Direct Torque Control of Induction Motor Using Seven-Level Cascaded Multilevel Inverter with reduced number of switches

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Abstract: With the headway of energy hardware and computerized advancements charge, a few control structures for the AC machines were proposed, keeping in mind the end goal to get execution indistinguishable to those of the DC machine. Among these structures, the direct torque control has been as of late towards the most critical research and most appropriate to mechanical necessities. direct torque control (DTC) is a control strategy in AC drive drives to acquire elite torque control. The traditional DTC drive contains a couple of hysteresis comparators and experiences variable exchanging recurrence and high torque swell. These issues can be unraveled by utilizing space vector relying upon the reference torque and flux. In this paper the space vector adjustment strategy is connected to the another seven-level cascaed multilevel inverter utilizing 5-switches control in the proposed DTC-based enlistment engine drive framework, coming about to a huge decrease of torque swell. Seven-level fell multilevel inverter have been broadly utilized as a part of medium voltage applications. This sort of inverters have a few points of interest over standard two-level VSI, for example, more noteworthy number of levels in the output voltage waveforms, less consonant twisting in voltage and current waveforms and lower exchanging frequencies. This paper underscores the inference of exchanging states utilizing the Space Vector Pulse Width Modulation (SVPWM) procedure. The control plan is actualized utilizing MATLAB/SIMULINK Tool.

Keywords-component - Direct Torque Control; Space Vector Pulse Width Modulation (SVPWM).

I INTRODUCTION

The direct torque control (DTC) method has emerged as an alternative to Field Oriented Control (FOC) method for high performance ac drives since it was firstly proposed in the mid- 1980 [1], [2]. The merits of DTC are fast torque response, simple structure (no need of complicated coordinate transformation, current regulation or modulation block), and robustness against motor parameter variation [3-7]. On the other hand, multi-level inverters have become a very attractive solution for high power application areas [8-11]. The seven-level cascaded multilevel inverter is one of the most commonly used multi-level inverter topologies in high power ac drives. By comparing to the standard two-level inverter, the seven-level inverter presents its superiority in terms of lower stress across the semiconductors, lower voltage distortion, less harmonic content and lower switching frequency [12]. Due to the above mentioned merits, the seven-level inverter fed DTC motor drive has become an important research topic in research and academic community over the past decade [13-14]. A variety of techniques have been proposed to overcome some of the drawbacks present in DTC. Some solution proposed are: DTC with

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the Space Vector Pulse Width Modulation (SVPWM) ; the use of a duty-ratio controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors; use of artificial intelligence techniques, such as neuro-fuzzy controller with SVPWM. However, the complexity of the control is considerably increased.

Among various modulation techniques for a multi-level inverter, SVPWM is an attractive candidate due to the following merits. It directly uses the control variable given by the control system and identifies each switching vector as a point in complex space. It is suitable for Digital Signal Processor (DSP) implementation and able to optimize switching sequences.

In this paper, Direct Torque Control-Space Vector Modulation (DTC-SVM) with seven-level cascaded multilevel inverter voltage source inverter is investigated. The proposed scheme is described clearly. Simulation results are reported to demonstrate its effectiveness. The entire control scheme is implemented using MATLAB/SIMULINK tool.

II. INDUCTION MOTOR MODEL

The dynamic model of an induction motor in the stationary reference frame can be written in d-q frame variables. Stator voltage Vector V_s of the motor can be expressed as follows:

$$Vds = \left(d\psi * \frac{ds}{dt}\right) + (Rs * Ids) \quad (1)$$

$$Vqs = \left(d\psi * \frac{ds}{dt}\right) + (Rs * Iqs) \quad (2)$$

$$\psi s = \left(d\frac{\psi s}{dt}\right) + (Rs * Is) \quad (3)$$

The stator flux vector ψs and components can be written as:

$$\Psi ds = Ls * Ids + Lm * Idr \quad (4)$$

$$\Psi qs = Ls * Iqs + Lm * Iqr \quad (5)$$

$$\Psi s = Ls * Is + Lm * Ir \quad (6)$$

The rotor flux vector ψr and components in the stator reference frame is

$$\psi dr = Lr * Idr + Lm * Ids \quad (7)$$

$$\psi qr = Lr * Iqr + Lm * Iqs \quad (8)$$

$$\psi r = Lr * Ir + Lm * Is \quad (9)$$

where Vds and Vqs are the stator voltages; Ids and Iqs are the stator currents; Idr and Iqr are the rotor currents; Ψds and Ψqs are the stator fluxes; ψdr and ψqr are the rotor fluxes; Is and Ir are the stator and rotor currents vectors; Rs is the stator winding resistance., and Ls , Lr, Lm are stator, rotor self inductance and mutual inductance respectively. The electromagnetic torque Te developed by the induction motor in terms of stator and rotor flux vectors can be expressed as:

$$Te = 3/2 * p(Lm/\sigma LsLr)\ \psi s * \psi r$$

$$Te = 3/2 * p(Lm/\sigma LsLr)\ |\psi s| * |\psi r|\ \sin(\delta) \quad (10)$$

Where $\sigma = 1 - (Lm\hat{}2/Ls * Lr)$ is the leakage factor; p is the number of pole pairs and δ is the torque angle. From the above equation, clearly, the electromagnetic torque is cross vector product between the stator and rotor flux vectors. Therefore, generally torque control can be performed by controlling torque angle δ with constant amplitude of the stator and rotor fluxes. An induction motor model is then used to predict the voltage required to drive the torque and flux to the reference values within a fixed time period. The required voltage is synthesized using space vector modulation. If the inverter is not capable of generating the required voltage, a voltage vector that will drive the torque and flux towards the reference values is used. These above fundamental equations with other equations and SVPWM switching states are used for implementing DTC using SVPWM in three-phase induction motor. A block diagram of this configuration is shown in Fig 1.

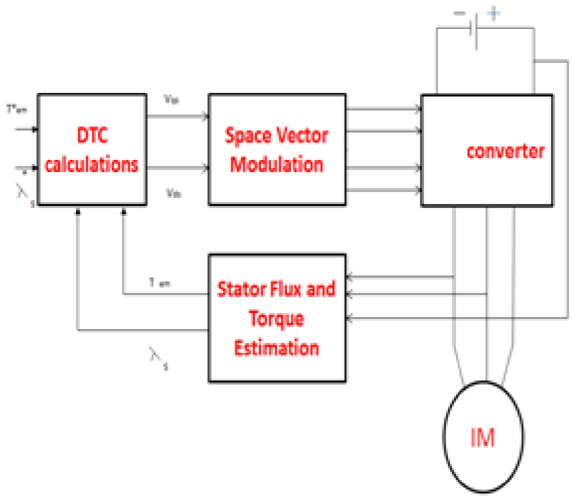


Fig 1. DTC using space vector modulation block diagram

III GENERATION OF SPACE VECTOR PWM SIGNALS FOR CASCADED INVERTER

An alternative PWM method is the Space Vector Modulation (SVPWM). This modulation method presents important advantages compared with PWM modulation. As it was seen before, PWM modulation calculates the multilevel converter switching configurations automatically. In fact, it is an automatic method that completely marks the switching of the converter and there is no any freedom degree and the control algorithm has not the possibility of changing for instance the order of the switching configurations in the switching sequence. So, there is no freedom in order to improve some characteristics of the converter as balancing of DC-link capacitors, harmonic content, load currents ripple,…etc. In front of this fact, SVPWM modulation calculates the switching configurations and chooses their order into the switching sequence. Besides, SVPWM modulation introduces the concept of the “redundant vectors” and their important contribution to the converter control. First of all, the State Vectors Space of a converter is going to be introduced to present this modulation method.

It is easy to determine the state vectors space for N-level cascaded multilevel inverter and it is shown in Fig 2. It is clear that increasing the number of levels, new and concentric hexagons appear. Besides, the redundancy of the vectors increases if the state vectors are close to the origin. Increasing the number of levels in the cascaded multilevel inverter , the number of triangular sectors that compose the total control region increases and the search for the three nearest state vectors increases its difficulty. Several generalized modulation algorithms for multilevel converters have been recently proposed. The proposed method was based on the decision-based pulse width modulation. Modulation algorithm has two different tasks. The first one is to identify the three nearest state vectors to the reference vector. After that, the modulation algorithm has to calculate each state vector duty cycle.

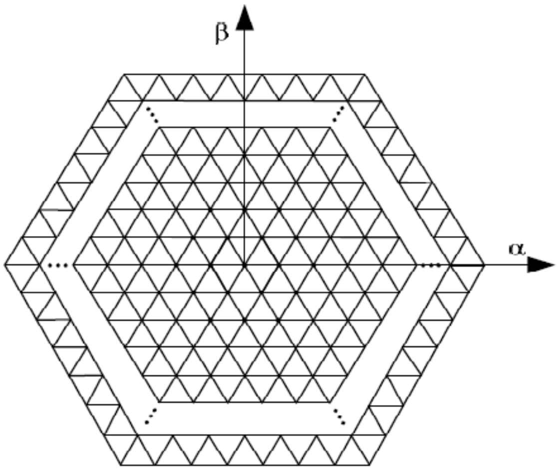


Fig 2. State vectors space for N-level cascaded multilevel inverter

One of the most important contributions is that the normalized reference voltage vector u^* is transformed into u_{flat} scaling u^* imaginary part and multiplying it by $1/\sqrt{3}$. The modulation algorithm input is the normalized reference voltage vector. The normalization depends on the number of levels of the multilevel converter and the voltage level value of the DC-link capacitors. Using the proposed transformation, multilevel converter state vectors space is flattened. The state vectors space after the transformation is a hexagon where all the sectors are separated by 45º lines. This property is very useful due to the fact that the modulation algorithm can easily find out the triangular sector where u_{flat} is pointing to by comparing their real and imaginary parts. This transformation drastically reduces the modulation algorithm computational cost doing it very fast and efficient. The state vectors space before and after the transformation is shown in Fig 3.

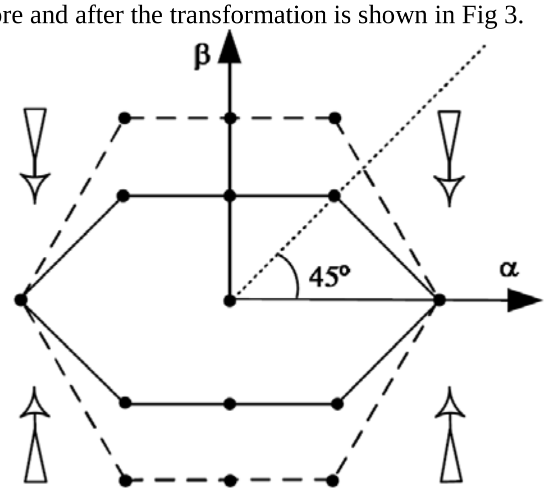


Fig 3. The State vectors space before and after the transformation

The state vectors space is flattened multiplying by $1/\sqrt{3}$ the imaginary part of the reference vector making the search for the nearest state vectors very simple and fast. The first problem is solved for the reference vector in the first sextant. However, this reference vector can be located in any of the six sectors of the regular hexagon which contain the switching state vectors. This problem was solved rotating the reference vector anti-clockwise by an angle $(n-1)\pi/3$, where n is the sextant number, $n = 1,\ldots 6$. This rotation displaces any reference vector to the first sextant to be studied there. This algorithm clearly improves the results of previous modulation algorithms due to the fact that its simplicity is very high. Nevertheless, there are several "complex" operations as the rotation to the first sextant and the inverse rotation to obtain the final switching sequence and the final on-state durations. In order to eliminate these complex operations, a new and faster modulation algorithm was proposed in. On the same way, the state vectors space is flattened in order to achieve 45º lines but online calculations are reduced due to the fact that the modulation algorithm implies only very simple calculations. The modulation algorithm obtains the switching sequence and the duty cycles in the simplest way. This modulation algorithm based on geometrical considerations. One N-level state vectors space sector is shown in Fig 4. Each state vector is represented using the expression $\{x, y, z\}$. For example, if it is considered the state vector $\{320\}$, that means that x=3 (phase a state is 3), y=2 (phase b state is 2) and z=0 (phase c state is 0). It can be easily determined x graphical, y can be calculated limiting vertically the region where the reference vector is pointing to. Thus, every reference vector located in this state vectors space sector fulfils that z component is always zero.

x = integer $(u_{\alpha n} + u_{\beta n})$

y=integer $(2u_{\beta n})$

z=0

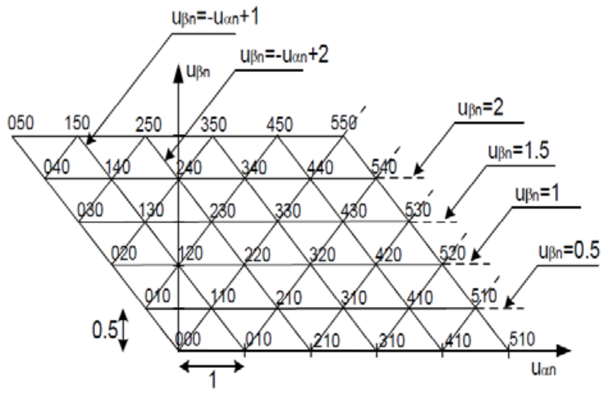


Fig 4. N-level state vectors space sector

Once x, y and z are determined, it is known that the reference voltage is pointing to a sub-region in this sector Fig 5. Shows a generic sub-region in zone 1. This sub-region is divided in two different triangles.

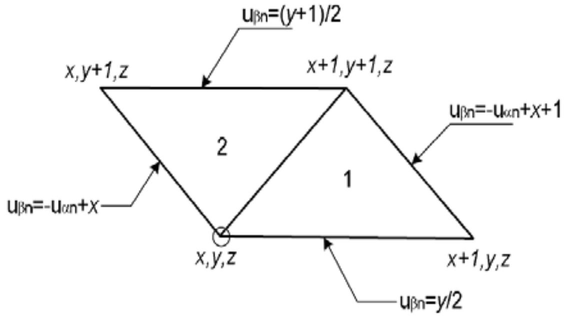


Fig 5. Sub-region of N-level state vectors space

It is necessary to know which is the triangle where the reference vector is found to determine the other states and the switching times. The condition that the reference vector should fulfill to be found in triangle number one is:

$$u_{\alpha n} < u_{\beta n} + y - x \longrightarrow u_{\beta n} - u_{\alpha n} < (y - x) \quad (11)$$

It must be noticed that this modulation algorithm drastically reduces the online calculations due to the fact that the search for the nearest state vectors implies only very simple calculations. The modulation algorithm obtains the switching sequence and the duty cycles in the simplest way. In below shows the switching sequence of svpwm for single space.

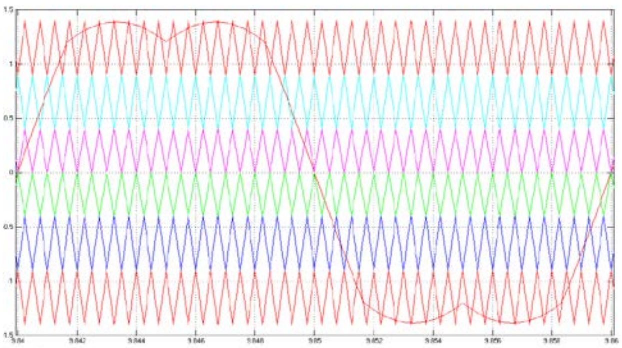


Fig 6: switching sequence of svpwm for single space.

IV. THE CASCADED MULTILEVEL INVERTER

The five switch 7 level MLI topology is shown in Fig. 7 is about redesigning of existing 12-switch topology eliminating 5 switch attaining the tag of 5 switch configuration. The circuit thus obtained is the simplest design compared to conventional and all other existing topologies. It consists of four dc sources of 7 levels, for 9-level, 5 dc sources and so on. Generalised expression for output voltage levels for the new topology proposed is $m = (2n-3)$, where m = number of output voltage levels, n = number of switches $m = (2\text{ V} - 1)$, where V = number of dc sources. The design of pulse generation circuit makes the topology differ from others so as to obtain the unique pulse pattern to trigger the switches at the proper instant. Switches $S1$, $S2$, and $S3$ need to be compulsorily unidirectional or else the output waveform will get distorted. Reduced switches make the circuit compact and user-friendly. Though the usage of 4 dc sources for the generation of 7-level MLI results in less utilisation of sources, switch reduction benefits in low switching losses. No H-Bridge is used. Just 2 switches play the role of polarity reversal. Table. 1 represent the switching scheme for the proposed topology

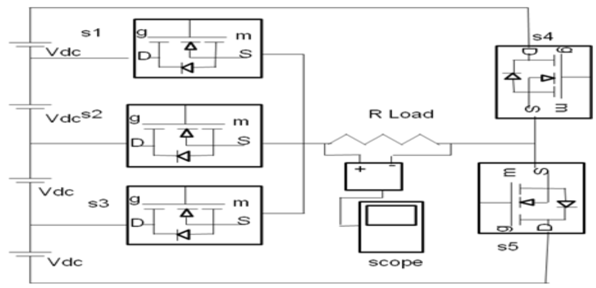


Fig. 7 Proposed Power circuit for 7-level output .

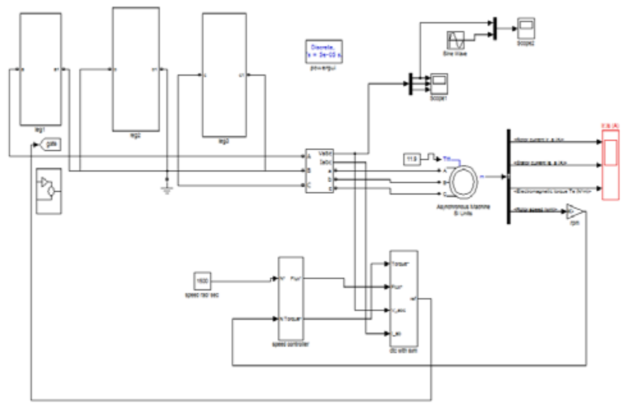
The pulse generation signal comparing with carrier generating pulse which is then modified feeding to logic gates in order to get the required pattern to trigger the switches at the proper instant. For examples switches $S1$ needs to have a pulse so as to obtain $+V$dc and $-3V$dc and $S2$ requires $+2V$dc and $-2V$dc. $S3$ conducts $+3V$dc and $-V$dc. Also, switches $S5$ and $S4$ conduct positive and negative half cycles, respectively.

The overall efficiency of converter is dependent on the number of switches involved in producing each voltage levels. In a seven-level cascaded topology ten switches conduct the inverter current at every instance. However, in the proposed topology the number of switches which conduct current ranges from three switches (for generating level 7) to five switches conducting for other level, while two of the switches are from polarity generator of the inverter. Therefore, the number of switches that conduct current in the proposed topology is lower than that of the cascaded inverter that reduces the switching losses and hence it has a better efficiency Fig.9 and Fig.10 show simulation results of output voltage waveform and THD content of proposed 5 switch 7- level multilevel inverter respectively.

Table.1 Switching Scheme for 7 level 5 switch topology

Output Voltage	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**
Vdc	0	0	1	0	1
2 Vdc	0	1	0	0	1
3 Vdc	1	0	0	0	1
0 Vdc	0	0	0	0	0
-Vdc	1	0	0	1	0

-2Vdc	0	1	0	1	0
-3 Vdc	0	0	1	1	0



The five switch 7 level three phase MLI with direct torque control of induction motor simulation figure shown in figure 8.

V. SIMULATION RESULT

To illustrate the effectiveness, the operation of three phase Direct Torque Control (DTC) of induction motor using cascaded multilevel inverter with reference torque twelve was simulated using MATLAB SIMULINK tool and simulation results are shown in following figure.

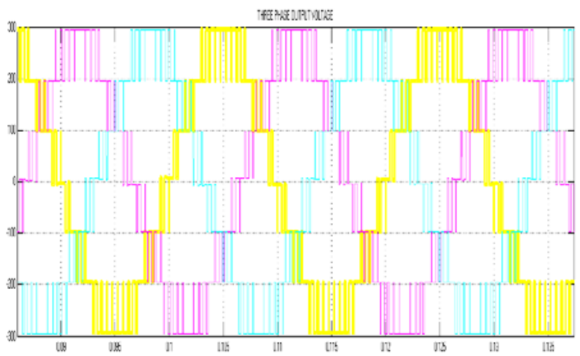


Fig 9. Inverter output voltage

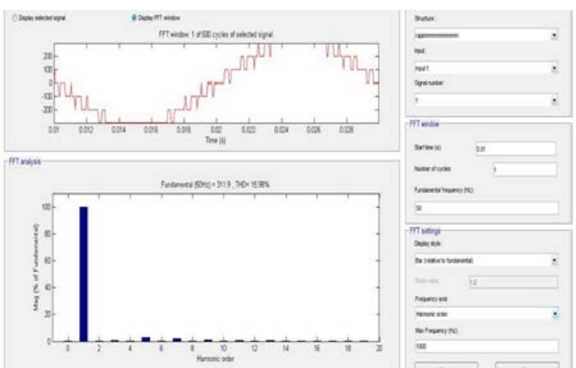


Fig.10 Harmonic Spectrum for Output voltage of seven level inverter

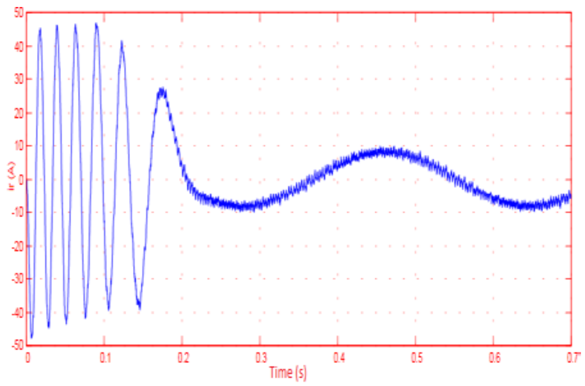


Fig 11. Rotor current

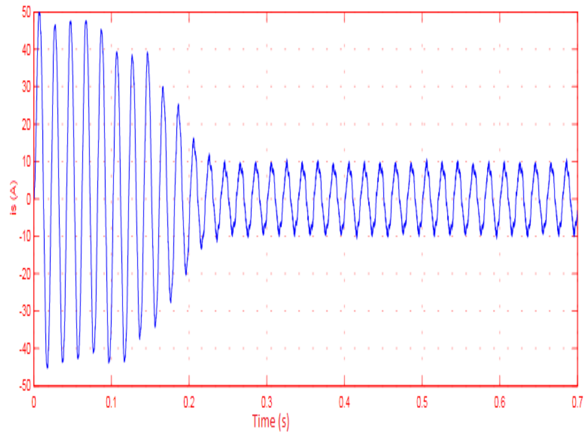


Fig 12. Stator current

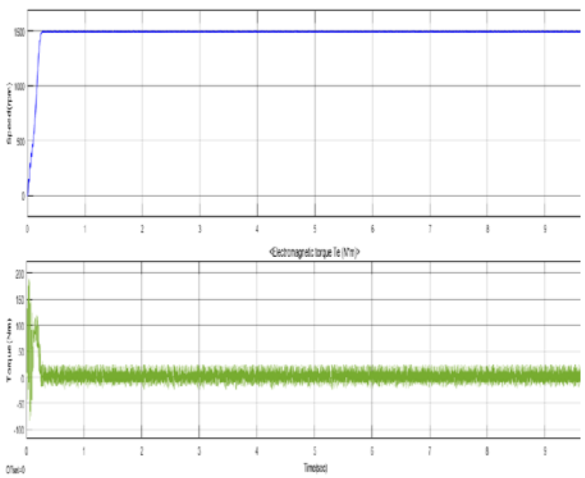


Fig 13.Speed and Troque

VI CONCLUSION

This paper has reviewed different DTC strategies for PWM inverter-fed AC motor drives. The DTC represents a viable alternative to FOC, another general philosophy for controlling AC drives. The main features of DTC can be summarized as follows:

•According to adopted definition, DTC operates with closed torque and flux loops but without current controllers

•DTC needs stator flux and torque estimation and therefore, is not sensitive to rotor parameters

•DTC has fast dynamic response

•DTC has simple and robust control structure.

In this paper, a new topology 5 switches are introduced and the same 7-level output is observed in either of the cases and shows the performance result of induction motor. Circuits are simulated using MATLAB/SIMULINK software and total harmonic distortions are obtained. It can be seen that the 5-switch topology is better than other presented topology because it requires a lesser number of switch and also THD content is lower in comparison with other mentioned topology.

APPENDIX

Simulation Parameters of Induction Motor Rating (Referred to Stator):

Table 2

Parameter	**Value**
Power	1.5 kW
Voltage (L-L)	415 V
Current	2.6 A
Frequency	50 Hz
Rated Torque	10 Nm
Speed	1415 rpm
Stator Resistance (Rs)	0.55 Ω
Rotor Resistance (Rr)	0.78 Ω
Stator Leakage Inductance (Lls)	0.00288H
Rotor Leakage Inductance (Llr)	0.00286H
Mutual Inductance between Stator and rotor (Lm)	0.0905H
Moment of Inertia (J)	0.019Kg-m2
Number of poles	4

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