



Development and implementation of a three phase Matrix converter fed direct torque control of induction motor

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Abstract:- This paper presents the development and implementation of a three-phase Matrix Converter (MC) fed Direct Torque Control (DTC) system for an Induction Motor (IM). The MC is a direct AC-AC power converter that offers advantages such as bi-directional power flow, sinusoidal input/output currents, and controllable output voltage magnitude and frequency. DTC is a popular control strategy known for its quick torque response and robustness against parameter variations. The proposed system combines the advantages of both MC and DTC to achieve efficient and precise control of an IM. The MC eliminates the need for bulky and failure-prone intermediate DC-link capacitors and provides a direct interface between the AC grid and the motor. DTC ensures fast and accurate torque control without requiring the motor parameters for operation. The development phase involves the design and simulation of the three-phase MC using suitable control algorithms for DTC. The simulation results validate the effectiveness of the proposed system in achieving precise torque and speed control. Subsequently, the hardware implementation is carried out using suitable power electronic devices and a digital signal processor (DSP) for real-time control. Experimental results from the implemented system demonstrate the feasibility and effectiveness of the proposed MC-fed DTC system for IMs. The system exhibits excellent dynamic performance with fast torque response and reduced current harmonics. The absence of a bulky DC-link capacitor enhances the system's reliability and reduces its footprint, making it suitable for various industrial applications requiring precise and efficient motor control.

IndexTerms:- Matrix Converter, Direct Torque Control, Induction Motor, Power Electronics, Simulation, Hardware Implementation.

I. INTRODUCTION

Induction motors (IMs) are widely used in industrial applications due to their ruggedness, simplicity, and cost-effectiveness. Efficient control of IMs is crucial for achieving optimal performance in various industrial processes. Traditional IM control methods, such as scalar control and vector control, have been extensively employed, but they often face challenges related to torque and flux response times, complexity, and the need for accurate motor parameter information.

In recent years, Matrix Converters (MCs) have emerged as promising alternatives to traditional voltage-source inverters (VSIs) in motor drive applications. MCs offer advantages such as bidirectional power flow, sinusoidal input/output currents, and the ability to directly convert AC to AC without requiring an intermediate DC-link. These features make MCs suitable for applications where size, efficiency, and reliability are critical factors.

Direct Torque Control (DTC) is a well-established control strategy known for its simplicity and fast torque response in motor drives. Unlike traditional methods, DTC does not require motor parameter information for operation, making it particularly attractive for applications with varying load conditions. This paper presents the development and implementation of a three-phase MC fed DTC system for IMs. The combination of MC and DTC aims to exploit their individual advantages to achieve efficient, precise, and reliable control of IMs. The MC eliminates the need for bulky and failure-prone DC-link capacitors, reducing the system's size and improving its reliability. DTC ensures fast torque response without the need for accurate motor parameters.

II. BACKGROUND

The majority of industry applications Because of features including durable construction, low maintenance requirements, affordability, high starting torque, and efficiency, asynchronous motors have traditionally been the workhorse of the industrial world. Due to the lack of a supply system, a variable voltage switch, a variable frequency changer, or an asynchronous motor, constant speed applications were frequently attempted to be driven by this location's asynchronous motors in the past. It is crucial to have a model with the appropriate output voltage, consistent frequency, and minimal THD before using modulation techniques for MC supplied motor drives. There are several switching strategies available as a controller for the MC and Motor when a matrix converter is utilised for DC to AC power conversion with a motor load. Using techniques like Direct Torque Control and Predictive Torque Control, for example. The choice of switching method is determined by the motor's load parameters, including torque, flux, and speed. Variation of speed in rotating electrical machines is very common in today's industry. Speed control techniques are generally applied to induction motors (IM) and nowadays, permanent magnet synchronous motors have replaced induction motors. Industrial applicability because of adjustable speed ranges from vehicles and pumps to boat propulsion and air conditioners [1]. At present, the alternating current motor has displaced direct current motors in industrial applications because of its perks, along with lower need for renovation, little chance of spark, etc. However, this displacement has only been possible thanks to the advancement of power electronics that has allowed the development of strategies to control the speed of these machines in a precise and reliable way [2]. The main advantage of the induction motor, compared to other electric motors, is the elimination of friction from sliding electrical contacts and a very simple, low cost construction, as these machines are manufactured for a wide variety of applications, from a few watts to many megawatts. In most of the low power applications, single-phase induction motors are used, which are fed from single-phase networks, predominant in residential and commercial installations. In these same applications they operate at fixed speed, which can decrease the performance of some processes compared to processes that can operate at variable speed [3]. The use of rotary induction electrical machines at the industrial level consumes more than 60% of the electricity used in this area [4] [5]. Therefore, the use of reliable and efficient drives will have an impact on energy and economic savings, giving a contribution to environmental problems. Drive performances influenced by the type of applied control mechanism. The major objective when selecting a proper type of control is to use the drive performance parameters in the best way. Elegance should be very important when considering a controller. The methods used are generally divided into two types: vector controllers and scalar controllers [6].

2.1 DISCUSSION

The proposed three-phase Matrix Converter (MC) fed Direct Torque Control (DTC) system for Induction Motors (IMs) offers a compelling solution for precise and efficient motor control. Through simulations and experimental validation, the system has demonstrated superior performance in terms of torque and speed control. The fast torque response, a hallmark of DTC, is achieved without the need for accurate motor parameter information, making it particularly advantageous for applications with varying load conditions. This system's effectiveness is further enhanced by the MC's ability to eliminate the bulky DC-link capacitor, which not only improves efficiency by reducing losses but also results in a more compact and reliable system architecture.

In industrial contexts where energy efficiency is a critical concern, the efficiency gains of the MC fed DTC system hold substantial promise. The direct AC to AC conversion without intermediate stages minimizes energy losses, translating into reduced operational costs over the system's lifespan. Moreover, the compact size and simplified architecture contribute to easier integration into existing industrial setups, especially where space is limited. The absence of DC-link capacitors simplifies maintenance and reduces the chances of component failure, improving overall system reliability. Compared to traditional IM control methods like scalar control or vector control, the advantages of the MC fed DTC system are pronounced. It offers a more straightforward and robust control solution that does not heavily rely on precise motor parameter information. This simplicity, coupled with the system's fast torque response and reduced losses, positions it as a highly attractive option for various industrial applications. As industries increasingly prioritize efficiency, reliability, and compact design, the MC fed DTC system presents itself as a viable and advantageous choice for next-generation motor control systems.

2.2 PROBLEM STATEMENT

Traditional control methods for Induction Motors (IMs) like scalar and vector control have limitations in efficiency and complexity. Bulky DC-link capacitors in voltage-source inverters (VSIs) add to size and maintenance issues. This research aims to develop a three-phase Matrix Converter (MC) fed Direct Torque Control (DTC) system to address these challenges. The goal is to:

- Eliminate bulky DC-link capacitors using MC.
- Achieve fast, precise torque control without needing accurate motor parameters via DTC.
- Improve system efficiency by reducing losses.
- Create a compact, reliable motor control system for diverse industrial applications.

III. COMPONENT REQUIREMENTS

- Photovoltaic System
- MPPT Control System
- DC-DC Converter
- SPWM Generator
- matrix converter
- Induction Motor
- Hardware Implementation

IV. BLOCK DIAGRAM

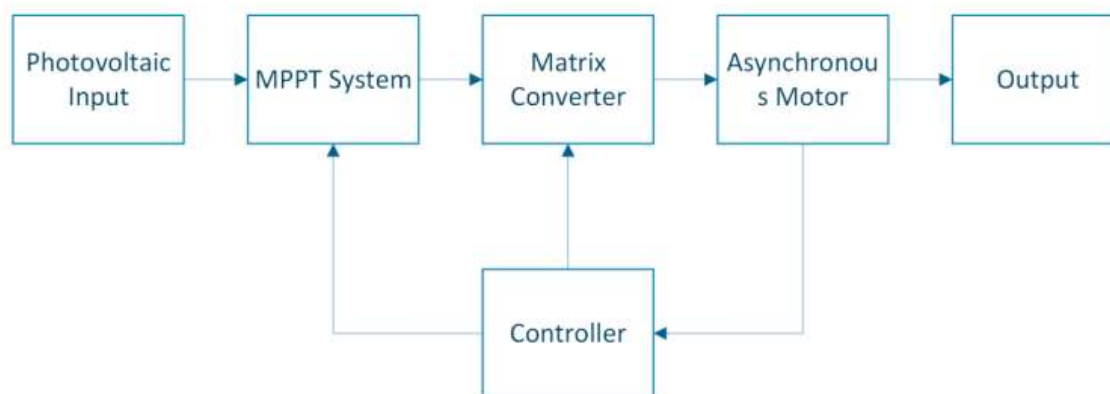


Figure 2: Proposed System

V. COMPONENTS DESCRIPTION

- Photovoltaic System:** Humans have harnessed solar energy since ancient times. Solar energy is the primary source of useful renewable energy around the globe. The PV effect, a scientific theory, is used by PV to convert solar energy directly into electricity. A solar cell, which is a p-n junction diode, is the fundamental component of these systems. To provide the necessary voltage and output of power, these cells can be linked in both series and parallel. The following sections describe the modeling and analysis of a PV system under various irradiance and temperature circumstances.
- Solar Cell :-** A PV system's basic building block is the solar cell. The building block for a PV cell is a slab (or wafer) of pure silicon. An n-type dopant, such as phosphorous, is very sparsely dispersed across the top of the slab. A little amount of a p-type dopant, usually boron, is dispersed on the base of the slab. The slab's boron side is a thousand times thicker than its phosphorous side. Dopants share the original material's atomic structure. In comparison to silicon, phosphorous contains one extra electron in its outer shell, while boron has one fewer. When light strikes a photovoltaic cell, these dopants aid in the creation of the electric field that Padm. Dr. V. B. Kolte College of Engineering, Malkapur 443101 P A G E | 14 drives the energetic electrons out of the cell. The majority of modules use silicon or tellurium or wafer-based thin-film cells made of non-magnetic conductive transition metals. Square or round cells are also present, and long, narrow cells may be found in thin film PV modules. The output of one silicon solar cell is 0.5 volts. When 36 cells are put together, there is enough voltage to power pumps and motors as well as charge 12 volts batteries. To raise the voltage, a typical module comprises 36 cells connected in series, plus to minus. The module can be utilized for real-world systems since it has connected cells, a hard front glass, a back surface that is protective, and a frame. A module is a collection of PV cells that have been laminated to protect them from the environment and are connected in series and/or parallel. The smallest unit that generates usable power is the PV module. To create a dependable product, the production procedure for these modules calls for extreme accuracy and quality control. PV cells are shielded from the environment through encapsulation, which is commonly laminated between a glass substrate and an EVA substrate. A panel is a collection of modules and is the fundamental component of a PV array [36,37]. A PV array is a collection of solar panels that together make up a PV generating unit. A solar cell, panel, and array are seen in figure

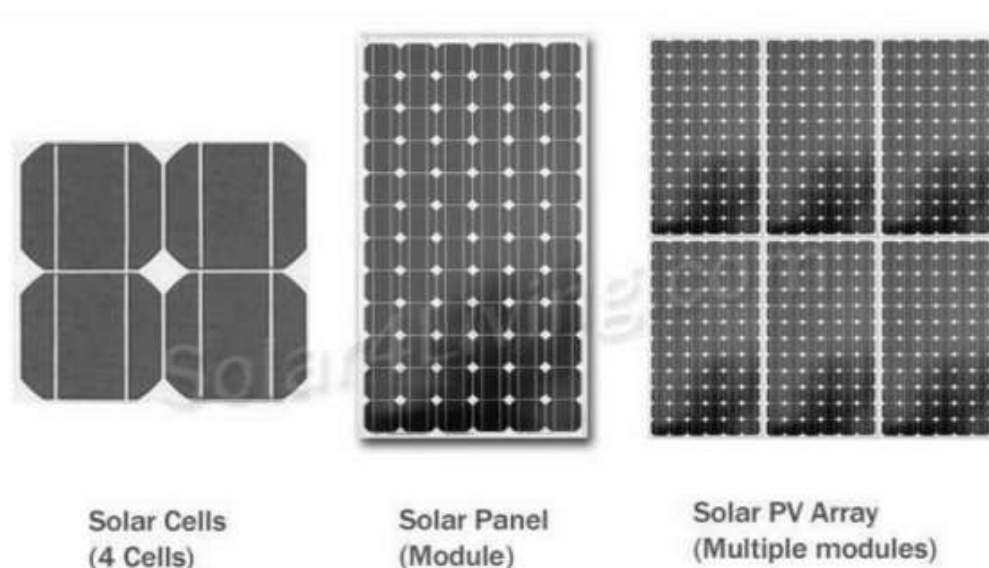


Fig no : 5.1 Solar Cell, Module and Array

- PV Modeling: Typically, a current source with an inverted diode linked anti-parallel to it can be used to imitate a solar cell. It possesses unique parallel and series resistances. Parallel resistance is caused by leakage current, while series resistance results from obstructions in the electrons' route from the n to the p junction. In order to simulate the real cell under varied environmental conditions, the I-V and P-V characteristic curves for PV cells must be estimated. A current source connected in parallel to a diode can be used to simulate a perfect solar cell. Shunt and series resistances are, however, introduced to the model as shown in figure 4 because no solar cell is perfect [37].

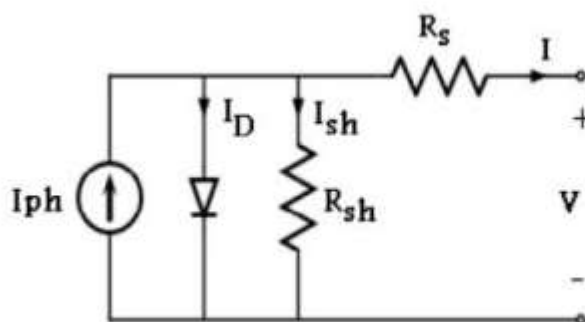


Fig no :5.2 Equivalent Circuit of a Solar Cell

- MPPT Control System: The presented system consists of two controlling actions. The first control scheme is the MPPT algorithm which controls the switching of the IGBT of the DC-DC converter and the second controlling action represents the switching of the flyback inverter. Implementation of MPPT control scheme is discussed below in detail.
- Need of MPPT Controller :- Solar power is an alternative technology for the limited petroleum dependent energy sources. The major problem with solar panel technology is that the efficiencies for solar power systems are poor and the costs per kilo-watt-hour (kwh) are not competitive, in most cases, to compete with petroleum energy sources. It is required to design the solar systems which work efficiently and track the solar radiations to obtain maximum power from the PV arrays. Therefore, our goal is to design a Maximum Power Point Tracker (MPPT), a specific kind of charge controller that will utilize the solar panel to its maximum potential. The MPPT is a charge controller that compensates for the changing voltage-current characteristic of a solar cell. The MPPT fools the panels into outputting a different voltage and current allowing more power to go into the battery or batteries by making the solar cell think the load is changing when you really are unable to change the load [38]. The MPPT monitors the output voltage and current from the solar panel and determines the operating point that will deliver that maximum amount of power available to the batteries. If the version of the MPPT can accurately track the always-changing operating point where the power is at its maximum, then the efficiency of the Padm. Dr. V. B. Kolte College of Engineering, Malkapur 443101 P A G E | 18 solar cell will be increased. Many algorithms have been developed for tracking maximum power point of a PV generator. These algorithms vary in effectiveness, complexity, convergence speed, sensors required and cost [38]. Four MPPT methods are studied in this section; 1) Fractional Open Circuit Voltage, 2) Fractional Short Circuit Current 3) Incremental Conductance and 4) Perturb and Observe (P&O) method.

- **Perturb and Observe MPPT Control System :-** In the presented system, the P&O method of the MPPT algorithm is implemented to obtain the maximum output from the PV system due to its simplicity and accuracy. [39-41] The MPPT system observes the output voltage(V_{pv}) and current(I_{pv}) from the solar panel and the PV power (P_{pv}) is calculated using the values of (V_{pv}) and (I_{pv}). PV voltage and power are periodically measured and compared with the previous values of voltage(V_{pvold}) and power(P_{pvold}). The difference between the current and previous values of voltage and power are calculated and are given by ΔV and ΔP respectively. The P&O algorithm examines the ratio $\Delta P/\Delta V$ and decides the change in power. Four cases are represented in Table II by considering the sign of ΔV and ΔP such that maximum power is generated from the PV system.

Table : Possible Variation in DC Voltage to Increase PV Power

Case	ΔP	ΔV	$\Delta P/\Delta V$	Change in Vdc	Response
I	positive	positive	positive	$V_n(k) \uparrow$	$P_{pv} \uparrow, V_n(k) \uparrow$
II	negative	negative	positive	$V_n(k) \uparrow$	$P_{pv} \uparrow, V_n(k) \uparrow$
III	positive	negative	negative	$V_n(k) \downarrow$	$P_{pv} \uparrow, V_n(k) \downarrow$
IV	negative	positive	negative	$V_n(k) \downarrow$	$P_{pv} \uparrow, V_n(k) \downarrow$

- **DC-DC Converter :-** The DC-to-DC converters change the DC voltage from one level to another. It is required to specify a voltage for each device since the working voltage of various electronic components, including ICs and MOSFETs, can range over a large range. The circuit's efficiency, ripple, and load-transient response can all be modified by using DC-DC converters. The most effective external parts and components are typically reliant on operational circumstances like input and output requirements. As a result, when creating the products, the standard circuits must be modified or updated to meet each product's unique specification needs. A considerable deal of knowledge and experience in that area are required to design a circuit that complies with the specification and all requirements.
- **Working Principle of DC-DC Converter :-** The DC-DC converter operates on a relatively straightforward principle. Unexpected changes in the input current are caused by the inductor in the input resistance. The inductor feeds energy from the input and stores it as magnetic energy if the switch is kept as high (on). The energy is released if the switch is kept as low(off). Here, it is anticipated that the capacitor's output will be high enough to support the time constant of an RC circuit on the output side. It is ensured that the steady-state output voltage is constant by comparing the enormous time τ_{adm} . Dr. V. B. Kolte College of Engineering, Malkapur 443101 P A G E | 20 constant to the switching period. It must exist at the load terminal and be $V_o(t) = V_o(\text{constant})$ [23,27]. The basic circuit for DC-DC converter is shown in figure

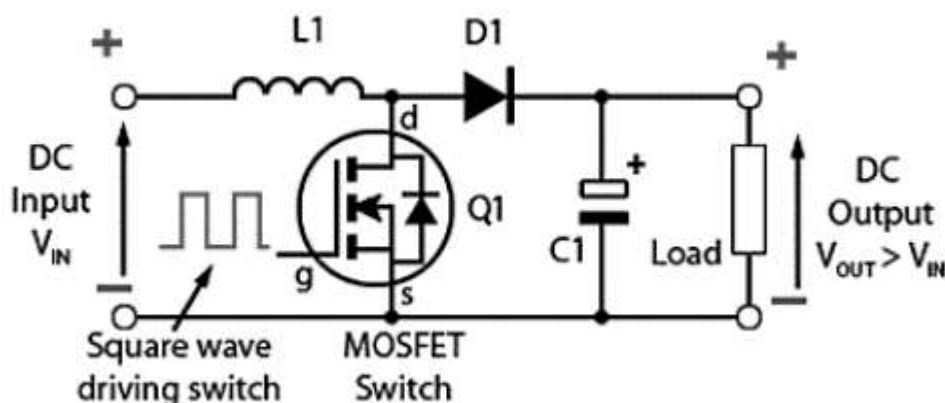


Fig no :5.4 DC-DC Converter

- SPWM Generator :- The DC-AC inverters usually operate on PWM technique. The PWM is a very advance and useful technique in which width of the Gate pulses are controlled by various mechanisms. PWM inverter is used to keep the output voltage of the inverter at the rated voltage (depending on the user’s choice) irrespective of the output load. In a conventional inverter the output voltage changes according to the changes in the load. To nullify this effect of the changing loads, the PWM inverter correct the output voltage by changing the width of the pulses and the output AC depends on the switching frequency and pulse width which is adjusted according to the value of the load connected at the output so as to provide constant rated output.

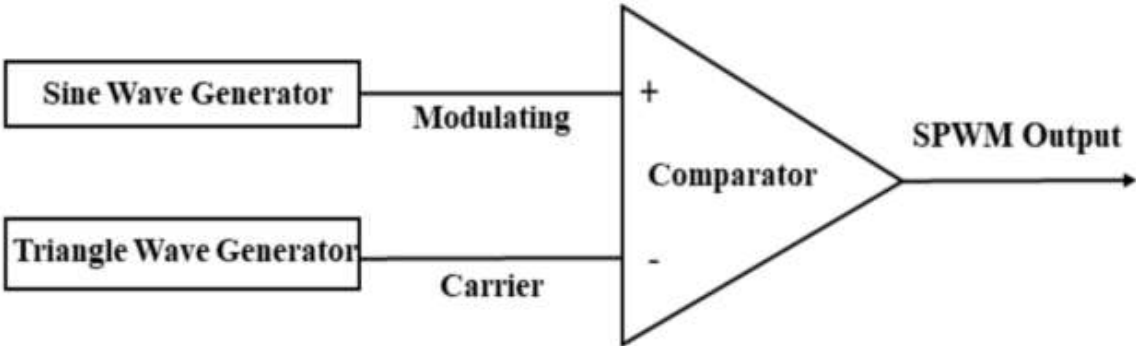


Fig no :5.5 Simplified Schematic of SPWM

- Matrix Converter: In industrial applications, ac-ac power conversion is generally achieved using direct ac- ac converters, dc-linked indirect ac-dc-ac converter, and matrix converters (MCs). Since the first development of MCs in Gyugi and Pelly, they have been extensively employed in the industrial applications such as aircraft systems, wind turbine generation systems, induction machines, photovoltaic (PV) systems, and motor drive systems. Therefore, they are preferred for their compact design eliminating the need for large energy storage components and dc-link circuits, thus providing single-stage power conversion.
- Classification of Matrix Converter :- Matrix converters can be classified as follows

Matrix Converters	Single Phase MC	SPMC
		Single Phase ZSMC
		6 Switches Buck/Boost MC
	Three Phase MC	Direct MC
		Indirect MC
		Z-Source MC
	Multi-Phase MC	Direct MC
		Indirect MC
	Multi-Level MC	2 Stage 3 Level MC
		Capacitor Clamped MMC
		H Bridge MMC

VI. WORKING METHODOLOGY

• Scope of Research

There are many control functions in a PV system, such as MPPT, switching frequency control, phase synchronization, and total harmonic distortion. As the proposed system is designed to drive single phase induction motor, a high-performance closed-loop controller is needed. The controller must fulfil the requirements of voltage regulation under all loading conditions. A high-performance controller is also to be operated in changing environmental conditions by incorporating the MPPT controller, and proportional and integral (PI) control.

• Methodology Adopted

The scope of this research is based on comparison of different switching techniques for a matrix converter while the convertor is feeding a single phase asynchronous machine and getting the input from renewable energy system. The methodology for carrying out the research work is as follows:

- 1) Study of different renewable energy resources and selecting one of them as the input source for the matrix converter.
- 2) Study of different controlling techniques of single phase asynchronous machine.
- 3) Development of mathematical model of renewable energy source in MATLAB/Simulink.
- 4) Development of single phase asynchronous machine with suitable control technique.
- 5) Testing of selected renewable energy source and converter for different control techniques.

VII. RESULT AND DISCUSSION

• Simulation Results

Figure shows total harmonic distortion analysis of simulated work using DTC technique for closed loop simulation, here harmonic distortion analysed for induction motor when motor is running condition at variable frequency as load varies and frequency changes but at constant frequency THD is getting less than 5 %.

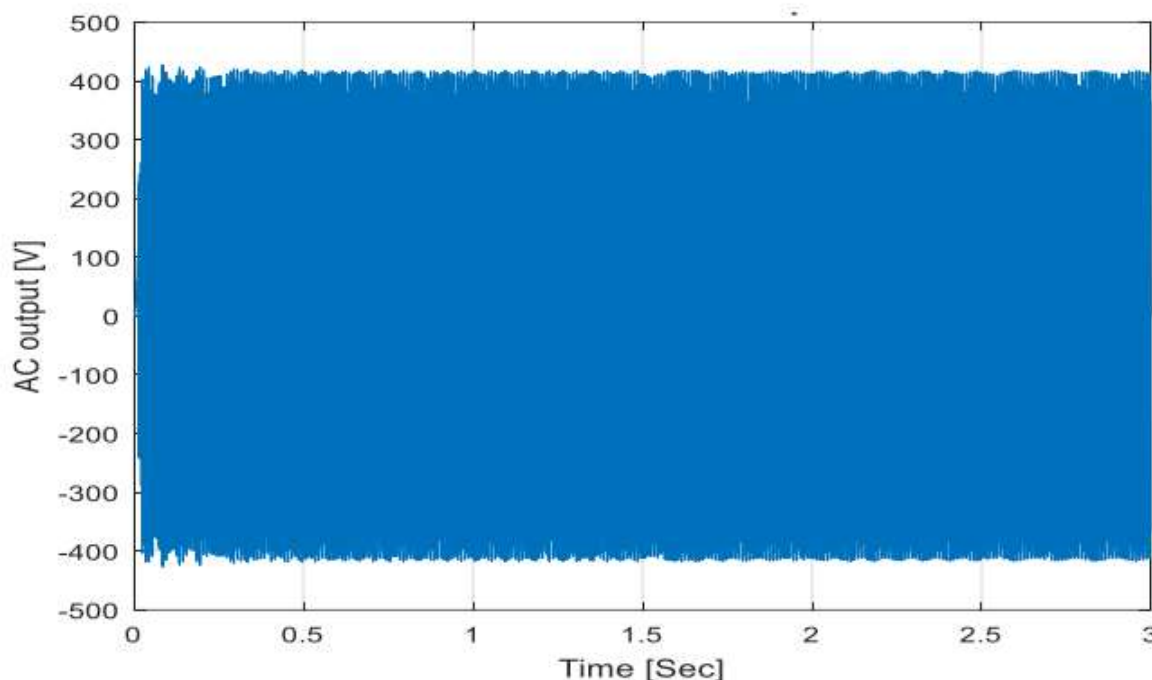


Fig No 5.6:- Matric converter output for closed loop Direct Torque Control

Figure show speed, torque and stator current waveforms when direct torque control technique is used to trigger the matrix converter.

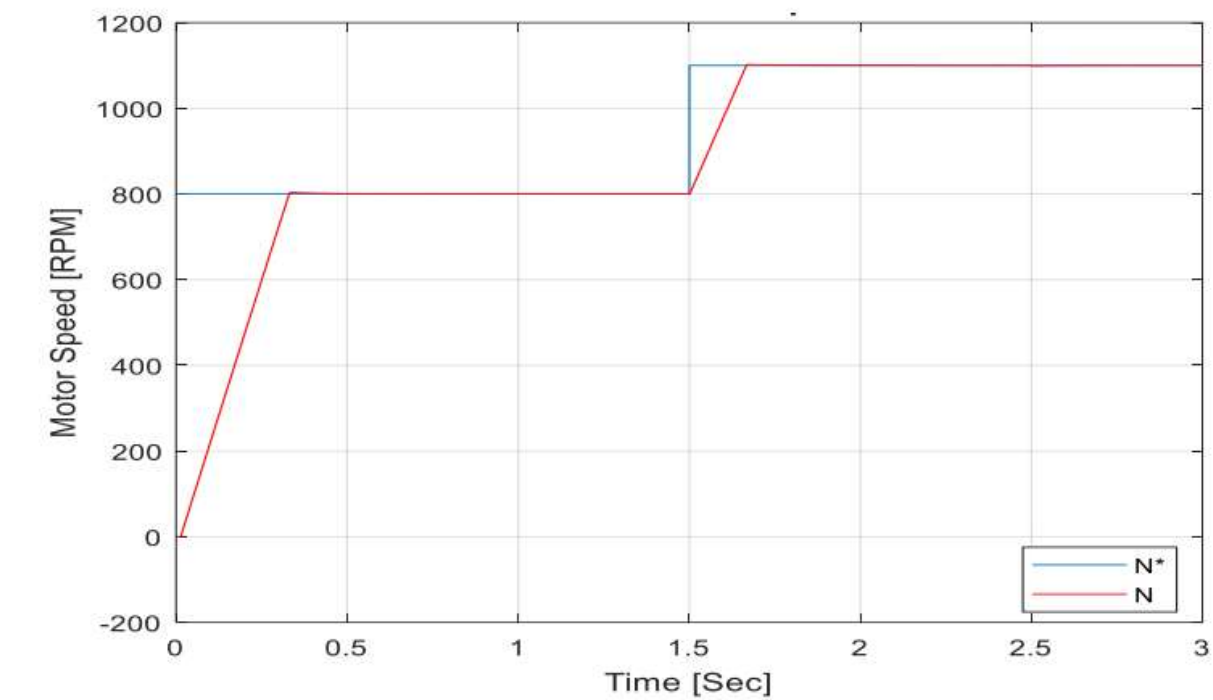


Fig No 5.7:- Graphical analysis for speed of induction motor

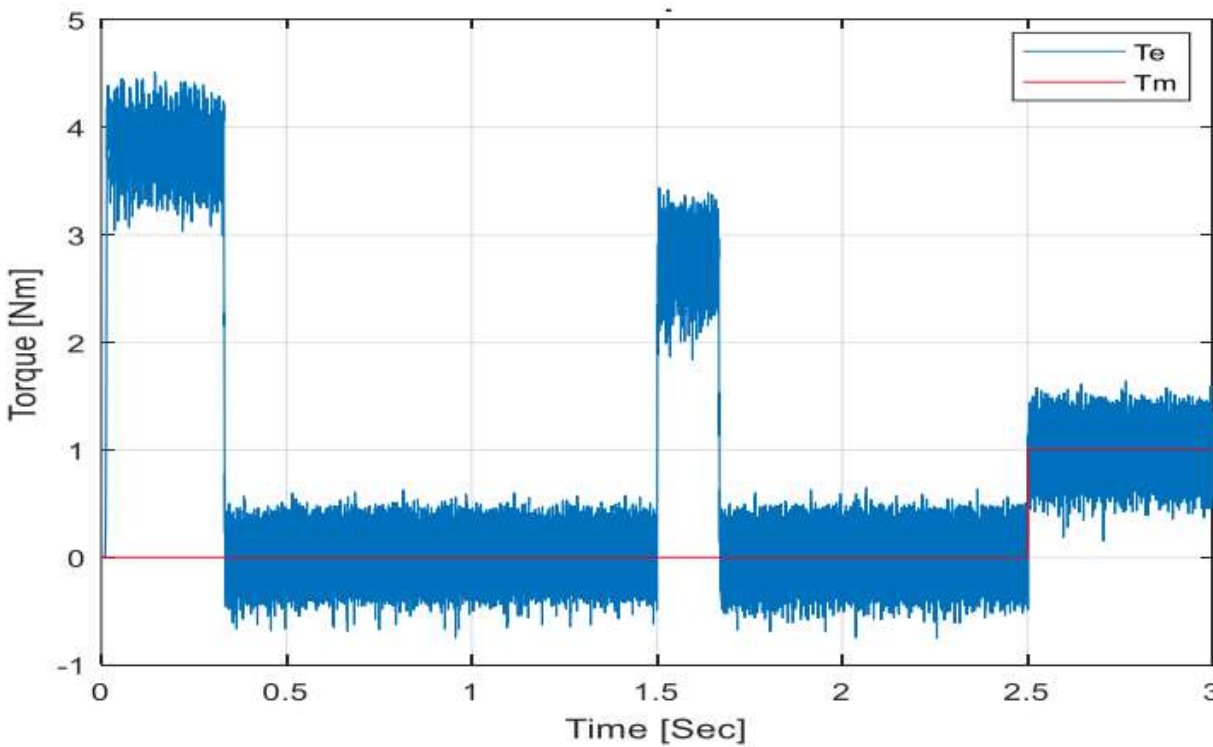


Fig No 5.8:- Graphical analysis of torque for Direct Torque Control

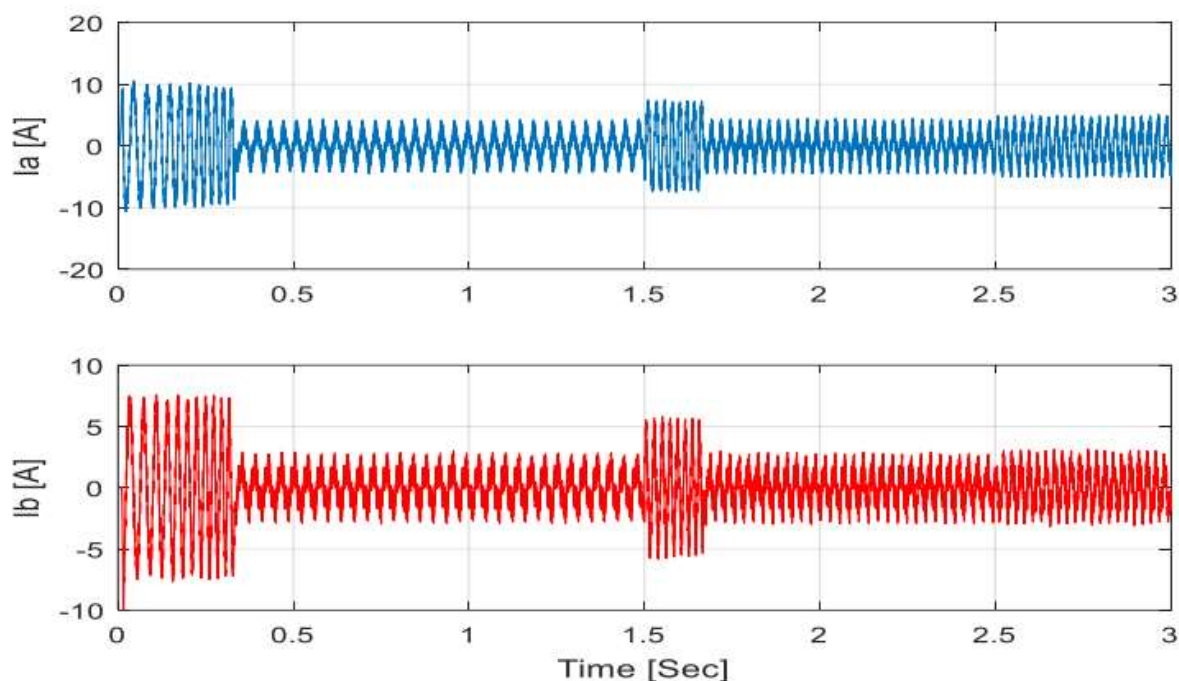


Fig No 5.9:- Graphical analysis of stator currents

VIII. CONCLUSIONS

Power quality has been increasingly critical, and sensitive loads in smart grids have emerged. In this study, a single phase induction motor driven by solar panels was developed and evaluated utilising hardware implementation, closed loop simulation, hybrid PI and SPWM control, and DTC. The built-in hybrid model using PI and SPWM has undergone two rounds of testing at a constant frequency of 50 Hz, first with capacitor-start type induction motors and subsequently with capacitor-start and run type induction motors. The THD for the input voltage supplied to SPIM of the start-run capacitor type was found to be lower than that of 1- IM with run capacitor at a temperature of 25° and solar irradiation of 1000 W/m², as compared to the conventional approach. The close loop simulation model using DTC's graphical analysis of speed, torque, and motor current characteristics showed that the THD value for constant frequency motors is within IEEE standards (less than 5%), and the variable frequency motors are operating effectively with the right speed and torque. Based on hardware implementation, it is clear that by lowering THD of voltage to less than 5% (nearly 4%), the power quality of the waveform at the motor's input has been improved. In terms of reduced THD for hardware implementation and closed loop simulation using hybrid control and DTC, respectively, Table 8 demonstrates that the new simulation model performs better than prior research work.

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