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# Performance Enhancement of Medium Voltage Inverters via MOPSO-Based Switching Frequency Optimization

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***Abstract –***
*The switching frequency of medium voltage inverters (MVIs) plays a critical role in determining their overall performance, influencing parameters such as power losses, thermal stress, electromagnetic interference (EMI), and output waveform quality. However, optimizing the switching frequency involves complex trade-offs between efficiency, reliability, and harmonic distortion. This paper proposes a novel multi-objective optimization framework using Swarm Intelligence (SI) algorithms, specifically the Multi-Objective Particle Swarm Optimization (MOPSO) technique, to identify optimal switching frequencies for MVIs operating under various load conditions. The proposed approach simultaneously minimizes total harmonic distortion (THD) and switching losses while maintaining output voltage quality and thermal limits. A comprehensive simulation model of a medium-voltage inverter system is developed in MATLAB/Simulink, and the MOPSO algorithm is employed to explore the trade-off space effectively. Performance metrics including THD, switching loss, and thermal profile are evaluated for various Pareto-optimal solutions. Results demonstrate significant improvements in inverter performance, with optimized switching frequencies reducing harmonic content by up to 30% and lowering switching losses by up to 25% compared to conventional fixed-frequency methods. The study confirms the potential of swarm-based multi-objective optimization in achieving efficient and reliable operation of MVIs, paving the way for advanced control strategies in industrial and renewable energy applications.*
***Keywords:*** *Medium Voltage Inverter (MVI), Switching Frequency Optimization, Multi-Objective Optimization, Swarm Intelligence, Particle Swarm Optimization (PSO), Total Harmonic Distortion (THD), Switching Loss Reduction, Power Electronics, Thermal Management, Inverter Efficiency,Pareto Optimization,MATLAB/Simulink*

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## I. Introduction:

### 1.1 INVERTERS

The power electronic device which converts DC input voltage to AC output voltage at required voltage and frequency level is known as inverter. The AC output voltage could be of fixed or variable magnitude at fixed or variable frequency. For low and medium power outputs, transistorized inverters can be used and for high power outputs, IGBTs can be used as switching devices. The DC input voltage to the inverter may be from batteries, fuel cells, solar cells, photovoltaic arrays or other DC sources. But in most industrial applications, inverter is fed by a rectifier. Inverters are mainly classified according to the nature of input source as voltage source and current source inverters. The inverters can also be classified according to the nature of output voltage waveform as square wave, quasi-square wave and PWM inverters. The PWM strategies involve either (i) single carrier or (ii) multi-carriers which can be (a) bipolar or unipolar (b) triangular or rectified sine along with references which can be single sinusoid or third harmonic injection or 60-degree PWM or stepped wave or trapezoidal amalgamated or triangular or discontinuous PWM. The inverters can be further classified based on method of connections as series inverters, parallel inverters and bridge inverters. Based on number of phases, the inverters can be grouped as single phase and three phase inverters[1]. The inverter gain is the ratio of the AC output voltage to DC input voltage (Vdc). The output voltage of inverter may not remain constant due to the disturbances in the input voltage or load of inverter. At the same time some special applications require variation of output voltage. Therefore, output voltage of inverter has to be controlled to the desired level. The various methods for the control of output voltage of inverters are as follows[3]:

1. External control of AC output voltage
2. External control of DC input voltage
3. Internal control of inverter

**1.2 MULTILEVEL CONVERTERS (MLCS)**

Medium voltage (MV) high power AC drives have found widespread applications in oil and gas industries, mining, marine propulsion, hydro pumped storage, electric traction, and chemical industries. In high power applications, better efficiencies can be achieved by increasing the voltage rating rather than current rating of power electronic converter. At present, multilevel converters (MLCs) are established as a standard power electronic solution for MV high power AC drives. The major advantages of MLCs over two-level converters are: higher operating voltage capability with low voltage (LV) semiconductor devices, better output voltage waveforms, reduced filters size and lower common-mode voltages. The switching losses in a semiconductor device depend upon the blocking voltage, commutated current, switching frequency and switching characteristics. For MV high power MLCs, low device switching frequency operation is preferred to reduce switching losses and then it is possible to operate semiconductor devices at its rated fundamental current with feasible cooling requirements. However, reducing the device switching frequency increases the harmonic distortion of ma-chine currents. Therefore, the challenge is to maintain quality of machine stator current waveforms while controlling MLCs with low device switching frequency [1]. However, several classical control techniques like sinusoidal pulse width modulation (SPWM) and space vector modulation (SVM) require higher device switching frequency to obtain machine stator currents with lower harmonic distortion. In literature, several low switching frequency modulation techniques have been reported for controlling MLCs in high power applications. Multilevel space-vector control (MSVC) technique has been discussed but it has limitation of variable fundamental component magnitude error which increases at lower number of voltage levels. An adaptive duty-cycle modulation has been discussed for low device switching frequency operation. Similarly, a novel Slope PWM (SLPWM) technique with a trapezoidal modulating signal and a sinusoidal carrier signal with operating switching frequency equal to 11 times the fundamental frequency has been discussed. Also, model predictive control (MPC) techniques have been discussed for controlling MLCs with low device switching frequency [1].

**1.3 SEVEN-LEVEL CASCADE INVERTER**

A typical 7L cascade inverter topology is shown in Figure. Each phase consists of a connected set of 5L-NPC inverter and the H-Bridge. The traditional cascaded 7L inverter consists of three H Bridges connected in series and thus three separate dc sources are required per phase. On the other hand, this 7L topology requires only two separate dc sources in each phase. The synthesized voltage levels of 7L cascade inverter are shown in TABLE I. The mid-point potential of 3L-NPC1 and 3L-NPC2 phase legs with respect to neutral point ‘N’ is denoted as V3L1 and V3L2, respectively and output voltage of H-Bridge is denoted as VHB. The output potential of 5L-NPC inverter is denoted as V5L, which is equal to V3L1-V3L2. The mid-point potential of 3L-NPC phase leg take three discrete voltage levels −Vdc, 0, and Vdc, which are obtained by switching on top two switches, middle two switches, and bottom two switches, respectively. Thus, the output voltage of 5L-NPC inverter V5L1 consists of five discrete voltage levels−2Vdc, −Vdc, 0, Vdc, and 2Vdc. The output voltage of H-Bridge consists of three discrete voltage levels −Vdc, 0, and Vdc, which are obtained by switching on (S9,S12), (S9,S11) or (S10,S12), and (S10,S11), respectively. The phase output voltage of 7L cascade inverter is equal to V5L + VHB and thus it consists of seven discrete voltage levels −3Vdc, −2Vdc,−Vdc, 0, Vdc, 2Vdc, and 3Vdc[1].

## II. Literature Survey:

The author [1] Using model predictive control (MPC) based on the Multi-Objective Practical Swarm Optimization Algorithm (MOPSO) and adaptive control approaches, the research produced an electrical frequency control solution for a hybrid renewable energy source smart grid power system. The proposed adaptive control approach is used to achieve on-line parameter tuning for load frequency control in order to address parameter tuning issues. The hybrid wind/PV/FC/Battery smart grid with variable demand load is the system under investigation during the electrical grid's integration. Instead of using a conventional objective function with fluctuating limits, a customised objective function and a particle swarm optimisation method are used to decide all of the controller settings for different units in power grids in order to obtain optimal outcomes. MPCs were created for each type of photovoltaic generator, wind turbine generation, and storage battery in order to suppress the balance between generation and consumption.

The author [2] One of the most important subjects to understand in order to find the best answer for a variety of applications is artificial intelligence (AI). This study describes the tendency and future trend of AI applications in power electronics in a systematic and comprehensive manner. IEEE Xplore is selected for the paper investigation during the process, and the results are ordered chronologically. In addition, a number of important AI techniques for power electronics are described, including particle swarm optimization, deep learning, neural networks, genetic algorithms, and multi-objective optimization. Additionally, a number of studies that have been published discuss the use of AI in power electronics for renewable energy systems.

The author [3] Reducing fuel expenses, associated energy losses, and total generated environmental emissions is the aim of a multi-objective approach to the optimal performance of such AC/DC electrical grids. One external repository included in the proposed IMPO is designed to hold no dominated persons. To find the best, acceptable operational solution for the combined AC/DC electricity grids, the fuzzy decision technique is frequently applied. The proposed IMPO is implemented on a modified standard power system of the standard IEEE 57-bus and is generated using the MATLAB environment. Furthermore, a comparative study is conducted to evaluate the suggested IMPO algorithm against particle swarm optimization, salp swarm optimization, bat optimization, dragonfly optimization, crow search optimization, grey wolf optimization, and multi verse optimization.

The author [4] In this study, surplus energy will be converted to hydrogen, which fuel cells will use to create energy instead of relying on batteries. The goal of this research is to address the economic sizing problem for the given micro-grid, namely the cost of energy (COE), using a multi objective particle swarm optimization (MOPSO) technique. The MOPSO algorithm keeps the loss of power supply probability (LPSP) as low as possible in an effort to reduce the COE to lower values.

## III. Proposal Of Innovative Method For Predicting Optimum Wind Generator Detailed Explanation:

Switching of modular multilevel converters can mainly be divided into two categories: low frequency switching and high frequency switching. In low frequency switching, a pre-calculated pulse pattern is used to drive the converter. Harmonic elimination methods can be used to improve the performance of the converter. These methods have low switching count and therefore high efficiency. However, their weakness is the dynamic response. In high frequency switching, a reference output voltage waveform (a modulation signal, sinusoid based) is compared in magnitude with a high frequency carrier waveform and switching logic signal is generated.

Generally, these methods yield low output voltage and current waveform harmonic distortion, enabling the converter to require smaller and lower cost passive filters and to have fast dynamic response to the source/load changes. Although high frequency switching methods tend to have higher switching count (which means higher switching loss) than low frequency switching; with suitable design, losses can be decreased and the major disadvantage of high frequency switching can be overcome. Additionally, the third category of switching method, namely mixed switching, can be added to take the advantages of the two methods above. As the name refers, this method has characteristics of both low frequency and high frequency switching. The switching methods for modular multilevel converters are illustrated in Figure.

High frequency switching methods are widely considered for modular multilevel converter due to satisfactory performance and ease of implementation. In high frequency switching, the carrier frequency is constant and in each switching period, reference and output voltage mean values are made equal. For this aim, scalar method can be used. Scalar method uses a reference (modulation) waveform having the desired output voltage magnitude and frequency, and a high frequency carrier waveform. Magnitudes of reference and carrier are compared and at the crossover points, switching occurs.

The level shifted modulation scheme is a modulation technique similar to the phase shifted PWM technique in relevant aspects such as the number of carrier calculation and the frequency modulation. Nonetheless, this technique differs from phase shifted PWM in the disposition of the triangular carriers, which in this case are vertically situated one after another. In this regard, the bands cover the whole interval and the amplitude modulation index is calculated as shown as in equation 4.1 ˆ m = V ma a ˆ V cr ( n volatge level − 1 ) m a ∈ [ 0 , 1 ] These methods require N identical triangular carriers being displaced contiguously in the whole dc-link voltage; Vdc. In order to provide a balanced exploitation of circuit elements that create different voltage levels, peak-to-peak amplitudes of the carriers are set equal to each other, Vdc/N, which is a necessary but not a sufficient condition. They have frequency of fc carriers do not cross. In phase disposition method, all the carriers are in phase. For an MMC having 4 sub-modules per phase arm (N=4), carriers of PD method are displaced in the Vdc band as illustrated in Figure .

Reduces switching is more necessary for decreasing the stress in the system. Here we design the new approach for the seven-level inverter topology which uses one stage methodology for conversion of the dc voltage. Figure shows the proposed model of the system. Here use total five switches for generating ac voltage. There is four dc voltage is used for developing steps of the output voltage. Switches S1, S2 and S3 is used for stepping the voltage that is it is called active switches. These switch is responsible for stepping the voltage with the addition of dc voltage. Table 4.1 shows the switching scheme used in the operation of all switches. Switch S4 and S5 is used for circulating current when the active switches are not operated.

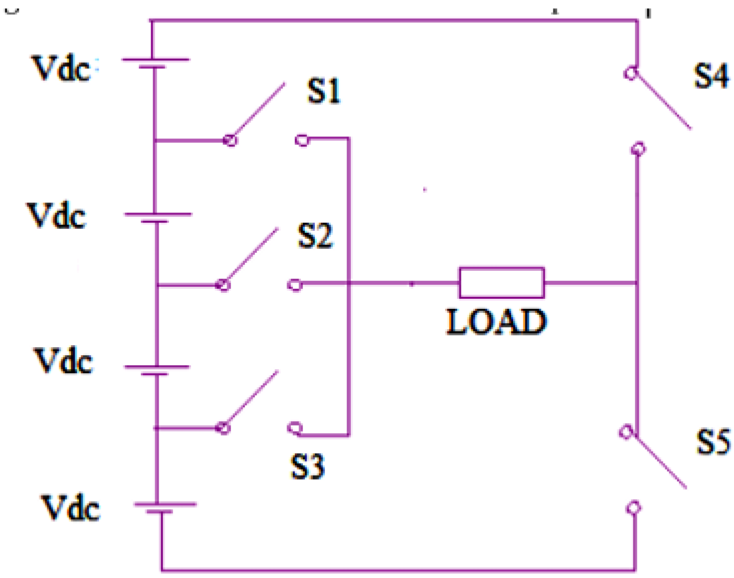


Fig 3.1 modular multilevel converters

## IV .Conclusion And Future Work:

A novel PSWM scheme has been simulated for multilevel inverters. The switching vectors and optimum switching sequence are automatically generated by the principle of mapping. The vector at the center of the particle containing the reference space vector was directly identified in this model space vector is mapped to the innermost particle, and the switching vectors for the seven level inverters are generated. The seven-level inverter vectors are translated to the vectors of the multilevel inverter by the principle of reverse mapping proposed in this paper. The PSWM for any n-level inverter including an inverter with an even number of levels can be implemented without any additional complexity. To control the output voltage and reduce the undesired harmonics, different sinusoidal pulse width modulation (PWM) and space-vector PWM schemes are suggested for multilevel inverters. however, PWM techniques are not able to eliminate low-order harmonics completely. Another approach is to choose switching angles so that specific lower order dominant harmonics are suppressed. This method is known as selective harmonic. The harmonic minimization problem in multilevel inverters is determination of the switching angles of inverter so that the specified lower order harmonics are suppressed. The swarm algorithm work with the pulse width modulation techniques. The design algorithm and model used 7 level inverters. This algorithm has been successfully applied to the SHE-PWM problem that involves large number of switching angles, where other conventional methods are not able to solve it. Simulation and experimental results are provided for a 7-level cascaded inverter to validate the accuracy of computational results. Results show that all undesired harmonics up to 50th order have been effectively minimized at the output voltage wave form of inverter.

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