A NEW SVM STRATEGY TO CONTROL THE MATRIX CONVERTER UNDER UNBALANCED INPUT VOLTAGE CONDITIONS

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ABSTRACT The direct Matrix Converter (MC) can contribute to the realization of low volume, sinusoidal input current, bidirectional power flow and lack of bulky reactive elements. Due to absence of a DC-link energy storage element in the direct Matrix Converter(MC), any abnormality/disturbances in the input voltages is directly reflected on the output voltages. A new SVM strategy to control the 3x3 direct Matrix Converter (MC) under unbalanced input voltage conditions is proposed. The Space Vector Modulation(SVM)technique is utilized to calculate the duty cycles of the active voltage vectors that must be applied in each switching cycle period in order to satisfy the input and output requirements. The proposed strategy ensures that optimal performance of the MC over the entire operating range, when the converter operates with an output voltage greater than the maximum attainable balanced output voltage under unbalanced input voltage conditions is achieved.

Keywords:- *matrix converter, space vector modulation, unbalanced input voltages*

1.INTRODUCTION

1.1 GENERAL

The Matrix Converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any DC-link circuit and does not need any large energy storage elements. The matrix converter capable of converting a input voltage directly into an arbitrary AC voltage.

The ideal characteristics of Matrix converter are

i. Simple and compact power circuit.

ii. Generation of load voltage with arbitrary amplitude and frequency.

iii. Sinusoidal input and output currents.

iv. Operation with unity power factor for any load.

v. Regeneration capability.

The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms with minimal higher order harmonics and no sub-harmonics. It has inherent bi-directional energy flow capability because of the presence of bidirectional switches. The input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime limited energy storing capacitors.

Due to absence of DC link in the Matrix Converter, unbalanced voltage conditions in the input voltage source affect the performance of the Matrix Converter and the output waveform is not a sinusoidal waveform. In some cases, harmonics present in the input current may also degrade the sinusoidal output voltage and current waveform. The output performance can be improved by Space vector Modulation Technique and obtained a maximum voltage transfer ratio can be increased up to 86.6%.

The concept of space vector is derived from the rotating field of ac machine which is used for modulating the converter output voltage. The switching operation of the Matrix Converter is performed based on SVM technique. The Space Vector algorithm is based on the representation of the three phase input current and three phase output line voltages on the space vector plane. To obtain a good performance of the matrix converter, it is necessary also the design of an L-C filter to smooth the input currents and to satisfy the EMI requirements. It has been shown that the presence of a resonant L-C filter could determine instability phenomena that can prevent the matrix converter to deliver the rated power to the load. The proposed Space Vector Modulation Technique determine best switching states and to calculate the duty cycle to improve the performance of matrix converter.

1.2 LITERATURE SURVEY

The literature survey is organized under several categories of discussions. This is to provide a clear historical overview of the major stages of development in this area. The absence of DC-link energy storage makes the direct Matrix Converter (MC) more sensitive to any disturbance in the input voltages. Majority of modulation strategies developed for the MC are based on the assumption of balanced input voltages. Consequently, if the input voltages of the MC are subjected to any disturbance/imbalance, low-order harmonics are introduced in the output voltages and input currents of the converter. A few methods have been proposed to mitigate the impacts of unbalanced input voltages on the performance of the MC.

Authors of [1] proposed the maximum input-output transformer ratio or output voltage ability of direct AC-AC pulse width modulated converters. A suitable novel converter control algorithm is discussed which achieves such maximum output amplitude .Finally, the opportunity to implement ac-ac converter control with the use of feedback techniques is considered, and a feedback-based control algorithm for the new converter .

Authors of [4] proposed two control strategies of the input current displacement angle are presented and compared in order to emphasize their influence on the input current harmonic content. The first one is based on keeping the input current vector in phase with the input voltage vector. In the second one, the input current displacement angle is dynamically modulated as a function of positive and negative sequence components of the input voltages. In both cases, the harmonic content and the three-phase rms value of the input current have been evaluated analytically. The input current harmonic spectrum is quite different for the two control strategies and can be related to the input and output unbalance .

H. Karaca et al.[10] proposed a fuzzy logic control (FLC) based novel compensation method which performs close loop control of the output current to improve the output performance of the MC. The behaviors of the MC have been investigated under the distorted input voltage conditions.

X. Wang et al.[18] focuses on the indirect Space Vector Modulation (SVM) strategy to calculated the gain of the MC based on the instantaneous values of the input voltages and the duty cycles of the switches.

Authors of [19] suggested a novel PWM technique for direct AC-AC matrix converters. The algorithm is based on the well-known Venturini method but taking the measured input voltage into consideration. The technique enables generating balanced output voltages when input voltages are unbalanced and preventing the input voltage harmonics from propagating on to the output line-to-line voltages . Jaya Deepti Dasika et al.[20] proposed space vector modulation technique to solve the complex optimization problem to determine the dutycycles for matrix converter under unbalanced input voltage conditions. Dr.C.Ponmani et al [21] proposed the internal model control technique to control the matrix converter under unbalanced input conditions.

Based on all literature surveys, the proposed Space Vector Modulation algorithm is absolutely necessary to increase the efficiency of direct Matrix Converter and the voltage transfer ratio is 0.866.

2. MATRIX CONVERTER

2.1 INTRODUCTION

Matrix converter is a device which converts AC input supply to the required variable AC supply as output without any intermediate conversion process. It is worth noting that the three phase to three phase configuration is just one of the possible direct AC-AC converter topologies The matrix converter consists of nine bi-directional switches that allow any output phase to be connected to any input phase. The input terminals of the converter are connected to a three phase voltage-fed system, usually the grid, while the output terminal are connected to a three phase current-fed system, like an induction motor might be. The passive filter is placed between the AC source and the Matrix converter. Their size is inversely proportional to the matrix converter switching frequency. With nine bi-directional switches the matrix converter can theoretically assume 512 (2^9) different switching states combinations. The arrangements of bi-directional switches are shown in figure 2.1.2. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching states combinations to be used must comply with two basic rules.

Taking into account that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. From a practical point of view these rules imply that one and only one bi-directional switch as shown in the figure 2.1.1 per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 are the permitted switching combinations.

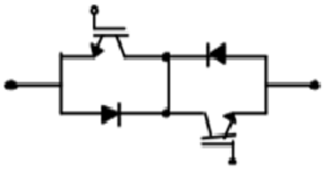


Figure 2.1.1 Bidirectional switch

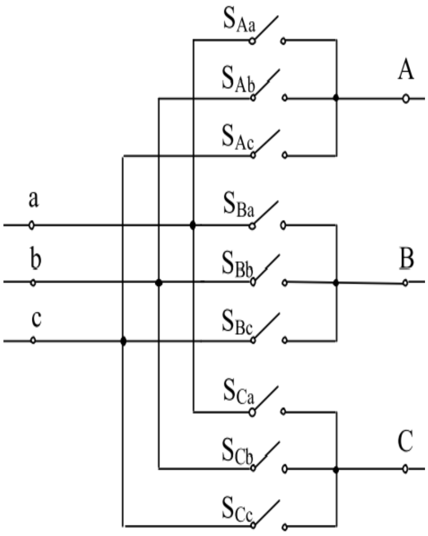


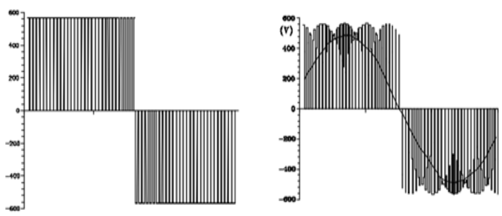
Figure 2.1.2Bidirectional switches arrangement

2.2 THE PERFORMANCE

This section gives a short description of what are the performances of a matrix converter. A qualitative analysis of some performance parameters is carried out.

2.2.1 The output Voltage

Since no energy storage components are present between the input and output sides of the Matrix Converter, the output voltages have to be generated directly from the input voltages. Each output voltage waveform is synthesized by sequential piecewise sampling of the input voltage waveforms. The sampling rate has to be set much higher than both input and output frequencies, and the duration of each sample is controlled in such a way that the average value of the output waveform within each sample period tracks the desired output waveform. As consequence of the input-output direct connection, at any instant, the output voltages have to fit within the enveloping curve of the input voltage system. Under this constraint, the maximum output voltage the matrix converter can generate without entering the over-modulation range is equal to √3/2 of the maximum input voltage. This is an intrinsic limit of matrix converter.



(a) VSI ***(b)Matrix Converter***

Figure 2.2.1 Output voltage waveforms generated by a VSI and a matrix converter

Entering in the over-modulation range, thus accepting a certain amount of distortion in the output voltages and input currents, it is possible to reach higher voltage transfer ratio. In Figure 2.2.1 the output voltage waveform of a matrix converter is shown and compared to the output waveform of a traditional voltage source inverter (VSI). The output voltage of a VSI can assume only two discrete fixed potential values, those of the positive and negative DC-bus. In the case of the matrix converter the output voltages can assume either input voltage a, b or c and their value is not time-invariant, the effect is a reduction of the switching harmonics.

2.2.2 The input current

Likewise to the output voltages, the input currents are directly generated by the output currents, synthesized by sequential piecewise sampling of the output current waveforms. If the switching frequency of the matrix converter is set to a value that is much higher than the input and output frequency, the input currents drawn by the converter are sinusoidal, their harmonic spectrum consists only of the fundamental desired component plus a harmonic content around the switching frequency.

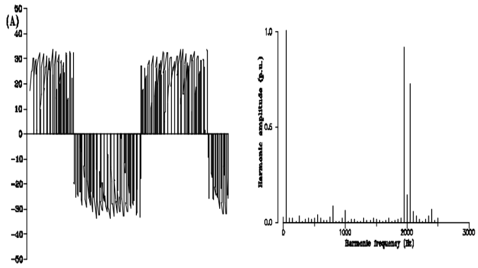


Figure 2.2.2 Matrix converter input current and harmonic spectrum. Switching frequency 2kHz.

In Fig.2.2.2 the input current drawn by a matrix converter for a 2 kHz switching frequency is shown. It can be noted that the amplitude of the switching harmonic components is comparable to the fundamental amplitude. It is then obvious that an input filter is needed in order to reduce the harmonic distortion of the input line current to an acceptable level. It follows that care should be used in speaking about matrix converters as an “all silicon” solution for direct AC/AC power conversion, since some reactive components are needed.

The matrix converter performance in terms of input currents represent a significant improvement with respect to the input currents drawn by a traditional VSI converters with a diode bridge rectifier, whose harmonic spectrum shows a high content of low-order harmonics. By the light of the standards related to power quality and harmonic distortion of the power supply. This is a very attractive feature of matrix converter.

2.2.3 The input power factor control

The input power factor control capability is another attractive feature of matrix converters, which holds for most of the control algorithms proposed in literatures [1]-[9]. Despite of this common capability it is worth noting that a basic difference exists with respect to the load displacement angle dependency. The difference approaches of matrix converter require the knowledge of load displacement angle whenever the reference input power factor is different from unity.

2.3 IMPLEMENTATION OF MATRIX CONVERTER

Looking at the basic features of the matrix converter that have been briefly described in the previous sections it might be surprising to establish that this converter topology.

2.3.1 The bi-directional switch realization and commutation

A first key problem is related to the bi-directional switches realization. By definition, a bi-directional switch is capable of conducting currents and blocking voltages of both polarities, depending on control actual signal. Figure 2.3.1 shows different bi-directional switch configurations which have been used in proposed system.

Another problem, tightly related to the bi-directional switches implementation, which has represented a main obstacle to the industrial success of the matrix converter, is the commutation problem. The commutation issue basically rises from the absence, in the matrix converters, of static freewheeling paths. As consequence it becomes a difficult task to safely commutate the current from one bi-directional switch to another, since a particular care is required in the timing and synchronization of the switches command signals.

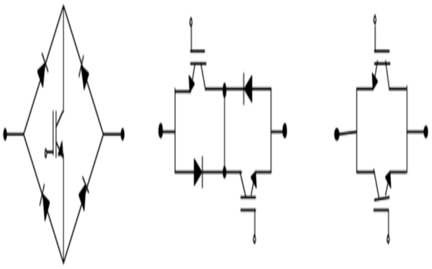


Figure 2.3.1 Possible discrete implementations of a bi-directional switch

2.3.2 The input filter

In general, the design of an input filter for static power converters operating from an ac power system has to meet three main requirements:

1) Carrying out the required switching noise attenuation.

2) Having a low input displacement angle between filter input voltage and current.

3) Guaranteeing overall system stability.

In addition to these requirements, a set of considerations related to cost, voltage attenuation, system efficiency and filter parameter variation have to be made for an optimized input filter design.

The first requirement is usually dictated by the EMI control standards. The input filter has to reduce the input current and output voltage total harmonic distortion below given values. In order to achieve this result, the resonant frequency of the filter has to be positioned accordingly to the converter switching frequency and its PWM pattern. When the input current harmonic spectrum generated by the converter is known, the filter resonance frequency is positioned where no unwanted harmonic components exist, which is usually the frequency range comprised between the fundamental and the switching frequency. In practice, due to the presence of imperfections and asymmetry in gating signals as well as implementation inaccuracies, some unwanted or uncharacteristic harmonics with small amplitude might exist in this region. If no damping is provided, these unwanted harmonics can be amplified by the filter to unacceptable level. On the other hand, a highly damped filter could not meet the harmonics attenuation requirements.

2.4 SWITCHING FUNCTION

$S_{io}(t)=1$,when switch is closed.

$S_{io}(t)=0$,when switch is open.

$i= \{a,b,c\} \quad o= \{A,B,C\}$

The constraints of switching function

$$S_{ao}(t)+S_{bo}(t)+S_{co}(t)=1$$

3. PROPOSED SYSTEM

3.1 BLOCK DIAGRAM

In general, a SVM controlled matrix converter system is typically built using the following component as shown in the figure 3.1.2

1) A Passive filter in the source side of the matrix converter mitigate the input current harmonics.

2) The bidirectional switches arrangement as shown in the figure3.1.1 is connected between the input filter and the Three phase Induction motor that converts input sinusoidal waveform into output sinusoidal waveform.

3) A direct Matrix Converter is connected between the sinusoidal voltage source and Three phase Induction motor.

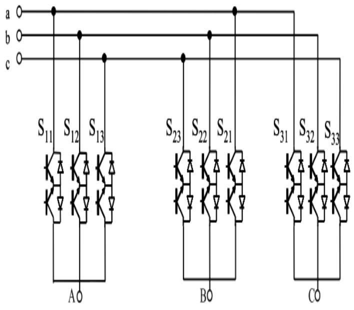


Figure 3.1.1 Complete scheme of the power stage usingcommon emitter arrangement

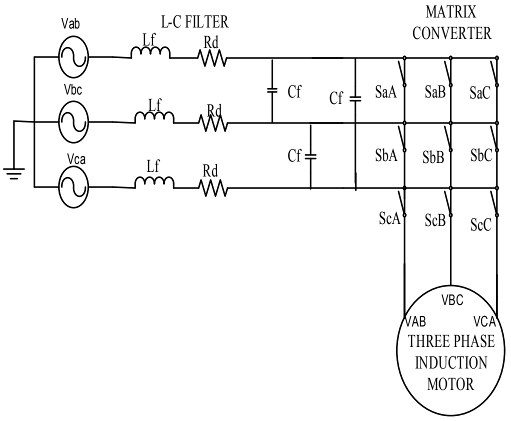


Figure 3.1.2 Block diagram of the matrix converter system

3.2 PASSIVE (L-C) FILTER

Although the Matrix Converter is sometimes presented as a silicon solution, due to the lack of the bulky and expensive DC-link capacitors of traditional indirect frequency converter, it also requires a minimum of reactive components represented by the input filter. The input filter acts as an interface between the matrix converter and the AC mains. Its basic feature is to avoid significant changes of the input voltage of the converter during each PWM cycle, and prevent unwanted harmonic currents from flowing into AC mains. Due to the discontinuous input currents, the matrix converter behaves as a source of current harmonics, which are injected back into the AC mains. Since these current harmonics results in voltage distortions that affect the overall operation of the AC system, they have to be reduced. The principal method of reducing the harmonics generated by static converters is provided by the input filter using reactive storage elements. Second Order Input L-C filter is used to reduce the harmonics, resistance(R) is connected in parallel with inductance (L) as shown in the figure 3.2 in order to have an adequate damping. The inductance value (L) at 60Hz should be negligible.

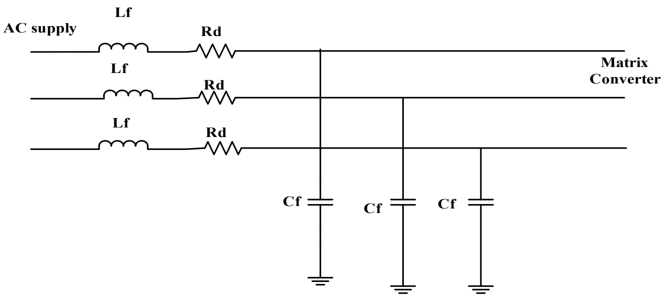


Figure 3.2 Passive input filter

3.3 SWITCHING STATES

It must be able to conduct positive and negative current and block positive and negative voltage. A three-phase to three phase MC in which the input and output voltages (currents) are Va,Vb,Vc (Ia,Ib,Ic) and VA,VB,VC (IA,IB,IC) respectively. The converter circuit is comprised of nine bidirectional switches that allow connection of any of the output phases to each of the input phases.

Since input terminals a, b, and c are connected to voltage sources, they must not be short circuited through the MC switches. Similarly, since output terminals A, B, and C are connected to current sources, they must not be open circuited at any instant.

Based on the constraints, the MC has 27 permissible switching states. The SVM strategy is based on instantaneous space vector representation of the output line-to-line voltages and input currents generated by the 27 permissible switching states. Out of 27 switching states, six of them are referred as the synchronous switching states. Eighteen of the switching states, referred as the active switching states. The remaining three switching states are zero states.

3.3.1 Synchronous switching states

For these switching states, each output phase is connected to a different input phase.

3.3.2 Active switching states

For these switching states, two of the output phases are connected to the same input phase and the third output phase is connected to a different input phase. Each of the eighteen active switching states is assigned a number between ± 1 and ± 9. The output voltage/input current vectors of a pair of active switching states with the same number and opposite signs have the same magnitude in opposite directions.

3.3.3 Zero states

For these switching states, each of the output phases are connected to the same input phases.

The switching states are classified into three groups, group I referred active switching states, group II referred synchronous switching states and group III referred zero states in the table 3.3.

Table 3.3 Switching configuration and vectors in Matrix Converter

	Switching Configurations				Output Voltage		Input Current	
	SC. No.	A	B	C	Vo	αo	Ii	βi
Group I	+1	a	b	b	$2/3v_{ab}$	0	$2/\sqrt{3}i_A$	-π/6
	-1	b	a	a	$-2/3v_{ab}$	0	$-2/\sqrt{3}i_A$	-π/6
	+2	b	c	c	$2/3v_{bc}$	0	$2/\sqrt{3}i_A$	π/2
	-2	c	b	b	$-2/3v_{bc}$	0	$-2/\sqrt{3}i_A$	π/2
	+3	c	a	a	$2/3v_{ca}$	0	$2/\sqrt{3}i_A$	7π/6
	-3	a	c	c	$-2/3v_{ca}$	0	$-2/\sqrt{3}i_A$	7π/6
	+4	b	a	b	$2/3v_{ab}$	2π/3	$2/\sqrt{3}i_B$	-π/6
	-4	a	b	a	$-2/3v_{ab}$	2π/3	$-2/\sqrt{3}i_B$	-π/6
	+5	c	b	c	$2/3v_{bc}$	2π/3	$2/\sqrt{3}i_B$	π/2
	-5	b	c	b	$-2/3v_{bc}$	2π/3	$-2/\sqrt{3}i_B$	π/2
	+6	a	c	a	$2/3v_{ca}$	2π/3	$2/\sqrt{3}i_B$	7π/6
	-6	c	a	c	$-2/3v_{ca}$	2π/3	$-2/\sqrt{3}i_B$	7π/6
	+7	b	b	a	$2/3v_{ab}$	4π/3	$2/\sqrt{3}i_C$	-π/6
	-7	a	a	b	$-2/3v_{ab}$	4π/3	$-2/\sqrt{3}i_C$	-π/6
	+8	c	c	b	$2/3v_{bc}$	4π/3	$2/\sqrt{3}i_C$	π/2
	-8	b	b	c	$-2/3v_{bc}$	4π/3	$-2/\sqrt{3}i_C$	π/2
	+9	a	a	c	$2/3v_{ca}$	4π/3	$2/\sqrt{3}i_C$	7π/6
	-9	c	c	a	$-2/3v_{ca}$	4π/3	$-2/\sqrt{3}i_C$	7π/6
Group II	0_a	a	a	a	0	x	0	x
	0_b	b	b	b	0	x	0	x
	0_c	c	c	c	0	x	0	x
Group III	x_1	a	b	c	x	x	x	x
	x_2	a	c	b	x	x	x	x
	x_3	b	c	a	x	x	x	x
	x_4	b	a	c	x	x	x	x
	x_5	c	a	b	x	x	x	x
	x_6	c	b	a	x	x	x	x

4. SPACE VECTOR MODULATION

4.1 INTRODUCTION

Space Vector Modulation refers to a special switching sequence which is based on the upper switches of a three phase matrix converter. Theoretically, SVM treats a sinusoidal voltage as a phasor or amplitude vector which rotates at a constant angular frequency as shown in the figure 4.1.1 This amplitude vector is represented in d-q plane where it denotes the real and imaginary axes as shown in the figure 4.1.2. Clark transformation can be used to convert three phase quantities into two phase quantities for space vector modulation as shown in the equation 4.1a. As SVM treats all three modulating signals or voltages as one single unit, the vector summation of three modulating signals or voltages are known as the reference voltage, V_{oref} which is related to the magnitude of output voltage of the switching topologies. The aim of SVM is to approximate the reference voltage vector, V_{oref} from the switching topologies.

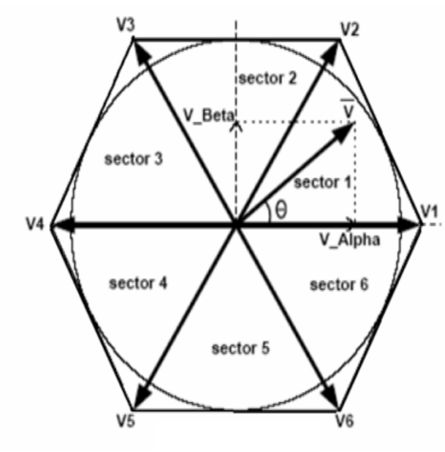


Figure 4.1.1 Representation of Rotating Vector in Complex Plane

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (4.1a)$$

$$\propto = \tan^{-1} vd/vq \qquad (4.1.b)$$

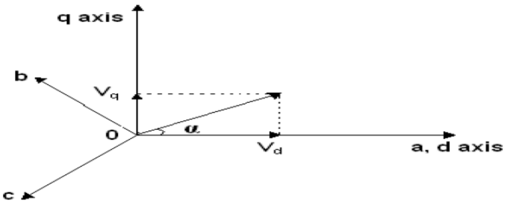


Figure 4.1.2 Voltage Space Vector and its Components in (d, q)

4.2 VECTOR SELECTION AND DUTYCYCLE CALCULATION

Based on the position of the reference output voltage shown in Figure 4.2.1 and current vectors shown in Figure 4.2.2, as, the SVM strategy selects four active switching states that have vector components along the desired direction and a zero switching state to modulate the MC. Table 4.2.3 lists the active vectors that can be used for various voltage sector (K_V) and current sector (K_I) combinations. In Fig.2.2.2 the input current drawn by a matrix converter for a 2 kHz switching frequency is shown. It can be noted that the amplitude of the switching harmonic components is comparable to the fundamental amplitude. It is then obvious that an input filter is needed in order to reduce the harmonic distortion of the input line current to an acceptable level. It follows that care should be used in speaking about matrix converters as an "all silicon" solution for direct AC/AC power conversion, since some reactive components are needed. The matrix converter performance in terms of input currents represent a significant improvement with respect to the input currents drawn by a traditional VSI converters with a diode bridge rectifier, whose harmonic spectrum shows a high content of low-order harmonics. By the light of the standards related to power quality and harmonic distortion of the power supply. This is a very attractive feature of matrix converter.

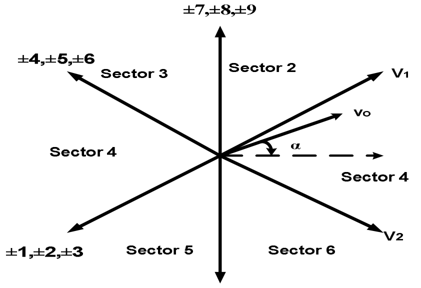


Figure 4.2.1 Space vector representation of output line-to-line voltages of the MC

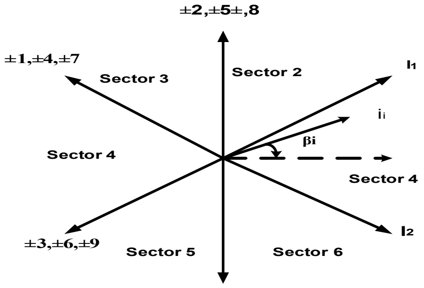


Figure 4.2.2 Space vector representation of input currents of the MC.

The duty cycles of the selected switching vectors,d_I, d_{II}, d_{III}, and d_{IV} , as well as the zero vector d_0 for unity power factor at the input, are $d_I=(2/\sqrt{3})q\cos(\propto o-(\frac{\pi}{3}))\cos(\beta i-(\frac{\pi}{3}))$

$$d_{II}=(2/\sqrt{3})q\cos(\propto o-(\frac{\pi}{3}))\cos(\beta i+(\frac{\pi}{3}))$$

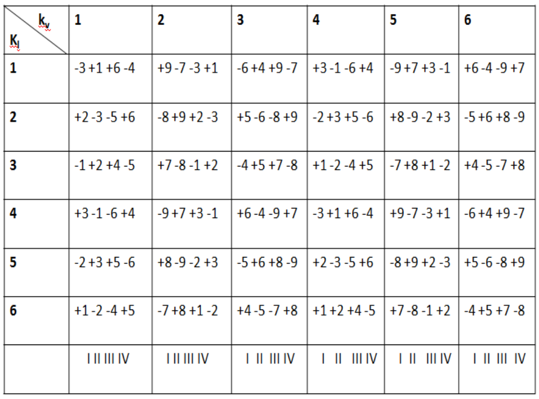
$$d_{III}=(2/\sqrt{3})q\cos(\propto o+(\frac{\pi}{3}))\cos(\beta i-(\frac{\pi}{3}))$$

$$d_{IV}=(2/\sqrt{3})q\cos(\propto o+(\frac{\pi}{3}))\cos(\beta i+(\frac{\pi}{3}))$$

$$d_o=1-(d_I+d_{II}+d_{III}+d_{IV})$$

where αo as shown in Figure 4.2.1 and (βi) as shown in Figure 4.2.2, represents the phase angle of output voltage (input current) vector with respect to the bisecting line of the sector and q is the gain of the converter(where q=0.866). Finally the active and zero switching states are arranged and applied in a sequence that requires minimum number of commutations.

Table 4.2.3 The switching states for various voltage and current sector combinations.



k_v K_I	1	2	3	4	5	6
1	-3 +1 +6 -4	+9 -7 -3 +1	-6 +4 +9 -7	+3 -1 -6 +4	-9 +7 +3 -1	+6 -4 -9 +7
2	+2 -3 -5 +6	-8 +9 +2 -3	+5 -6 -8 +9	-2 +3 +5 -6	+8 -9 -2 +3	-5 +6 +8 -9
3	-1 +2 +4 -5	+7 -8 -1 +2	-4 +5 +7 -8	+1 -2 -4 +5	-7 +8 +1 -2	+4 -5 -7 +8
4	+3 -1 -6 +4	-9 +7 +3 -1	+6 -4 -9 +7	-3 +1 +6 -4	+9 -7 -3 +1	-6 +4 +9 -7
5	-2 +3 +5 -6	+8 -9 -2 +3	-5 +6 +8 -9	+2 -3 -5 +6	-8 +9 +2 -3	+5 -6 -8 +9
6	+1 -2 -4 +5	-7 +8 +1 -2	+4 -5 -7 +8	+1 +2 +4 -5	+7 -8 -1 +2	-4 +5 +7 -8
	I II III IV	I II III IV	I II III IV	I II III IV	I II III IV	I II III IV

The circuit configuration of the MC allows generating the load voltages with controllable magnitude and frequency as well as maintaining the unity power factor at the input side. The objective of the developed modulation strategy is to synthesize the reference output voltage of the MC and to maintain unity power factor at the input. The developed modulation strategy is based on modification of the conventional direct SVM strategy to optimize the converter performance. In the proposed strategy, the corresponding duty cycles of the selected switching states are calculated by following step:

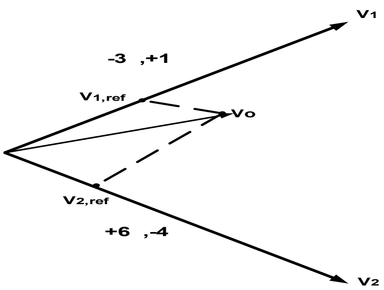
1) Determination of the direction of input current vector.

2) Identification of the location of reference output voltage and input current vectors.

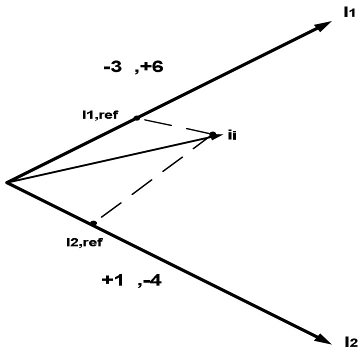
3) For a given voltage and current sector combination, determination of four switching

Vectors that have vector components in the desired directions.

4) Determination of the duty cycles of selected switching states.



(a)



(b)

Figure4.2.4 Components of: (a) the output voltage and (b) input current vectors of the selected switching states when $K_V = 1$ and $K_I = 1$.

Without loss of generality, both output voltage and input current reference vectors are assumed to be in Sector 1. As shown in the table 4.2.3, the switching states − 3, +1, +6, and – 4 are used to modulate the MC. The output voltage and input current vectors generated by these switching states are shown in Figure. 4.2.4. In Figure. 4.2.3, the boundaries of output voltage (input current) sector are represented by V_1 and V_2 (I_1 and I_2), respectively. The components of the reference output voltage (input current) vector along $V_1(I_1)$ and $V_2(I_2)$ are given as $V_{1,ref}$ and $V_{2,ref}$ ($I_{1,ref}$ and $I_{2,ref}$), respectively. As illustrated in Figure 4.2.4 (a), component of the output voltage vector generated by the switching states − 3 and +1 along V_2 is zero, i.e., V_2,I and V_2,II are equal to zero. Furthermore, component of the output voltage vector generated by the switching states +6 and − 4 along V_1 is also zero, V_1,III and V_1,IV are equal to zero. Similarly, component of the input current vector for the switching states − 3 and +6 (+1 and − 4) along $I_I(I_2)$ is zero.

4.3 SPACE VECTOR MODULATION IN MATRIX CONVERTER

1. Read the three phase sinusoidal voltage and current magnitude as a reference for space vector plane.

2. Converting three phase voltages (currents) into two phase quantities by Clark transformation.

3. Obtained magnitude and phase angle of voltage and current d-q frame.

4. From the phase angle ,the sector can be selected for both input current vector and output voltage vector.

5. Based on the sector combination, duty ratios are calculated.

6. Check the condition whether the duty cycle values are within the limits, The constraints are $d_I+d_{II}+d_{III}+d_{IV}\leq 1$

$d_0=1-(d_I+d_{II}+d_{III}+d_{IV})$, otherwise go to step3.

7. From the duty cycle values switching operations are performed.

8. The duty cycles values are compared with the ramp waveform, the comparison result is given the bidirectional switches of matrix converter.

4.4 FLOWCHART

The flow chart representation of Space Vector Modulation as shown in the figure 4.4

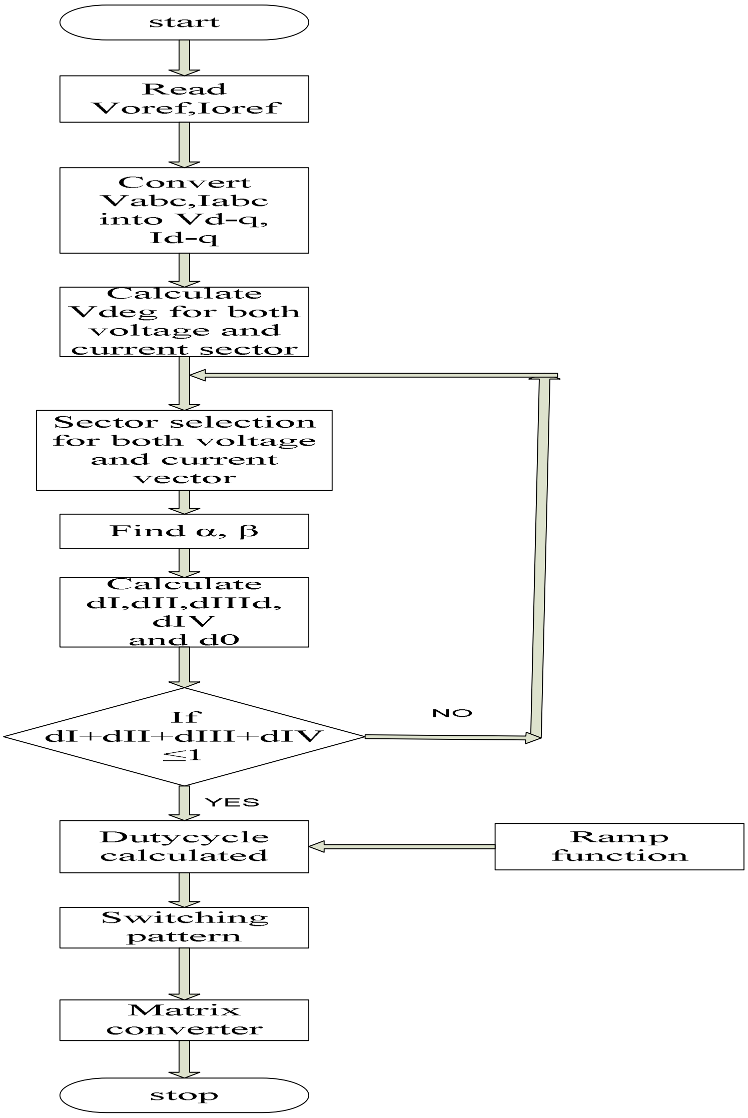


Figure 4.4 Flow Chart of the SVM performance

5. SIMULATION RESULTS AND DISCUSSION

The proposed system is modelled using Matlab /Simulink as shown in figure 5.1.

The following parameters are used in simulation as shown in the table

Table 5.1 Parameters of the proposed system

PARAMETER	VALUE
$V_{in(rms)}$	376 V
f_{in}	60 Hz
f_{sw}	6 kHz
L_f	1mH
C_f	100 µF
R_d	10Ω
V_L	460 V
Output power of three phase induction motor	3730W
Rated speed of three phase induction motor	1750 RPM
Rated frequency of three phase induction motor	60 Hz

5.2 Simulation diagram

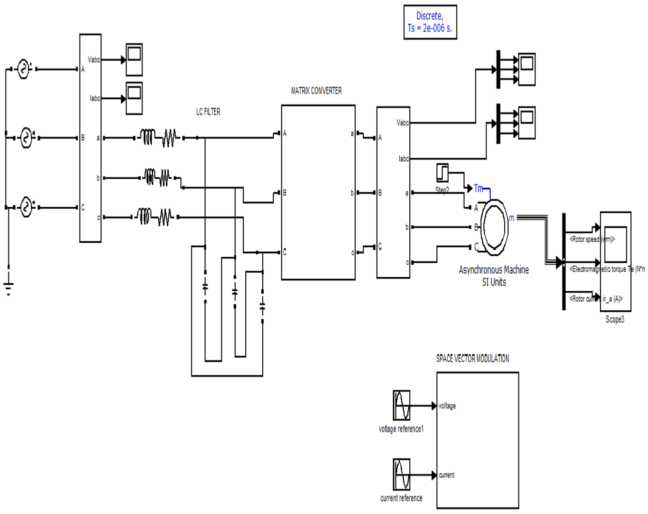


Figure 5.2 Simulation model of entire system

5.3 SIMULATION RESULTS

The model is simulated under no load condition of the induction motor with balanced input voltage. The measured output voltage, input current and rated speed, torque and current are shown in the figure(5.3-5.7).

The Harmonic Spectrum of the output voltage and input current are shown in the figure (5.8-5.9).

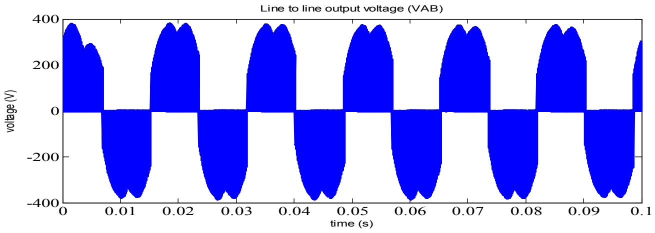


Figure 5.3 Line to line output voltage under balanced input voltage condition for no-load operation of induction motor.

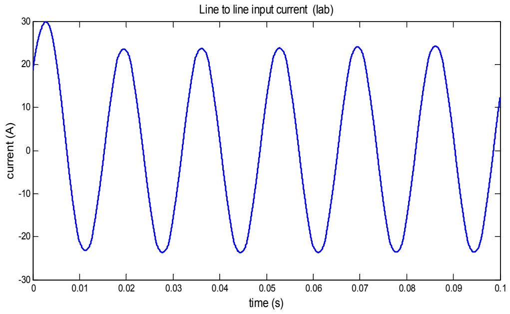


Figure 5.4 Line to line input current under balanced input voltage condition for no-load operation of induction motor.

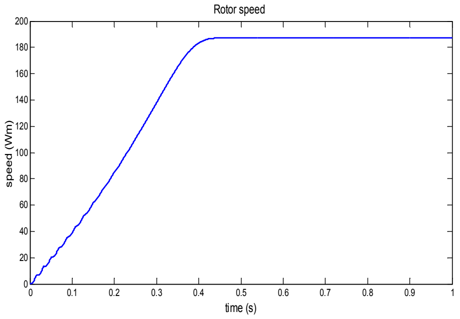


Figure5.5 Rotor speed of the induction motor under no-load condition with balanced input voltages.

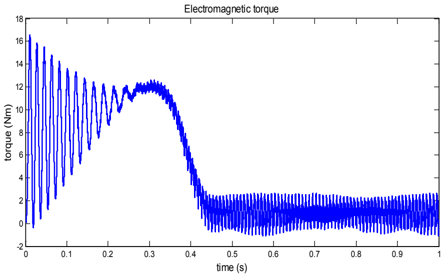


Figure 5.6 Electromagnetic torque of the induction motor under no-load condition with balanced input voltages.

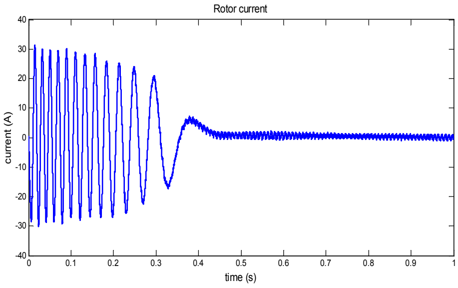


Figure 5.7 Rotor current of the induction motor under no-load condition with balanced input voltages.

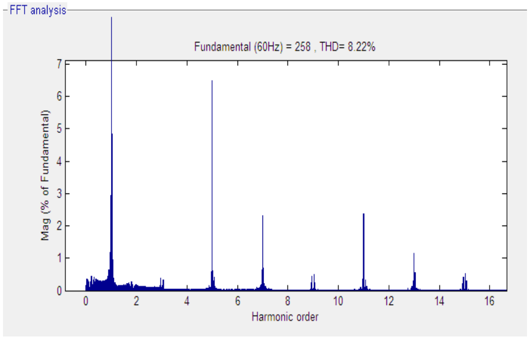


Figure 5.8 Harmonic spectrum for line to line output voltages under balanced input voltage condition with no load operation of induction motor.

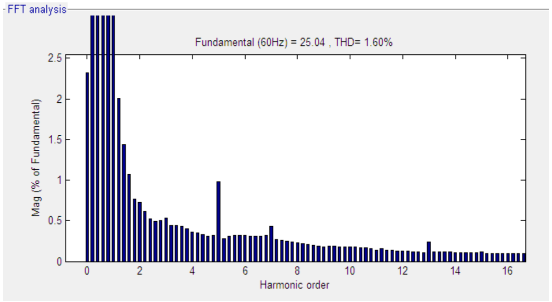


Figure 5.9 Harmonic spectrum for line to line input current under balanced inputvoltage condition with no load operation of induction motor.

The model is simulated under load condition of the induction motor with balanced input voltage. The measured output voltage, input current and rated speed, torque and current are shown in the figure(5.10-5.14).

The Harmonic Spectrum of the output voltage and input current are shown in the figure (5.15-5.16).

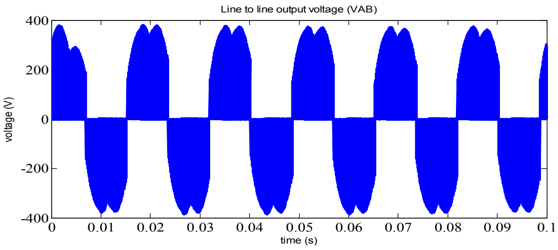


Figure 5.10 Line to line output voltage under balanced input voltage conditionwith loaded induction motor.

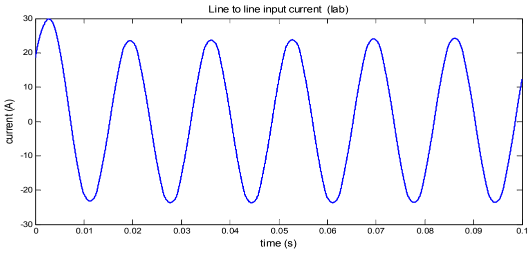


Figure 5.11 Line to line input current under balanced input voltages with loaded induction motor.

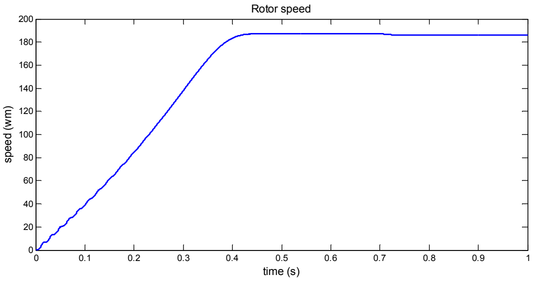


Figure 5.12 Rotor speed of the induction motor under loaded condition with balanced input voltages.

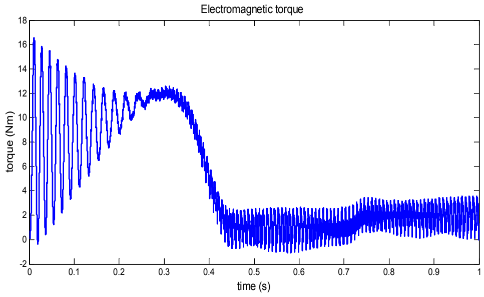


Figure 5.13 Electromagnetic Torque of the induction motor under loaded condition with balanced input voltages.

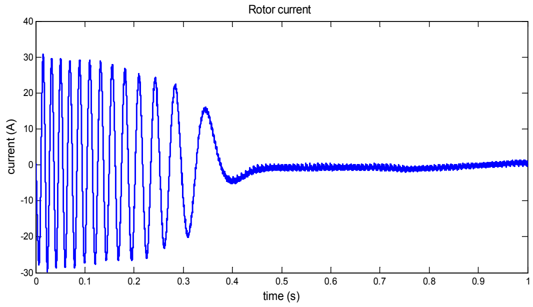


Figure 5.14 Rotor current of the induction motor under loaded condition with balanced input voltages.

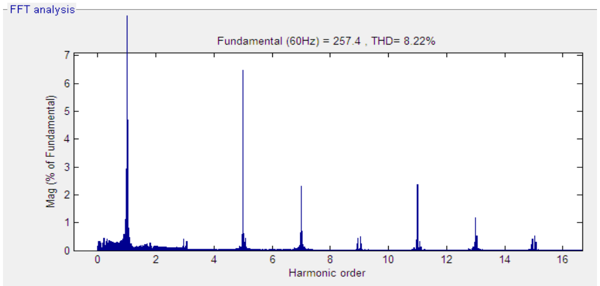


Figure 5.15 Harmonic spectrum for line to line output voltages under balanced input voltage condition with loaded induction motor.

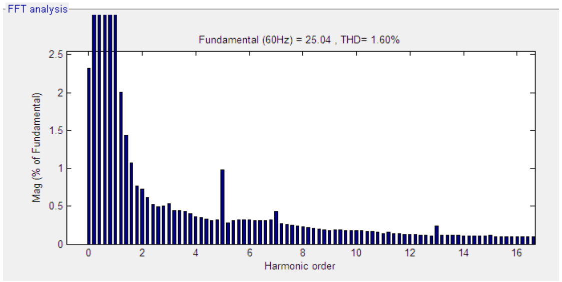


Figure 5.16 Harmonic spectrum for line to line input current under balanced input voltage condition with loaded induction motor.

The model is simulated under load condition of the induction motor with Unbalanced input voltage. The measured unbalanced input voltages, output voltage, input current and rated speed, torque and current are shown in the figure(5.17-5.22).

The Harmonic Spectrum of the output voltage and input current are shown in the figure (5.23-5.24).

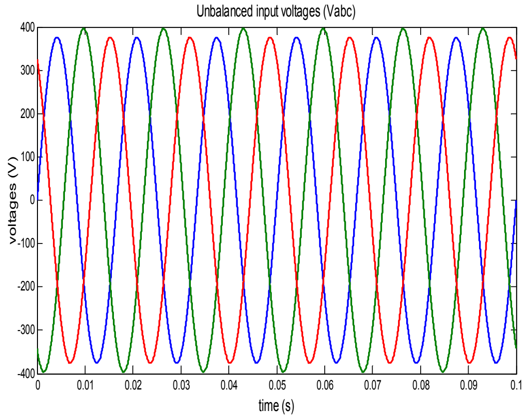


Figure 5.17 Unbalanced three phase input voltages

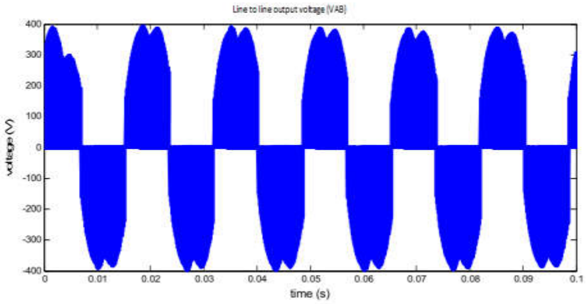


Figure 5.18 Line to line output voltage under unbalanced input voltage condition with loaded induction motor.

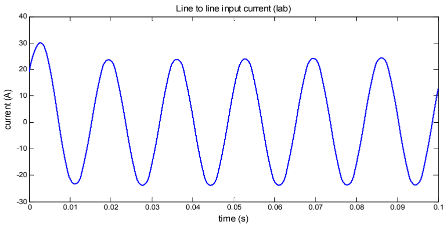


Figure 5.19 Line to line input current under Unbalanced input voltage condition with loaded induction motor.

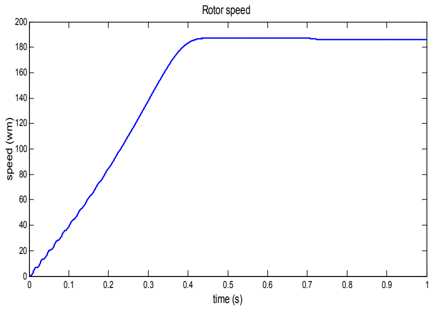


Figure 5.20 Rotor speed of the induction motor under loaded condition with unbalanced input voltages.

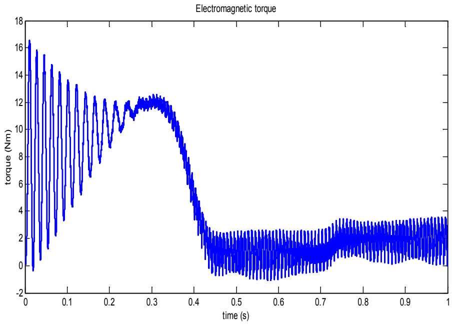


Figure 5.21 Electromagnetic Torque of the induction motor under loaded condition with Unbalanced input voltages.

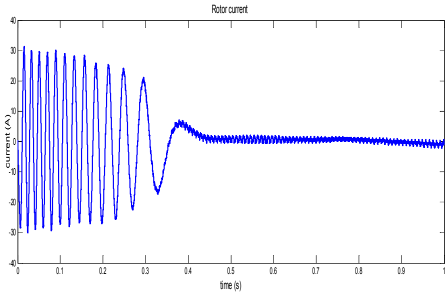


Figure 5.22 Rotor current of the induction motor under loaded condition with unbalanced input voltages.

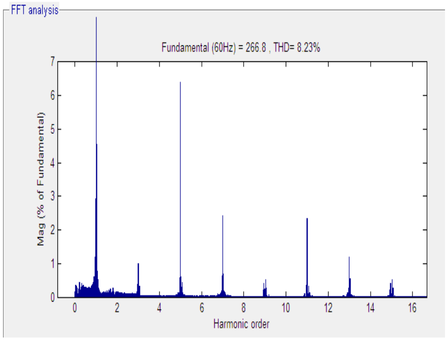


Figure 5.23 Harmonic spectrum for line to line output voltages under unbalanced input voltage condition with loaded induction motor.

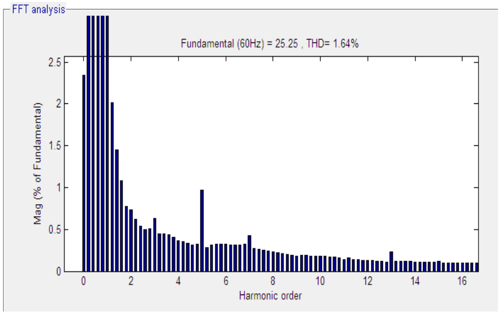


Figure 5.24 Harmonic spectrum for line to line input current under unbalance condition with loaded induction motor.

The THD values of the Input current and Output Voltage under Balanced and Unbalanced input Voltage condition with No-load and load condition of Induction Motor are tabulated as shown in the table 5.2.4

Table 5.2.4 Comparison of THD values of the input current and output voltages

CONDITIONS	INDUCTION MOTOR	PARAMETER	THD%
Balanced input Voltage	With load	Input Current	1.60
		Output Voltage	8.22
Unbalanced input Voltage	With load	Input Current	1.64
		Output Voltage	8.23

The model is simulated under load condition of the induction motor with Unbalanced input voltage using normal SVM technique. The measured unbalanced input voltages, output voltage, input current and rated speed, torque and current are shown in the figure(5.25-5.29). The Harmonic Spectrum of the output voltage and input current are shown in the figure (5.30-5.31).

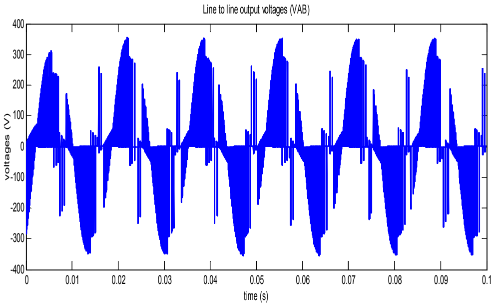


Figure 5.25 Line to line output voltage under unbalanced input voltage condition with loaded induction motor.

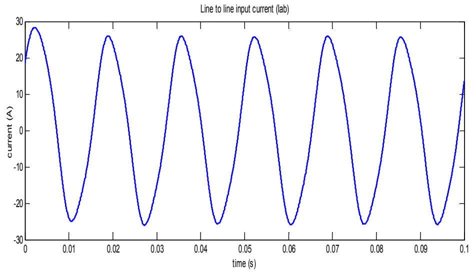


Figure 5.26 Line to line input current under Unbalanced input voltage condition with loaded induction motor.

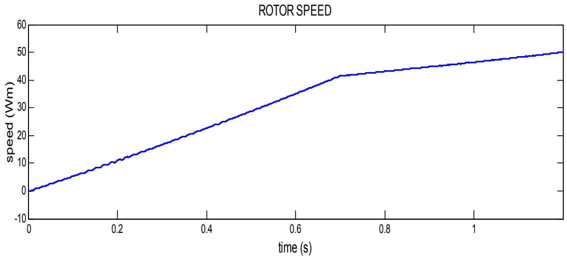


Figure 5.27 Rotor speed of the induction motor under loaded condition with unbalanced input voltages.

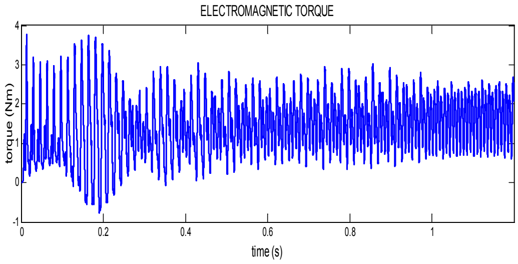


Figure 5.28 Electromagnetic Torque of the induction motor under loaded condition with Unbalanced input voltages.

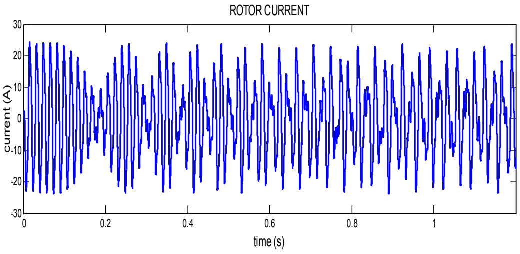


Figure 5.29 Rotor current of the induction motor under loaded condition with unbalanced input voltages.

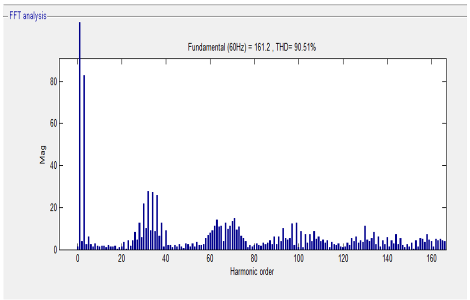


Figure 5.30 Harmonic spectrum for line to line output voltages under unbalanced input voltage condition with loaded induction motor.

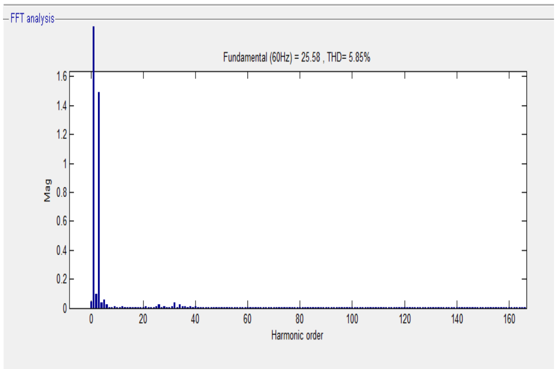


Figure 5.31 Harmonic spectrum for line to line input current under unbalance condition with loaded induction motor.

Table 5.2.4 Comparison of THD values of the input current and output voltages for both normal SVM technique and Proposed SVMtechnique.

TECHNIQUE	**CONDITIONS**	**INDUCTION MOTOR**	**PARAM-ETER**	**THD %**
Normal SVM technique	Unbalanced input Voltage	With load	Input Current	1.64
			Output Voltage	8.23
Proposed SVM technique	Unbalanced input Voltage	With load	Input Current	5.85
			Output Voltage	90.51

CONCLUSION

In this project, a new modulation strategy for the MC operating under unbalanced input voltage conditions is presented. The proposed strategy ensures that optimal performance of the MC over the entire operation range, including the case when the converter operates with an output voltage greater than maximum attainable balanced output voltage under unbalanced input voltage conditions, is achieved. The modulation strategy, which is based on modification of the conventional SVM strategy, determines the optimal duty cycles of switching states. The THD value obtained for both balanced and unbalanced input voltage condition is almost similar. This is achieved by Space Vector Modulation technique.

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