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Control Strategy for PWM Voltage Source Converter Using Fuzzy Logic for Adjustable Speed DC Motor

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ABSTRACT

The speed of a DC motor can be controlled by providing a DC input voltage that varies at the input terminals. It can be done by controlling a PWM-VSC (PWM-Voltage Source Converter). This paper analyzes an control strategy of PWM-VSC using fuzzy logic to obtain varying DC voltage and according to the DC motor speed as desired. The control strategy of PWM-VSC directly using the switch variable in dq rotating reference frame as input variables obtained from SVPWM (Space vector Pulse Width Modulation) methode. The fuzzy logic controller proposes to get a DC voltage variation stable by adjusting amplitudo of the network current. The simulation Fuzzy Logic Controller results show that the design fuzzy logic produce a good dynamic of DC voltage and DC motor speed without overshoot. On the network, Total Harmonic Distortion less than 5 % and unity power factor.

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1. INTRODUCTION

DC motors are one type of electric motor that is widely used in industry for adjustable-speed drive. Speed control of a DC motor can be done in several ways, e.g, by regulating the armature voltage (DC voltage). Regulating the armature voltage can directly be used to adjust the speed of motor at the time of starting and running. Controlling the DC voltage becomes easier and more efficient to use a PWM-VSC is to set duty cycle [1].

The previous researchers have concerned about DC motor speed control using PWM strategy in [2]-[4]. But use of PWM to control speed of DC Motor will produce current harmonics on the network and unstable of the DC voltage as a DC supply for DC Motor.

They have developed several strategies in order to control PWM on PWM-VSC. Controllers based on PID controllers with regulating the DC voltage and current harmonics in the network. PID controllers were considered as simple and cheap of implementation [5]-[7]. One of disadvantage in using PID controller was using of off-line tuning algorithm and very difficult to use in conditions of varying DC voltage.

Things that need to be observed that the PWM-VSC is a nonlinear system. The nonlinear impacts of PWM-VSC are not expected, for example, current harmonics (THD currents), the low value of power factor on the AC side , the DC voltage becomes unstable and occur ripples on the DC side so that is required proper controller that can compensate them. To solve this, the artificial intelligent control, such as Fuzzy logic control, neural network (NN, RNN) are very promising for the identification and control of nonlinear dynamical systems [7]-[10]. Fuzzy logic controller is an intelligent control that has a simple structure and having an adaptive process causes the PWM-VSC to get better performance despite a change in parameters due to changes in motor speed varies. The fuzzy controller has a wide range to get the variations of the DC voltage.

In this paper, the fuzzy logic controller proposed to obtain the variation of the DC voltage to adjustable-speed drive and overcome impacts of PWM-VSC that not expected. The Fuzzy Logic controller was to minimize error DC voltage to the reference value with regulating variation of current amplitude in the network. Hence, a regulated variation of network current amplitude was obtained with a low harmonic distortion of the network current, to obtain a DC voltage variation stable, unity power factor.

NOMENCLATURE

$v(t)$ = PWM-VSC Input Voltages
$i(t)$ = PWM-VSC Input Current
$i^*(t)$ = Complex Conjugate of $i(t)$
$e(t)$ = Input Network Voltages
$i_o(t)$ = PWM-VSC Output Current
$i_c(t)$ = Capacitor Current
$i_L(t)$ = Load Current
$s(t)$ = Switch variable
$v_o(t)$ = Output Voltage or DC Voltage
K_b = Back Emf Constant
R_a = Armature Resistance
I_a = Armature Current
V_a = Armature Voltage
ω_m = Angular Velocity

2. THE PROPOSED CONTROL STRATEGY

The speed of a DC motor can be controlled by providing a DC input voltage that varies at the input terminals. The control strategy to get variation of the DC voltage based on SVPWM for three phase of PWM-VSC and uses switching variable in d–q frame (s_d , s_q) as input instead of voltage (v_d , v_q) or current (i_d , i_q) that are often used. The system also used a fuzzy logic controller to control the amplitude of the network current based on the error and delta error of the DC voltage. Therefore, a regulated variation of network current amplitude will obtained a low Total harmonic distortion of the network current, a DC voltage variation stable, unity power factor, low ripple. The Fuzzy Control Proposed was showed in Figure 1.

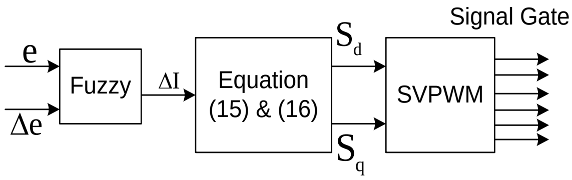

Figure 1. Block diagram of the Propose controller

3. MODELLING OF THE SYSTEM

3.1. Modelling of the DC Motor

A DC motor consists of stator and armature winding in the rotor as shown in Figure 2. A DC voltage from the output of PWM-VSC is as input voltage of the armatur winding that causes a DC current to flow in the winding. This kind of machines is preferred over AC machines in high power application, because of the case control of the speed and the direction of rotation of large DC motor. The filed circuit of the motor is exciting by a constant source. The steady state speed of the motor can be described as [11]:

$$\omega_m = \frac{V_a - I_a R_a}{K_b} \quad (1)$$

becomes constant, and the torque becomes directly proportional to the armature current so that

$$T_m = K I_a \quad (2)$$

Where K is a motor torque constant. When the armature is rotating, a voltage proportional to the product of the flux and angular velocity is induced in the armature. For a constant flux, the induced voltage e_b is directly proportional to the anguler velocity ω_m. Thus

$$e_b = K_b \omega_m \quad (3)$$

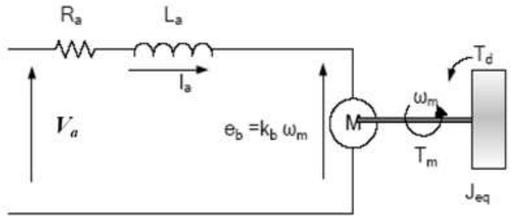

Figure 2. Permanent Magnet DC Motor

Where K_b is a back emf constant.

The armature current produces the torque which is applied to the inertia and friction. Now the torque balance equation will be given by [12].

$$T_m = J_{eq}\, d\omega_m/dt + B_m\, \omega_m + T_d \quad (4)$$

Assuming that all initial conditions are zero and taking the Laplace Transforms of equation (2)–(4), we obtain the following equations :

$$e_b(s) = K_b \omega_m(s) \quad (5)$$

$$V_a(s) = L_a(s) + R_a I_a(s) + e_b(s) \quad (6)$$

$$T_m(s) = J_{eq} s \omega_m + B_m \omega_m(s) \quad (7)$$

From equations (5)-(7) the transfer function of this system is obtained as

$$\frac{\omega_m(s)}{V_a(s)} = \frac{K}{(L_a J_{eq} s^2 + (L_a B_m + R_a J_{eq}) s + R_a B_m + K K_b} \quad (8)$$

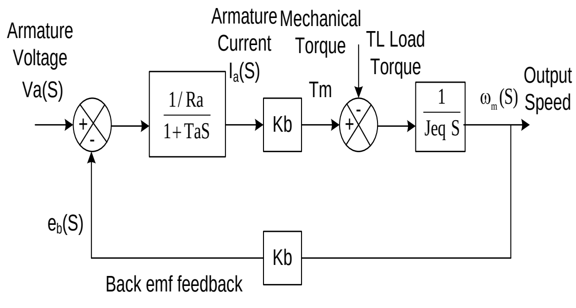

Figure 3. Modelling Block diagram of DC Motor

Table 1. Parameters of the DC Motor

Description of the parameter Parameter value
Resistance of Armature (R_a) 0.55Ω
Inductance of Armature (L_a) 0.025 H
Mechanical inertia (j_{eq}) 0.1 Kg.m2
Friction coefficient (B_m) 0.009 N.m/rad/sec
Constant of Back emf (k) 1.28 V/rad/sec
Constant of Motor torque 1 N.m/A

3.2. Mathematical Model of the System

Figure 4 describes a system, has a three-phase PWM-VSC with DC motor load. The System of PWM-VSC has a three-phase network have connection b three-phase supply voltage e_a, e_b, e_c, three R-L impedances, the three-phase input network currents i_a, i_b, i_c and the three-phase voltages generated by the PWM-VSC v_a, v_b, v_c, a DC capasitor, and the DC motor load. A system can be explained on the stationary frame in using space vectors.

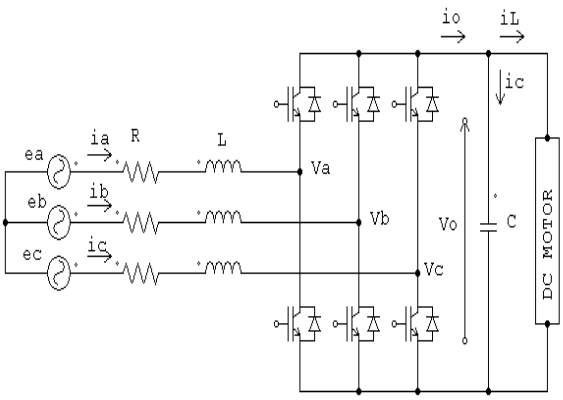

Figure 4. Topology of Three Phase PWM-VSC

The mathematical equations of the three-phase system have three components that is x_a (t) , x_b(t) dan x_c (t) can be wrote in space vectors was as [13]:

$$x(t) = 2/3[x_a(t) + a\,x_b(t) + a^2x_c(t)] \quad (9)$$

Where $a=e^{j2\pi/3}$

This equation of the PWM-VSC was explained in space vector:

$$V(t) = e(t) - R\,i(t) - L\,di(t)/dt$$

$$V(t) = {}^1/_2\,S(t)V_o(t) \quad (10)$$

$$i_0(t) = {}^3/_4\,Re\{S(t)i^*(t)\}$$

$$i_c(t) = C\,dv_o/dt = i_o(t) - i_L(t)$$

The matematical system can be wrote in state space as

$$dV_o(t)/dt = 1/C\{3/4\,Re\{S(t)i^*(t)\} - i_L(t)\} \quad (11)$$

$$di(t)/dt = 1/L[-Ri(t) + e(t) - 1/2S(t)V_o(t)] \quad (12)$$

The both equation in (11), (12) described that the system was nonlinear equation and its action depended upon the switch variable S(t). From equation (12), the voltage on R can be ignored so that value of switching variable S(t) could be calculated from equation (13)

$$S(t) = 2/V_o\,(t)[e(t) - L\,di(t)/dt] \quad (13)$$

Thus it appears that the control strategy to obtain DC voltage variation based on SVPWM for three phase of PWM-VSC and uses switching variable in d–q frame (s_d , s_q) as input.

3.3. Fuzzy Logic Controller Design for Three Phase PWM-VSC

Fuzzy Logic Controller is an intelligent control that has a simple structure and have adaptive process causes performance to be better though parameter changes occur due to changes in variation motor speed. Figure 5 is a block diagram fuzzy logic controller of three phase of PWM-VSC. The fuzzy has two input variables, the error between the reference and the measured value of the DC voltage is the first input variable. The variation of this error is the second input variable. The two variables are represented by :

$e(k) = V_{dcref}(k) - V_{dc}(k)$

$\Delta e(k) = e(k) - e(k-1)$

$\Delta I(k) = I(k) - I(k-1)$

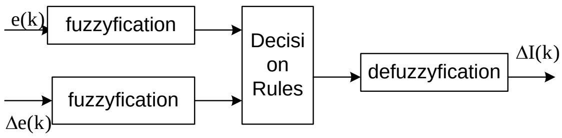

Figure 5. Fuzzy Logic Control Block Diagram

The output variable of fuzzy logic is variation of network current amplitude (ΔI_k). Fuzzy logic controller controlled the DC voltage by regulating network current amplitude. Each of input variables has seven trianggular membership function, seven trianggular membership function for the output, implication using mamdani's min operator, defuzzification using centroid methode. The fuzzy control has seven membership functions called from negative big (NB) to positive big (PB). Tabel 2 Shows fuzzy rules table change in control output.

Tabel 2. Fuzzy Rules of ΔI_k

		e(k)						
Δe (k)		NB	NM	NS	ZE	PS	PM	PB
	NB	NB	NB	NM	NM	NS	NS	ZE
	NM	NM	NM	NM	NS	NS	NS	PS
	NS	NS	NM	NS	NS	ZE	ZE	PS
	ZE	NS	NS	NS	ZE	PS	PS	PM
	PS	NS	NS	ZE	PS	PS	PS	PM
	PM	NS	ZE	PS	PS	PM	PM	PB
	PB	ZE	PS	PS	PM	PM	PB	PB

3.4. Space Vectors of Pulse Width Modulation

Algorithm of Space Vector Pulse Width Modulation can be represented in the form as shown in Figure 6. This algorithm explaines the process for obtaining a control signal to the switches variable three phase voltage source converter with a reference switch vector. In general the reference switch is determined from the component d and q of the switching variable.

$$s_d = \frac{2}{v_o}\left\{E_m - \frac{L}{T_s}\Delta I\right\} \quad (13)$$

$$s_q = \frac{2}{v_o}\left[-\omega LI\right] \quad (14)$$

Equation (13), (14) were convered into the α and β in form stationary frame (s_α and s_β). Both of them were used as inputs for SVPWM. Two of the components will be used to determined m state to be actived. The next time state Tm, Tm+1 and T0 is calculated from the difference between the sampling time

Ts and (Tm + Tm+1). Switching signal can be determined after the sector m, an active state time Tm and Tm + 1, a state-zero T0 obtained.

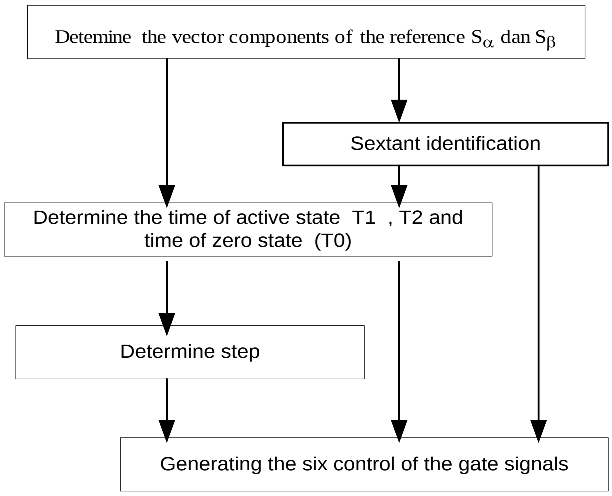

Figure 6. Algorithm of Space Vector Pulse Width Modulation [14]

4. RESULT AND ANALYSIS

The proposed controller of three phase PWM-VSC was evaluated through several simulations. The output voltage of three phase PWM-VSC are used as DC voltage sources of DC Motor. The fuzzy logic controller performance was showed in form simulations with Matlab which have data $E_m = \sqrt{2}$. 220volt, Vdc = 650 volt, $\omega = 2\pi$ x 50 rad/s , R = 0.5 Ω , L = 6 mH, C =1100 μF.

Figure 7 presents the DC voltage of PWM-VSC with fuzzy logic controller. The simulation results showed the DC voltage has a ripple equal to 0.35% without overshoot as well [7] generate a DC voltage without overshoot for fuzzy logic controller and have the overshoot for the PI Controller. Observations were also performed on the network side, voltage and current have the same phase, has a power factor close to unity (Pf = 0.9984) and has a sinusoidal current waveform. THD value of current equal to 3.844%, whereas in [6] THD value is > 4 % and has network current not sine. Current and voltage waveforms are shown in Figure 8.

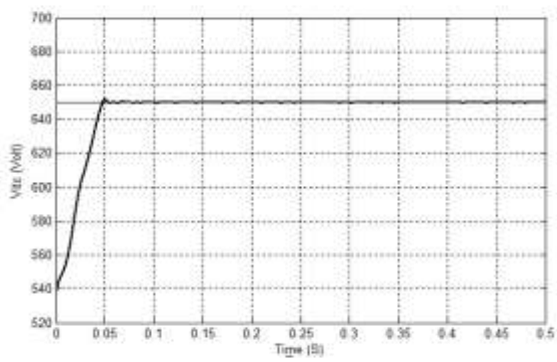

Figure 7. The DC Voltage source for DC Motor

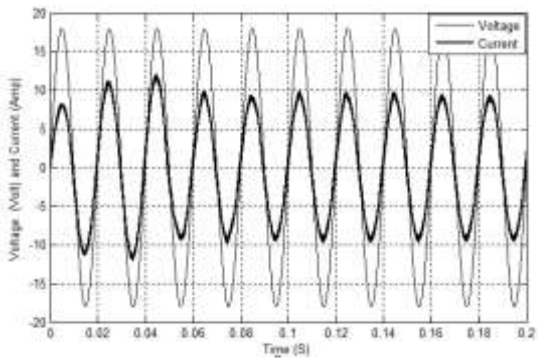

Figure 8. demonstrates the grid phase voltage and network phasa current

Figure 9 shows the results simulations of error of DC voltage vs time response. Simulation results showed stable DC voltage at t = 0.05 Sec. The simulation ouput of the speed of the DC Motor vs time response is in Figure 10. The perfomance of the speed showed stable at time 0.1 seconds.

In this simulation, we observed the motor's behavior by varying the values of the DC Voltage. Figure 11 demonstrates under various values of the DC voltage without overshoot, not so [9] changes the DC voltage value causing overshoot. In Figure 12 shows speed variation of the DC Motor vs time response for voltage variation in Figure 11 and denotes the stability of speed of the DC Motor. In this condition THD = 4.241, Pf = 0.998.

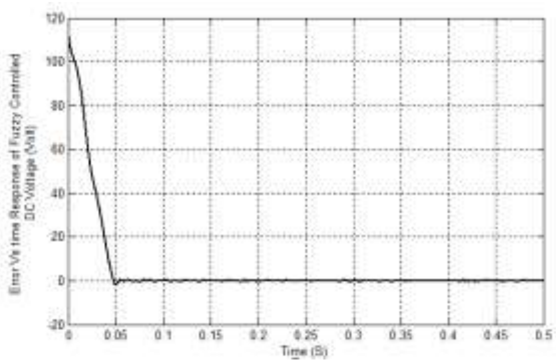

Figure 9. Error of DC voltage vs Time Response with Fuzzy Logic

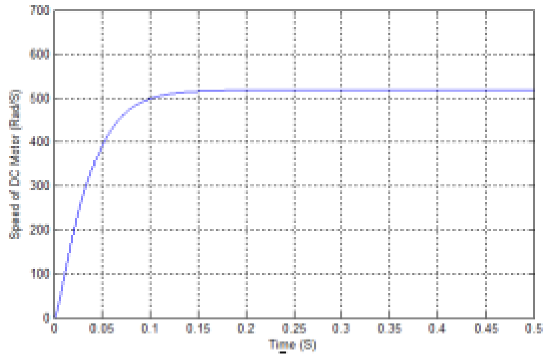

Figure 10. Speed vs Time Response of DC Motor

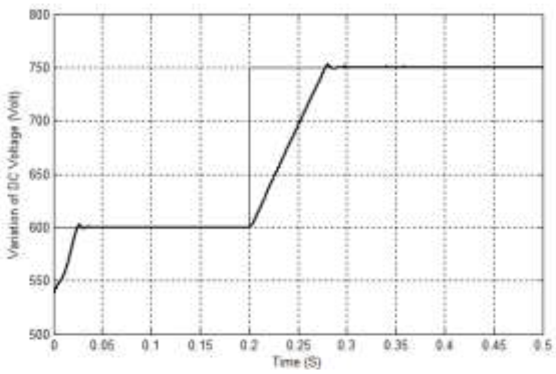

Figure 11. Voltage variation of the DC Voltage vs Time response

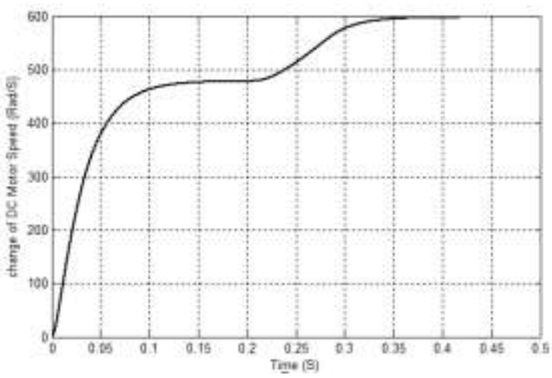

Figure 12. Speed variation of the DC Motor vs Time Response for voltage variation in Figure 11

4. CONCLUSION

The steady state operation and its various DC voltage, network harmonics and power factor, and various torque-speeds of DC motor are studied. This project introduces a design methode of two inputs and one output fuzzy controller and make use of MATLAB fuzzy toolbox to design fuzzy controller. The simulation result showed stable DC voltage without ripple, overshoot and steady state at 0.05 second. THD less than 5 % and a power factor close to unity. Speed of DC motor showed stable and no oscillations.

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