Doubly Fed Induction Motor Supplied Via a Three Level Three Phase Voltage Source Inverter

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ABSTRACT: *The essay evaluates the modeling, control and analysis of a doubly-fed induction machine (DFIM) using a three level three stage voltage source inverter known as voltage source converter (VSC). VSC is utilized to control the extent and period of the rotor voltage in a proficient way and can consequently be used to control the dynamic and receptive force of the doubly fed induction machine. The stator circuit of the DFIM may either be supplied by a variable recurrence VSC or straightforwardly from the a.c. system. Both cases are exhibited and analyzed. Distinctive torque and rate control strategies could be examined with the goal of wiping out the back electromotive power (EMF), which adversely affects the rotor current often considered as a load disturbance. Similarly, the essay will expound on the system of space vector control of doubly fed induction machine driving a permanent magnet synchronous generator that supplies a three stage a.c. load. The control methodology composed here is attempting to accomplish the utmost reduction of harmonic distortion in the voltage and current generated. The findings were analyzed in Simplorer 7 to demonstrate the adequacy of the proposed strategies for velocity and voltage control of doubly fed induction machine utilizing VSC.*

Keywords: Three Phase Three Level Voltage Source Inverter, Simplorer 7, Space Vector Control, Speed And Voltage Control And Doubly-fed Induction Motor

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1. Introduction

Doubly fed induction machine is typically supplied from both sides through a variable recurrence VSC framework; in this manner fluxes are created by both stator and rotor winding. Relatively, if the rotor supply recurrence is practically equivalent to the supply repetition of the stator, the rotor voltage is likewise tantamount to stator supply voltage and the machine torque is little. The torque control like this allows control of the machine power. The essays present the voltage and speed control methodology for a synchronous generator driven by a doubly-fed induction machine (DFIM) supplied either from both sides, from stator and rotor side or just from rotor side.

The DFIM is an electrical three-stage offbeat machine with open circuited wound rotor supplied using three levels VSC. Since the force conveyed from the stator circuit to the rotor side (slip force) is corresponding to the relative movement between the stator magnetic field and the mechanical rate of the rotor (slip), the energy necessitates a force converter at the rotor-side which handles just a little part of the general framework power [1, 4]. It is useful for both energy creation and high power drive applications. Despite the fact that, this non-direct control approach utilized as a part of a.c. drive frameworks may bring about better execution and security, yet it is likewise extremely touchy to machine parameter varieties and burden unsettling influences. Consequently, utilizing an ordinary PI controller with a variable increase for the generator will bring about an overshoot in the following administration of DFIM. Feeble dismissal of the load disturbance parameter ought to more often than not be tuned in a versatile route since it is hard to set the addition of the controller to conquer this issue of overshoot and load unsettling influences at the same time. In that perspective, to explain this convoluted circumstance, it might be ideal to utilize a PI controller. Ideally, the PI in question is classical since its corresponding and indispensable gains are tuned using a particular strategy to get a steady framework [1, 14].

The three-level neutral point clipped single stage voltage source inverter is a multilevel converter that offers an options approach to scaling down the quantity of series aligned switches. In the three-level VSC, every switch cell ought to withstand half of the dc side voltage. Along these lines, the number of switches to be associated in an arrangement can be decreased. Additionally, the three-level VSC can give a three-stage a.c voltage with a lower consonant contortion as compared to an equal two-level VSC [1, 13]. The paper seeks to present the manner in which the three-level three stage span inverter is elaborated. It is shown that the three-level single stage extension VSC can be considered as the blend of two-level half-connect converters; one half-connect converter creates a controlled positive AC voltage, though the other one produces a controlled negative AC voltage [1, 13].

2. Development of the System Model's Equations and Equivalent Circuit

This section presents a space-phasor domain dynamic model for a symmetrical three-phase electric machinery system represented by a doubly fed induction machine that is used to drive a synchronous generator as shown in figure 1.

2.1 Mathematical Model of a Synchronous Generator

The mathematical model of an a.c generator is obtained using the space vector relations between the voltages and currents of the stator and rotor circuits. The formulation of the state estimation equation for a synchronous generator is based on a mathematical model which represents the synchronous generator in the conditions under study. This model may comprise three stator windings, one field winding, and two damper windings. The model of the synchronous generator considered here in this paper assumes symmetry of stator windings as it is precisely explained in [3].

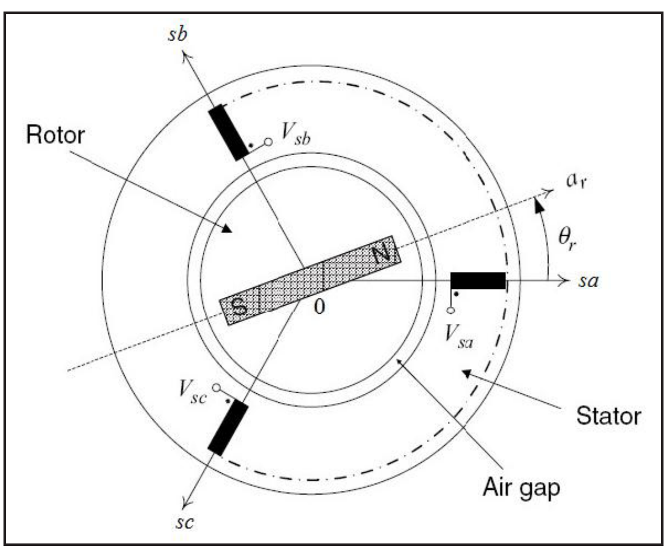

Figure 1. Description of a stator and rotor circuit of a PMSG

2.2 Mathematical Model of an Induction Machine

Figure 4 outlines a streamlined electrical structure of a symmetrical three-stage doubly fed induction machine. The rotor and the stator each has three windings associated in wye. The stator windings are supplied by a three-stage generator from a three level three stage inverter with a consistent voltage at the input. Nonetheless, the rotor windings can be either short circuited or energized from a three phase a.c. system using a three level three stage inverter. The windings of the stator and the rotor circuit shape a three stage adjusted framework, as it is characterized by the balanced structures, the voltages (streams) of stages b and c slack the voltage (current) of stage a, separately, by - 120^0 and - 240^0. The rotor point, θ, is then characterized as the edge between the magnetic axes of the rotor and stator stage winding. In this manner, as Figure 2 delineates, the rotor stage a, step b, and stage c windings are, separately, situated at θ, θ + 120^0, and θ, + 240^0.

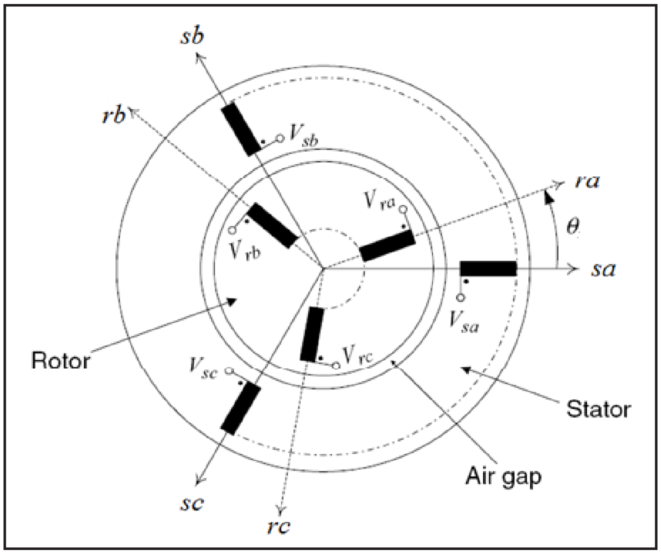

Figure 2. Description of a stator and rotor circuit of a DFIM

Each of the concrete coils of the stator circuit *sa, sb, sc* on that of the rotor circuit *ra, rb* and *rc* has self-inductances *Lss* respective *Lrr* and conventional inductances, Mss between every loop of the stator and another stator connects rep. *M*1, *M*2 and *M*3 between every loop of the stator with each of the three coils of the rotor circuit. The magnetic flux linkages λj with each of the stator and rotor curls *sa, sb, sc, ra, rb* and *rc* are because of its current and the streams in the remaining loops of the stator and rotor circuits. Flux-linkage conditions are in this manner composed in the wake of substituting for every stator and rotor current for each of the six loops as illustrated below:

$$\begin{bmatrix}\lambda_{sa}\\ \lambda_{sb}\\ \lambda_{sc}\\ \lambda_{ra}\\ \lambda_{rb}\\ \lambda_{rc}\end{bmatrix} = \begin{bmatrix} L_{ss}\, M_{ss} M_{ss} M_1 M_2 M_3 \\ M_{ss}\, L_{ss} M_{ss} M_3 M_1 M_2 \\ M_{ss} M_{ss} L_{ss} M_2 M_3 M_1 \\ M_1\, M_2 M_3 L_{rr}\, M_{rr}\, M_{rr} \\ M_3\, M_1 M_2 M_{rr}\, L_{rr}\, M_{rr} \\ M_2\, M_3 M_1 M_{rr}\, M_{rr}\, L_{rr} \end{bmatrix} \begin{bmatrix} i_{sa}\\ i_{sb}\\ i_{sc}\\ i_{ra}\\ i_{rb}\\ i_{rc}\end{bmatrix} \quad (1)$$

The mutual inductances between each of the stator and rotor coils are given as follows:

$$M_1 = M_{sr}\; cos\,\theta,\;\; M_2 = M_{sr}\cos(\theta +\; 120^{\circ}), M_3 =\; M_{sr}\cos(\theta -\; 120^{\circ}) \quad (2)$$

Where M_{sr} is the maximum mutual inductance between a stator winding and a rotor winding occurring at $\theta = \frac{2\pi}{3}$[53].

Multiplying both sides of (2), respectively, by (2/3) e^{j0}, (2/3) $e^{j2\pi/3}$, and (2/3) $e^{j4\pi/3}$, adding the resultants, and employing the definition of the space phasor, it yields:

$$\begin{aligned} \boldsymbol{\lambda_r} &= L_r \boldsymbol{i_r} + L_m e^{-j\theta} \boldsymbol{i_s} \\ \boldsymbol{\lambda_s} &= L_s \boldsymbol{i_s} + L_m e^{j\theta} \boldsymbol{i_r} \end{aligned} \quad (3)$$

L_s and L_r are the stator and rotor inductances, respectively, and L_m is the magnetizing inductance, defined as follows:

$$L_s = L_{ss} - M_{ss},\ L_r = L_{rr} - M_{rr},\ L_m = \left(\frac{2}{3} M_{sr}\right) \quad (4)$$

To develop an equivalent circuit, let's eliminate the terms $e^{-j\theta}$ and $e^{j\theta}$ in eq. 4, using the following transformations known as referring the rotor side to the stator side:

$$f_r' = f_r e^{j\theta} \quad (5)$$

The equations governing the dynamics of a symmetrical three-phase ac machine may be expressed as follows:

$$\begin{aligned} \lambda_s &= L_m\left[(1+\sigma_s)i_s + e^{j\theta_r} i_r\right] \\ \lambda_r &= L_m\left[(1+\sigma_r)i_r + e^{-j\theta_r} i_s\right] \end{aligned} \quad (6)$$

Where the stator and rotor leakage factors σ_s and σ_r are defined as

$$\sigma_s = \frac{L_s}{L_m} - 1,\ \sigma_r = \frac{L_r}{L_m} - 1 \quad (7)$$

The mechanical speed of the machine, ω_r, is related to the machine torque, τ_e, by:

$$J\frac{d\omega_r}{dt} = \tau_e + \tau_{ext} \quad (8)$$

Where τ_{ext} is the torque corresponding to the mechanical load/source that also embeds friction and wind age losses. The machine torque is then given as follows:

$$\tau_e = \frac{3}{2} L_m\ Im\{\boldsymbol{i_s} \boldsymbol{i_r'^*}\} \quad (9)$$

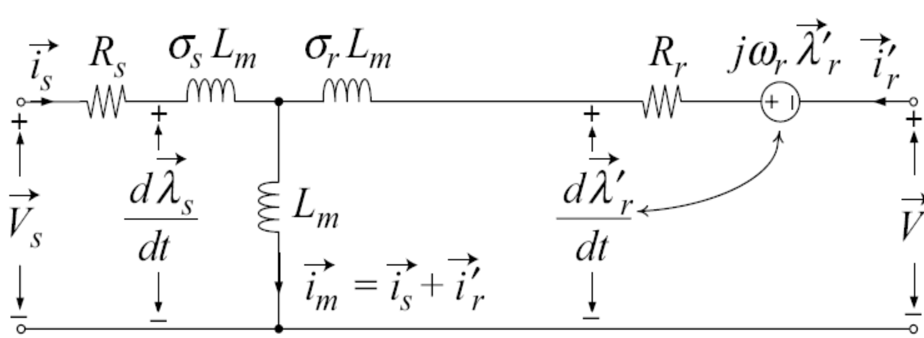

Figure 3. Rotating phasor-domain equivalent circuit of the symmetrical

Based on the above mentioned equations, Figure 3 presents an equivalent circuit for the doubly-fed machine. In the doubly-fed asynchronous machine, in addition to V_s, the rotor, voltage vector V_r' is also controllable. The equivalent circuit of Figure 3 is valid for both dynamic and steady-state conditions.

3. Dynamic and Steady-state Model of a Three Level Three Phase Bridge Voltage Source Inverter (Vsc) with Natural Sampling

The circuit arrangement of the multilevel three stage inverter is often comprised of three modules, known as half scaffold switch cells (phases) as illustrated in Figure 4. Each of these cells is separated into two parts, and the directed dc voltage at the input terminal of the inverter is isolated similarly between the flying capacitors C1, C2 at the input of the inverter. The midpoint nonpartisan, 0, is associated with the multi-level VSC using the clamp diodes D1, D2, D3, D4, D5, and D6. All voltages in Figure 6 are expressed concerning the midpoint neutral. The rule of operation of VSC framework is clarified in [3].

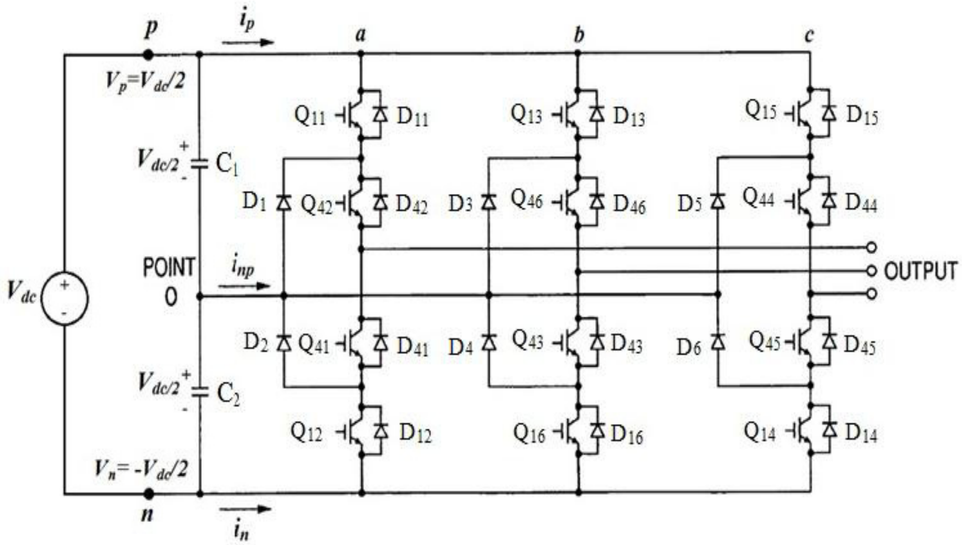

Figure 4. Schematic diagram of the multilevel three phase bridge VSC

4. Control Strategy of Controlled Frequency VSC System for a Doubly Fed Machine

Ideally, this subtitle will introduce the control techniques for the variable-recurrence VSC arrangement of Figure 4 to control a doubly fed asynchronous machine as clarified in [1]. Figure 5 outlines that the machine stator is specifically associated with an AC framework with the ostensible recurrence *ωo*, though the rotor is interfaced with the variable-recurrence VSC framework. The fundamental point of preference of the structure manifests itself when the rotor speed shifts just a couple of rates about the AC system framework recurrence, that is, ω_*r* = ω_*o* ± ω. Under this condition, the proportion of the positive force moving through the rotor circuit to the genuine aggregate power of the machine is corresponding to ω [43]. Consequently, the VSC can be of a littler force rating contrasted with the machine, and the greater part of the force is straightforwardly traded between the machine stator circuit and the AC framework. A practical scenario for the implementation of the system of Figure 9 is the situation of a variable-speed wind-power unit where the extracted wind force can be substantially shifted if the turbine rate is controlled just over a thin range [86, 87]. The wind power can then be controlled (and boosted) by changing *ωr* through the variable-recurrence VSC arrangement of Figure 5 while the VSC handles just a small portion of the aggregate machine power.

The model of a symmetrical three-phase doubly fed ac machine is obtained as follows. Let's express $\overrightarrow{\boldsymbol{\lambda_s}}$ as:

$$\overrightarrow{\boldsymbol{\lambda_s}} = \lambda_s e^{j\theta(t)} \tag{10}$$

Where θ is the angle of the space phasor and a function of time, in general. Defining the change of variable $\theta(t) = \varepsilon(t) + \theta_r(t)$, eq. 10 can be rewritten as:

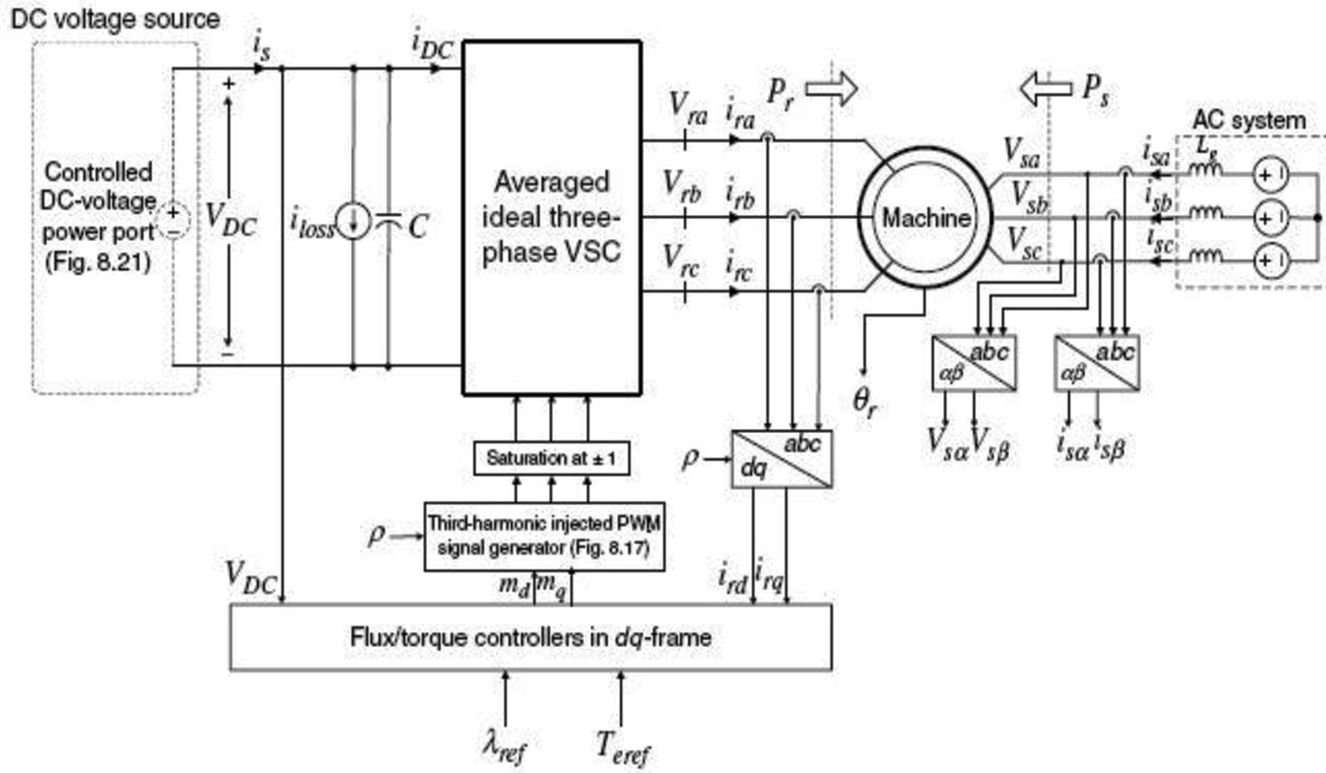

Figure 5. Variable-frequency VSC system used to control the doubly-fed asynchronous machine

$$\overrightarrow{\lambda_s} = \lambda_s e^{j(\varepsilon + \theta_r)} \tag{11}$$

where θ_r is the rotor angle. Substituting for $\overrightarrow{\lambda_s}$ in (11), from (12), and solving for $\overrightarrow{i_s}$, it yields:

$$\overrightarrow{i_s} = \frac{\lambda_s e^{j\varepsilon} - L_m \overrightarrow{i_r}}{(1+\sigma_s)L_m} e^{j\theta_r} \tag{12}$$

After substituting for $\overrightarrow{i_s}$, and $\overrightarrow{i_r} = i_{rd} + j i_{rq}$ and considering $I_m\{\overrightarrow{i_r}\overrightarrow{i_r^*}\} = 0$, it yields:

$$\tau_e = -\frac{3}{2}\frac{1}{1+\sigma_s}\lambda_s i_{rq} \tag{13}$$

Equation 14 indicates that the machine torque can be linearly controlled by *i_rq*, provided that *λ_s* is regulated at a constant value. 9

The diagram of a Flux Observer is illustrated in Figure 6. The Flux Observer on Figure 6 is identical to the other one for the squirrel-cage asynchronous machine. However, it is relatively complicated since calculations of v_sd^'= V_s cos(ω_o t+ θ_o- ε- θ_r) and v_sq^'= V_s sin(ω_o t+ θ_o- ε- θ_r) necessitates abc-frame to dq-frame transformations, on top of the other one that is required for the irabc to irdq transformation.

5. Simulation and Results

A Doubly Fed Induction Motor driving a permanent magnet synchronous generator through a gearbox is simulated by the

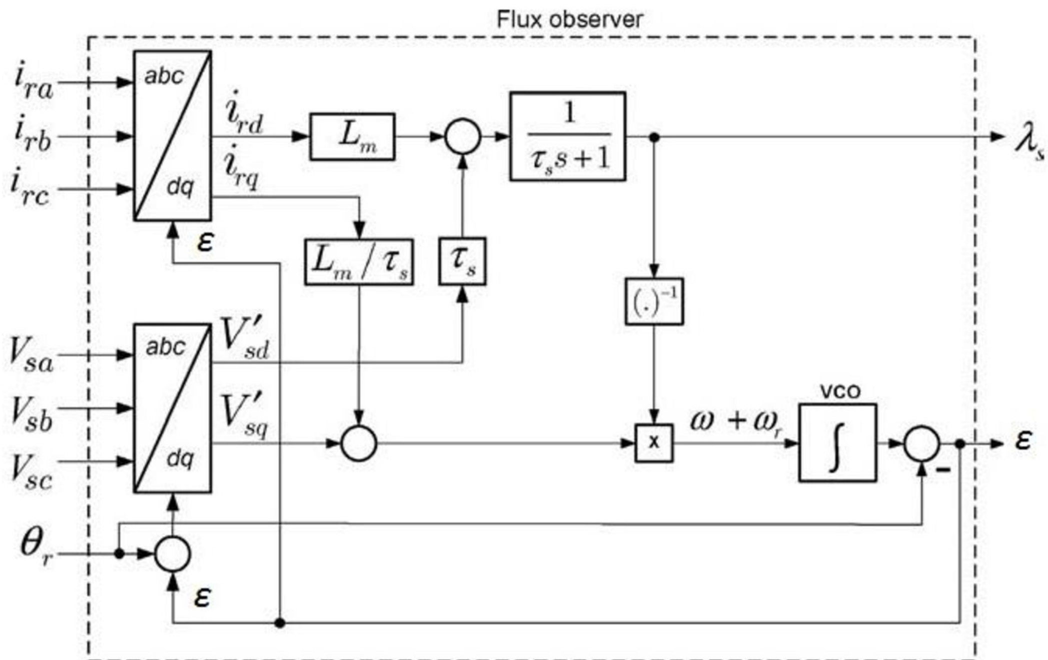

Figure 6. Block diagram of stator-flux model (flux observer) for the doubly-fed asynchronous machine

nature of Simplorer 7 under various working conditions just to study its dynamic qualities and conduct. The stator side of the engine is supplied using a three stage voltage source inverter however its rotor side is provided through a three phase three stage voltage source inverter. Some of the accompanying parameters of the generator are illustrated in Table 1:

Name of a parameter	**Symbol**	**Actual value**
Stator resistance:	R_s	0.439Ω
Stator inductance (direct component):	L_d	50mH
Stator inductance (quadrature component):	L_q	25mH
Number of poles:	p	2
Nominal frequency:	f_n	8Hz
Nominal field e.m.f:	U_p	30V
Zero component resistance:	R_0	925.8mΩ
Zero component inductance:	L_0	0.3mH
Damper resistance:	R_D	6.2Ω
Damper inductance (direct component):	L_D	0.17mH
Damper inductance (quadrature component):	L_Q	0.28mH
Coupling inductance between direct components:	L_{dD}	2.5mΩ
Coupling inductance between quadrature components:	L_{qQ}	2mH

Table 1. Parameters of synchronous generator

At first, the generator supplying an a.c. load representing the a.c. network is subjected to a constant speed of the doubly fed induction motor, N=1200rpm. Using a gearbox with parameters mentioned in table 2 the speed of the generator is almost double that of the motor and the waveforms of the output currents and voltages are then illustrated in Figure 7.

Name of a parameter:	**Symbol**	**Actual value**
Input moment of inertia	J_1	0.54kg.m^2
Output moment of inertia	J_1	0.1kg.m^2
Torsional stiffness	C	1Meg Nm/rad

Table 2. Parameters of Gearbox

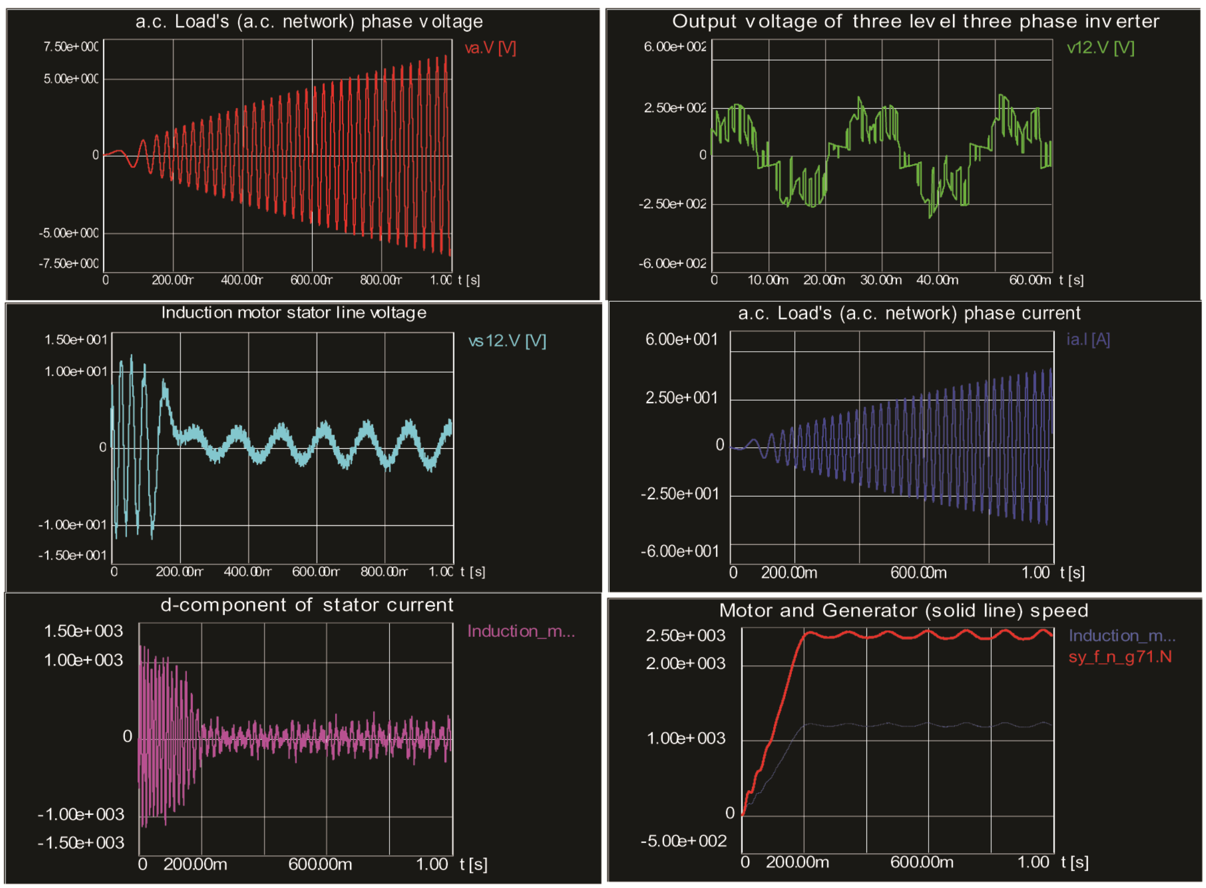

Figure 7. Description of a motor and generator parameters waveforms as both sides of the motor are controlled

Secondly, the dynamic behavior of the motor and the generator is demonstrated for the condition of a stator circuit of the induction motor being supplied directly from the a.c. network with the same voltage as previously. The currents and voltages waveforms are shown in Figure 8.

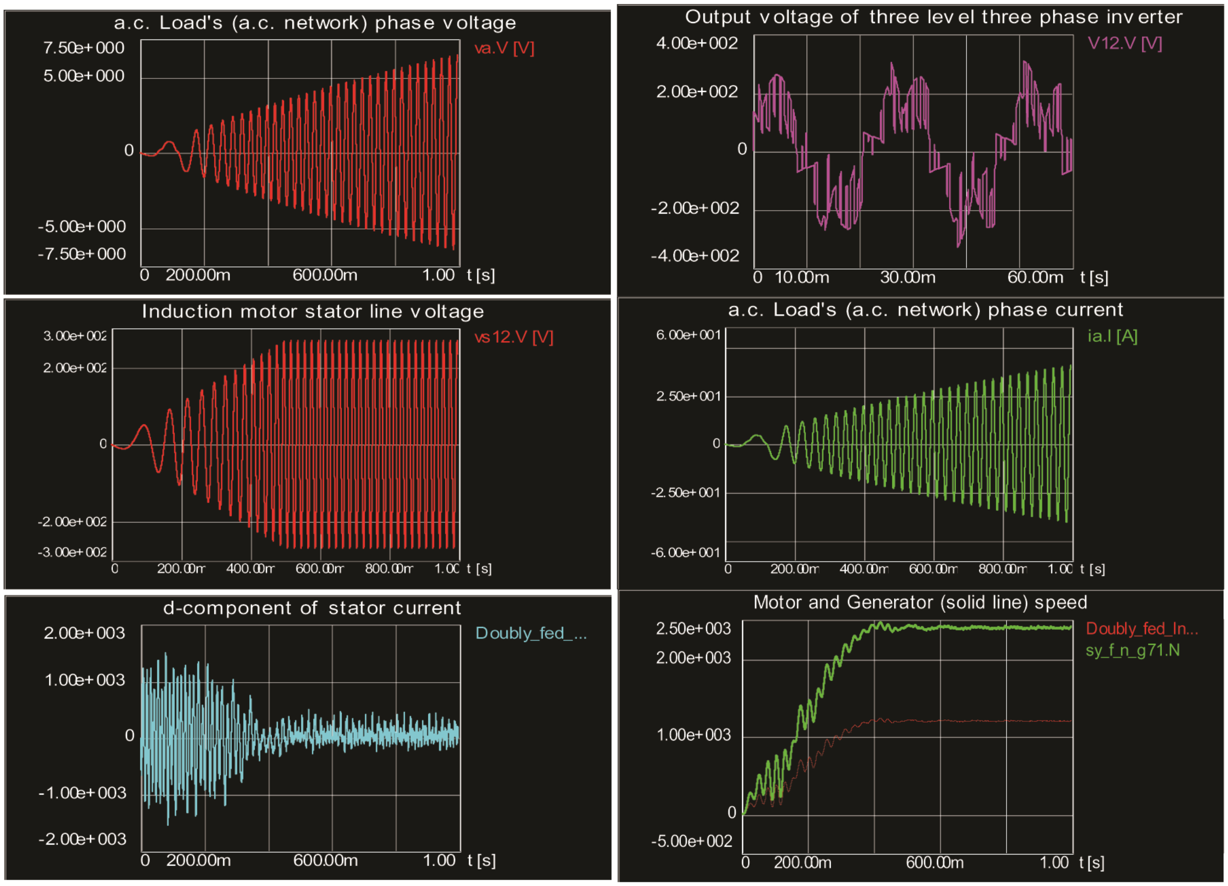

Figure 8. Description of a motor and generator parameters waveforms as only rotor side of the motor is controlled

6. Conclusion

The essay has been advanced to outline the control system of a Doubly Fed Induction Motor and to see the impact of controlling both sides of the engine, stator side and rotor side on the engine speed. With the chance of utilizing quick exchanging strategies, it is relatively easy to control the rotor side effortlessly along these lines showing signs of improvement element execution of the engine. The reproduction results demonstrate the proposed three level three stage inverter which offers great reactions as far as optimizing, little overshoot, and little enduring lapses by a significant element execution. Another point of reference performance is its simple modern application with an intelligent controller and field situated control technique.

Figure. 8 outlines the VSC interface with the machine rotor windings, through the stator windings, are specifically associated with a consistent recurrence A.C. system. The fundamental point of preference is that when a small amount of the machine force is taken care of by VSC and it is proposed for a synchronous generator driven by a Doubly Fed Induction Motor. It is evident that the transient conduct of the engine and generator speed is for this situation all the more wobbling. The proposed exchanging procedure of both the, rotor, and stator side, of the Doubly Fed Induction Motor driving a synchronous generator shows great execution, exhibiting that this switching system is an option arrangement the routine field situated control and gives significant enhancements appreciation to the established control strategy of either side of the engine.

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