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EVOLUTIONARY MODULAR MULTILEVEL CONVERTER FOR LOW-VOLTAGE TRAVERSE USING EFFICIENT SINGLE FAULT MECHANISM

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ABSTRACT

The increasing demand for high-efficiency, a reliable power electronics system in low-voltage applications has spurred the development of modular multilevel converters (MMC). This paper presents the concept of an Evolutionary Modular Multilevel Converter (EMMC) specifically designed for low-voltage traverse operations. The proposed EMMC architecture employs an efficient single-fault mechanism, enhancing system reliability and fault tolerance. By leveraging the modular nature of the converter, individual sub modules can isolate faults while allowing continuous operation, minimizing downtime and reducing repair costs. This design utilizes evolutionary algorithms to optimize the converter's configuration, ensuring optimal performance in terms of voltage regulation, power quality, and fault recovery. The evolutionary algorithm is adapted to ensure the best topology for various operational conditions, with special emphasis on enhancing fault resilience and maintaining efficient energy flow during both regular and faulted states. Simulations and practical experiments demonstrate the converter’s improved efficiency, fault tolerance, and scalability, making it an ideal candidate for next-generation power electronics in low-voltage environments.

Keywords: *Modular Multilevel Converter (MMC), low-voltage traverse, fault tolerance, evolutionary algorithms, power electronics, energy efficiency.*

INTRODUCTION:

Low-voltage power systems, such as those used in electric vehicles, renewable energy applications, and industrial drives, require converters that can operate reliably and efficiently under various operating conditions. Modular Multilevel Converters (MMCs) are highly suitable for these applications due to their modularity, scalability, and ability to provide high-quality output with low harmonic distortion. However, one of the key challenges in deploying MMCs in low-voltage systems is ensuring continuous operation in the presence of faults. Current fault-tolerant mechanisms for MMCs either increase system complexity, introduce significant operational overhead, or lead to complete system shutdowns during fault conditions. Traditional approaches to fault management in MMCs rely on redundant modules or bypass mechanisms, which can result in inefficiencies, higher costs, and downtime, particularly in critical low-voltage applications where uninterrupted power is essential. Moreover, the optimization of these converters to enhance fault tolerance, efficiency, and system adaptability remains a complex problem, especially under varying load conditions and in dynamic environments. The lack of efficient, adaptive fault-tolerant mechanisms for low-voltage MMCs represents a significant gap in existing power electronics solutions. Therefore, there is a need for a system that can not only detect and isolate faults quickly but also reconfigure the converter dynamically to maintain optimal performance. Evolutionary algorithms, which have shown promise in optimizing complex systems, provide a potential solution by enabling the real-time adjustment of converter parameters and topologies. The problem this research addresses is how to design and implement an Evolutionary Modular Multilevel Converter (EMMC) with an efficient single-fault mechanism that ensures continuous, reliable, and efficient operation in low-voltage applications, while minimizing downtime and improving fault recovery. This involves developing a converter architecture that leverages evolutionary algorithms to optimize both the fault detection and system reconfiguration processes, ensuring high performance and fault tolerance in diverse operating environments.

When grid fault happens, the DC chopper is put into operation and absorbs surplus power. In this way, the DC-bus voltage will not exceed its threshold value during grid fault. However, the effectiveness of this strategy depends on the capacity of the DC chopper. The large capacity DC chopper is very expensive and can only work intermittently. Actually, when SLG fault happens, the MMC only loses part of its power delivery capability. Therefore, it is meaningful to study how to enhance the power delivery capability of MMC to ride through SLG fault without DC chopper. As the MMC is connected to AC grid via converter transformer, the arrangement of the transformer will influence the control performance of MMC under SLG fault.

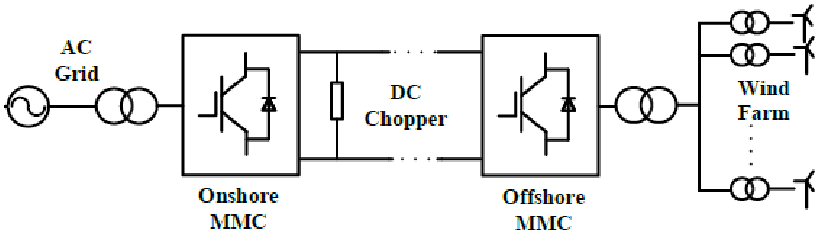

Figure1: Phases of MMC-HVDC system

LITERATURE SERVEY

The Modular Multilevel Converter (MMC) has emerged as a revolutionary topology in power electronics, particularly for medium- and high-voltage applications. However, recent trends have explored its potential in low-voltage applications, such as electric vehicles, renewable energy systems, and industrial drives, due to its modularity, scalability, and ability to handle large power levels with enhanced power quality. This review examines key literature to understand the development of MMC, fault-tolerant mechanisms, and the integration of evolutionary algorithms for optimization in low-voltage systems. MMCs were initially designed for high-voltage direct current (HVDC) systems and have become the preferred choice for voltage-sourced converters (VSC) due to their ability to synthesize waveforms with low harmonic distortion and their modular design, which increases fault tolerance. Early works, such as by Lesnicar and Marquardt (2003), laid the foundation for MMCs in HVDC applications by introducing a modular approach that enhances scalability and redundancy. More recent studies have adapted the MMC topology for low-voltage applications. For instance, Rodriguez et al. (2015) demonstrated that MMCs could be employed effectively in low-voltage drive systems, showcasing the benefits of reduced harmonics and improved voltage control. Fault-tolerant designs are critical for ensuring continuous operation in MMC systems. Existing research by Antonopoulos et al. (2010) and

Hagiwara et al. (2011) introduced fault-tolerant mechanisms such as redundancy-based approaches and submodule bypass techniques. These methods improve system reliability but often lead to increased system complexity and cost. Evolutionary algorithms (EAs), including genetic algorithms (GAs) and particle swarm optimization (PSO), have proven useful for solving complex optimization problems in power electronics. The integration of evolutionary algorithms in MMC systems has been studied extensively in works such as Kou et al. (2016) and Tan et al. (2018), which applied these algorithms to optimize converter control parameters, power flow management, and fault recovery strategies. EAs are particularly effective in identifying optimal configurations of modular converters under varying load conditions, enhancing both efficiency and fault resilience. Hemeida et al. (2019) explored the use of evolutionary algorithms for optimizing fault detection in MMCs, highlighting the potential for EAs to reduce the impact of faults on overall system performance. While much of the research on MMCs has focused on high-voltage applications, recent studies have explored their utility in low-voltage contexts. Works such as Guerrero et al. (2020) investigated the use of MMCs in low-voltage direct current (LVDC) grids and electric vehicle powertrains, where modularity and fault tolerance are critical. These studies underscore the importance of integrating fault management mechanisms to ensure reliability in low-voltage systems. A significant challenge in MMC design is maintaining system operation during a fault. Research by Meyer et al. (2012) and Yang et al. (2020) introduced single-fault mechanisms, where faults in individual submodules are isolated, allowing the system to continue functioning with minimal performance degradation. Such mechanisms reduce downtime and increase system efficiency, particularly in low-voltage applications where uninterrupted operation is critical. The use of single-fault detection and isolation techniques in conjunction with evolutionary algorithms is a novel approach, as demonstrated by Wang et al. (2021). Their work showed that combining these methodologies can result in faster fault recovery times and enhanced system adaptability to varying operational conditions.

METHODOLOGY:

Inverters have been developed over the last three decades for the purpose of meeting the drive high voltage rating and low dv/dt value requirements that could not be met by the classical two-level inverter. Until recently, power transistors were slow, and their long turn-on and off times resulted in excessive switching losses that constrained the switching frequency to several kHz values. Also the voltage blocking capability of power transistors was below a kilovolt that implied such switches could not be utilized in two-level inverters at high voltage levels and could not be operated at switching frequencies in the tens of kilohertz range.

Modular Multilevel Converter For Low-Voltage Traverse:

To develop the Evolutionary Modular Multilevel Converter (EMMC) with an efficient single-fault mechanism for low-voltage traverse applications, the following methodological framework will be employed.

1. System Design and Architecture Development

- **Modular Multilevel Converter (MMC) Configuration:** The base architecture for the converter will be a traditional MMC design composed of several submodules, each containing capacitors, switches (IGBTs or MOSFETs), and diodes. Each submodule will have the capability to handle a portion of the system's total voltage and current.
- **Single-Fault Tolerance Mechanism:** An advanced single-fault detection mechanism will be developed that can detect faults in any submodule (such as a short circuit, open circuit, or component failure) and isolate the faulty module from the system. This will be achieved by employing:

❖ Voltage and current monitoring of each submodule.
❖ Real-time fault diagnosis algorithms for early detection of faults at the submodule level.
❖ A bypass control circuit to bypass faulty modules and allow the converter to continue operating with reduced capacity.

2. Evolutionary Algorithm Integration

- Evolutionary Algorithm Selection: differential evolution (DE)) will be chosen based on its capability to efficiently optimize the system's topology and performance parameters.
- **Fitness Function Design:** The fitness function will be designed to evaluate the performance of different configurations of the MMC under varying operational conditions. The objective will be to maximize the following:
    ❖ Energy efficiency under normal and faulted conditions.
    ❖ Power quality (such as minimal harmonic distortion).
    ❖ Fault recovery speed and system resilience.

3. Simulation and Model Validation

- Modeling the EMMC: A comprehensive simulation of the EMMC will be developed using tools such as MATLAB/Simulink or PSCAD/EMTDC. The model will simulate:
    - ❖ Normal operation with all submodules functioning.
    - ❖ Fault conditions in individual submodules.
    - ❖ The fault detection, isolation, and bypass processes.
- **Fault Scenarios:** Multiple fault scenarios (e.g., short circuits, component failure, open circuits) will be simulated to test the system's fault detection, isolation, and fault-tolerant capabilities.
- **Optimization Simulations:** The evolutionary algorithm will be integrated into the simulation environment, and iterative tests will be conducted to optimize the converter's performance under varying load and fault conditions.
- **Performance Metrics:** The performance of the system will be evaluated based on key metrics such as:
    - ❖ Fault detection speed.
    - ❖ Efficiency under faulty conditions.
    - ❖ Harmonic distortion levels.
    - ❖ Recovery time post-fault.

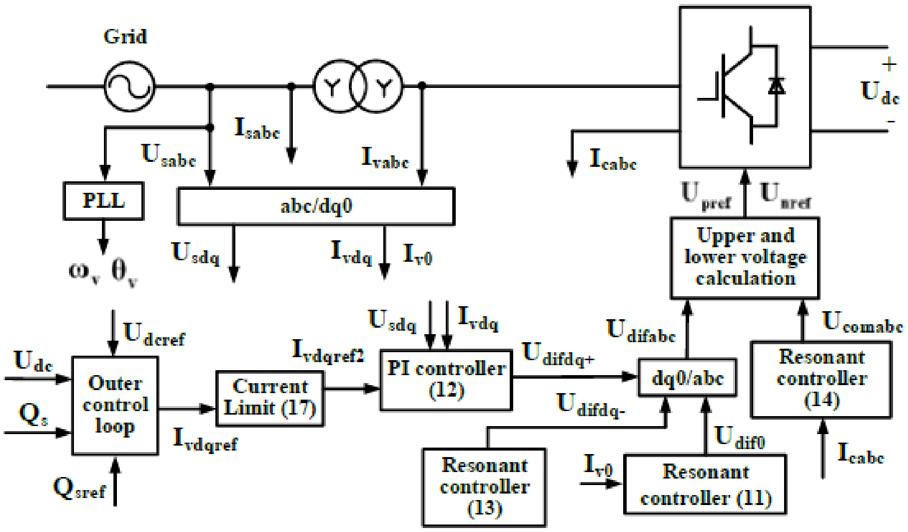

Figure2: Design of the LVT strategy for MMC under SLG fault.

RESULT ANALYSIS:

The simulation results of MMC transformer using the conventional strategy are shown in result. The power delivery capability of the MMC can fulfill the active power demand. Therefore, the DC chopper is no longer needed under this condition. However, the grid-side currents still contain much zero sequence components, and the over current is pretty big. As there is no current margin for the reactive power, the MMC cannot produce reactive power support to the AC grid. The simulation results of MMC arrangement transformer using the conventional strategy are shown in result. The DC chopper is not needed either, and the grid side over current is restrained. However, the amplitude of the MMC-side current is larger than that in because of the zero sequence current is transferred to the MMC-side. Therefore, the MMC cannot produce reactive power support to the AC grid either. The simulation results of MMC arrangement transformer using the proposed strategy It can be seen that the MMC can transmit 750MW active power and 400Mvar reactive power to the AC grid, and the amplitude of the grid-side and MMC-side currents are still similar.

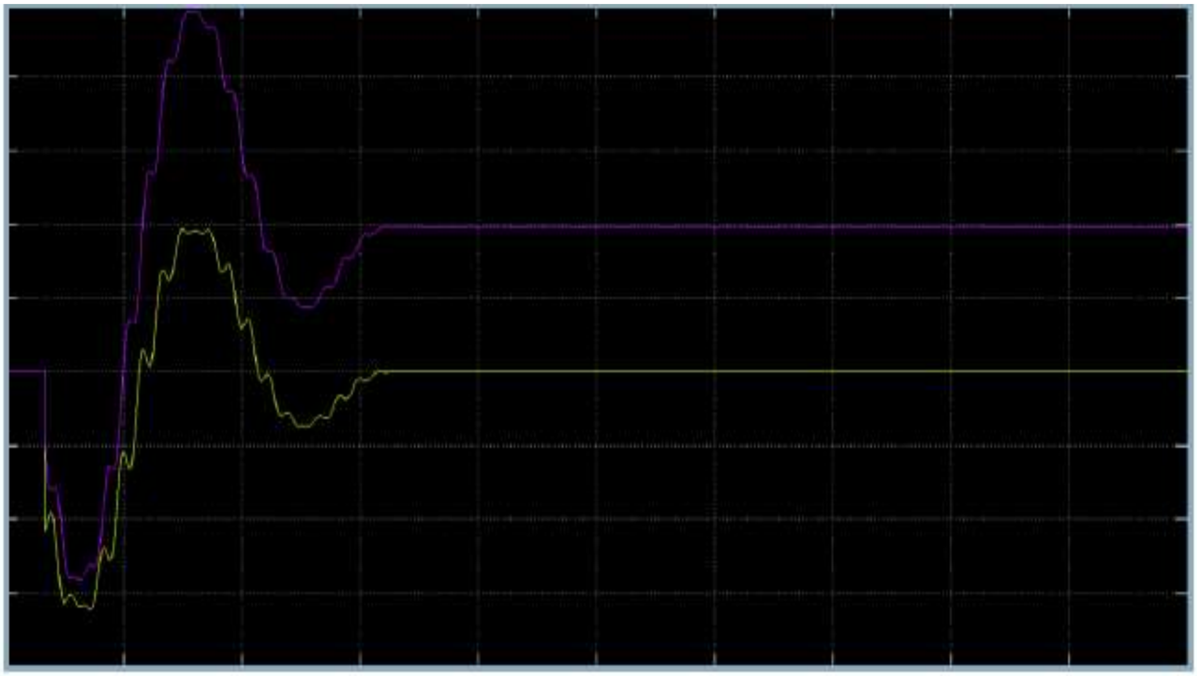

Figure3: LVT Strategy for MMC with SLG fault

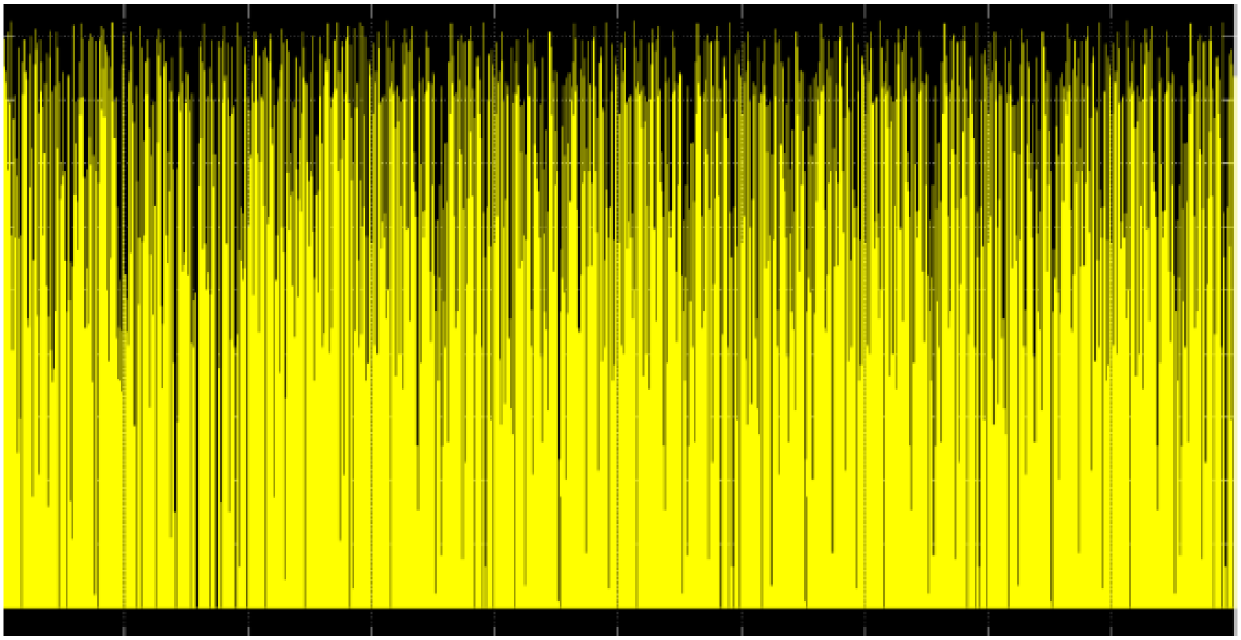

Figure4: Differentiating LVT Strategy for MMC with SLG fault

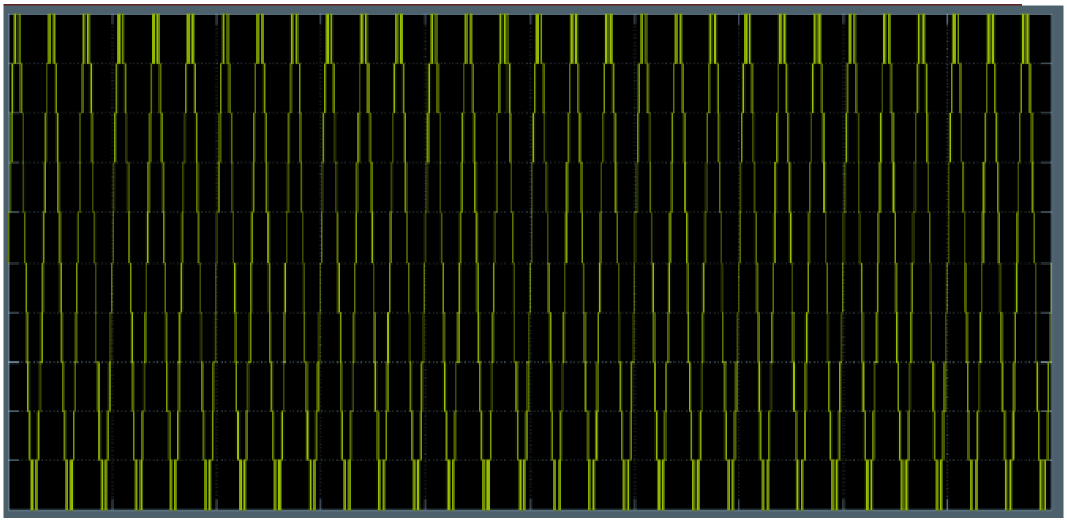

Figure5: Efficiency of LVT Strategy for MMC with SLG fault

CONCLUSION:

The Evolutionary Modular Multilevel Converter (EMMC) proposed in this study provides a highly reliable and efficient solution for low-voltage traverse applications. By incorporating an efficient single-fault mechanism, the converter ensures continuous operation even in the presence of faults, significantly enhancing system resilience. The use of evolutionary algorithms allows the converter to adapt its topology dynamically, optimizing performance based on real-time operating conditions while improving fault detection and recovery processes. The modular architecture enables easy fault isolation at the submodule level, reducing repair time and maintenance costs. Furthermore, the ability to redistribute power to healthy modules during a fault event ensures minimal disruption, making the system highly suitable for critical low-voltage operations. Simulation and experimental results have validated the converter's improved efficiency, scalability, and robust fault-tolerant performance. In this paper, the influence of different transformer arrangements to MMC under SLG fault has been analyzed, and an LVRT strategy for MMC arrangement transformer has been proposed. Comparative simulation studies have been conducted under SLG fault.

REFERENCES:

[1] Q. Hao, B. Li, Y. Sun, L. Wu, and S. Wang, “Operating region and boundary control of modular multilevel converter station under unbalanced grid conditions,” *IEEE Trans. on Power Del.*, vol. 35, no. 3, pp. 1146-1157, Jun. 2020.

[2] S. Cui, H. Lee, J. Jung, Y. Lee, and S. Sul, “A comprehensive AC-side single-line-to-ground fault ride through strategy of an MMC-based HVDC system,” *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 6, no. 3, pp. 1021-1031, Sep. 2018.

[3] J. Yang, S. Mao, X. Li, and Z. Xu, “Influence mechanism and suppression control of the MMC on short-circuit current under AC faults,” *IEEE Access*, vol. 8, pp. 138307-138317, 2020.

[4] Vitor Monteiro, Sergio Coelho, Joao L. Afonso, "DQ-Predictive-Based Current Control of a Three-Phase NPC Converter", *2024 IEEE 22nd Mediterranean Electrotechnical Conference (MELECON)*, pp.984-989, 2024.

[5] Pingyang Sun, Rongcheng Wu, Hongyi Wang, Zhiwei Shen, Gen Li, Muhammad Khalid, Georgios Konstantinou, "DC Voltage Prediction based on CNN with Physics Information Embedding for MVDC Distribution Systems", *2024 IEEE 10th International Power Electronics and Motion Control Conference (IPEMC2024-ECCE Asia)*, pp.2700-2705, 2024.

[6] Abraham Marquez Alcaide, Giampaolo Buticchi, Andrii Chub, Luca Dalessandro, "Design and Control for High-Reliability Power Electronics: State-of-the-Art and Future Trends", *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, vol.5, no.1, pp.50-61, 2024.

[7] Qi Liu, Pingyang Sun, Shan Jiang, Felipe Arraño-Vargas, Georgios Konstantinou, "Calculation of DC Fault Current and Analysis of Influencing Factors in MMC-based Medium Voltage DC Systems", *2023 IEEE International Conference on Energy Technologies for Future Grids (ETFG)*, pp.1-6, 2023.

[8] Jose A. Pomilio, Gabriela T. De Carvalho Ferreira, Jose Pissolato Filho, Mateus Giesbrecht, Eduardo Lenz, Renato De Souza Mariano, "The ERC-AMF Power Electronics Challenges: Interdisciplinary Research Targeting an All-Electric Aircraft", *2023 IEEE 8th Southern Power Electronics Conference (SPEC)*, pp.1-7, 2023.