UNIVERSITI PUTRA MALAYSIA

DESIGN AND IMPLEMENTATION OF A SINGLE-PHASE TO THREE-PHASE SPACE-VECTOR PWM-BASED MATRIX CONVERTER SYSTEM FOR INDUCTION MOTOR DRIVES

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By

VENGADESHWARAN VELU

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Chair: **Prof. Ir. Norman Bin Mariun, PhD**
Faculty: **Engineering**

The advancement in the power electronics devices and modules creates an avenue to design and develop innovative direct ac-ac converters with more efficient and effective characteristics. Poly phase devices such as three phase induction motors have many advantages compared to its single phase counter parts in terms of performance efficiency and load characteristics. In real life, three phase power supply is not readily available in many places, especially in the remote locations, rural areas, hill stations, ordinary homes etc. Thus, having a converter that's capable of converting the available single phase source to a three phase power supply will be very useful in such environments.

Matrix Converter is an emerging power electronics technology based direct ac-ac converter that replaces the existing multi-stage and energy storage element conversion topologies. Compared to the other available ac-ac converters, Matrix converter has many advantages such as bidirectional energy flow capability, less harmonics and high power factor operation. Matrix Converter arrays are made of IGBT based bidirectional switches with reverse blocking capabilities. Similar research initiatives reported that the switching sequences of the bidirectional switches are controlled by different modulation algorithms such as pulse width modulation technique, sinusoidal pulse width modulation technique etc. However, the output voltages of these topologies suffer from low voltage transfer ratio and high harmonic content.

The objective of this research is to design and develop a single phase to three phase direct ac-ac Bidirectional switches based Matrix Converter system for operating the poly phase loads using a single phase source. A novel approach is adopted by employing the Space Vector Pulse Width modulation algorithm to produce the switching sequences of the bidirectional switches of the single-phase to three-phase Matrix Converter. A novel technique of employing a sinusoidal signal as reference is used in order to phase shift the space vector pwm pulses during negative cycle operations. A novel segregation technique is adopted in order to segregate the input signal into six sectors voltages to distribute equally among the output phases. A unique finding to achieve the balanced output voltages with relatively high voltage transfer ratio is presented. The proposed topology was modelled in the Matlab/Simulink environment and tested for functional efficacy. The hardware of the Matrix Converter system is implemented using six IGBT based bidirectional switches in a (2 x 3) array. Digital Signal Processor is used as a control system to produce the switching sequences

of the individual bidirectional switches based on space vector Pulse Width Modulation algorithm. Six sets of IGBT core drivers are used to provide the necessary switching pulses to gate terminals of the individual bidirectional switches based on the digital signal processor outputs.

The hardware circuit was tested under different power factor loads such as unity, lagging and leading power factor loads and under different frequency operations. The characteristics of the proposed system were studied under variable reference frequencies operations. The experimentation results showed that the proposed system achieved high voltage transfer ratio compared to other similar research initiatives. Furthermore, based on the variation of reference frequency characteristics it has been observed that when the reference frequency is adjusted beyond 150 Hz, the output voltages are found to be converging and becoming more balanced. Under low reference frequency operation, the output voltages are not balanced due to the low number of segregations of input signal that made the converter operating under high segregation angle. However above 150 Hz of reference frequency operation, the output voltages are found to be balanced due to the considerable reduction in the segregation angle. Under the balanced condition, the matrix converter produces an output line to line voltage of 80.8% of the available input voltage. Under this condition, a voltage transfer ratio of 0.466 is achieved. These unique findings provide more opportunity for further expansion of research to attain a higher voltage ratio with balanced voltages and less percentage total harmonic distortion. The project attained all its objectives with unique findings.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKAAN DAN PELAKSANAAN SATU FASA KEPADA TIGA-FASA RUANG VEKTOR PWM BERASASKAN KEPADA SISTEM PENUKAR MATRIK BAGI PEMACU MOTOR ARUHAN

Oleh

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Kemajuan dalam bidang peranti dan modul elektronik kuasa telah mencipta ruang untuk merekabentuk dan membangunkan penukar langsung ac-ac yang inovatif dengan ciri-ciri yang lebih cekap dan berkesan. Peranti polifasa seperti motor aruhan tiga fasa mempunyai banyak kelebihan berbanding dengan pesaingnya fasa tunggal dari segi kecekapan prestasi dan ciri-ciri bebanan. Dalam kehidupan sebenar, bekalan kuasa tiga fasa tidak terdapat di kebanyakan tempat terutamanya di kawasan terpencil, kawasan luar bandar, stesen-stesen bukit, rumah-rumah biasa dan lain-lain. Maka, mempunyai penukar yang mampu menukarkan sumber fasa tunggal yang sedia ada, kepada bekalan kuasa tiga fasa adalah sangat berguna dalam persekitaran sedemikian.

Penukar Matrix ialah teknologi elektronik kuasa yang membangun berasaskan penukar langsung ac-ac yang menggantikan topologi penukar multi tahap dan elemen penyimpanan tenaga yang sedia ada. Berbanding dengan penukar ac-ac lain yang sedia ada, Penukar Matrix mempunyai banyak kelebihan seperti keupayaan aliran tenaga dwiarah, kurang harmonik dan operasi faktor berkuasa tinggi. Tatasusunan Penukar Matrix diperbuat dari suis dwiarah berasaskan IGBT dengan keupayaan sekatan berbalik. Inisiatif penyelidikan yang sama melaporkan jujukan pensuisan daripada suis dwiarah adalah dikawal oleh algoritma modulasi yang berbeza seperti teknik modulasi denyut lebar, teknik modulasi denyut sinusoidal dan lain-lain. Walau bagaimanapun, voltan output topologi ini mengalami nisbah pemindahan voltan rendah dan kandungan harmonik yang tinggi.

Objektif kajian ini adalah merekabentuk dan membangunkan sistem Penukar Matrix berasaskan suis dwiarah ac-ac langsung fasa tunggal (fasa tunggal) kepada tiga fasa untuk mengendalikan beban polifasa menggunakan sumber fasa tunggal. Pendekatan novel diterimapakai dengan menggunakan algoritma Ruang-Vektor denyutan modulasi lebar untuk menghasilkan urutan beralih daripada suis dwiarah se-fasa kepada Penukar Matriks tiga fasa. Satu teknik novel menggunakan isyarat bentuk sinus sebagai rujukan digunakan untuk peralihan fasa denyut ruang vektor PWM semasa operasi kitaran negatif. Satu teknik pengasingan novel digunapakai untuk mengasingkan isyarat input kepada enam sektor voltan bagi pengagihan sama rata di antara keluaran fasa. Penemuan unik untuk mencapai voltan keluaran yang seimbang dengan nisbah pemindahan voltan agak tinggi dibentangkan. Di bawah operasi frekuensi rujukan rendah, ketidakseimbangan voltan keluaran disebabkan oleh bilangan pengasingan isyarat masukan yang rendah yang mana membuatkan penukar beroperasi di bawah

sudut pengasingan tinggi. Walaubagaimanapun, operasi frekuensi rujukan di atas 150 Hz, voltan keluaran didapati tidak seimbang disebabkan oleh pengurangan yang besar dalam sudut pengasingan. Di bawah keadaan yang seimbang, penukar matriks menghasilkan garis keluaran voltan 80.8% daripada kemasukan voltan yang ada.

Dalam keadaan ini, nisbah pemindahan voltan 0.467 dicapai. Topologi yang dicadangkan telah dimodelkan dalam persekitaran Matlab / Simulink dan diuji keberkesanan fungsinya. Perkakasan sistem Penukar Matrix dilaksanakan menggunakan enam suis dwiarah berasaskan IGBT dalam tatasusunan (2 x 3). Pemproses Isyarat Digital (DSP) digunakan sebagai sistem kawalan untuk menghasilkan jujukan pensuisan daripada suis dwiarah individu berdasarkan ruang vector algoritma nadi modulasi lebar. Enam set pemacu teras IGBT digunakan untuk menyediakan denyutan pensuisan yang sesuai dengan gerbang terminal suis dwiarah individu berdasarkan keluaran daripada Pemproses Isyarat Digital (DSP).

Litar perkakasan ini telah diuji di bawah beban faktor kuasa yang berbeza seperti perpaduan, bebatan dan faktor kuasa mendulu dan di bawah operasi frekuensi yang berbeza. Ciri-ciri sistem yang dicadangkan ini telah dikaji berdasarkan pembolehubah operasi frekuensi rujukan. Keputusan ujikaji menunjukkan bahawa sistem yang dicadangkan mencapai nisbah pemindahan voltan yang tinggi berbanding dengan inisiatif penyelidikan lain yang serupa. Selanjutnya berdasarkan perubahan ciri-ciri frekuensi rujukan, pencerapan menunjukkan apabila frekuensi rujukan yang diselaraskan melebihi 150 Hz, voltan output didapati menjadi menumpu dan lebih seimbang. Penemuan unik ini memberikan lebih banyak peluang untuk mengembangkan lagi penyelidikan bagi mencapai nisbah voltan yang lebih tinggi dengan voltan yang seimbang dan peratusan jumlah herotan harmonik berkurang. Projek ini mencapai semua objektif dengan penemuan unik.

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I certify that a Thesis Examination Committee has met on 05 February 2016 to conduct the final examination of VELU VENGADESHWARAN on his thesis entitled DESIGN AND IMPLEMENTATION OF A SINGLE-PHASE TO THREE-PHASE SPACE-VECTOR PWM BASED MATRIX CONVERTER SYSTEM FOR INDUCTION MOTOR DRIVES in accordance with the Universiti Putra Malaysia [P.U.(A) 105] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS

FPGA	Field Programmable Gate Array
DSP	Digital Signal Processor
IGBT	Insulated Gate Bipolar Transistor
AC	Alternating Current
DC	Direct Current
PWM	Pulse Width Modulation
NCC	Naturally Commutated Cycloconverter
FCC	Forced Commutated Cycloconverter
MC	Matrix Converter
DCSP	Direct Current to Single Phase
DCTP	Direct Current to Three Phase
SPSP	Single Phase to Single Phase
TPSP	Three Phase to Single Phase
TPTP	Three Phase to Three Phase
SPTP	Single Phase to Three Phase
VTR	Voltage Transfer Ratio
SPTPMC	Single Phase to Three Phase Matrix Converter
SVPWM	Space Vector Pulse Width Modulation
THD	Total Harmonic Distortion
BR-I	Bridge Rectifier - Inverter
SR-I	Switched Rectifier - Inverter
α	Firing Angle
SPWM	Sinusoidal Pulse Width Modulation
M	Modulation Index
V_{ref}	Reference Voltage
V_{tri}	Triangular Voltage
V_{in}	Input Voltage
f_r	Reference Voltage Frequency
f_c	Carrier Frequency
N	Carrier Wave Ratio
f_o	Output Frequency
SVM	Space Vector Modulation
Ni	Magneto-motive force
φ	Magnetic Flux
$\mathcal{R}$	Reluctance in Siemens
B	Flux Density in Wb/m^2
$\emptyset_m$	Maximum Flux
A	Area in m^2
I_m	Maximum or Peak Current
i_a	Phase-a Instantaneous Current
i_b	Phase-b Instantaneous Current
ic	Phase-c Instantaneous Current
Vs-T	Volt-Sec
$\emptyset_r$	Resultant Flux
Ts	Sampling Time Duration
fs	Sampling Frequency
$V_{AO}(Average)$	Average Phase-a Output Voltage
$V_{BO}(Average)$	Average Phase-b Output Voltage

$V_{CO}(Average)$	Average Phase-c Output Voltage
ω	Angular Velocity in radians
V_T	Triplen Voltage
LC	Inductor – Capacitor Circuit
µF	Micro Farad
kW	Kilo Watts
V	Voltage
I	Current
kHz	Kilo – Hertz
Hz	Hertz
RSG	Reference Signal Generator
α-β Transform	Alpha – Beta Transform
RG	Ramp Generator
STC	Switching Time Calculator
LG	Logic Gates
Vs	Source Voltage
SS	Sub Section
Pf	Power Factor
h.p	Horse Power
Nm	Newton Metre
CCS	Code Composer Studio
IDE	Integrated Development Environment
GPIO	General Purpose Input Output
CT	Concept Technologies
ASIC	Application Specific Integrated Circuits
RBSOA	Reverse Bias Safe Operating Area
V_{ab} / V_{RY}	Line to Line Voltage between Phase-a and Phase-b / Phase-R and Phase-Y
V_{bc}/ V_{YB}	Line to Line Voltage between Phase-b and Phase-c / Phase-Y and Phase-B
V_{ca}/ V_{BR}	Line to Line Voltage between Phase-c and Phase-a / Phase-B and Phase-R
V_a / V_R	Phase Voltage across Phase-a / Phase-R winding
V_b / V_Y	Phase Voltage across Phase-b / Phase-Y winding
V_c / V_B	Phase Voltage across Phase-c / Phase-B winding
I_a / I_R	Current through Phase-a / Phase-R winding
I_b / I_Y	Current through Phase-b / Phase-Y winding
I_c / I_B	Current through Phase-c / Phase-B winding
RMS / rms	Root Mean Square value

CHAPTER 1

INTRODUCTION

1.1 Background of Matrix Converter

In recent times, electrical engineers are required to incorporate energy efficiency, global warming, natural resources and sustainability in the design and development of electrical systems. Inverter controlled electrical machines are widely employed in air-conditioners, refrigerators, elevators, traction and other home applications. State of the art power electronics devices and modules are used to create more energy efficient and economical products. Even though the inverter circuits are more efficient, they require additional power semiconductor devices, electrolyte capacitors and reactors in the design that increase the size and price (Takahashi, Hisamichi, & Haga, 2009). The newer design should avoid the electrolyte capacitors and reactors in the design for more efficient power converter products.

Matrix converter is one of the advanced all silicon based direct ac-ac converters with fully controlled variable frequency outputs. Three phase squirrel cage and phase wound Induction Motors have many advantages compared to the single phase induction motors in terms of performance characteristics, stability and output torque. Thus, the three phase induction motors are preferred in many applications and its single phase counterpart is being replaced by poly phase induction motors. This replacement requires the three phase power supply source readily available everywhere. However, in reality, three phase power supply is not readily available everywhere especially in remote locations, rural areas, hill stations, low voltage home supply etc. Having a direct ac-ac power electronics converter that has a capability of converting the available single phase alternating source to a three phase supply will be beneficial.

Pulse width modulation based variable frequency drives technology is being employed for effective speed control mechanism of three phase induction motor. These drives are widely employed in many applications such as Electric/Hybrid Vehicles, Industrial drives etc (Sahoo, Meenakshe, Dash, & Thyagarajan, 2007). Thus there is an additional requirement that the proposed converter should have the capability of converting the constant frequency single phase source to variable frequency three phase source. Numerous similar research initiatives presented different topological structures of matrix converter incorporating additive parts of reactors, switches and capacitors (Xiao, Zhang, Omori, & Matsui, 2009).

State of the art research initiatives in the field of power electronics yielded advanced power bidirectional switches and other microelectronic devices that operate under high speed switching operations. Further, advancements in the FPGA and Digital Signal Processors / Controllers research had led to many innovations in the design of advanced controllers with sophisticated performance characteristics.

AC to AC converters using Insulated Gate Bipolar Transistor (IGBT) based Bi-directional switches are gaining more popularity for its unrestricted performance characteristics (Xiao et al., 2009). In general, the Matrix Converters can be classified into direct matrix converters and indirect matrix converters. The direct matrix converter has the capabilities of directly converting any available input sinusoidal source to the

any desired values of sinusoidal outputs. However, in indirect matrix converters, the available input sinusoidal source is converted to a dc signal in a dc link and then inverted back to desired sinusoidal output signals. The dc link of the indirect converter slows down tremendously the transient response of the converter circuit. The indirect matrix converters suffer with many drawbacks such as the input currents contain huge content of harmonics which causes distortion to the input voltages. The indirect converter is also found to be sensitive to the temperature variations due to the dc link capacitor. In the direct matrix converters, a constant frequency alternating signal is directly converted in to a variable frequency alternating signal through an array of static power electronics switches connected between input and output terminals. Pulse Width Modulation (PWM) technique is used to segregate the input constant sinusoidal signal into the output signal at desired amplitude and frequency.

Cycloconverter is a direct converter which is widely employed in the design of variable frequency drives. Based on the commutation employed, the Cycloconverter can be classified into Naturally Commutated Cycloconverter (NCC) and Forced Commutated Cycloconverter (FCC). In Naturally Commutated Converters, switches can be turned off naturally by the supply voltage whereas in the Forced Commutated Converters, the control of the turn off is independent of the supply voltage. Thus, Forced Commutator Converters are highly employed in the higher frequency operation switch uses with high sampling frequency for the production of pulse width modulation control switching sequences.

The definition for the Matrix Converter is as follows:

> "Matrix converter provides sinusoidal input and output waveform with minimum higher order harmonics; its input current wave form is pure sinusoidal and the input power factor is unity, bi-directional energy flow capability, four-quadrant operation and High reliability and long life due to the lack of energy storage reactive components, which allows a compact design" (M. Imayavaramban, 2004).

Matrix Converters can also be classified into various types based on the number of phases used in input and output terminals. It can be classified into Direct Current to Single Phase (DCSP) matrix converter, Direct Current to Three Phase (DCTP) matrix converter, Single Phase to Single Phase (SPSP) matrix converter, Two Phase to Single Phase (TPSP) matrix converter, Three Phase to Three Phase (TPTP) matrix converter and Single Phase to Three Phase (SPTP) matrix converter. The design and development of the Single Phase to Three Phase direct ac-ac matrix converter is more challenging compared to other types of Matrix Converters. This is due to the complexity of segregating a single constant frequency sinusoidal signal into three balanced signals with the phase angle shift of 120° between each other.

Many topologies on the single phase to three phase matrix converter have been suggested by researchers through similar research initiatives which will be discussed in detail later in the thesis. If it is required to select a topology for an efficient direct ac-ac conversion without any added storage elements, then the Matric Converter is the best option.

1.2 Problem statement

In conventional direct matrix converter topologies, six to nine bidirectional switches are used along with filter circuit, clamp circuit and snubber circuits between the single phase input source and the three phase load terminals. The matrix converter switches are to be programmed in a unique and sophisticated way to avoid the direct short circuit between input terminals and the open circuit across the load terminals.

The purpose of the filter circuit is to eliminate the harmonics content of the Matrix Converter from the supply mains. Clamp circuits are being used to block the reverse over voltages transients across the open circuited switches. However, an unique problem is reported in many papers that all the existing topology models of single to three phase matrix converters suffer from the low voltage transfer ratio (VTR) (Xiao et al., 2009).

The voltage transfer ratio is defined as the ratio of the output phase voltage to that of the input source voltage. It is reported that only a voltage transfer ratio of 0.31 has been achieved in the separation and link topology of single phase to three phase matrix converter system. (Xiao et al, 2009).

The input supply voltage is the only source available in a Single Phase to Three Phase Matrix (SPTP) Converter. Thus, this source voltage has to be segregated equally and distributed across all the three phases with the phase angle difference of 120°.

Due to this distribution on input signal, the output voltage of the matrix converter is found to be only one third of the input voltage, thus only a reduced voltage is applied to the load which significantly affects the performance of the induction motors.

It has been observed and reported that the low voltage transfer ratio in most cases is around 0.31 to 0.33 (Xiao et al., 2009)., thus there is a need to explore ways and means to improve the low voltage gain transfer ratio at least to a significant level. This research attempts to minimize or (if possibly) eradicate the low voltage transfer ratio problem in single phase to three phase matrix converters.

A unique and novel space vector pulse width modulation (SVPWM) scheme is employed to generate the switching sequence of the Insulated Gate Bipolar Transistor based bi-directional switches of the Matrix Converter. Similar research initiatives have not been reported using Space Vector Pulse Width Modulated algorithm for producing the PWM Switching sequences so far. Thus it creates a new avenue to explore the operational efficacy of the Matrix Converter system under Space Vector Pulse Width Modulation based control system particularly for the single phase to three phase direct conversion.

1.3 Research aim and objectives

The aim of this research is to design and develop a direct ac-ac converter capable of producing the three phase balanced output voltages that are displaced at 120 degrees away from each other from a single phase alternating sinusoidal source in view of operating the three phase loads by adopting the Space Vector Pulse Width Modulation

to generate the necessary switching sequences of the IGBT based bidirectional switches of the Matrix Converter.

The performance characteristics of the proposed model will be tested through both simulation and practical experimentation. A detailed analysis will be conducted on the obtained results. The objectives of the research are carefully drafted based on the aims of the research undertaken.

The objectives of this research are:

- To design and implement the single-phase to three-phase matrix converter model to produce the balanced output voltages across the load.
- To implement the Space Vector Pulse Width Modulation scheme for generating the switching sequences of the bidirectional switches of the matrix converter
- To achieve a higher voltage transfer ratio of the proposed single-phase to three-phase matrix converter model
- To analyse the characteristics of the single-phase to three-phase matrix converter for the performance efficiency and to recommend the unique findings.

1.4 The scope and limitation of the research

The scope of this research initiative is limited due to the uniqueness and novelty of the technology adopted. Only limited research papers are available even for the direct ac-ac conversion of single phase to three phase system without using a rectifier stage. Among the available papers, none of them has reported using the space vector pulse width modulation algorithm for switching the bidirectional switches of the Matrix Converter. Adopting the SVPWM Algorithm creates a new opportunity to be explored. Due to its complexity and state of the art nature, the scope of this research is limited to practical implementation of the fully functional Matrix Converter system. The recommendation of expansion of this research initiative will be discussed in the last chapter of this thesis. There are many limitations identified on the practical implementation of the hardware circuitry.

The major limitation is the functional characteristics of the Digital Signal Processors which is used as the backbone for generating the pwm signals. Digital Signal Processors are unable to process the continuous signals, only discrete signals are only processed. Bidirectional switches of the Matrix Converter had to be custom made based on the design parameters. The second limitation expected is in the inter-operability of bidirectional switches with the Insulated Gate Bipolar Transistor Core Drivers and the Digital Signal Processor / Controllers. The Matrix Converter system is to be designed carefully either to eliminate completely or to minimize all the inter-operability issues that arise during the hardware implementation.

1.5 Structure of the thesis

The structure of this thesis consists of Six Chapters inclusive of the Introduction Chapter. The other Chapters are the Literature Review, Simulation of the System Design, Hardware Implementation and Realization, Results and Analysis and Summary, General Conclusion and recommendation for future research.

Chapter 1 is the Introduction chapter in which the background the Matrix Converter has been introduced. The problem statement is defined and the research aims and objectives are stipulated. It also provides the scope of the research and its limitations. Finally the structure of the thesis has been explained in detail.

Chapter 2 provides the details of the Literature Review performed. It explains the types of ac-ac converters available in the market and the constructional details of the conventional Matrix Converter. It introduces the Space Vector Pulse Width Modulation and other modulation schemes. It also explains how the switching sequences are produced. Lastly, it provides the details of the available topologies of the Matrix Converter and comparison study on its performance efficiency.

Chapter 3 provides the details of the Simulation of System Design and modelling. It also explains the stages involved in the design and development of the system model. It provides the generalized theory and modelling of Space Vector Pulse Width Modulation Algorithm, modelling of bidirectional switches based Matrix Converter System and the simulation models of Matrix Converter under different power factor conditions.

Chapter 3 deals with the Hardware Implementation and Realization. It provides the details of the various stages of the hardware circuits, particularly the details of the Digital Signal Processor circuits, the Interface circuits, Core driver and base band circuits, Synchronization circuits and Matrix Converter Circuits. It also provides the details of various power factor loads and protective devices used to test the converter circuits.

Chapter 5 is the Result and Analysis chapter in which the detailed analyses of the obtained results are reported. The per unit voltage transfer ratio and the per unit voltage variation are defined. The Percentage Total Harmonic Distortion (% THD) is discussed for each case in detail. Secondly, the effects of changes in the reference frequencies are discussed in detail. Finally the modulation index characteristics under different frequency conditions are discussed.

Chapter 6 provides the detailed summary of the adopted research along with the general conclusion based on the obtained results and findings. It also provides the recommendations for future research initiatives with details of potential scope for the expansion of the currently research initiative.

1.6 Contribution

The following are the list of contributions made by this thesis:

a) A novel approach is adopted in employing the Space Vector Pulse Width Modulation algorithm to produce the switching sequences of the bidirectional switches to control the operations of the Matrix Converter. None of the papers reported employing Space Vector Pulse Width Modulation as a control algorithm in direct ac to ac single phase to three phase Matrix Converter.
b) Techniques of generating the PWM signals using the digital signal processor as the control system is presented which is used to control the IGBT Core driver circuits.

c) Techniques in adopting the IGBT based Bidirectional switches to construct the single phase to three phase matrix converter is presented.
d) A unique finding to achieve the balanced output voltages with high voltage transfer ratio is presented.
e) Recommendation for further improvement and enhancement of the operation of the matrix converter is presented for further research.

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