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SIMULATION OF AN INDUCTION MOTOR DRIVEN BY A MODULAR MULTILEVEL CASCADED INVERTER WITHOUT SPEED SENSOR WITH FUZZY CONTROLLER

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ABSTRACT-The main aim of this document is to validate the effectiveness and practicability of a speed-sensor less start-up process meant for a DSCC based induction motor drive, in which the motor-poweredtwitches rotate as of halt to mid speed by a slope change. This motor drive is apt mainly for a large-capacity fan- or blower-like load. The load torque is proportionate to a square of the motor mechanical speed. Here we are with the fuzzy regulatorrelate to other controller i.e. the fuzzy regulator is the utmost appropriate for the human decision-making means, run the function of an electronic arrangement with result of expert. The start-up method is characterized by combining capacitor-voltage control in the company of motor-speed control. The motor-speed control by the minimal stator current plays a vital role in eliminating a speed sensor from the drive structure and in dropping an ac voltage fluctuation happening across every dc capacitor. Numerous start-up waveforms illustrate steadypresentation from stop to mid speed with dissimilar load torques. By means of the fuzzy Regulator for a nonlinear system permit for a decrease of indecisive special effects in the system control and progress the effectiveness. By means of the simulation outcomes we can verify that the motor-speed regulatorplanned for the DSCC-based drive system.

Index Terms—Medium-voltage induction motor drives, minimal stator current, modular multilevel cascade inverters, speed sensor less start-up method, Fuzzy logic controller.

I.INTRODUCTION.

A modular multilevel cascade inverter base on twofold star chopper cell (MMCI-DSCC) has been estimated as one of the next-generation medium-voltage multilevel pulse width modulation (PWM) inverters for such speed drive. The motor-speed control makes it achievable to remove a speed sensor from the drive system and to diminish the ac-voltage oscillation in all frequency arrays.

The motorspeed control makes it achievable to abolish a speed sensor from the drive system and to alleviate the ac voltage oscillation in all frequency range.This motor-speed control relies on a correspondent circuit of an induction motor, which was anticipated.By means of this document is to validate the efficiency and achievability of a speed-sensor less start-up scheme for a DSCC based induction motor drive, in which the motor starts revolving from standstill to middle speed with a slope alteration. For the sake of ease, the MMCI-DSCC is referred to as the "DSCC" in this thesis.Every support ofDSCC consists of two up and about and off-putting arms and a center-tapped inductor sit among the two arms. Each arm consists of manifold bidirectional dc/dc choppers call as "chopper cells." The low voltage side of the chopper cells is associated in cascade, whereas the electrically balanced high-voltage side of chopper cells is outfitted by means of a dc capacitor and a voltage sensor.

As soon as a DSCC is applied to an ac motor drive, the DSCC would endure from ac-voltage fluctuations in the dc-capacitor voltages of every chopper cell in a low-speed assortment, because the ac-voltage oscillation gets more severe as a stator-current frequency gets lesser. Therefore, theoscillation must be attenuated acceptably to attain firm low-speed along with start-up performance.

This outcome in producing a reduced motor torque. A severe ac-voltage oscillation in a low-speedrange can be mitigated by inserting a common-mode voltage along with superimposing a circulating current on each leg of the DSCC. in general, it is advantageous to remove a speed sensor from a motor drive, especially when a motor drive is introduced to a unfriendly surroundings, as soon as a new DSCC is applied to an already-existing line-started motor with no speed sensor, or as a lengthy lead cable is essential to fix a new DSCC by way of a new motor.

CASE STUDY OF PROPOSED THEORY CIRCUIT CONFIGURATION AND CAPACITOR VOLTAGE CONTROL OF THE DSCC

A. Circuit Configuration

Fig.1 (a)demonstrates the major circuit configuration of the DSCC discussed in this thesis.

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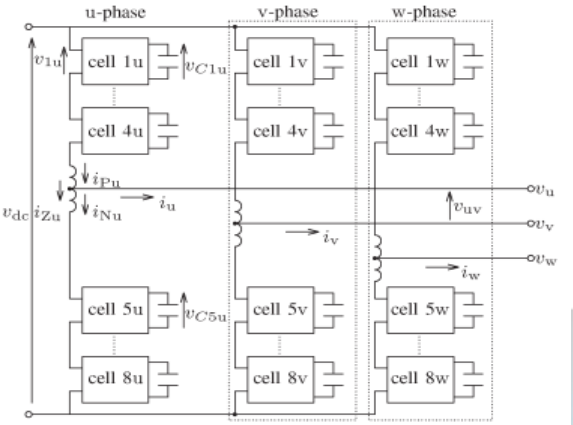
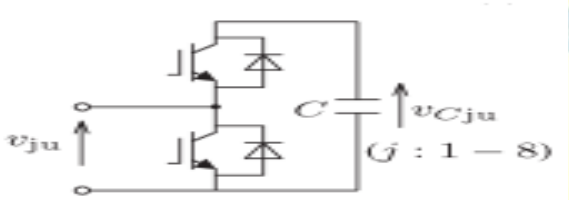
Every leg comprises of eight cascaded bidirectional chopper cells given away in Fig. 1(b) and a center tapped inductor per phase, as exposed in Fig. 1(c).

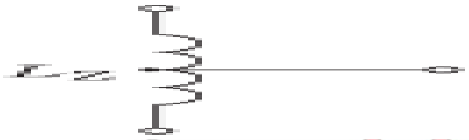


(a)

Fig. 1. Circuit configuration used for an MMCI-DSCC. (a) Power circuit.



(b)



(c)

Fig. 1. Circuit design for an MMCI-DSCC. (a) Control circuit. (b) Chopper cell. (c) Center-tapped inductor.

The middle tap of each inductor is coupled straight to each of the stator terminals of an induction motor; everywhere iuis the u-phase stator current. The center-tapped inductor is extra price efficient than two noncoupled inductors for each leg, as the centertapped inductor present inductance LZ merely to the circulating currentiZand no inductance to the stator currentiu. This compensation in the center-tapped inductor is generally welcomed, for the greatest part applications to motor drives, in which no ac inductors be necessary connecting the motor along by means of the inverter. In Fig. 1, instantaneous currents iPu and INu are the u-phase positive and negative-arm currents, correspondingly, and iZu is the u-phase circulating current define as follows:

$$i_{Zu} \triangleq \frac{1}{2}(i_{Pu} + i_{Nu}) \quad (1)$$

The individual ac components incorporated in the three-phase circulating currents˜iZu,˜iZv, and˜iZwrevoke each other out, so that no ac component appear in either motor current or dc-link current.

The arm currentsiPu and iNucan express as linear function of binaryself-governing variables iu and iZu as surveys:

$$i_{Pu} = \frac{i_u}{2} + i_{Zu}(2)$$

$$i_{Nu} = -\frac{i_u}{2} + i_{Zu} \quad (3)$$

The dc-capacitor voltage in every chopper cell comprises of dc and ac components cause an ac-voltage oscillation. When neither common-mode voltage nor ac circulating current is superimpose, the peak-to-peak ac-voltage flux ΔvCju is approximated as follows:

$$\Delta v_{Cju} \cong \frac{\sqrt{2}I_1}{4\pi f C} \quad (4)$$

WhereI1 is the rms value of the stator current, f is the frequency of the stator current, andCis the capacitance value of every dc capacitor. According toward ΔvCju is inversely proportional tof as well as proportional toI1. Therefore, ΔvCjurises as the stator-current frequency declines. [6] presented a short overview on widely used microwave and RF applications and the denomination of frequency bands. The chapter start outs with an illustrative case on wave propagation which will introduce fundamental aspects of high frequency technology.

- It disturbs the voltage rating of insulated-gate bipolar transistors.
- It origins moremodulation to every chopper cell.
- It makes the arrangement unbalanced because the ac-voltage fluctuation can be considered as an interruption to the control system. As a result, the ac-voltage oscillation should be mitigated to an appropriate stage.

B. Capacitor-Voltage Control

Fig. 2 illustrates the over-allcontroller block figure of the startup process.

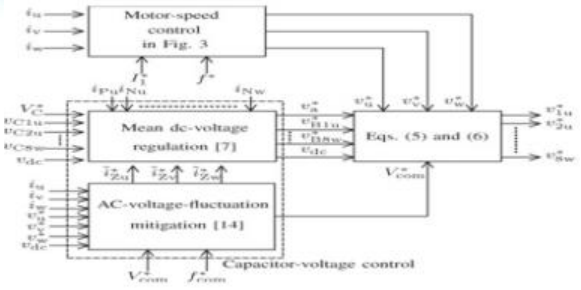


Fig. 2.Overall control block diagram for the start-up method.

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This thesis employs two kinds of accessible capacitor-voltage control techniques for amendablemean dc voltage of every dc capacitor and for extenuating the ac-voltage fluctuation at the stator-current frequency.The mean dc-voltage regulation can be achieved by using the "arm" balancing control applied to the six arms and the "individual" balancing control applied to the one arm at the similar instance. This is able to diminish the acvoltage oscillation at the stator-current frequency, hence leading to start up from standstill. The circulating-current response control incorporated in the mean dcvoltage parameter block yields a command voltage of v ∗ A

Lastly, commandu-phase voltages for every chopper cell, i.e., v ∗ju, are known as follows:

$$v_{ju}^{*} = v_{a}^{*} + v_{Bju}^{*} - \frac{v_{u}^{*}+v_{com}^{*}}{4} + \frac{v_{dc}}{8}(j = 1-4) \quad (5)$$

$$v_{ju}^{*} = v_{a}^{*} + v_{Bju}^{*} + \frac{v_{u}^{*}+v_{com}^{*}}{4} + \frac{v_{dc}}{8}(j = 5-8) \quad (6)$$

Now v∗a and v∗Bju are used to control the mean dc voltage, v∗u is the command motor voltage given by Fig. 3 described in the later section,v∗com is the command common-mode voltage, andvdcis the dc-link voltage use as feedforward control. In addition, here is no association connecting common-mode voltage and powerevaluation of the motor. This manuscript switches over the two capacitor-voltage control techniques according to the stator-current frequency as follows.

C.MOTOR-SPEEDCONTROL

This segment describes a motor-speed control forming a feedback loop of three-phase stator currents for achieving a steady start-up of an induction motor. Primary, the motor-speed control is discussed in conditions of an appearance and purpose. Next, it is compared with conventional motor-speed control techniques,i.e., "volts-per-hertz" and "slip-frequency" control techniques.

A. Control Principles

The motor-speed control forms a feedback loop of threephase stator currents to realize a stable establishes from *idle*. This requires the current sensors attach to the ac terminal. The stator current in single phase is considered by the parallel arm currents detected. For that reason, no further current sensor is essential. Fig. 3 shows the block figure designed for the motor-speed control.

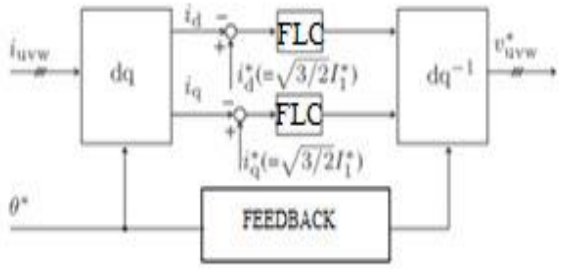

Fig. 3. Block figure for the motor-speed control based on a feedback control of the stator current.

Although the identical torque quantities by with thed–qconversion to improve current controllability. In Fig. 3, θ∗ is the phase information used for the d–qtransformation, whereas I ∗d and I∗ q be the control currents set by

$$i_{d}^{*} = i_{q}^{*}\sqrt{\frac{3}{2}}I_{1}^{*} \quad (7)$$

Wherever I∗1 is the control intended for the stator rms current. Note that I∗1 and f∗ are specified not by feedback control, however by feed forward control, as described later on. Fig. 4 shows a per-phase equivalent circuit of an induction motor based on the whole linkage flux of the secondary windings.

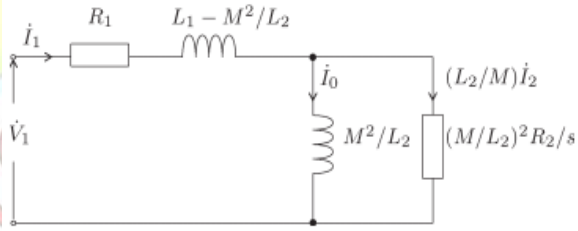

Fig. 4. Per-phase equivalent circuit based on the whole linkage flux of the secondary windings

Though this circuit is appropriate only underneath steady-state circumstances, it is appropriate to a fan- or blower-like load, in which the motor mechanical speed is attuned measured adequate to be measured as the steady-state situation. Here, I1is the phasorstator current, I0 is the phasor magnetizing current, and I2 is the phasor torque current. Note that I0 and I2 are orthogonal to everyone in steady-state circumstances. The rms value of ˙ I1, I1is given in Fig. 4 as follows:

$$I_1 = \sqrt{I_0^2 + \left(\frac{L_2}{M}I_2\right)^2} \quad (8)$$

The motor torque TMis articulated by means of I0and I2 to facilitate the rms standards of I0 and I2, correspondingly, as follows:

$$T_M = 3PMI_0I_2$$

WhereverPis the pole-pair numeral. Fig. 5 displays a phasor diagram for three poles apart

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phasor stator currents I1i, I1j, and I1k but by means of producing the similar torque, in which a relation of I1i<I1j<I1k holds. The imaginaryframeI resembles to the magnetizing currentI0, and the genuine framer parallels to the torque currentI2. It is vibrant in (9) and Fig. 5 that the motor torque TM is proportionate to the area of the triangle bounded by I1, I2, and I0.

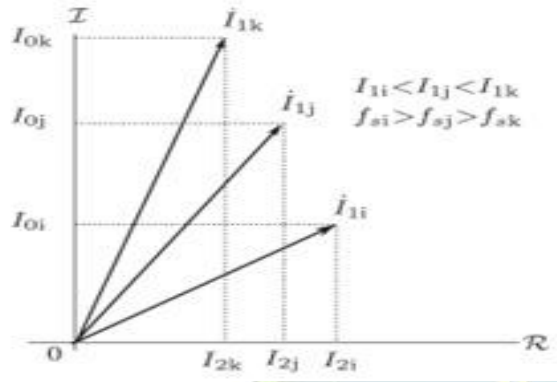

Fig. 5. Phasor diagram meant for the stator currents with dissimilar amplitudes

The slip frequencyfs isdefined by resources of I2 andI0 as follows:

$$f_s = \frac{R_2}{2\pi M}\frac{I_2}{I_0} \quad (9)$$

B. Comparisons of Three Motor-Speed Control Techniques

The "volts-per-hertz" control or curtly "V/f" control has two self-governing variables V1andf, in which V1is the stator voltage andfis the stator frequency. Going on the further supply, the binary dependent variables be the stator current I1 as well as the slip frequencyfs.

Table I summarizes comparisons amongst the three motorspeed control techniques, by means of a focal point on resemblance and divergence

Table I

comparisonamongstexistingvolts-Per-Hertz Andslip-Frequencycontrol Techniques along with Theprojectedmotor-Speedcontrolsystem

Independent Variables	v_s**and f**	v_s**and** f_s	I_1 **and f**
Dependent Variables	$I_s$and f_s	$v_1$and f	$v_1$and f_s
Voltage control	Feed forward		
Current control	-	feedback	feedback
Speed sensor	No	yes	NO

The slip-frequency control is able to give a quicker torque response than theV/fcontrol as of the subsistence of a feedback control for the motor mechanical speed.The motor-speed control projected for the DSCC-based induction motor drive has binary self-governing variablesI1 andf, and the two reliant variables *areV1and fs.*

COMMANDSTATORCURRENTS

This sector describes how to establish the command of the stator rms currentI ∗1 and the stator-current frequency f ∗. The subsequent two approachescan be used to establish ∗1 and f ∗:

• Determination as of the equivalent circuit given away in Fig. 4;

• Determination from SIMULATIONs.

A. Design Considerations

• The utmost rate of each arm current is lesser than the amplitude of the rated stator current. The ac circulating current superimposed consequences in extenuating the ac-voltage fluctuation appearing across the dc capacitor of every chopper cell. For this reason, I∗1 be supposed to be minimized as the ac module of the arm current is relative to I∗1.

B. Determination from the Equivalent Circuit Shown in Fig. 4

As soon as a speed-versus-load-torque attribute is recognized, the equivalent circuit shown in Fig. 4 is able to be used to decide I∗1 and f∗, along with the motor parameters as well as the moment of load inertia. The motor torque should gratify the following equation through the start-up:

$$T_M - T_L > (J_M + J_L)\frac{d\omega_{rm}}{dt} \quad (10)$$

WhereTLis the load torque, JMis the moment of inertia of the motor, JLis that of the load, and ωrm is the mechanicalangular velocity. The right-hand term on (11) corresponds to an acceleration torque for the start up. For makinganalysis simple and easy, the following reasonable approximations are made.

• The stator-current frequencyfagrees well with its command f ∗ (i.e., f=f∗).

• The slip frequency fs are much lesser than f (i.e., fsf).

• The moment of inertia of the loadJLis much larger than that of the motorJM (i.e.,JMJL).

These three assumptions are applicable to fan- or blower-like loads for the subsequent reasons. The primary statement is appropriatesince the motor frequency, or the motor mechanical speed, is attuned gradually, e.g., spending a small amount of or several proceedings to complete its start-up procedure. Lastly, (11) is simplified as follows:

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$$T_M - T_L > J_L \frac{2\pi}{P}\frac{df^*}{dt} \quad (11)$$

Whereωrm =2πf∗/P. Equation (12) means that the acceleration torque is proportional to the slope of change inf∗. The stator rms current essential to generate a motor torque gets the minimum when the next relation is met:

$$I_0 = \frac{L_2}{M} I_2 \quad (12)$$

Substituting (13) into (9) yields

$$I_2 = \sqrt{\frac{T_M}{3PL_2}} \quad (13)$$

Finally

I1is obtained by substituting (14) into (8) as follows:

$$I_1 = \sqrt{\frac{2L_2T_M}{3PM^2}} \quad (14)$$

C. Determination from Simulations

The first value of I∗1 is deposit to nil. After that, I∗1 is being enlarged increasingly where the motor starts turning up. Lastly, Simulation tuning of the slope ofI1/f (=I∗1/f) is necessary to attain the steady start-up. The so-called "torque boost" role at small speeds, which is used in theV/f control, is applicable to the motor-speed control.

III. FUZZY LOGIC CONTROLLER

During FLC, crucial control accomplishment is determined by a set of linguistic rules. These rules are determined by the system. As the arithmetical variables be transformed into linguistic variables, numerical modeling of the scheme is not essential in FC.

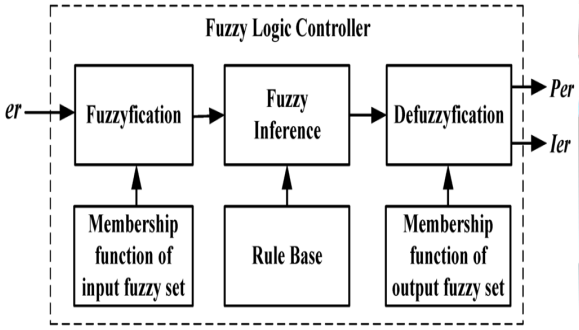

Fig.6.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy groups for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification by means of incessant creation of discourse. iv. Implication with Mamdani's, 'min' machinist. v. Defuzzification with the height method.

TABLE III: Fuzzy Rules

e / ė	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fuzzification: Membership function standards are allocated to the linguistic variables, by means of seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The separation of fuzzy subsets and the shape of membership CE (k) E(k) function acclimatize the form up to appropriate system. The importance of input error and change in error are standardized by an input scaling factor. In this structure the input scaling factor has remained intended such that input values are sandwiched between and +1. The triangular shape of the membership function of this arrangement presumes that for some E (k) input there is only unique dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (15)$$

$$CE(k) = E(k) - E(k\text{-}1) \quad (16)$$

Inference Method:several composition approaches such as Max–Min and Max-Dot have been projected in the literature. In this thesis Min method is used. The output membership function of eachregulation is specified by the smallest operator as well as maximum operator. Table 1 displays rule base of the FLC.

Defuzzification: while a plant usuallyneeds a non-fuzzy charge of control, a defuzzification phase is required. To compute the output of the FLC, „height" procedure is used and the FLC output alters the control output. More, the output of FLC wheels the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are essential to be sustained. Toestablish these limitations, they are detected and related by means of the reference values. To attain this, the membership functions of FC are: error, modification in error and output

The set of FC rules are derivative from

$$u=-[\alpha E + (1-\alpha)*C] \quad (17)$$

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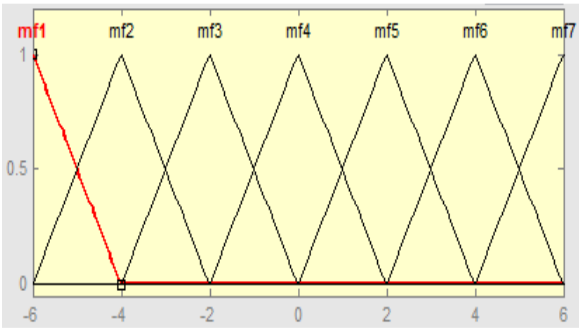

Fig 7 input error as membership functions

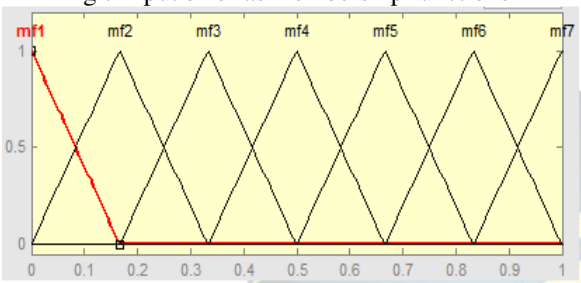

Fig 8 change as error membership functions

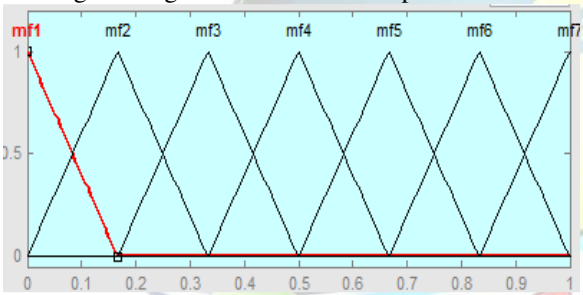

Fig.9 output variable Membership functions

Where α is self-adjustable factor which can control the whole process. E is the error of the system, C is the change in error and u is the controller variable.

SIMULATION

Chart II précises the circuit limitations used in the SIMULATIONs.

Table III
Circuit constraints used in the SIMULATIONs

Rated active power		15kw
Rated line to line rms voltage	v_s	400v
Rated dc link voltage	V_{dc}	570v
Center tapped inductor	L_Z	4.0mH(12%)
DC capacitor of chopper cell	C	3.3mF
Dc capacitor voltage	V_c	140v
Unit capacitance constant	H	52ms(19)
Cell count per leg	N	8
Triangular wave carrier frequency	f_C	2Khz
Triangular wave carrier frequency	f_C	2Khz

A square-wave common-mode voltage as well as square wave circulating currents be used to diminish the ac-voltage oscillation of each dc capacitor, in which the rms value of the common-mode voltage Vcom along with its frequencyfcom be set toVcom= 180V andfcom=50Hz, correspondingly, for the subsequent reasons.

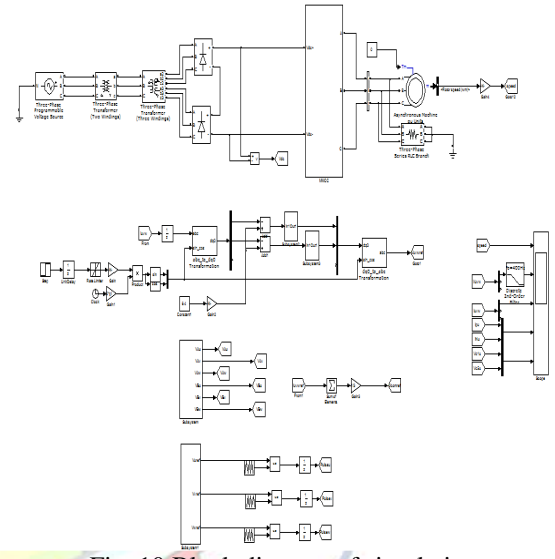
Fig. 10.Block diagram of simulation

• The command common-mode voltage V∗ com be put to build the modulation index of the DSCC be aboutunity.

• The command frequency f∗com be set to be a smaller amount than one-tenth of the carrier frequency offC (i.e., fcom≤fC/10 = 200Hz) to attain superior controllability of the ac circulating current.

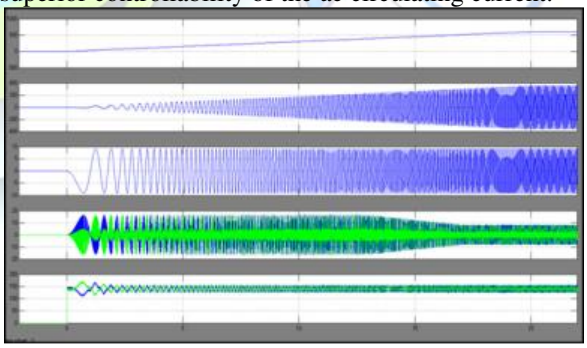
Fig. 11. Simulation start-up waveforms when I∗1=6.4 A (20%) and TL=0%, whereI0=6.4A (35%)

The command for the stator rms current I∗1 in the motor speed control was determined by SIMULATIONs.

B. Start-Up Performance

Figs. 11–15 show Simulation start-up performance with dissimilar load torques. The harmonic voltages

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included in the line-to-line voltage vuv were eliminated by means of a low-pass filter with a cutoff frequency of 400 Hz.

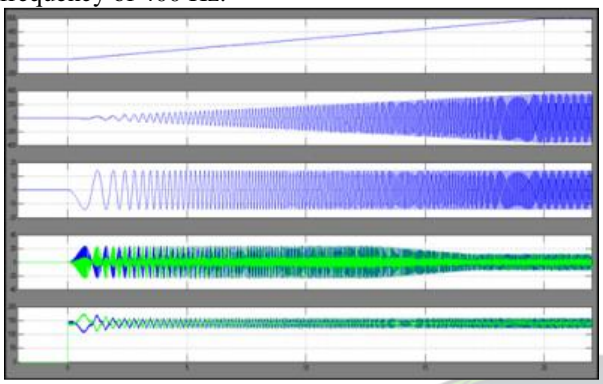

Fig. 12. Simulation start-up waveforms when I∗1=10A (31%) and TL= 20%, whereI0=7.0A (38%)

Fig.13 shows theSimulation start-up presentation with TL= 20%. Here, I∗1 was set to 17 a (53%), which is intended for evaluations with Fig. 8.

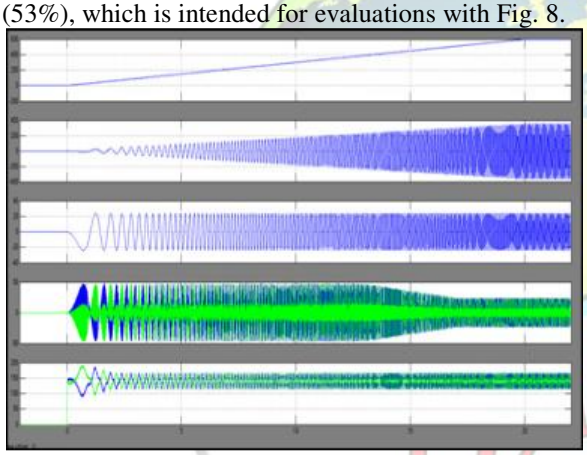

Fig. 13. Simulation start-up waveforms when I∗1=17A (53%) and TL= 20%, whereI0=16.6A (90%).

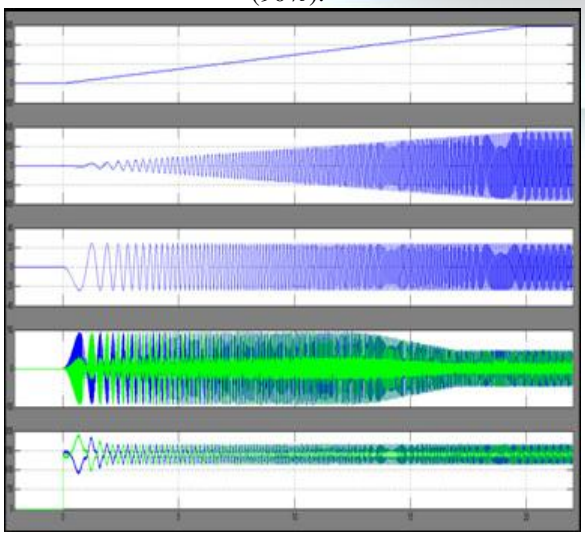

Fig. 14. SIMULATIONal start-up waveforms when I ∗ 1 =14A(44%),and TL= 40%, where I0=9.9A(54%)

Fig.14displays the Simulation start-up presentation with TL= 40%. Here, I∗1 was adjusted to √2 periods of that when TL= 20%, because I∗1 is proportionate to a square root of torque, rendering to (15).

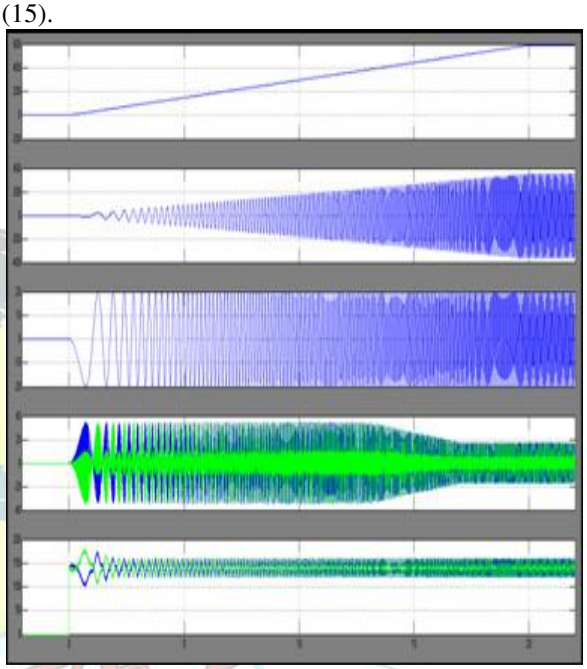

Fig. 15. Simulation start-up waveforms when I ∗ 1 =17A (53%), and TL=60%, where I0=12.0A (65%).

Fig. 15 shows the Simulation start-up performance with TL= 60%. Here, I∗1was set to 17 A (=√3×10A, 53%).Themagnetizing currentI0 reached 12.0 A (= 17 A/√2, 65%). The supreme amplitudes of the arm current and the peak-to peak ac-voltage oscillationstood the same as those in Fig. 9, because I∗1 wasconventional to the same value as Fig. 12.

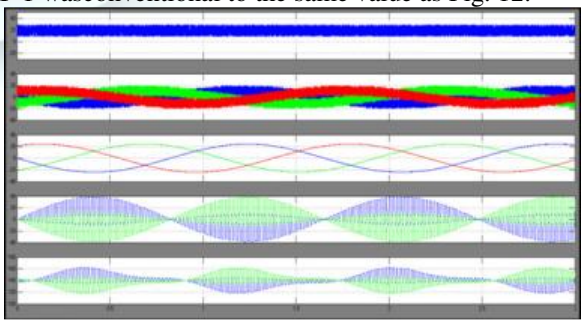

Fig. 16. Simulation steady-state waveforms when I∗1=17A (53%), f∗=1Hz, andTL= 60%, where I0=12.0A (65%)

Fig. 17displays those at f∗=15Hz. Here, Vcomwas condensed to 113 V, and the amplitude of the square-

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wavecirculating currents was condensedconcurrently. The motor mechanical speed in addition the slip frequency was Nrm = 438 min −1 and fs=0.4Hz, correspondingly.

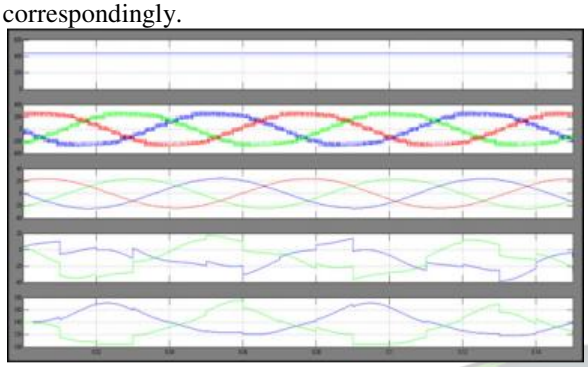

Fig. 17. SIMULATIONal steady-state waveforms when I ∗ 1 =17A(53%),f∗ =15Hz, andTL= 60%,whereI0=12.0A(65%)

Fig. 18 shows those at f∗=20Hz. Here,Vcom and the amplitude of the square-wave circulating currents were abridged to nil, since the ac-voltage fluctuation of separately dc-capacitor voltage is not grave at this frequency. However the peak charge of the arm currents can continueconcentrated to 19 A, which is 42%

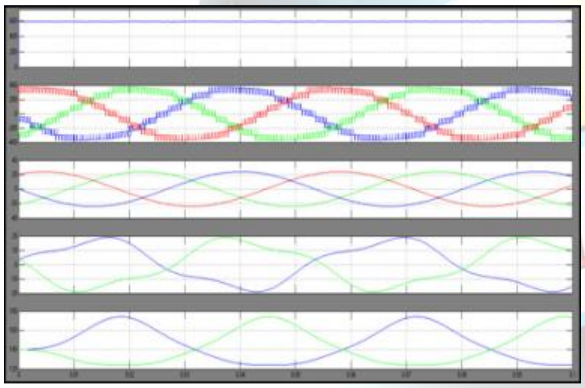

Fig. 18. SIMULATIONal steady-state waveforms with I∗1=17A(53%),f∗=20Hz, andTL= 60%,whereI0=12.0A(65%).

CONCLUSION

This thesis is to validate the efficiency and possibility of a speed-sensor less start-up method for a DSCC based induction motor drive, in which the motor jumpsrevolving from standstill to midspeedinessby means of a gradientvariation.This start-up way is categorizedby means of combining capacitor-voltage control in addition motor-speed control. At this juncture, we are using the fuzzy controller related to further controllers i.e. the fuzzy controller stands the utmostapt for the human decision-making mechanism, provided that the operation of an electronic system bychoices of professionals.The arm-current amplitudes in addition ac-voltage fluctuations diagonally each of the dc capacitors can be condensed to tolerablepoints. By means ofusing the fuzzy controller for a nonlinear system tolerates for a decrease of indeterminateproperties in the scheme controland progresses the effectiveness.The start-up torque has continuedincreasingin a aspect of three, by no additionalstress on equally arm currents as wellas ac-voltage fluctuations.

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