Modeling and Simulation of Matrix Converters for Marine Electric Propulsion

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ABSTRACT

Marine electric propulsion systems for ships typically use an electronic power converter to drive a variable speed electric propulsion motor connected to propellers. Several types of converters are in use, each with their own advantages and disadvantages. This paper discusses the potential of matrix converter in marine electric propulsion system with a comparative analysis of other converters. The operational performance of the converter topology is investigated using computational modeling methods. The results reveal that the proposed converter has superior performance over the other converters in terms of dynamic performance, efficiency, and cost.

Introduction

Electric propulsion is a technology that uses electrical power to propel vehicles, including ships, submarines, aircraft, and spacecraft. Electric propulsion systems offer several advantages over conventional mechanical propulsion systems, including higher efficiency, lower emissions, and reduced maintenance requirements. Electrical energy can be provided by a variety of sources, including batteries, fuel cells, or generators powered by fossil fuels, nuclear energy, or renewable sources such as solar or wind power (Leverett, 2016). Marine electric propulsion utilizes many practical power electronic converters including DC rectifier, AC cyclo converter and Voltage Source Inverter (VSI). It is clear from the results that no single power converter has all the required characteristics required for an ideal marine propulsion system.

Marine propulsion systems require a high degree of reliability and efficiency because of the harsh environment in which they operate. Matrix converter has the capability to operate a wide range of speeds and dynamic response. Further, the number of components required is less than the other converters and its increases the efficiency. The increasing importance of energy efficient drives forced the development of Matrix converters in marine applications. Low power matrix converters are available commercially which may not be used for large power applications like electric propulsion (Wilkinson & Yan, 2011).

In this paper, we have designed a three-phase matrix converter topology for PMSM drives. The modeling and simulation of the proposed converter is carried out in MATLAB/ SIMULINK environment. The simulation results reveal that the matrix converter operate with constant switching frequency, minimizes the torque ripples and fast torque dynamics.

Matrix Converter

The simplified circuit diagram of a Matrix converter is as shown in Fig.1. It consists of nine bidirectional switches that can be used to connect any input line and any output line. By utilizing effective control methods, the matrix converter can perform voltage and frequency conversion directly from an AC power source without relying on an intermediate DC link. The matrix converter controls the output voltage by employing a modulation strategy that involves switching between permissible switching states. This ensures that the average output voltage conforms to the desired waveform. The matrix converter generates the input current by utilizing segments of the three output currents and blank intervals during which the output currents are recirculated within the converter. The input current spectrum mainly comprises a component at the supply frequency, as well as high-frequency components, which are attenuated through an input filter to produce an almost sinusoidal supply current. As a result, the matrix converter can operate with input and output currents that are approximately sinusoidal. It is possible to maintain a unity input displacement factor, irrespective of the output displacement factor. Additionally, the matrix converter is intrinsically bi-directional and can operate in all four quadrants.

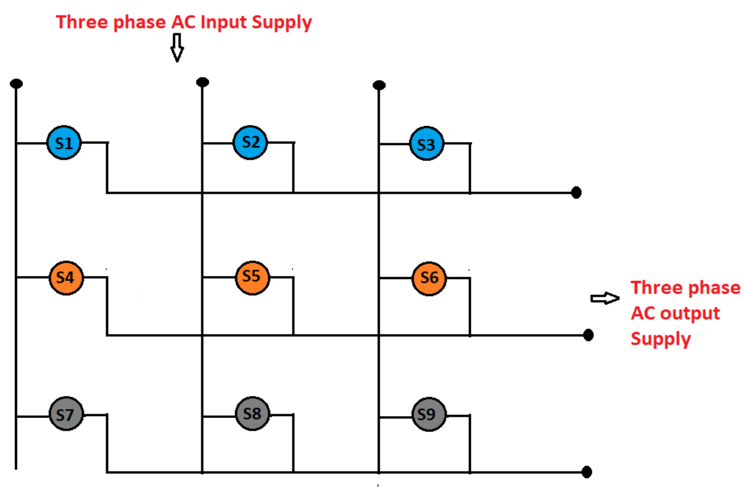

Figure 1. Matrix Converter

Table 1. Matrix Converter VTR under different input and output configurations

Input Phases	Output Phases						
	3	4	5	6	7	8	9
3	86.60	75.00	78.86	75	76.93	75.00	76.16
4	81.65	70.71	74.35	70.71	72.53	70.71	71.80
5	104.44	90.45	95.11	90.45	92.78	90.45	91.85
6	100	86.60	91.06	86.60	88.83	86.60	87.94
7	109.75	95.05	99.94	95.05	97.49	95.05	96.51
8	106.68	92.39	97.14	92.39	94.76	92.39	93.81
9	111.99	96.98	101.98	96.98	99.48	96.98	98.48

Voltage Transformation Ratio (VTR) is one of the major drawbacks in Matrix converters. For the basic configuration as shown in Figure 1, it produces reduced output voltage when compared with other power electronic converters. The increase in output voltage can be achieved by increasing the number of phases by shifting transformers. Table 1 shows the utilization factor of input and output voltages under different configurations. From Table 1, there are combinations of input and output which achieve 100% of the supply utilization.

Design of Matrix Converter

The process of designing a matrix converter starts with selection of a topology for the operating range, dynamic performance, with minimal distortion and minimizes the space requirements in the vessel.(Vyas, M., & Vyas, S. (2022). The researchers analyzed different topologies with parametric survey and variant four among them seems more beneficial which is used for the present study. It has two converters which can drive a six-phase propulsion motor with six input phases and three output phases. These are supplied by phase shifting transformers each having two output phases from input. The bidirectional switch topology selected for the matrix converter is as shown in Figure 2.

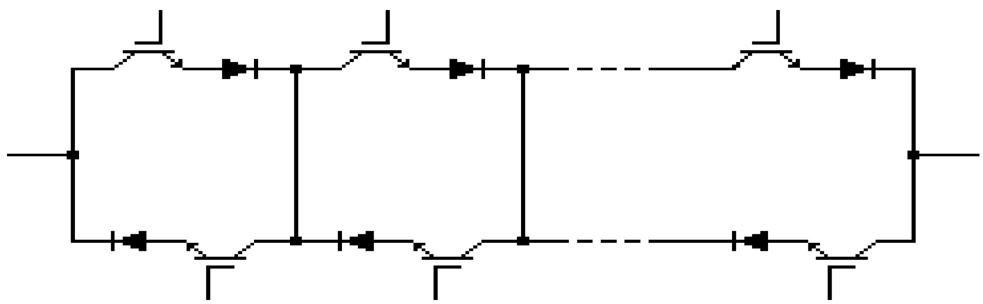

Figure 2. Bidirectional Switch

Each bidirectional switch therefore contains two sets of four series-connected PP-IGBT devices with series diodes as shown above. The switching combinations are selected carefully considering that the supply phases are not short circuited, and output should not be interrupted during operation of the converter.

Simulation Results and Discussion

The design procedure is followed, and the simulation model of the proposed converter is developed in MATLAB / SIMULINK as shown in Figure 3 and Figure 4. The performance of the simulation model is verified under the switching frequency 25 Hz to 1 KHz. The quality of the output wave forms depends on the switches and the switching sequence between the supply voltages. However, the losses and voltage drop across the IGBT will vary with the conduction current and temperature. This needs to be analyzed in comparison with the other power electronic devices like SCR, MOSFET etc.,.

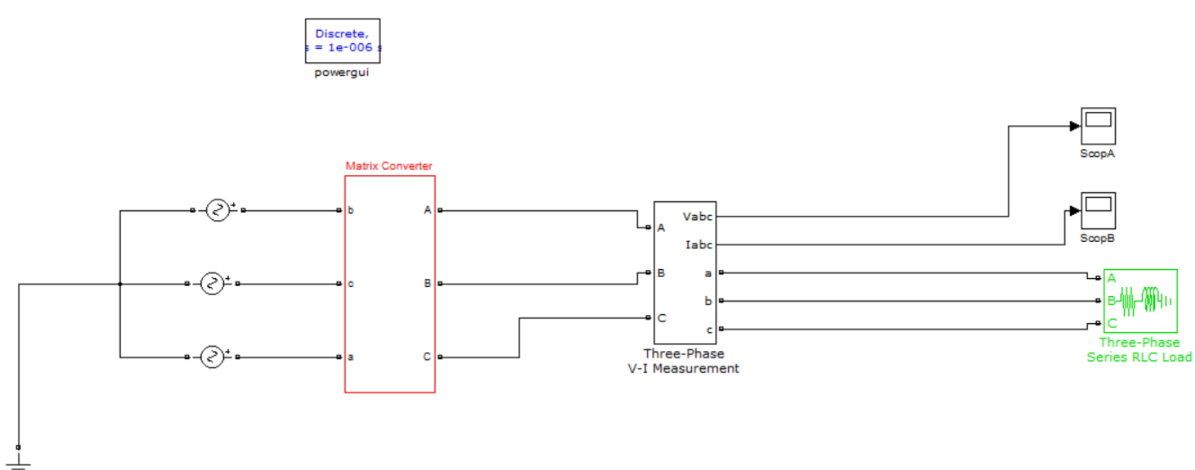

Figure 3. MATLAB/Simulink Model

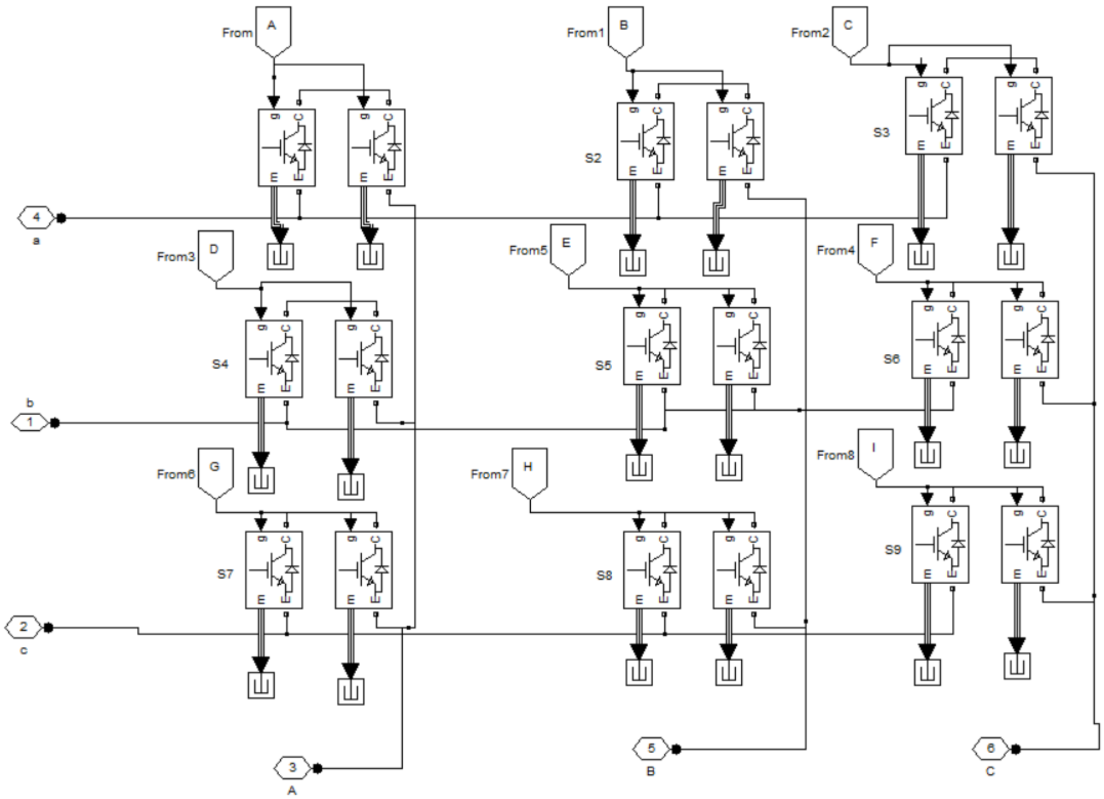

Figure 4. Matrix Converter (Sub System)

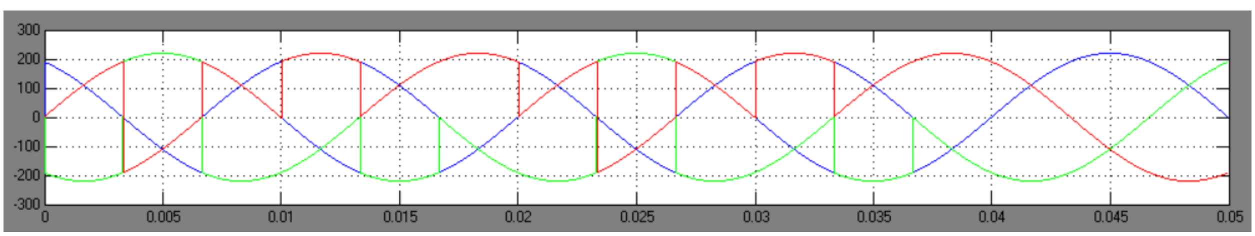

Figure 5. Phase to Ground values of Voltages.

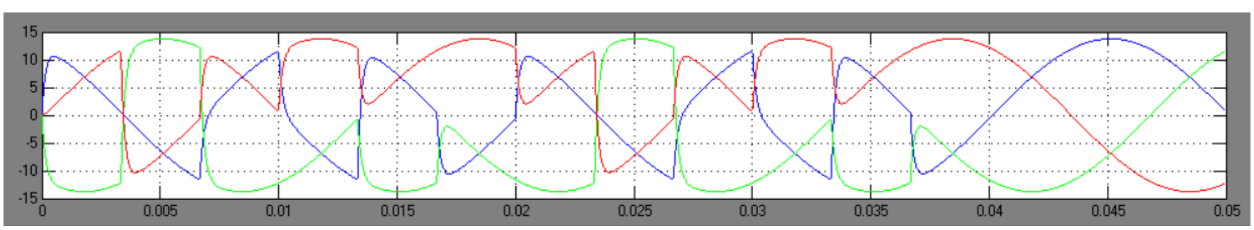

Figure 6. Phase to Ground values of currents .

The output response curves of the matrix converter is as shown in Figure 5 and Figure 6. It is clear from the graph that output switches are operated very fact to provide the smoother output with tun 0.035 seconds. The switching frequency of the currents can be changed instantly to provide a wider range of control to the load. The output wave form generated for motor current is in Figure 7. If the commutation of the power electronic devices increased the waveform will become smoother.

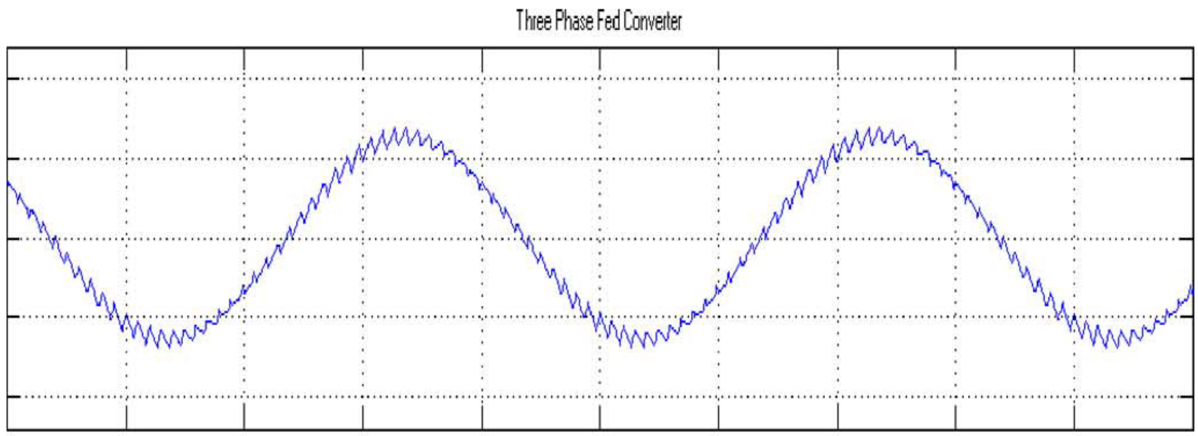

Figure 7. Output Current to the load /Motor current

Conclusion

This paper proposes a matrix converter for marine electric propulsion. The study included topology, device selection and expected performance. There are many types of topologies available in literature, however the proposed topology found suitable and met the requirements. The converter is designed and simulated using IGBT as a switching device which requires less no devices for H bridge converter for the same operating parameters. The waveform quality can be improved and analyzed with different power electronics components which can be considered as future work.

References

Wilkinson, A. J., & Yan, X. (2011). Research on matrix converter control multi-phase PMSM for all electric ship. International Conference on Electrical and Control Engineering. https://doi.org/10.1109/iceceng.2011.6057186

Klumpner, C., Per Halfdan Nielsen, Ion Boldea, & Frede Blaabjerg. (2002). A new matrix converter motor (MCM) for industry applications. IEEE Transactions on Industrial Electronics, 49(2), 325–335. https://doi.org/10.1109/41.993265

Mirzaeva, G. and Liu, Y. (n.d.). MATRIX CONVERTERS: CHALLENGES AND SOLUTIONS Copyright Material IEEE Paper No. PCIC. [online] Available at: https://ieeepcic.com/2022conference/wp-content/uploads/sites/7/2022/09/2022-PCIC-0540.pdf [Accessed 30 Apr. 2023].

Rmili, L., Ktata, S., Yefrni, K., Rahmani, S., & Al-Haddad, K. (2022, December 1). Overview of Matrix Converter: Topologies and Modulation. IEEE Xplore. https://doi.org/10.1109/STA56120.2022.10018982

Vyas, M., & Vyas, S. (2022). Matrix Converter: A Solution for Electric Drives and Control Applications. Optimal Planning of Smart Grid with Renewable Energy Resources. https://www.igi-global.com/chapter/matrix-converter/293180

Klumpner, C., Nielsen, P., Boldea, I., & Blaabjerg, F. (2000, October 1). A new matrix converter-motor (MCM) for industry applications. IEEE Xplore. https://doi.org/10.1109/IAS.2000.882067

Podlesak, T. F., Katsis, D. C., Wheeler, P. W., Clare, J. C., Empringham, L., & Bland, M. (2005). A 150-kVA vector-controlled matrix converter induction motor drive. IEEE Transactions on Industry Applications, 41(3), 841–847. https://doi.org/10.1109/TIA.2005.847303