STATOR ACTIVE AND REACTIVE POWER RIPPLES MINIMIZATION FOR DVC CONTROL OF DFIG BY USING FIVE-LEVEL NEURAL SPACE VECTOR MODULATION

Habib BENBOUHENNI
Ecole Nationale Polytechnique d'Oran Maurice Audin, Oran, Algeria
Tel. +213663956329, e-mail: habib_benbouhenni@yahoo.com

ABSTRACT

This paper presents a direct vector control (DVC) strategy for the doubly fed induction generator (DFIG)based wind turbine systems. The major disadvantages that are usually associated with DVC control scheme are the electromagnetic torque, reactive power and active power ripples. To overcome these disadvantages an advanced five-level space vector modulation (5L-SVM) strategy based on neural networks (NNs) controller is proposed. The proposed controller is shown to be able to reduce the reactive and active powers ripples and to improve the performances of the DVC control. Simulation results are shown by using Matlab/Simulink.

Keywords: *Direct vector control; doubly fed induction generator; five-level space vector modulation; neural space vector modulation; neural networks.*

1. INTRODUCTION

Doubly fed induction generator is one of the most popular variable speed wind turbines (WTs) in use nowadays. It is normally fed by a voltage source inverter. In the most WTSs configurations, the stator side is directly connected to the grid and the rotor side is connected to the grid through a back-to-back converter [1, 2]. Many control schemes such as vector command (VC) [3, 4], artificial intelligent control (AIC) [5], sliding mode control (SMC) [6, 7], LQR control of DFIG [8], direct torque control (DTC) [9-11] and direct power control (DPC) [12, 13] have been proposed to control especially stator active and reactive powers of the DFIG. In literature [14] VC control is the most popular technique used in the DFIG-based WT systems. However, the principle of the VC control scheme is to direct the flow vector to make this machine similar control standpoint to a DC machine with separate excitation. This control technique based on traditional controllers (proportional control, integral and derivative) [15].

Many researchers focus their studies based on field oriented control (FOC) using linear regulator proportional integrator (PI) in order to control rotor side converter (RSC) as mention in [16-18], by calculationg *Kp* and *Ki*.

In this paper, we proposed a direct vector control (DVC) law for DFIG based on the orientation of the stator flux. The latter shows the relationship between the stator and the rotor variables. These relationships will enable the rotor to act on signals to control the exchange of real and reactive power between the stator of the machine and the network. On the other hand, the DVC control is a simple control scheme and easy to implement compared to other controls. However, it has some disadvantages, such as its dependence on the machine parameters variation due to the decoupling terms. This technique gives more total harmonic distortion (THD) of rotor current and powers ripples of a DFIG based WTSs.

Since the SVM (Space Vector Modulation) technique is usually used in control of machine drive. However, this technique scheme is difficult to implement. This technique is a complex modulation scheme and needs to calculate the sector and angle. However, this technique gives more THD of the rotor current and high ripple in torque, rotor flux and powers of the DFIG machine. To overcome the drawbacks of the SVM technique, a new modulation strategy for the inverter control was proposed by [19, 20] as neural space vector modulation (NSVM) to control reactive and active powers. However, this technique gives 80% more voltage output compared to the conventional SVM strategy [21]. In this article, we proposed an NSVM technique of five-level inverter based on the calculation of minimum (min) and maximum (max) of three-phase voltage [22]. The advantages of the proposed NSVM inverter is not needed to calculate the angle and sector, easy to implement, simple modulation scheme and reduce the THD value of stator and rotor current compared to conventional SVM inverter [23].

In our paper, two different DVC strategies will be compared with each other. These strategies are conventional DVC and DVC strategy using five-level NSVM technique. The proposed strategies are described clearly and simulation results are reported to demonstrate its effectiveness. The used strategies are implemented in Matlab/Simulink software.

2. FIVE-LEVEL NSVM TECHNIQUE

The principale of space vector modulation is represented in a frame in Fig. 1. The SVM technique is widely used in control of AC machine drives. This proposed technique not needed to calculate sector and angle. However, this modulation strategy is detailed in [20]. In this work, we propose a neural space vector modulation of five-level NPC inverter based on the calculation of maximum (min) and minimum (max) of three-phase voltages. Fig. 2 represents the block diagram of the hysteresis comparators for the five-level inverter. On the other hand, the advantage of the proposed SVM inverter is a simple modulation scheme, easy to implement and gives a strong performance for the real-time feedback control [24]. The NSVM strategy block represents the five-level inverter model as shown in Fig. 3.

The principle of neural space vector modulation is like to traditional SVM technique. The difference is using artificial neural networks (ANNs) to replace the hysteresis comparators.

A neural network (NN) is newly getting increasing stress in drive command applications. The main preference of the ANN controller is that is easy to implement the control that it has the capability of generalization [25].

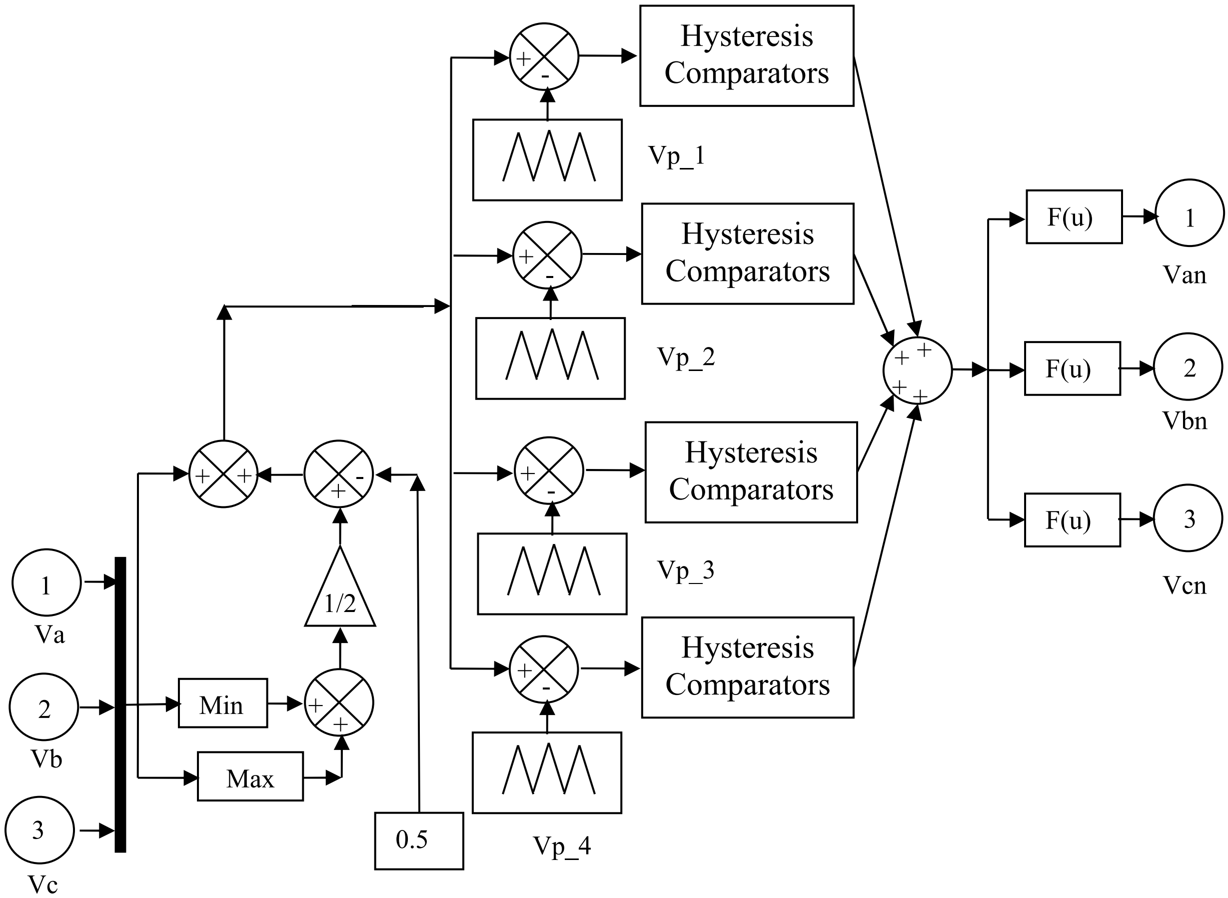

Fig. 1 Block diagram of the five-level SVM technique.

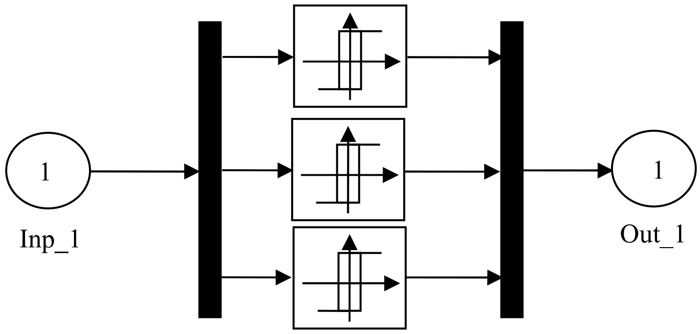

Fig. 2 Block diagram of the hysteresis comparators.

Fig. 4 represents the block diagram of the neural hysteresis comparators for five-level NSVM technique.

The training used is that of the algorithm, Gradiant descent with momentum & Adaptive LR.

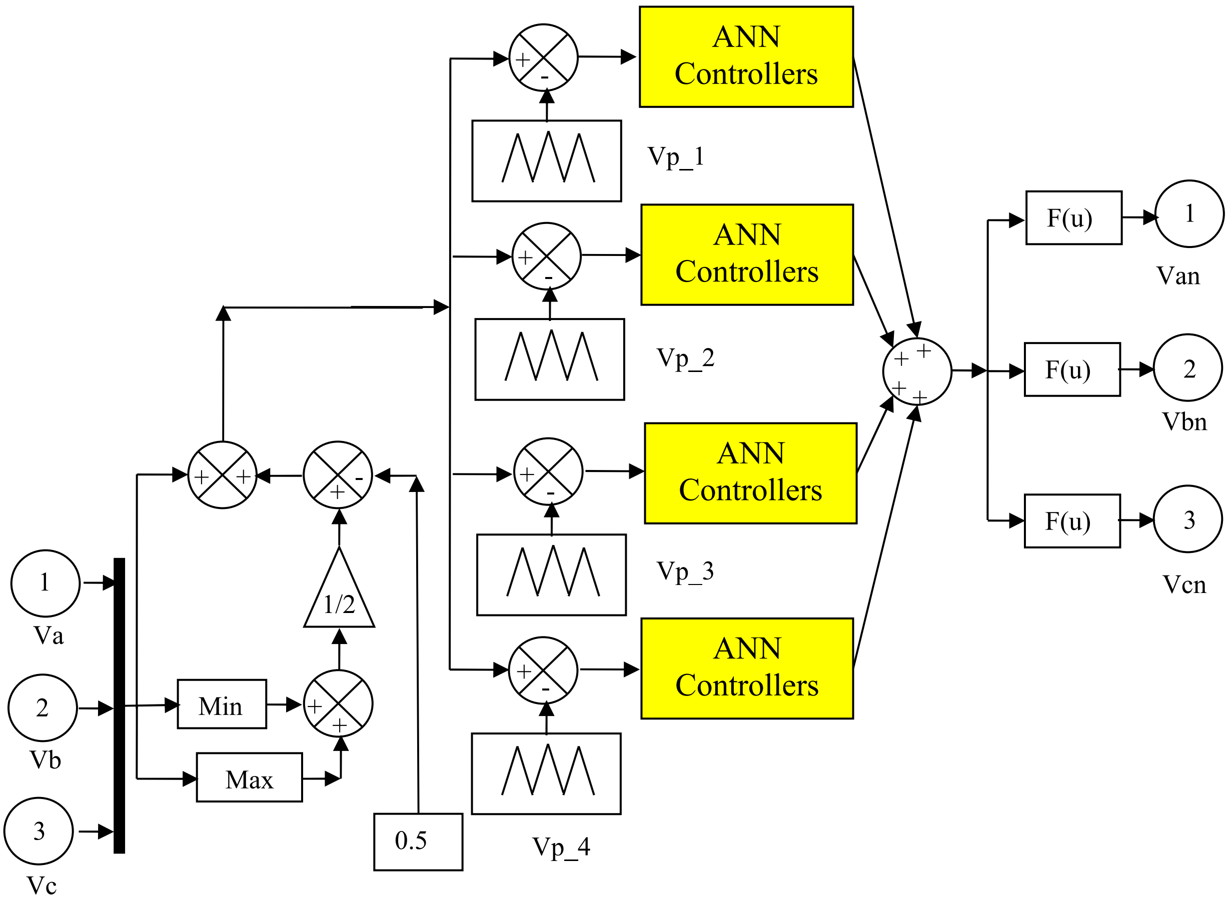

Fig. 3 Block diagram of the five-level NSVM technique

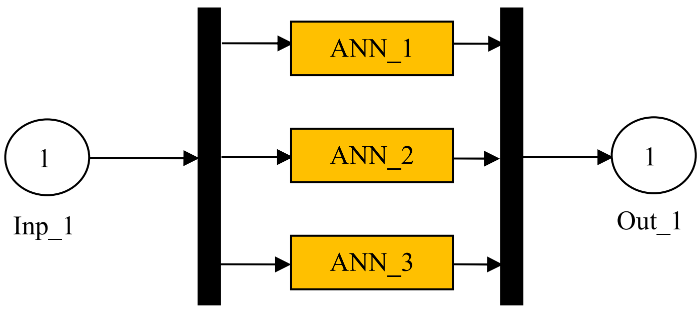

Fig. 4 Block diagram of the neural hysteresis comparators

The block diagram of the ANN based hysteresis comparators are shown in Fig. 5. The block diagram of the Layer 1 and layer 2 is shown in Fig. 6 and Fig. 7 respectively.

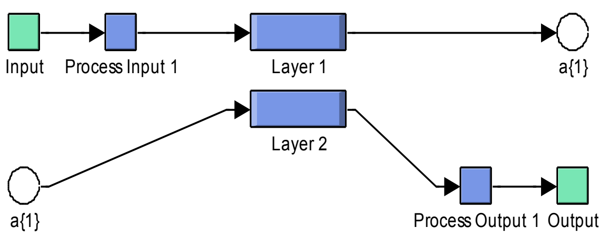

Fig. 5 The ANN controller

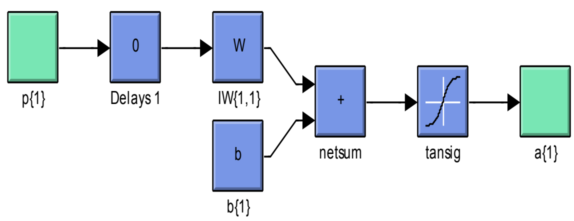

Fig. 6 Layer 1.

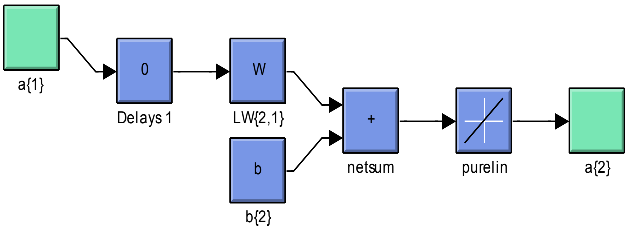

Fig. 7 Layer 2

The convergence of the network in summer obtained by using the value of the parameters grouped in the Table 1.

Table 1 Parameters of the LR for hysteresis comparators

Parameters of the LM	**Values**
Number of hidden layer	12
TrainParam.show	50
TrainParam.eposh	1000
TrainParam.Lr	0.005
Coeff of acceleration of convergence (mc)	0.9
TrainParam.goal	0
TrainParam.mu	0.9
Functions of activation	Tensing, Purling, gensim

3. DIRECT VECTOR CONTROL

Fig. 8 represents the direct vector control (DVC) strategy of DFIG driven by a five-level NSVM technique. This technique is detailed in [26]. This control scheme is a simple control technique and easy to implement. However, this control has some advantages and disadvantages. The basic disadvantages of DVC control scheme using five-level SVM inverter are the variable switching frequency, the stator active and stator reactive powers ripples [27]. In the aim to improve the performance of the electrical drives based on DVC control, space vector modulation inverter and neural networks are combined (5L-NSVM) to reduce the active, reactive powers ripple and minimize the THD value of rotor current. The internal structure of the DVC control technique is shown in Fig. 9.

4. SIMULATION RESULTS

The DVC strategy of a DFIG is implemented with simulation tools of MATLAB/Simulink. The DFIG (1.5 MW) attached to a 398 V/50 Hz grid. The both control strategies, DVC using 5L-SVM and DVC control scheme using 5L-NSVM strategy are simulated and compared regarding rotor current harmonics distortion, reference tracking and robustness against DFIG parameter variations.

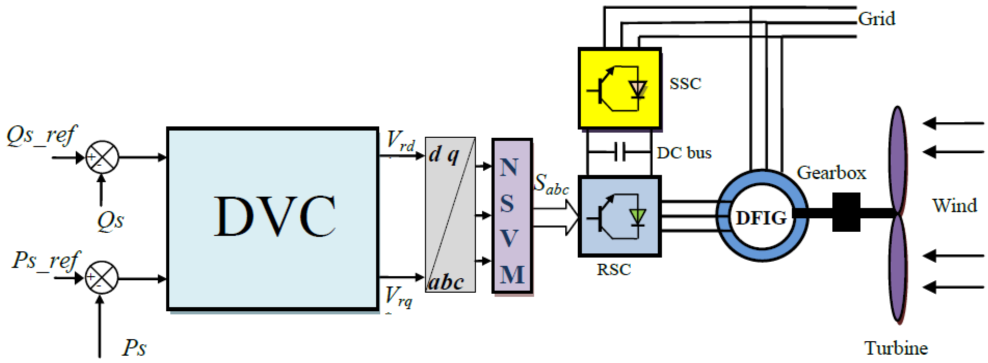

Fig. 8 Block diagram of DVC control with NSVM.

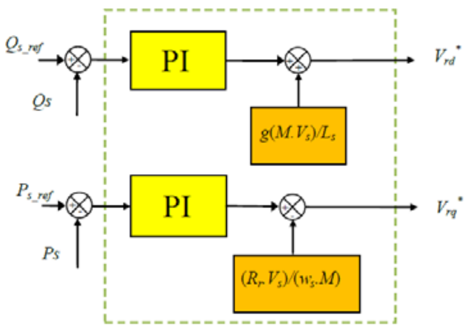

Fig. 9 Structure of DVC strategy.

A. Reference tracking test (RTT)

Figs 10-14 show the obtained simulation results. As it's shown in Figs 10-12, for the two DVC control strategies, the stator active power (Ps) and stator reactive power (Qs) tracks almost perfectly their references values (Ps_{ref} and Qs_{ref}). Moreover, the DVC control scheme using the five-level NSVM inverter minimized the powers ripples and electromagnetic torque (Te) ripple compared to the DVC using five-level SVM technique (See Figs 15-17). Figs. 13-14 show the THD of rotor current of the doubly fed induction generator for both DVC command schemes. It can be clearly observed that the THD value is minimized for DVC control using the five-level NSVM strategy (THD = **0.04%**) when compared to DVC control scheme using the 5L-SVM (THD = 0.66%).

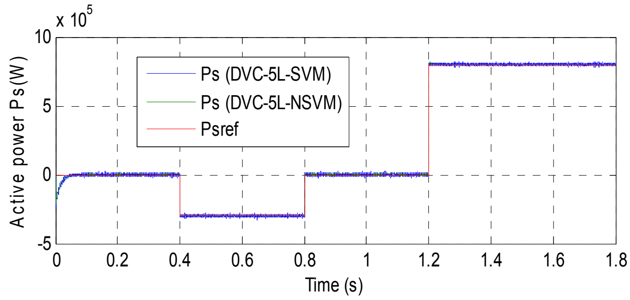

Fig. 10 Active power (RTT).

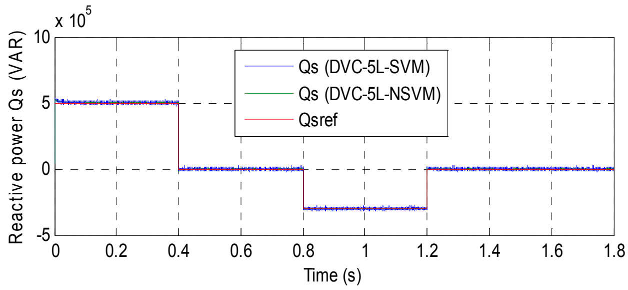

Fig. 11 Reactive power (RTT)

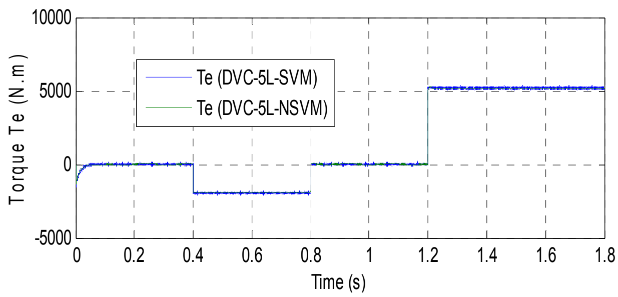

Fig. 12 Torque (RTT)

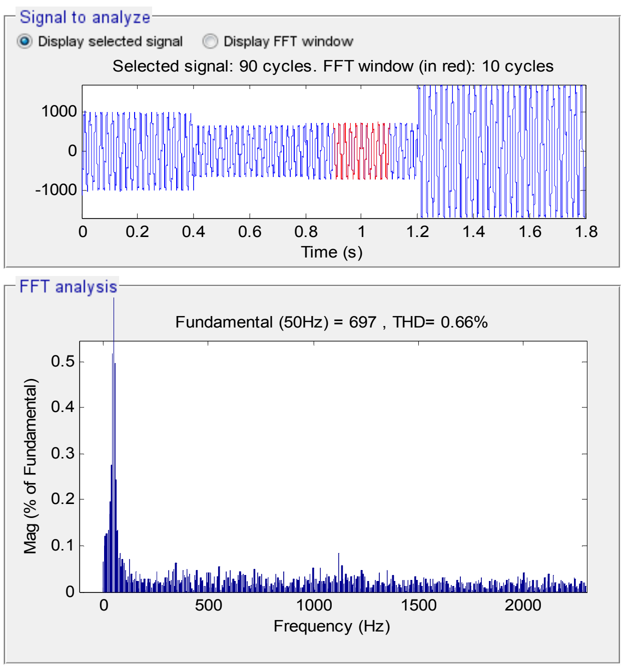

Fig. 13 THD of rotor current for DVC-5L-SVM control (RTT)

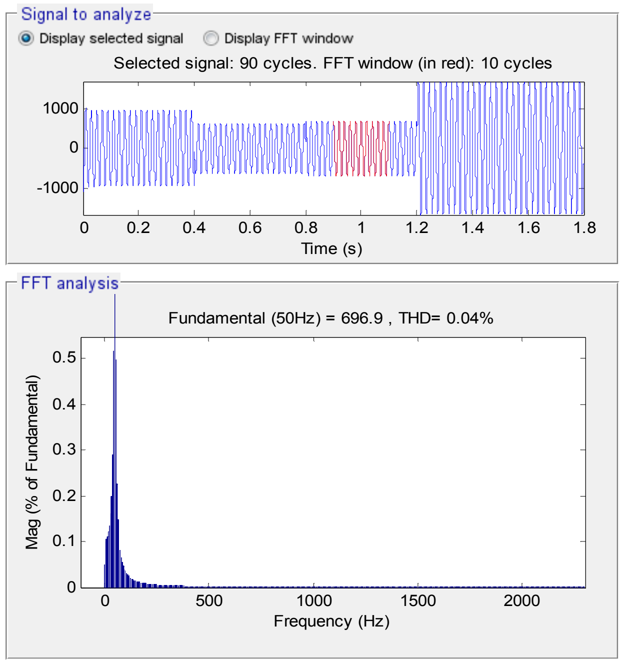

Fig. 14 THD of rotor current for DVC-5L-NSVM control (RTT)

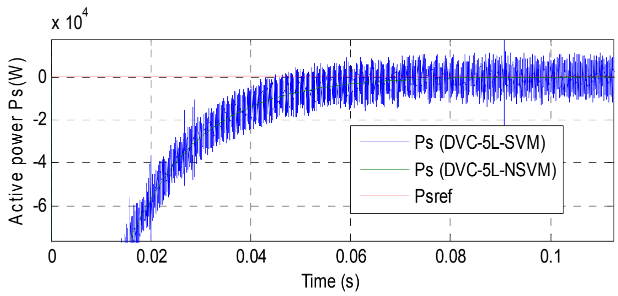

Fig. 15 Zoom in the active power (RTT)

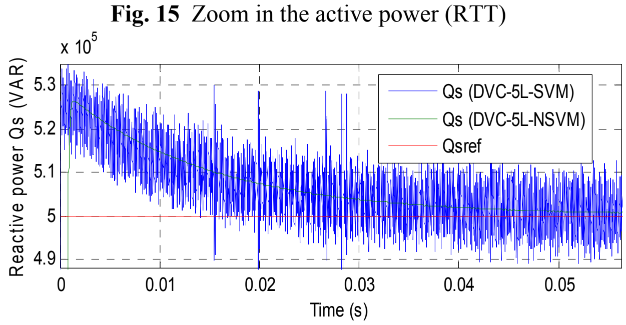

Fig. 16 Zoom in the reactive power (RTT)

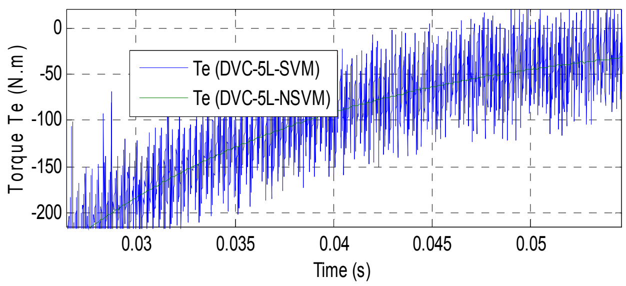

Fig. 17 Zoom in the electromagnetic torque (RTT)

B. Robustness test (RT)

In this section, the nominal value of the R_r and R_s is multiplied by 2, the values of inductances L_s, M, and L_r are multiplied by 0.5. Simulation results are presented in

Figs 18-22. As it's shown by these figures, these variations present an apparent effect on the stator reactive power, stator active power, and electromagnetic torque curves and that the effect appears more significant for the DVC control using 5L-SVM technique compared to DVC using 5L-NSVM (See Figs. 23-25).

The THD value of rotor current in the DVC control using 5L-NSVM inverter has been minimized significantly (See Figs. 21-22). Table 2 shows the comparative analysis of THD value. Thus it can be concluded that the proposed DVC control using 5L-NSVM inverter is more robust than the DVC control using 5L-SVM technique.

Table 2 Comparative analysis of THD value (RT)

	THD (%)	
	DVC-5L-SVM	**DVC-5L-NSVM**
Rotor current	3.60	**0.06**

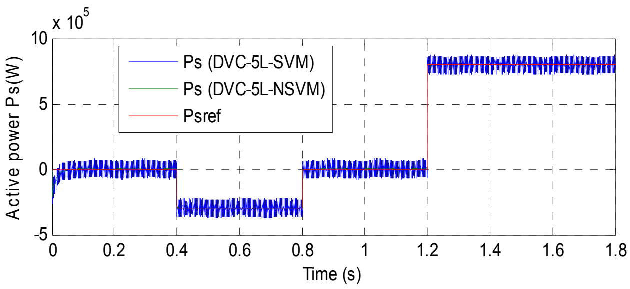

Fig. 18 Active power (RT)

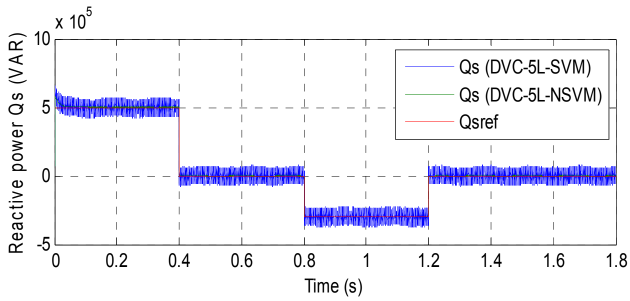

Fig. 19 Reactive power (RT)

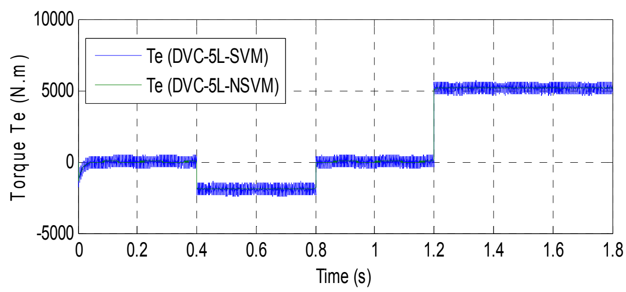

Fig. 20 Torque (RT)

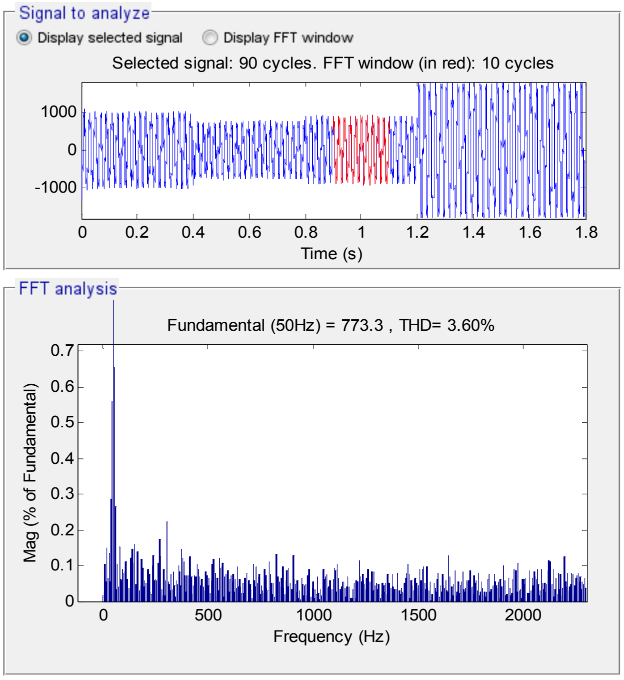

Fig. 21 THD of rotor current for DVC-5L-SVM control (RT)

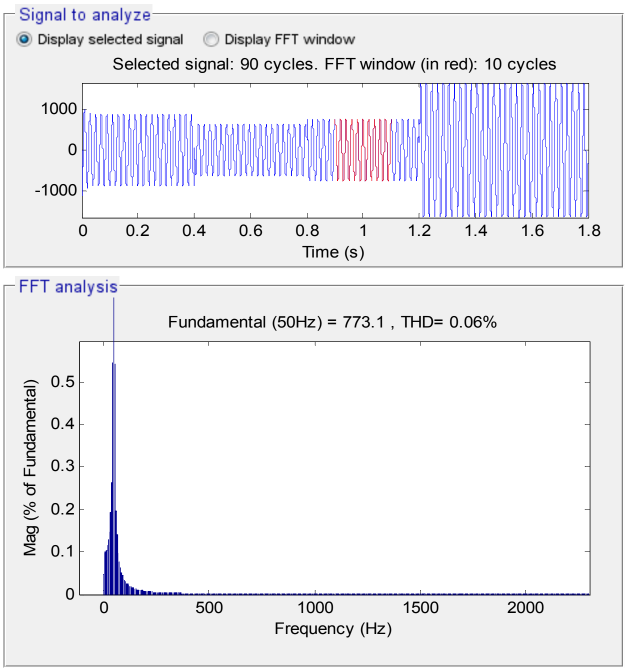

Fig. 22 THD of rotor current for DVC-5L-NSVM control (RT)

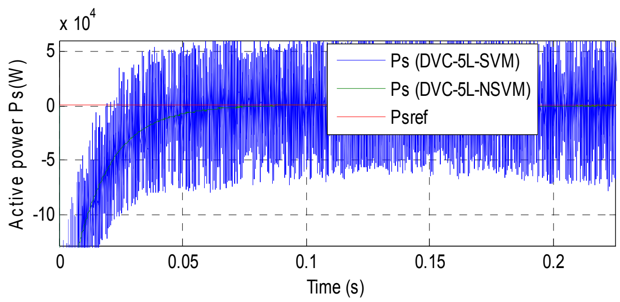

Fig. 23 Zoom in the active power (RT)

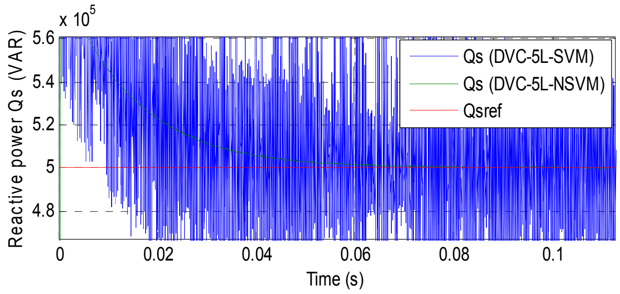

Fig. 24 Zoom in the reactive power (RT.

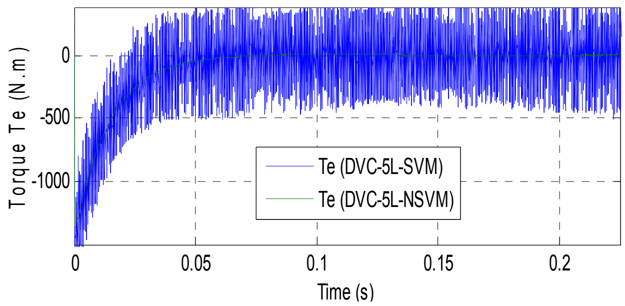

Fig. 25 Zoom in the electromagnetic torque (RT)

5. CONCLUSION

This work presents a DVC control technique of a DFIG using a five-level neural space vector modulation compared to the conventional five-level SVM inverter. With results obtained from the simulation, it was clear that for the similar operation conditions, the DVC control with five-level NSVM inverter presents high-quality performance compared to the DVC control using a five-level SVM strategy and that was clear in the THD of rotor current which the use of the five-level NSVM reduce the THD more than the classical five-level SVM technique.

REFERENCES

[1] BEKAKRA, Y. – BEN ATTOUS, D.: Comparison study between SVM and PWM inverter in sliding mode control of active and reactive power control of a DFIG for variable speed wind energy, International Journal of Renewable Energy Research, Vol. 2, No. 3, pp. 471-476, 2012.

[2] HOSSEINABADI, M. – RASTEGAR, H.: DFIG based wind turbines behavior improvement during wind variations using fractional order control systems, Iranian Journal of Electrical & Electronic Engineering, Vol. 10, No. 4, pp. 314-323, 2014.

[3] MEDJBER, A. – MOUALDIA, A. – MELLIT, A. – GUESSOUM, M. A.: Comparative study between direct and indirect vector control applied to a wind turbine equipped with a double-fed asynchronous machine article, International Journal of Renewable Energy Research, Vol. 3, No. 1, pp. 88-93, 2013.

[4] HAMANE, B. – DOUMBIA, M. L. – BOUHAMIDA, M. – DRAOU, A. – CHAOUI, H. – BENGHANEM, M.: Comarative study of PI, RST, sliding mode and fuzzy supervisory controllers for DFIG based wind energy conversion system, International Journal of Renewable Energy Research, Vol. 5, No. 4, pp. 1174-1184, 2015.

[5] BAKOURI, A. – MAHMOUDI, H. – ABBOU, A.: Intelligent control for doubly fed induction generator connected to the electrical network, International Journal of Power Electronics and Drive System, Vol. 7, No. 3, pp. 688-700, 2016.

[6] YAHDOU, A. – HEMICI, B. – BOUDJEMA, Z.: Second order sliding mode control of a dual-rotor wind turbine system by employing a matrix converter, Journal of Electrical Engineering, Vol. 16, No. 4, pp. 1-11, 2016.

[7] BOUDJEMA, Z. – MEROUFEL, A. – DJERRIRI, Y. – BOUNADJA, E.: Fuzzy sliding mode control of a doubly fed induction generator for wind energy conversion, Carpathian Journal of Electronic and Computer Engineering, Vol. 6, No. 2, pp. 7-14, 2013.

[8] KHAJAH, A. – GHAZI, R.: GA-based optimal LQR controller to improve LVRT capability of DFIG wind turbine, Iranian Journal of Electrical & Electronic Engineering, Vol. 9, No. 3, pp. 167-176, 2013.

[9] MASSOUM, S. – MEROUFEL, A. – MASSOUM, A. – WIRA, P.: A direct power control of the doubly-fed induction generator based on the SVM strategy, Elektrotehniski Vestnik, Vol. 45, No. 5, pp. 235-240, 2017.

[10] BOUDJEMA, Z. – TALEB, R. – DJERRIRI, Y. – YAHDOU, A.: A novel direct torque control using second order continuous sliding mode of a doubly fed induction generator for a wind energy conversion system, Turkish Journal of Electrical Engineering & Computer Sciences, Vol. 25, pp. 965-975, 2017.

[11] RAO, Y. S. – LAXMI, A. J.: Direct torque control of doubly fed induction generator based wind turbine under voltage dips, International Journal of Advances in Engineering & Technology, Vol. 3, Vol. 2, pp. 711-720, 2012.

[12] TAVAKOLI, S. M. – POURMINA, M. A. – ZOLGHADRI, M. R.: Comparison between different DPC methods applied to DFIG wind turbines, International Journal of Renewable Energy Research, Vol. 3, No. 2, pp. 446-452, 2013.

[13] AMRANE, F. – CHAIBA, A.: A novel direct power control for grid-connected doubly fed induction generator based on hybrid artificial intelligent control with space vector modulation, Rev. Roum. Sci. Techn.-Electrotechn. Et Energ, Vol. 61, No. 3, pp. 263-268, 2016.

[14] MOHAMED, J. – VAEZ-ZADEH, S. – AFSHARNIA, S. – DARYABEIGI, E.: A Combined vector and direct power control for DFIG-based wind turbines, IEEE Transactions on Sustainable Energy, Vol. 5, No. 3, 2014.

[15] SENANI, F. – RAHAB, A. – BENALLA, H.: Modeling and control of active and reactive powers of

wind energy conversion system in variable speed based on DFIG, Revue des Energies Renouvelables, Vol. 18, No. 4, pp. 643-655, 2015.

[16] MARQUES, G. D.– IACCHETTI, M. F.: Stator frequency regulation in a field-oriented controlled DFIG connected to a DC link, IEEE Transactions on Industrial Electronics, Vol. 61, No. 11, pp. 5930-5939, 2014.

[17] IACCHETTI, M. F. – MARQUES, G. D. – PERINI, R.: A scheme for the power control in a DFIG connected to a DC bus via a diode rectifier, IEEE transactions on Power Electronics, Vol. 30, No. 3, pp.1286-1296, 2015.

[18] GAYEN, P. K. – CHATTERJEE, D. – GOSWAMI, S. K.: Stator side active and reactive power control with improved rotor position and speed estimator of a grid connected DFIG (doubly-fed induction generator), Energy, 2015.

[19] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: Using three-level Fuzzy space vector modulation method to improve indirect vector control strategy of a DFIG based wind energy conversion systems, International Journal Of Smart Grid, Vol. 2, No. 3, pp. 155-171, 2018.

[20] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: Neuro-second order sliding mode control of a DFIG supplied by a two-level NSVM inverter for wind turbine system, Iranian Journal of Electrical and Electronic Engineering, Vol. 14, No. 4, pp. 362-375, 2018.

[21] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: Indirect vector control of a DFIG supplied by a two-level FSVM inverter for wind turbine system, Majlesi Journal of Electrical Engineering, Vol. 13, No. 1, 2019.

[22] BENBOUHENNI H. : Fuzzy second order sliding mode controller based on three-level fuzzy space vector modulation of a DFIG for wind energy conversion systems, Majlesi Journal of Mechatronic Systems, Vol. 7, No. 3, 2018.

[23] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: DFIG-based wind turbine system using three-level neural space vector modulation technique, Majlesi Journal of Mechatronic Systems, Vol. 7, No. 2, pp. 35-45, 2018.

[24] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: A comparative study between four-level NSVM and three-level NSVM technique for a DFIG-based WECSs controlled by indirect vector control, Carpathian Journal of Electronic and Computer Engineering, Vol. 11, No. 2, pp. 13-19, 2018.

[25] BENBOUHENNI H.: Seven-level direct torque control of induction motor based on artificial neural networks with regulation speed using fuzzy PI controller, Iranian Journal of Electrical and Electronic Engineering, Vol. 14, No. 1, pp. 85-94, 2018.

[26] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: Direct vector control of a DFIG supplied by an intelligent SVM inverter for wind turbine system, Iranian Journal of Electrical and Electronic Engineering, Vol. 15, No. 1, pp.45-55, 2019.

[27] BENBOUHENNI, H. – BOUDJEMA, Z. – BELAIDI, A.: DFIG-based wind turbine system using four-level FSVM strategy, Majlesi Journal of Energy Management, Vol. 6, No. 3, 2017.

Received December 13, 2018 , accepted June 10, 2019

BIOGRAPHY

Habib Benbouhenni was born in chlef, Algeria. He is a PhD student in the Departement of electrical engineering at the ENPO-MA, Oran, Algeria. He received a M.S. degree in Automatic and informatics industrial in 2017. His research activities include the application of robust command in the wind turbine power systems.