Journal Of Harmonized Research (JOHR)

Journal Of Harmonized Research in Engineering
5(1), 2017, 28-33

ISSN 2347 – 7393

Original Research Article

INDUCTION MOTOR FED BY MATRIX CONVERTER, MODELING, SIMULATION AND IMPLEMENTATION

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Abstract: This paper presents a mathematical model for the analysis of Matrix Converter (MC). The converter system is modeled in Matlab/Simulink environment using Sim-power block-sets. Simulations are carried out at different switching frequencies in view to analyze the effect on harmonic distortion of output voltage. The simulation results are verified using a prototype. The open loop speed-torque characteristic of Induction Motor (IM) is also studied. A novel four-quadrant vector controlled induction motor (IM) adjustable speed drive (ASD) system based on a recently proposed matrix converter topology called quasi-Z-source direct matrix converter (QZSDMC). The QZSDMC is formed by cascading the quasi-Z-source impedance network and the conventional direct matrix converter (DMC). The QZSDMC can provide buck-boost operation with voltage transfer ratio controlled by controlling the shoot-through duty ratio and bidirectional operation capability. The control strategy, which is based on the indirect field oriented control algorithm, is able to control the motor speed from zero to the rated value under full load condition during motoring and regenerating operation modes. The operating principle of the proposed system is presented in detail.

Keywords-Direct matrix converter (DMC), indirect field oriented control (IFOC), induction motor (IM), quasi-Z-source converter (QZSC), quasi-Z-source DMC (QZSDMC), Z-source converter (ZSC).

Introduction*:* Electrical Energy already constitutes more than 30 % of all energy usage on Earth. And this is set to rise in the upcoming years. Its huge popularity has been triggered by its efficiency of use, easiness of transportation, ease of generation, and environment-friendliness. The demand of energy is continually increasing in recent years. However, reserves of fossil fuels are limited, and inherited pollution has become a global environmental concern. One of the solutions for these issues is to introduce renewable energy, such as photovoltaic and wind energy.

They, however, are not suitable for transportation and portable applications. Fuel cells are considered

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Received on: January 2017
Accepted after revision: January 2017

to be one of the promising solutions for portable energy generation devices.

There has been a lot of effort to develop new dc/dc converters and inverters suitable for hybrid electric vehicles (HEV) applications [1]. Induction motors have many advantages compared to DC motors and synchronous motors in many aspects, such as size, efficiency, cost, life span and maintainability. Low cost and ease of manufacturing have made the induction motors a good choice for electric and hybrid vehicles [2]. However, one must be able to achieve energy regenerative braking and be able to control the torque and the speed of an induction motor in traction drives such as hybrid electric vehicles [3].

Power electronic static converters have played an important role in the transformation of energy. In the recent past, MC has gained importance for the speed control of IM in industrial application particularly where size is of much importance. MC is a direct AC to AC converter with both voltage and unrestricted output frequency control. The MC structure has nine bidirectional switches which connect input phases to output phases in controlled manner. The absence of dc-link justifies the topology of MC over the bulky two-stage converter. Furthermore, controllable power factor and sinusoidal input currents are salient features of MC [1, 2] but lack of bi-directional switches and low voltage transfer capabilities have affected the considerable growth of the aforesaid converter. Due to current commutation problems of bi-directional switches, complex control algorithms and protection issues, the power converter performance is adversely affected. Several control strategies have been developed with the aim to achieve better converter performance. The fictitious DC link concept was developed to exploit the control algorithms already developed for voltage source inverters. An integrated module of the MC IGBT's was presented in [4]. Mathematics is a precise and concise language, with well-defined rules for manipulations and helps us to formulate ideas and underlying assumptions [5].

In this paper, a detailed mathematical analysis of the MC based system is presented. The MC is modeled using Matlab/ Simulink block-sets. Power circuit, switching logic controller and load are considered during modeling of MC. The block diagram of the proposed mathematical model is shown in the Fig. 1. The same input voltage is used for power circuit and control circuit so as to maintain synchronization. Simulations of the MC are carried out with RL load and IM speed control in open loop is performed.

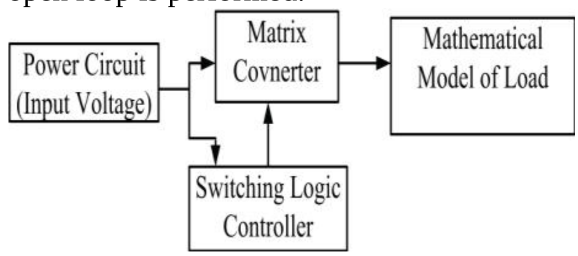

Fig. 1 Block diagram of the system

Theory: The matrix converter is an attractive alternative to the back to back converter because it can convert an ac voltage directly into an ac output voltage of variable amplitude and frequency without the need for an intermediate dc-link and capacitor. Furthermore, it provides bidirectional power flow, sinusoidal input/output currents, controllable input power factor, and has compact design. The volume savings of a matrix converter compared with a back-to-back converter has been estimated to be a factor of three [3]. The large dc-link capacitor and large input inductors of the back-to-back converter are replaced by small input filter with capacitors and inductors in the matrix converter. Furthermore, because of a high integration capability and higher reliability of the semiconductor devices, the matrix converter topology is a better solution for extreme temperatures and critical volume/weight applications [5]. Matrix converters can be divided into two categories: the DMC and IMC, as shown in Fig. 1. The DMC performs the voltage and current conversion in one stage (direct) power conversion while the IMC features a two-stage (indirect) power conversion. The DMC and IMC circuit topologies are equivalent in their basic functionality. The difference in the categories results from a difference in loading of the semiconductors and a different commutation scheme. The IMC has a simpler commutation due to its two-stage structure, however, this is achieved at the expense of more series connected power devices in the current path, which results in a higher semiconductor losses and typically a lower achievable efficiency compared with the DMC. However, the differences between the control performances of DMC and IMC are quite negligible in practice. Therefore, the DMC will be investigated within this paper as a candidate topology to achieve highest conversion efficiency [6]. For all these attractive properties, the matrix converter has not yet gained much attention in the industry due to its several unsolved problems. The most critical problem is the reduced voltage transfer ratio, which is defined as the ratio between the output and the input voltages, and has been constrained to 0.866 when using linear modulation [5]. Several researches on the over modulation have been carried out to overcome the problem of low voltage transfer ratio. However, the over modulation can only be achieved at the expense of the quality of both output voltage and input current [7].

Operating Principle of Matrix Converter: The MC system is based on a high frequency synthesis control which connects 'm' input phases to 'n' output phases. In particular, it is a three-phase to three-phase forced commutated cyclo-converter, consists an array of bidirectional switches that connect each output phase to each input phase without using dc-link elements as shown in Fig. 2. The general structure consists of input power circuit, a small input filter, MC and the load.

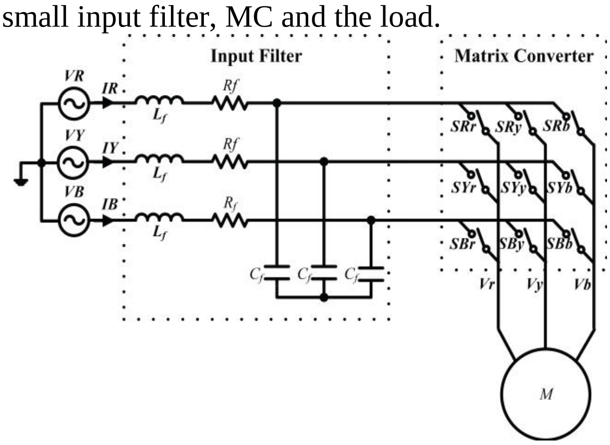

Fig. 2 Basic power circuit of MC

The output voltage is constructed by proper cutting of the input voltages using an appropriate switching algorithm. MC has several advantageous features over the other existing ACAC commercial converters [7, 8] such as prolonged life and less maintenance, controllable power factor, four-quadrant operation and regenerative capability due to presence of bidirectional switches.

The prototype of MC demands the Bi-directional Switches

(BS) which is capable of bi-directional flow of power, but there is scarcity of such switches. Hence, these BS are implemented using the proper combination of switching. device and diodes. In the present study, diode bridge arrangement of BS is considered as shown in Fig. 3. This configuration is preferred over other existing arrangements to avoid the need of two isolated power supplies for the two gate drivers of the MOSFET's. For smooth input current, a small filter is required at the front end of the converter. A suitable switching frequency is responsible for sinusoidal output voltage and input current.

Principle: Each switch Sij, i = {A, B, C}, j ={a, b, c}, can connect or disconnect phase i of the supply to phase j of the load and, with a proper combination of the conduction states of these switches, arbitrary output voltages VjNcan be synthesized.

Each switch is characterized by a switching function, defined as follows:

Sij(t) = 0 if switch Sijis open

Sij(t) = 1 if switch Sijis closed

When BS are operated, then control algorithm must ensure the following [3]:

a. No two input lines should be connected to the same output line - *to avoid short circuit.*

b. At least one of the switches in each phase should be connected to the output - *to avoid open circuit*.

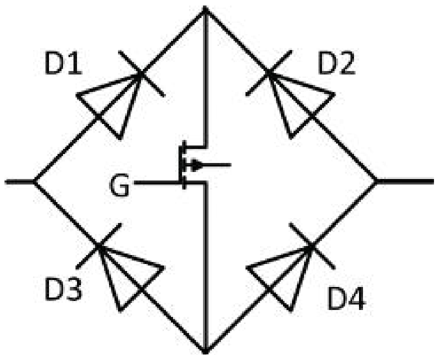

Fig. 3 Diode bridge arrangement BS

Simulation and Implementation of Converter Fed IM drive: The Venturini algorithm equations have been used to calculate the duty cycle of the bidirectional switches. Venturini modulation algorithm model basically consists of three main parts. First part contains the supply voltage blocks. Generation of the duty cycles of the devices are placed in the second part and finally third part consists of nine bidirectional switches. switching of all nine switches of matrix converter are calculated by equations(5) to (13).Equations (3) and (4) are evaluated at every sampling period with updated values to calculate the duty cycles for the switches. For the real-time implementation, it is required to measure any two of three input line-to-line voltages. Then, *imV* and *i*⌉*t* are calculated as.

$$V_{im}^{2} = \frac{4}{9}\left[V_{ab}^{2} + V_{bc}^{2} + V_{ab}V_{bc}\right]$$

$$\omega_i t = \arctan \frac{-V_{bc}}{\sqrt{3}\left(\frac{2}{3}V_{ab} + \frac{1}{3}V_{bc}\right)}$$

Where Vab,Vbc are the instantaneous input line voltages. Hence, the duty periods of the switches which connect each input phase to one output phase during one switching period can be calculated by using equations (3) and (4) (for instance these times will be tAa, tAb, tAc for output phase, A). The three phase instantaneous output voltages are obtained by simulink implementation, and then these voltages are applied to three phase induction motor.

Similarly the A. Zuckerberger algorithm equations has been used to calculate the duty cycle of the bidirectional switches to calculate average values of output voltages given by matrix converter.. It basically consists the m values for all nine switches, which are calculated using equation and by these calculated m values the average output voltages of matrix converter are calculated using equation

Simulation Results: In this paper, three-phase to three-phase matrix converter using Venturini algorithm and A. Zuckerberger algorithm has been modeled, simulated and implemented. The output of three phase voltages using A. Zuckerberger algorithm has been shown in Figure. 4 to 6 and similarly three phase output voltages using Venturini algorithm has been shown in Figure. 11 to 13.The results of three phase voltages obtained from both algorithms are compared and it shows that Venturini algorithms shows better results as instantaneous voltages are obtained by this technique. The proper switching of all nine switches are obtained at every instant as total 172 combinations of switching has been produced to obtain instantaneous voltages by this technique in only one cycle.

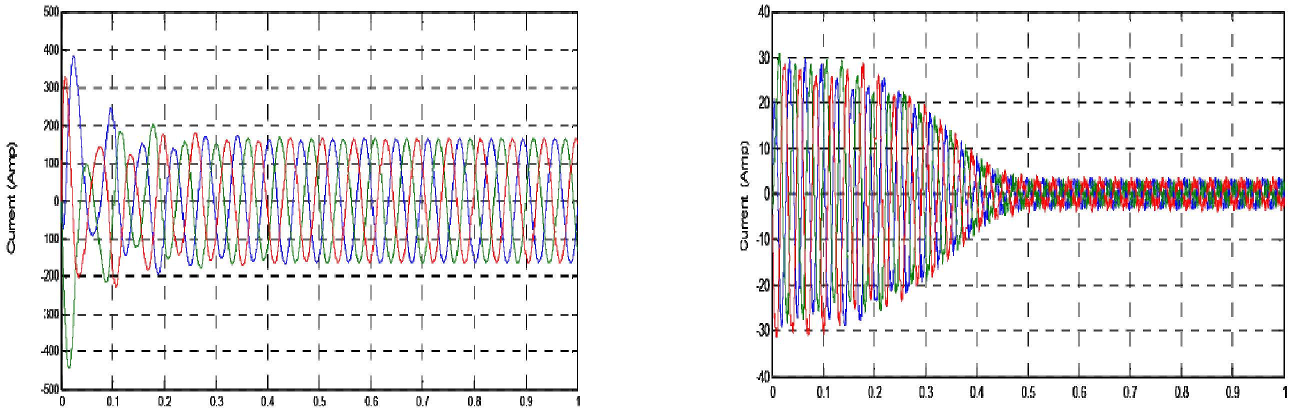

Figure 4. Induction motor three phase current

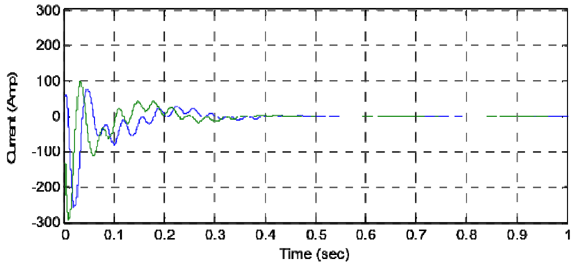

Figure 5. Induction motor dq current

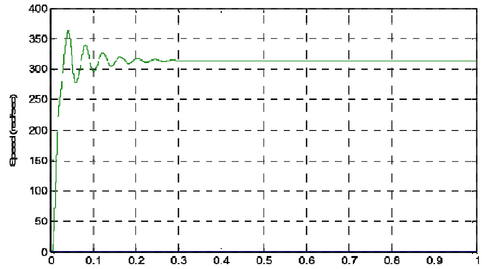

Figure 6. Induction motor speed

The output of the three phase matrix converter of both algorithms are applied to the three phase induction motor and the output as three phase currents, d axis and q axis current, and finally motor speed in Figure 5-7using A. Zuckerberger algorithm and in Figure 7-8 using venturini algorithm. The results from three phase currents, d axis and q axis currents from both algorithms shows that the ratio of initial currents to final currents are less in Venturini algorithm , which is better for the performance of induction motor. Similarly the speed results from A. Zuckerberger algorithm shows the more speed transients as compared to Venturini algorithm and also shows the speed overshoot at steady state.

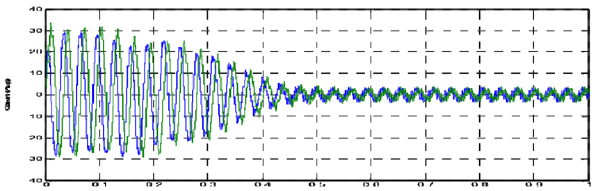

Figure 7: Induction motor dq current

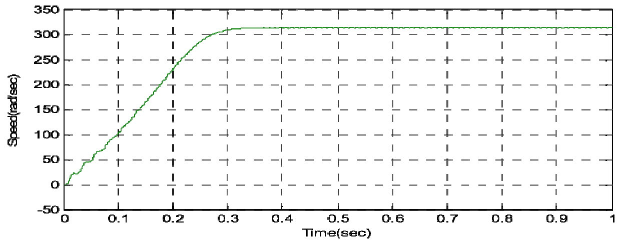

Figure 8. Induction motor speed

Conclusion: Three-phase to three-phase matrix converter modeling and simulation using Venturinialgotithm and A. Zuckerbergerhave been done. The average three phase voltages are obtained by A. Zuckerberger algorithm whereas instantaneous voltages are obtained using Venturini algorithm. Venturini algorithm provides better results as compared to A. Zuckerbergeralgorithm because it gives the proper switching instants of all the switches of matrix converter so output of this technique is applied to three phase induction motor and obtained the three phase currents, d axis and q axis current, induction motor torque and the induction motor speed. As seen from the simulation results the output of the induction motor is same as the output when the three phase input applied is sinusoidal. In this paper, it was observed that the most important is that the switching pattern obtained from the simulation study can be applied to the practical control of the matrix converter directly, which has great value in practices and deserves further studies on its applications.

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