 24. Current wind

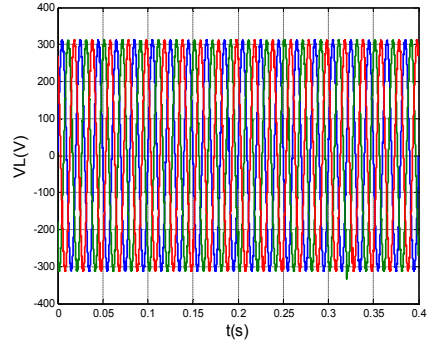


Fig. 27. Load voltage

Case 4 : balanced sinusoidal voltage source with a voltage sag occurs at 0.15s-0.25s of 30% and with harmonic voltage occurs at 0.2s-0.32s where is:

- Fifth harmonic: ordre5; amplitude=0.2pu; phase=+35°; sequence=2
- Seventh harmonic: ordre7; amplitude=0.3pu; phase=-25°; sequence=2

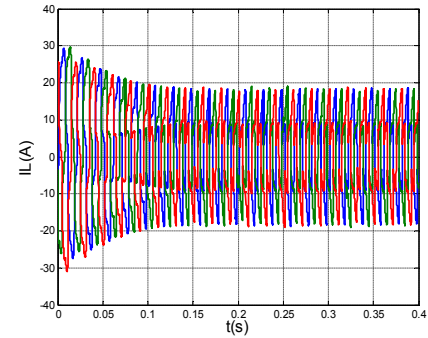


Fig. 28. Load current

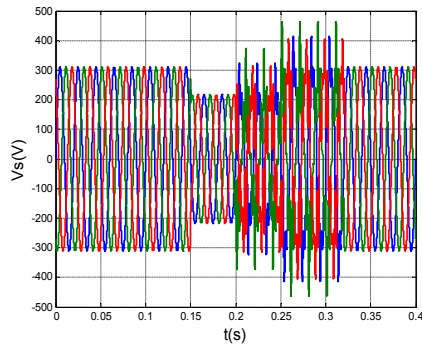


Fig. 25. Source voltage

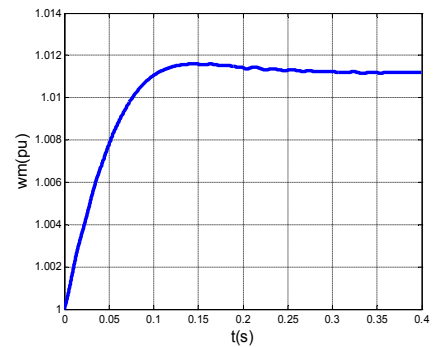


Fig. 29. Rotor speed

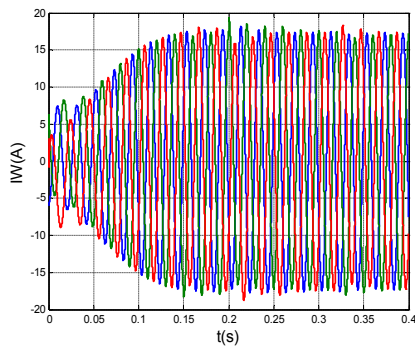


Fig. 30. Current wind

4. Discussion

The results obtained show the effectiveness of UPQC, which for both offset of a 90 V voltage drop for a period of 0.1 s (between 0.15s and 0.25 s) with and without harmonic. Lists of figures are illustrated in the previous section the compensation process of three phase voltage sags of power quality for the four cases presented. The same results are obtained.

The results tabulated in Table 2 show the harmonic distortion.

Table:2
The THD values for all cases

	THD%				
	V_s	I_s	I_L	V_L	I_w
Case1	0.00	3.97	19.64	0.10	0.44
Case2	13.11	5.03	19.62	0.11	0.43
Case3	13.11	5.74	19.68	0.11	0.44
Case4	13.11	4.99	19.63	0.11	0.46

In all three cases (Case2, 3and4) where the voltage is polluted, there is :

- A small increase of the THD source current
- Slight insignificant increase of THD Load current
- Slight insignificant increase of THD wind current

The sequences of the harmonic voltage of the source voltage have no great influence on the filter characteristics as is clearly shown by the THD values.

5. Conclusions

This study describes a combined operation of the unified power quality conditioner with wind power generation system. The aim objective of this paper is to study the impact of the harmonic voltage sequences. They are rarely studied in the literature. According to

the obtained result, we can conclude that their effects are minors in this topology.

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