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ARTIFICIAL NEURAL NETWORK BASED UNIFIED POWER QUALITY CONDITIONER FOR POWER QUALITY IMPROVEMENTS OF DOUBLY FED INDUCTION GENERATOR

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ABSTRACT

To reduce the mathematical operations and different transformations, the artificial neural network (ANN) approach is proposed for the unified power quality conditioner (UPQC). This paper proposes a voltage source inverter (VSI) based UPQC with ANN controller when a Doubly Fed Induction Generator (DFIG) is connected to the grid. The performance of UPQC with ANN controller is tested under different sag, harmonic and swell conditions, the algorithm used for the ANN control is Gradient Descent with Momentum to generate the referencing signals and maintain the UPQC dc link capacitor voltage. The simulations are carried out in the software Matlab/Simulink. Results shows efficiency of the ANN control strategy in compensating currents and voltages of the system.

***Keywords**: DFIG, UPQC, ANN, Sag, Swell, Harmonic*

1. INTRODUCTION:

In last few years, problems of power quality are rising due to the grid codes of renewable energy integration especially wind energy which is not a predicted energy [1]. Variable speed wind turbines pose many challenges concerning the fault Ride through capability and the control of reactive power [2]. The Doubly Fed Induction Generator (DFIG) is the most robust wind turbine due to its variable speed (fig. 1) , also its independence of active and reactive power control [3], even though the DFIG is the most used type, it is very sensitive to the electrical grid voltage interruption; during the fault, the generation of active power reduces due to the drops of the voltage [4]; also, when integrating a large wind farms to the electrical grid, many problems occur like the voltage sag and swell, flicker and harmonics…

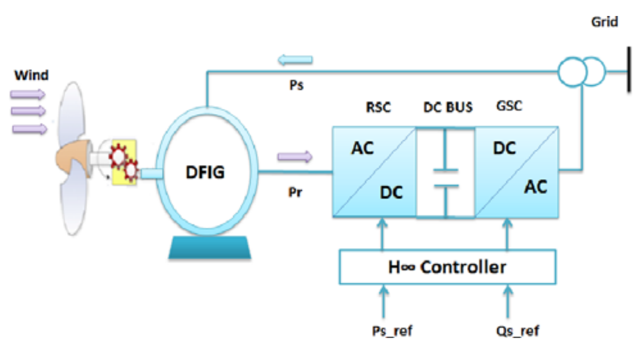

Fig. 1: schematic of the DFIG

To meet the requirements of sag and harmonic regulation, electronic power devices are used, they provide multiple function such as load balancing, power factor compensation, voltage flicker reduction and regulation, harmonic filtering, active and reactive power control [5].

When the grid side has a short circuit, the rotor currents increase, if there is no protection for the converter opposing the high currents, the converter will be deteriorated [6]. There are two operation modes: compensation with series voltage using Dynamic Voltage Restorer (DVR) [7]; where the voltage sags are not totally mitigated, so in this paper, the proposed solution is a system using

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Unified Power Quality Conditioner (UPQC) for the voltage compensation.

UPQC is one of the important electronic device, it is used for the mitigation of harmonics current and voltage sag [8], it is a single device of series and shunt active power compensators (fig. 2), the series converter acts on the voltage grid, while the shunt converter reduces the harmonics [9]. Thus, many researches have been done about the control strategies for the UPQC; the control system plays a fundamental role for power conditioner, a quick response of signal disturbance and rapid extraction of referencing signal are the major requirement for a good compensation [10].

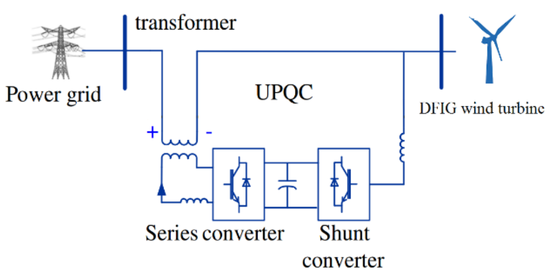

Fig. 2: Schematic of Unified Power Quality Conditioner

In this paper, the control strategy used for the UPQC is the Artificial Neural Networks (ANN); it is a new control approach, used in many engineering area [11], it has many advantages; first ANN do not need to be reprogrammed, they learn from the first program even when an error occurs in the network; they continue working by dint of their parallel nature, the ANN can be implemented easily in any application without any problem, they depend on the database and prototype [12] without a mathematical analysis.
Therefore, the main contribution of this paper is to study the efficiency of ANN approach applied to the UPQC when the DFIG wind turbine connected to the electrical grid under sag, swell and harmonics conditions.

In the proposed work, the first section presents a modeling of the DFIG, the UPQC and the system understudy are discussed in the second section, the ANN control strategy is explained in the third section, the Matlab/Simulink simulation results under different conditions are discussed in the fourth section, finally the last section is a conclusion.

2. DFIG MODELING:

The rotor of the DFIG WT is connected to the grid via slip rings via the Rotor Side Converter (RSC) and the Grid Side Converter (GSC), the stator is connected directly to the grid

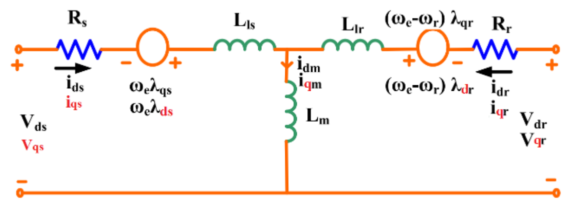

Fig. 3: T-representation of the DFIG equivalent circuit in dq reference frame

The doubly fed induction generator is modeled in reference Park [13,14], leading to the following equations:

$$\begin{aligned}
V_{ds} &= R_s i_{ds} + \frac{d\phi_{ds}}{dt} - w_e\phi_{qs}\\
V_{qs} &= R_s i_{qs} + \frac{d\phi_{qs}}{dt} + w_e\phi_{ds}\\
V_{dr} &= R_r i_{dr} + \frac{d\phi_{dr}}{d_t} - (w_e - w_r)\phi_{qr}\\
V_{qr} &= R_r i_{qr} + \frac{d\phi_{qr}}{d_t} + (w_e - w_r)\phi_{dr}
\end{aligned} \quad (1)$$

$[\phi_{ds},\ \phi_{qs}]$, $[\phi_{dr},\ \phi_{qr}]$: the components of the flux of the stator and the rotor

$[V_{ds}, V_{qs}]$, $[V_{dr}, V_{qr}]$: the components of the voltage of the stator and the rotor

$[i_{ds}, i_{qs}]$, $[i_{dr}, i_{qr}]$: the components of the current of the stator and the rotor

Rs, Rr: the stator and rotor resistance respectively.

The stator and rotor inductance (Ls, Lr) are given in equation 2,

(L_{ls}, L_{lr}): the leakage inductance

L_m: the magnetizing inductance

$$\begin{aligned}
L_s &= L_{ls} + L_m\\
L_r &= L_{lr} + L_m
\end{aligned} \quad (2)$$

The flux linkages are given in equations 3:

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$$\begin{aligned}\phi_{ds} &= L_s i_{ds} + L_m i_{dr}\\ \phi_{qs} &= L_s i_{qs} + L_m i_{qr}\\ \phi_{dr} &= L_m i_{ds} + L_r i_{dr}\\ \phi_{qr} &= L_m i_{qs} + L_r i_{qr} \qquad (3)\end{aligned}$$

The active and reactive power equations at the stator and rotor windings are:

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs})$$
$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \quad (4)$$

3. CONFIGURATION OF THE UPQC :

The topology of the UPQC is shown in fig. 4, it consists of 2 voltage source inverters (VSI) which are connected back to back with each other, they share a common DC link, the first VSI acts as a shunt active power filter (APF), the other as a series one [15]

The series converter imposes a sinusoidal current in phase with power supply through the coupling transformer, while the shunt converter acts as a current source with high value impedance, it isolates the grid from the currents harmonic.
Both shunt and series APF are IGBT based three leg bridge inverters, at the output of the APFs interfacing inductors are used, also to filter high frequency high pass RC filter are used.

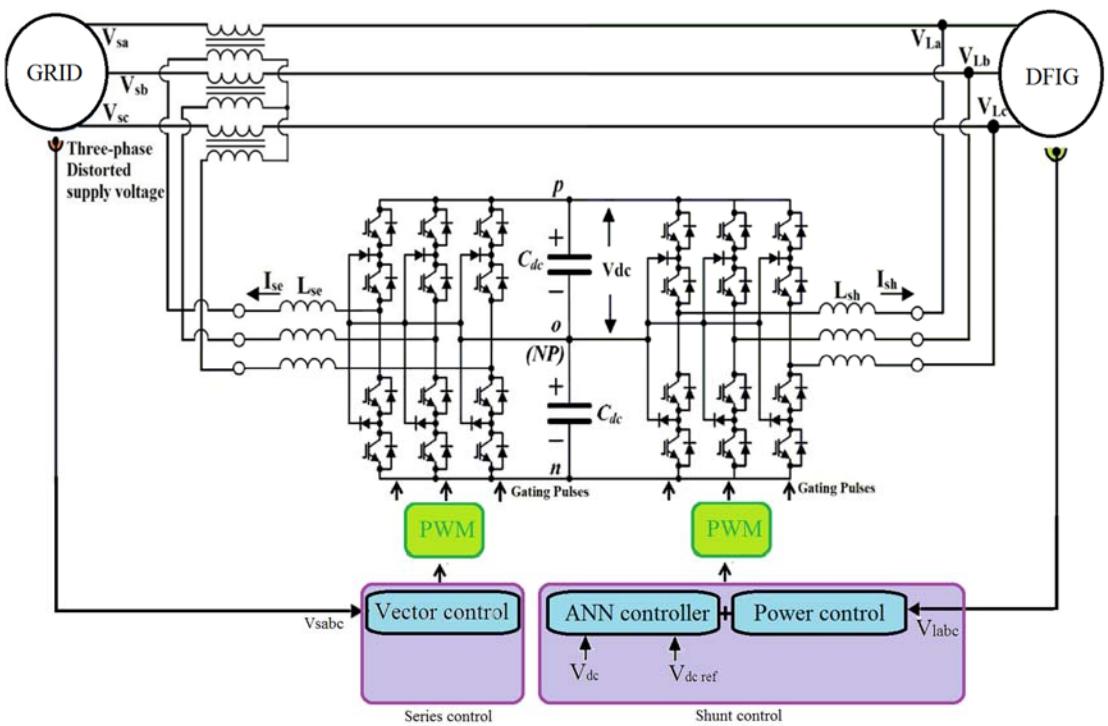

Fig. 4: UPQC and strategy control topology

In order to attenuate harmonics produced by the wind turbine (WT), the shunt inverter injects a current as the following equation:

$$i_{sh} = i_{sref} - i_{lwt} \qquad (5)$$

Where $i_{sh}, i_{sref}, i_{lwt}$ are respectively the shunt APF current, reference supply current and WT current

The series APF of the UPQC injects voltage expressed by equation:

$$V_{sr} = V_{lwt} - V_s \qquad (6)$$

Where i_{st}, i_{lwt}, i_s are respectively the series injected voltage, the WT voltage and the supply voltage

The UPQC eliminates the harmonics in the supply current, therefore the quality current is improved, the voltage and current are in phase, thus the factor correction of the system is improved and there is no need for an additional equipment to compensate the reactive energy.

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4. Proposed control strategy:

In this paper; the performance of the UPQC is enhanced by using the ANN control strategy. The advantage of the ANN control is a fast-dynamic response and the maintain of system stability. The ANN is interconnected artificial neurons, it has three layers, the first one acts as input neurons; it sends data to the second layer which in turn sends orders to the third output layer; so a defined topology characterizes the ANN [16]. The instruction of ANN is to control the shunt APF; the reference signal generation to balance the dc link voltage.

The reference voltage (400 V) is compared with (Vdc) the actual voltage to balance the capacitor voltage. The input data is the corresponding error, the number of hidden layers is 20, the algorithm used for the network training is Gradient Descent with Momentum, the Simulink/matlab model of the ANN for the capacitor voltage in the shunt controller of the UPQC is shown in fig. 5

The NN is trained in order to afford fundamental reference voltage, the active power is estimated by application of 3 phase PLL to Vacb (the DFIG voltage), the control strategy used is the Stationary Reference Frame with its ɖ-β components, the active power estimation is shown in fig. 6

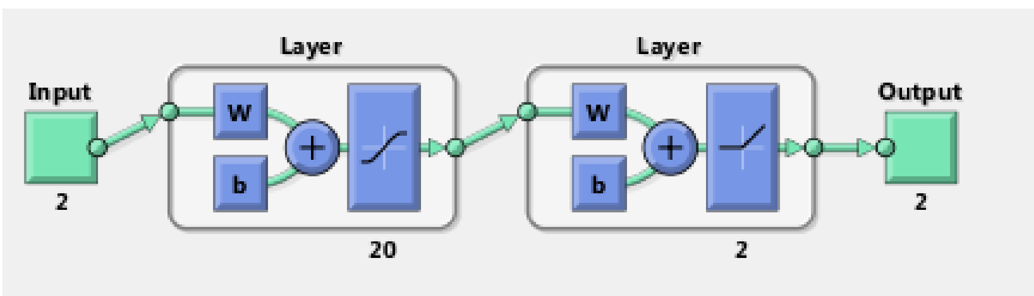

Fig. 5: ANN structure for capacitor voltage balancing

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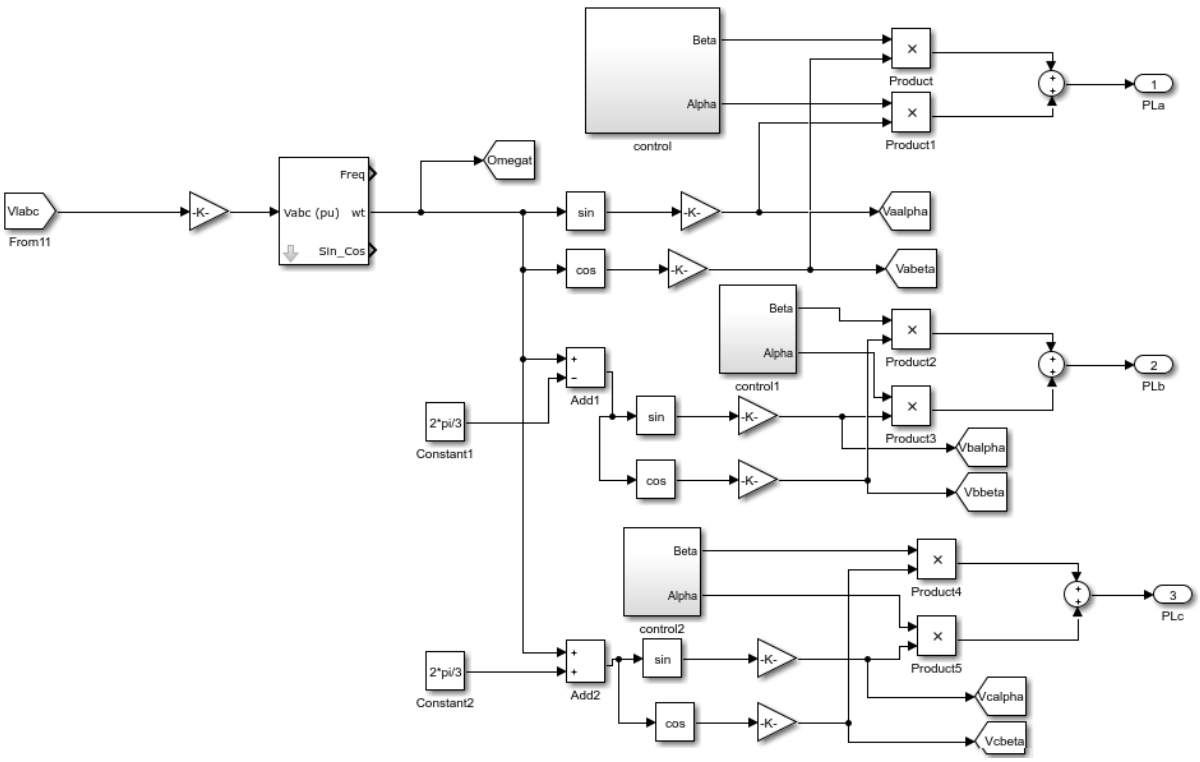

Fig. 6: Active power estimation

From values of active power estimation and the refence voltage trained by the ANN, it results currents signals that are compared in a hysteresis band current, then the switching signal of the VSI are provided (fig. 7)

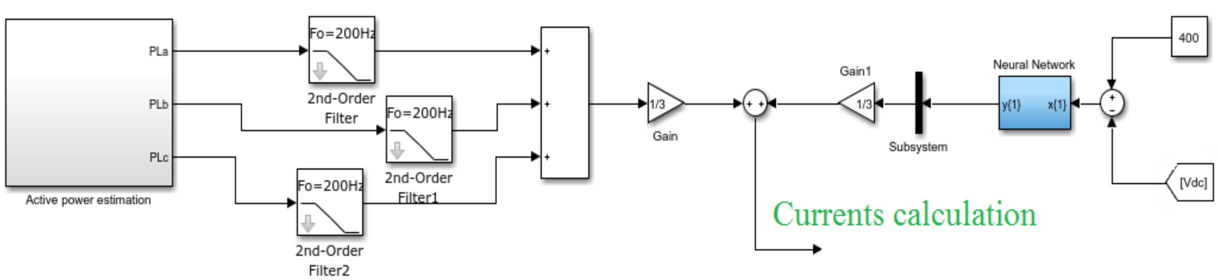

Fig. 7: ANN trained voltage and active power estimation

For the proposed control in the series APF of the UPQC, a voltage vector strategy is proposed, the grid voltage V_{abc} is vector controlled.

5. SIMULATION RESULTS:

The topology of the proposed system is shown in fig. 4, the parameters of the DFIG, shunt and series resistance and inductance, the source are described in table 1

	Parameters	Value
DFIG		1,4 MW
Capacitor		C= 5000 µF
Resistance	Series	Rgrid= 0.1Ω
Inductance	Series	Lgrid= 3 mH
Resistance	Shunt	R_L= 0.1Ω

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Inductance	Shunt	L_L= 3 mH
Source	Voltage(phase-phase)	100 Vrms

Table. 1: Parameters of the UPQC system connected to the DFIG

1.1. Operating condition type: Normal

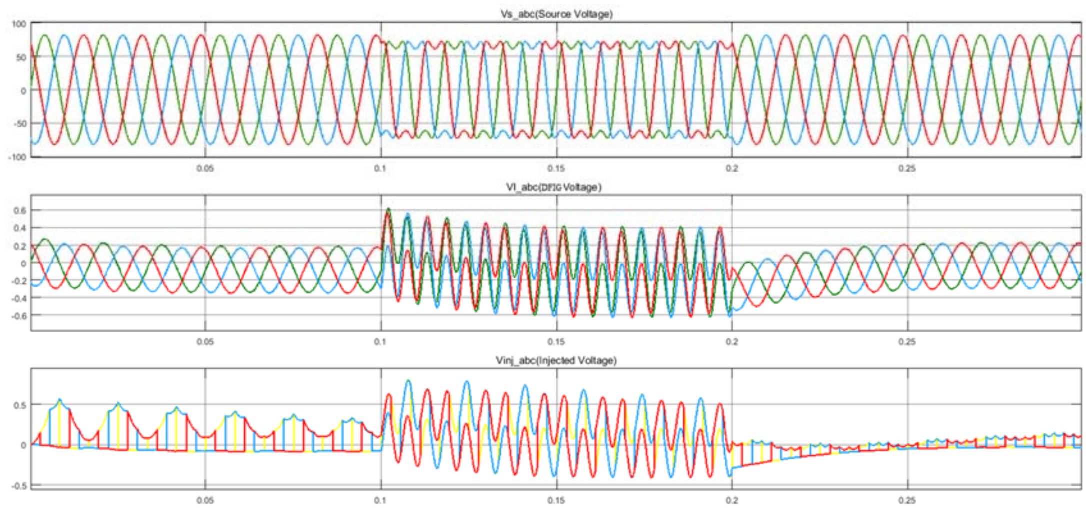

Fig. 7: Compensation using the ANN UPQC; V_{sabc} source voltage, V_{iabc} the DFIG voltage, V_{inj} injected voltage

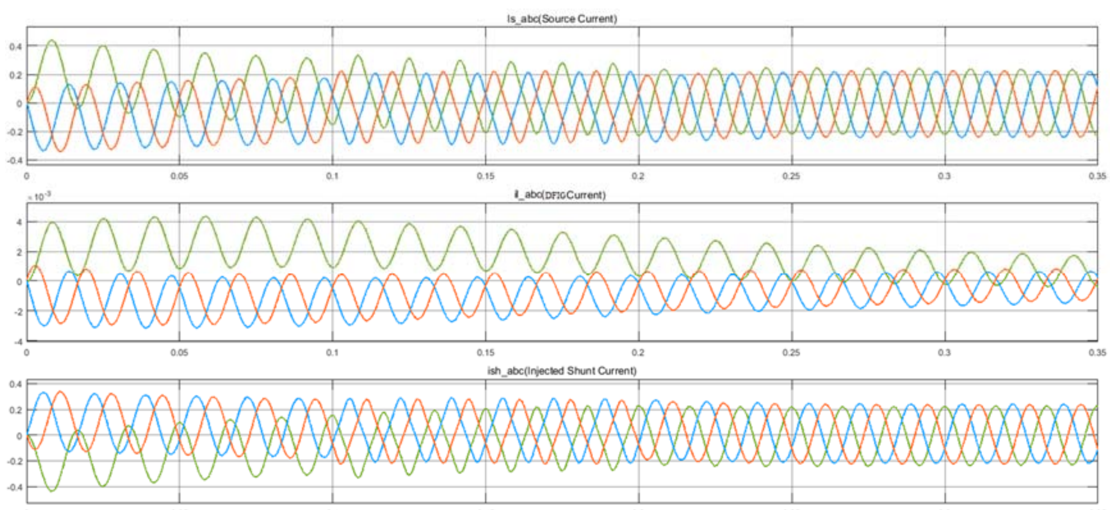

Fig. 8: Compensation using the ANN UPQC; I_{sabc} source current, I_{iabc} the DFIG current, I_{inj} injected current

At instant t=0.1s, the converters based UPQC becomes active and compensate the voltage and current harmonics, the DFIG voltage and source current are shown in fig.8 and fig.9.

Before the instant t=0.15s the DFIG current was high 3 times of the rated current, then the shunt converter acts on the signal of the system through the ANN control strategy, a convergence of currents is observed due to the rapid charging of

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capacitor, from instant t=0.25s the signals currents become more compensated.

The voltage compensation starts at instant t=0.1 s and current compensation starts at t=0.15 s.

From fig. 8 it is noticed that the DFIG voltage is compensated, the harmonics in DFIG current is remarkably reduced.

1.2. **Operating condition type: under voltage Sag**

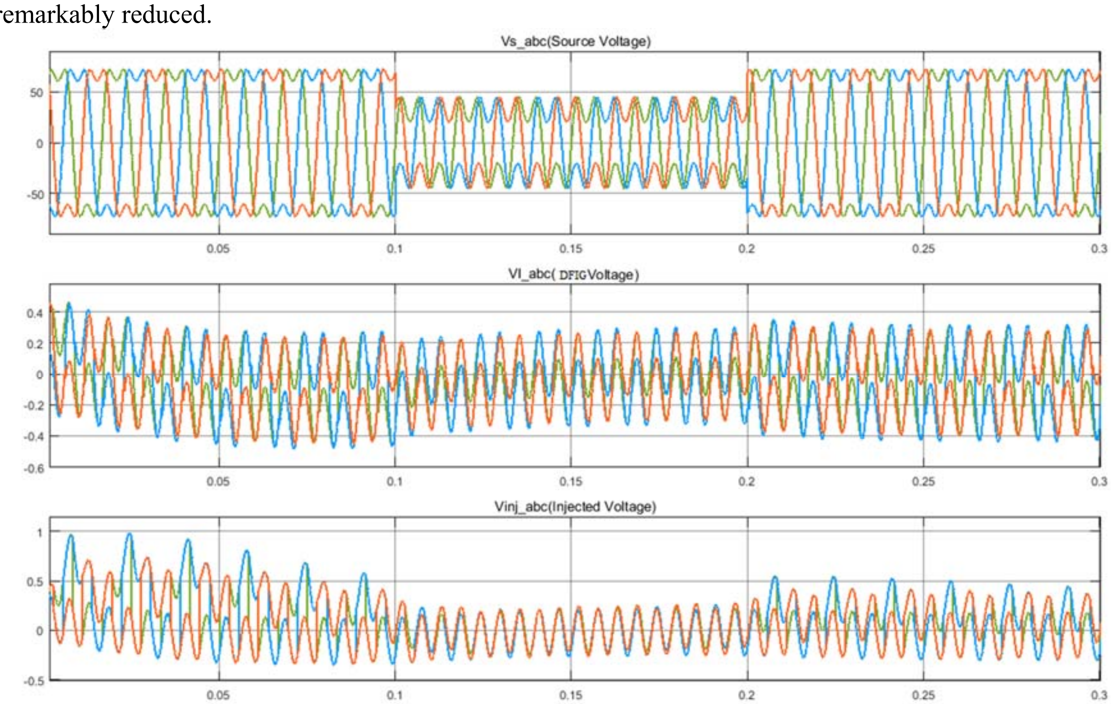

Fig. 9: Compensation using the ANN UPQC during sag condition; V_{sabc} source voltage, V_{iabc} the DFIG voltage, V_{inj} injected voltage

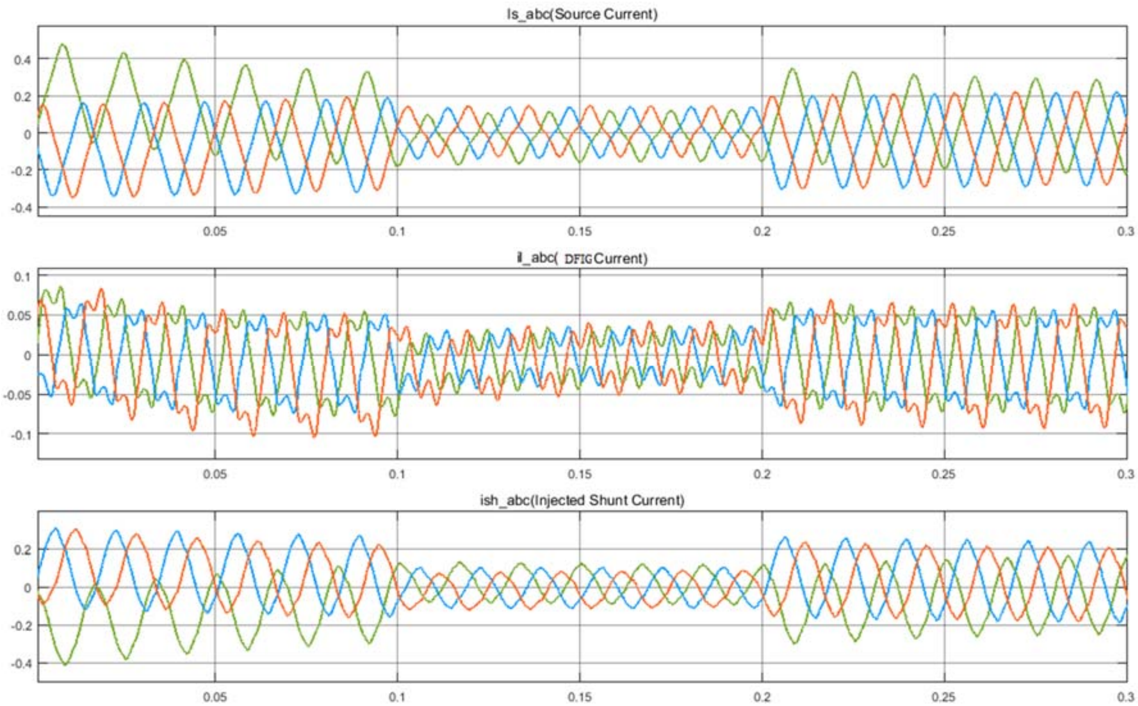

Fig. 10: Compensation using the ANN UPQC during sag condition; I_{sabc} source current, I_{iabc} the DFIG current, I_{inj} injected current

The system is tested under 30% of voltage sag from the instant t=0.1s to t=0.2s, the voltage values are reduced from 75V to 47V as it is shown in fig. 9.

In fig. 10, it is noticed that the UPQC based ANN control strategy compensates the sagged voltage and harmonics in the DFIG voltage, the signal is maintained sinusoidal and constant after the instant 0.2s, the harmonics of the DFIG current are also reduced and maintain constant signal

1.3. Operating condition type: under voltage Swell

The efficiency of the UPQC with ANN control strategy is approved for 30% of voltage swell, as it is noticed in fig. 11, the period of the voltage swell is from instant t=0.1s to t=0.2s, during the voltage swell, the source voltage is increased from 70V to100V as it is shown in fig. 11, the DFIG voltage (fig. 11) and DFIG current (fig. 12) are successfully compensated, they maintain a constant sinusoidal voltage, and constant current.

Fig. 12 shows that the source current and the injected current become free of harmonics with a sinusoidal signal from after the voltage swell (instant 0.2s)

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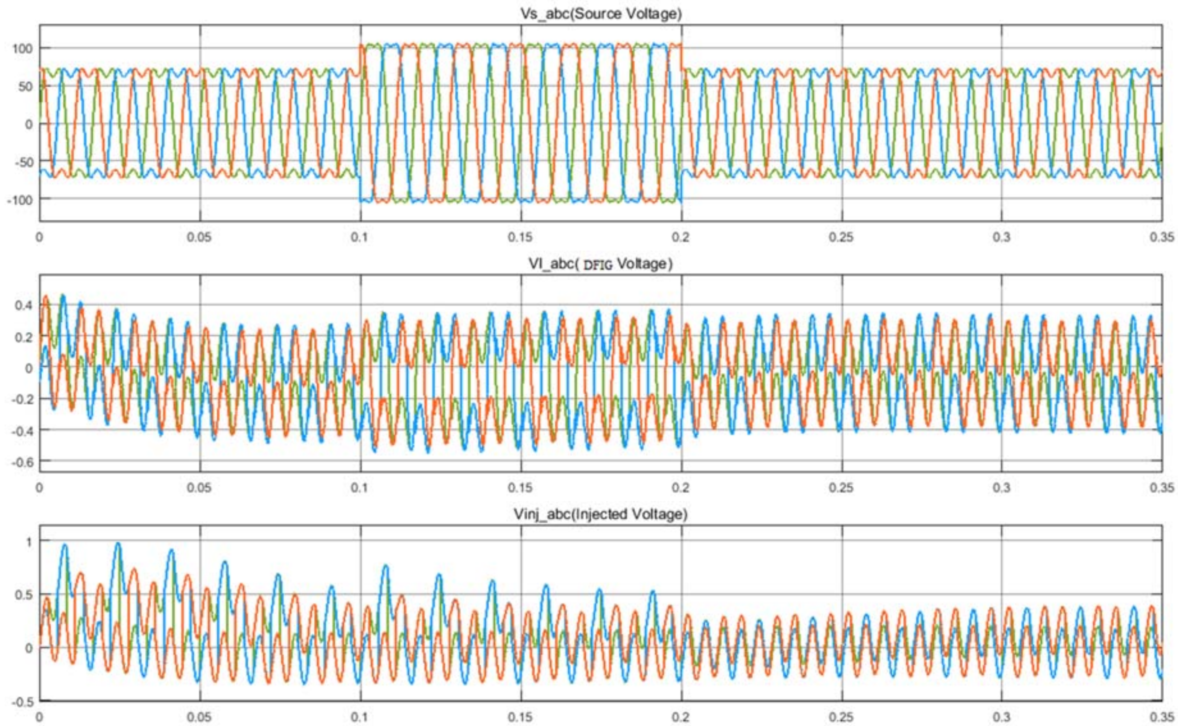

Fig. 11: Compensation using the ANN UPQC during swell condition; V_{sabc} source voltage, V_{iabc} the DFIG voltage, V_{inj} injected voltage

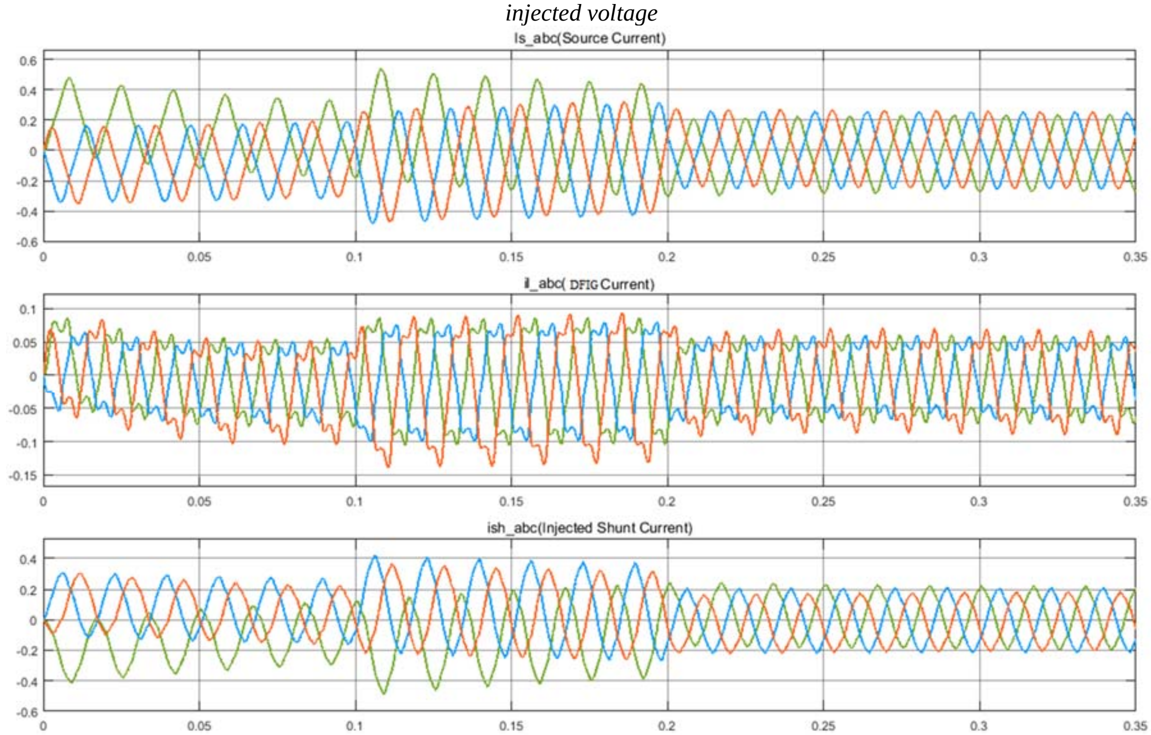

Fig. 12: Compensation using the ANN UPQC during swell condition; I_{sabc} source current, I_{iabc} the DFIG current, I_{inj} injected current

Comparing the results of the UPQC based ANN to other solutions like the Dynamic Voltage Restorer (DVR), the ANN approach is more simple and efficient, it takes only 0.1 s (between instant t=0.1s and t=0.2s) to enhance the performance of the DFIG, as it is shown in graphs bellow where

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harmonics, sag and swell are reduced and corrected. For more details, reader can refer to articles [17,18]

CONCLUSION:

When the DFIG WT is connected to the electrical grid; many disturbances occur due to the speed variation of the DFIG. The drops of voltage reduce the generation of active power and create voltage sag and swell, harmonics and flicker. Therefore, the need to use the UPQC; which is an important device to overcome these disturbances, to get more performed results, the ANN approach is proposed, the performance of the UPQC based ANN control strategy is tested while it is connected to the DFIG WT and under variable supply voltage. It is noticed that the UPQC compensates the voltage swell and sag efficaciously and reduces harmonic distortion in the DFIG WT and the supply currents. The proposed ANN control scheme and vector control reduces the total harmonic distortion of the system, the facility use of the ANN process eliminates the use of mathematical operations comparing with others control strategy.

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