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Advancements in Microgrid Technology: Challenges and Solutions for Renewable Energy Integration

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Abstract: *The development and implementation of microgrids play a pivotal role in transitioning towards sustainable and renewable energy sources, fostering a shift in global energy paradigms. Microgrids, as small-scale power grids, integrate various renewable energy sources alongside complex control circuits and distributed energy storage systems, ensuring reliable and robust energy distribution. However, the integration of wind and solar energy into microgrids presents challenges, particularly regarding stability and power quality due to the intermittent nature of renewable sources. This paper addresses these challenges and proposes innovative solutions, focusing on optimization algorithms for solar PV efficiency, wind turbine operations, and control system development using advanced techniques such as genetic algorithms. The research underscores the importance of adaptive protection strategies and the necessity for sophisticated control mechanisms to ensure the resilience and efficiency of microgrids under diverse operating conditions. Through simulation and analysis, this study demonstrates the effectiveness of hybrid solar-wind systems with common AC lines in mitigating power fluctuations and enhancing energy quality, offering insights into the future of renewable energy integration.*

Keywords: *Microgrids, Renewable Energy Integration, Solar PV Efficiency, Wind Turbines, Control System Development, Optimization Algorithms, Hybrid Solar-Wind Systems.*

I. INTRODUCTION

The development and implementation of microgrids has become an important tactic in the shift of many countries to new energy paradigms as the globe moves toward a future centered on more sustainable and renewable energy sources. Leading the way in this change are microgrids, which are essentially small-scale power grids that can function both independently and alongside the main power network. They are made up of various renewable energy sources, including hydroelectric generators, solar photovoltaic (PV) panels, wind turbines, and distributed energy storage systems, in addition to complex control circuits, AC and DC converters, and distributed energy storage systems. In addition to making it possible for the microgrid to acquire and distribute renewable energy more effectively, this composition ensures a more reliable and robust energy source. The integration of wind and solar energy into microgrids introduces a dynamic and flexible approach to energy production and distribution, significantly reducing reliance on fossil fuels and minimizing environmental impact. However, this increased reliance on variable renewable energy sources also presents new challenges, particularly concerning the stability and power quality of the microgrid. The wind and solar power’s intermittent nature might lead to fluctuations in energy production, potentially impacting the microgrid's ability to provide a stable and continuous power supply. This variability reduces the system's standby inertia, crucial for maintaining the stability of the power grid during sudden modifications in energy demand or supply.

Moreover, the inherent flexibility of microgrid operations, which allows for seamless transitions between grid-connected and islanded modes of operation, poses additional complications. These operational shifts can severely impact the effectiveness of conventional Overcurrent Relays (OCRs) based protection systems, which typically rely on fixed settings. The dynamic nature of microgrid topologies, influenced by changes in operational states, demands a more adaptive and intelligent approach to protection. This entails developing protection strategies that can dynamically adjust to the fluctuating power flows and fault current levels induced by the integration of DERs and the operational flexibility of the microgrid. Addressing these protection challenges requires innovative solutions that can accommodate the unique characteristics of microgrids, ensuring that the system remains robust, responsive, and reliable under all operating conditions. Such advancements in microgrid protection technology will be critical for harnessing the full potential of DGs and DERs, paving the way for a more resilient, efficient, and sustainable power grid.

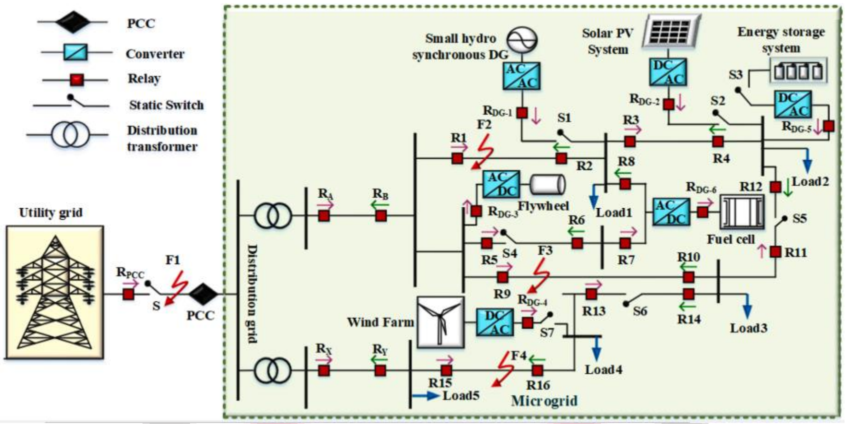

Figure 1 A Multi-source AC Microgrid

A. *Optimization of Solar PV Efficiency and MPPT Strategies*

In moments of energy scarcity or during periods of less-than-ideal operating conditions, the electrical grid plays a pivotal role in supplying power to various sites. Particularly in remote areas, such as rural villages and isolated industrial operations, stand-alone Photovoltaic (PV) systems emerge as vital sources of power. These systems are not only instrumental in providing essential electricity to support a myriad of applications—ranging from healthcare services and agricultural operations to general utility needs—but also in promoting sustainable energy use. Solar PV panels harness sunlight, transforming it directly into electrical energy. This generated power can either be utilized immediately to operate devices or stored in batteries for future use. Despite the apparent benefits, the deployment of PV systems is accompanied by several challenges that can impede their efficiency and overall effectiveness. Among these issues are the low conversion efficiency of solar panels, the high costs associated with PV technology, and the occurrence of multiple local energy peaks. These peaks are often the result of Partial Shading Conditions (PSCs), a common phenomenon in PV installations where solar panels receive uneven sunlight distribution. PSCs can significantly affect the performance of solar panels, leading to fluctuations in the Maximum Power Point (MPP), which is the point at which a PV system operates at its maximum efficiency. Addressing these challenges, the pursuit of optimizing energy extraction from PV systems has led to the development and proposal of various Maximum Power Point Tracking (MPPT) methods. These methods are designed to adapt to both uniform solar irradiance conditions and the complexities introduced by PSCs. MPPT algorithms play a crucial role in enhancing the adaptability and efficiency of PV systems, particularly in navigating the variable and often unpredictable nature of solar energy availability. By optimizing the tracking of the MPP, these algorithms help in significantly reducing power fluctuations and improving the overall yield of solar panels, even under rapidly changing weather conditions or in the presence of shading.

Data over the past decade indicates a significant surge in solar energy generation capacity, evidencing a remarkable growth trajectory. This upward trend suggests that, by 2030, the capacity could escalate to approximately 1700 Gigawatts (GW), underscoring the vast potential of solar PV systems to contribute to the energy mix. Such an expansion not only emphasizes the scalability of solar energy but also its role in transitioning towards a more sustainable and less carbon-intensive energy future. However, despite these promising developments and the potential for solar PV systems to serve as a viable substitute for fossil fuels, there remain operational inefficiencies that hinder their full potential. These challenges include the previously mentioned issues of low conversion efficiency, high installation costs, and the impact of Partial Shading Conditions (PSCs) on energy output. Such obstacles underscore the need for ongoing research, innovation, and investment in technologies that enhance the efficiency and cost-effectiveness of solar PV systems. Addressing these challenges is critical for maximizing the utility of solar PV systems and achieving their projected contribution to global renewable energy goals.

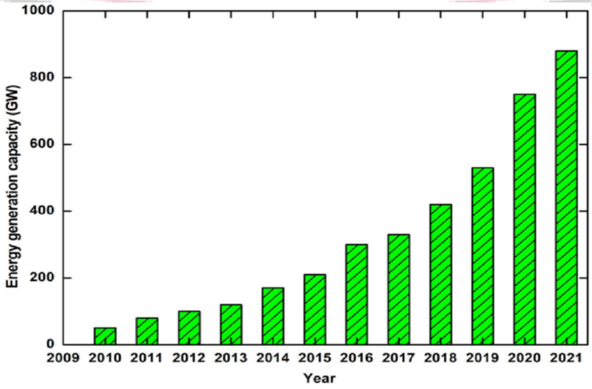

Figure 2 Photovoltaic energy generation capacity over the years

B. Wind Turbines

Wind turbines are designed to function within a specific range of wind speeds, delineated by the minimum wind speed necessary to start generating power (cut-in speed, Vcut-in) and the maximum wind speed beyond which the turbine must be shut down to prevent damage (cut-out speed, Vcut-out). Operation outside these bounds requires the turbine to be halted to protect the generator and the turbine itself. This leads to the identification of three distinct operational zones. The first zone is the low-speed region, where the turbine remains inactive and disconnected from the grid to prevent the generator from driving the turbine. The second, or moderate-speed zone, spans from the cut-in speed, at which the turbine begins to generate power, up to the rated speed (Vrated), where the turbine produces its maximum designated power. It's in this zone that turbines, especially those capable of varying their speed, excel by adapting their rotational speed to match changes in wind speed, thus maintaining an optimal ratio between rotational speed and wind speed (Tip Speed Ratio, TSR) for efficient energy extraction. Variable speed wind turbines, which can adjust their rotational speeds to instant changes in wind velocity, are particularly adept at optimizing the TSR to maximize energy capture. The instantaneous variability of wind speeds necessitates such adaptability in rotational speed to consistently achieve the optimal TSR. Wind energy systems utilize power electronic converters to operate effectively under varying speed conditions. These converters are essential for converting the generator's output, which fluctuates in voltage and frequency, into a consistent voltage and frequency that can be fed into the electrical grid. Optimal power extraction from the wind is dependent on maintaining an optimal tip-speed ratio (TSR), which is unique to each turbine model. When integrating wind turbines into the power grid, there are typically two main types of power electronic interfaces utilized: the back-to-back power converter and a setup consisting of a diode rectifier, a boost circuit, and an inverter.

II. LITERATURE REVIEW

Badal, F.R., et al. (2019) emphasize the significant role of renewable energy in the global electricity generation landscape. They highlight its potential to enhance power systems, particularly in the context of microgrids. The study explores challenges associated with integrating renewable energy sources into grids and managing microgrids efficiently, focusing on voltage control strategies and their effectiveness assessed through MATLAB/Simulink simulations.

X. Liu et al. (2023) delve into the literature on microgrids, emphasizing their importance in transitioning towards greener energy systems. They discuss energy management models and methodologies, categorizing microgrids and energy storage mechanisms. The study evaluates various energy management strategies, including transactive energy management, and proposes directions for future research in dynamic modeling, stability, resilience, and computational technologies.

Sheta, A.N., et al. (2023) examine the growth of electrical power systems with a focus on microgrids. They highlight the benefits of microgrids in enhancing efficiency, reducing costs, and lowering emissions through the integration of renewable energy sources and advanced management techniques. The study reviews existing research on protection schemes for AC microgrids and discusses challenges, solutions, applications, and future directions in the field.

Qinghui Li et al. (2023) introduce a demand response program tailored for renewable-powered microgrids, proposing a multi-objective approach to minimize operational costs and mitigate power transmission failures. They employ the Grey Wolf optimization algorithm and deep learning frameworks to predict renewable energy production, demonstrating superior performance over existing algorithms in managing smart microgrids.

Zhifei Zhang et al. (2022) present an improved iteration of the crow search algorithm (CSA-PSO) for optimizing microgrid scheduling. They demonstrate its superiority in reducing total operational costs, emphasizing its efficiency and effectiveness compared to other algorithms.

Dar'enkov, A., et al. (2022) focus on enhancing the efficacy of voltage source inverters through an Adjustable Discontinuous Pulse Width Modulation (ADPWM) approach. They demonstrate its effectiveness in reducing losses compared to conventional methods through simulation and experimental validation.

Jin, X., et al. (2023) introduce Optimized Discontinuous Carrier Pulse Width Modulation (ODCPWM) to address output voltage harmonics in synchronous carrier modulation. Experimental validation confirms its effectiveness in reducing harmonics, improving system stability, and enabling smooth switching transitions.

Gudipati, K., et al. (2023) propose an innovative modulation technique to reduce harmonics in multilevel inverters, demonstrating its potential to enhance performance and efficiency through simulation studies.

Das, S., et al. (2019) analyze Continual-clamp and Split-clamp pulse width modulation techniques, deriving closed-form expressions for associated distortion factors and validating them through experimental investigations on induction motor drives.

III. OBJECTIVES

The designing of hybrid solar wind energy system has been targeted in this research work. The work aims to design a common AC line inverter system which is driven by an effective controller. The following key objectives are to be attained by the algorithm designed for the converters in the hybrid system:
The work has concentrated on achieving the following key objectives:

- Designing of an effective optimization algorithm based hybrid approach for driving the DC/Ac converters such that they balance the fluctuations at the main line.
- Analysis of the performance of the controller in the system when the voltage sag and swell are created.
- Analysis of the power outcomes in the system with enhancement in the active power and balancing of available reactive power by improving the power factor.

IV. METHODOLOGY

In the quest for efficient and reliable power conversion, the role of DC/AC converters stands as a cornerstone in a broad spectrum of applications, ranging from renewable energy systems and electric vehicles to uninterrupted power supplies and industrial automation. The inherent complexity of power systems, combined with the dynamic nature of electrical loads and the intermittent characteristics of renewable energy sources, necessitates sophisticated control mechanisms that can ensure optimal performance under varying conditions. This research work is anchored on the premise that optimization algorithms can significantly enhance the control systems of DC/AC converters, leading to improved efficiency, reduced harmonic distortion, and increased system stability.

The criticality of DC/AC converters in modern power systems cannot be overstated, as they serve as the pivotal interface between DC power sources and AC loads or grids. However, conventional control strategies often fall short in addressing the non-linear and time-varying behaviors of electrical systems, especially in the face of external disturbances such as voltage sags, swells, and harmonic interference. To bridge this gap, our research introduces advanced optimization algorithms that are tailored to adaptively tune the control parameters of DC/AC converters in real time

A. Hybrid system development using MATLAB

Designing solar-wind hybrid systems with a common AC line is important for several reasons, which are focused on optimizing the implementation of renewable energy resources, improving efficiency, and ensuring a reliable power supply. Having multiple sources of energy feeding a common AC line can decrease dependency on the grid or any single energy source, enhancing energy security. The biggest challenge is the inherent variability and unpredictability of both solar irradiance and wind speed, which can lead to fluctuating power outputs and pose difficulties in maintaining a stable supply. Designing a control system that can handle inputs from both solar and wind systems and maintain a consistent output in the common AC line is complex. It requires advanced algorithms and real-time adaptive controls.

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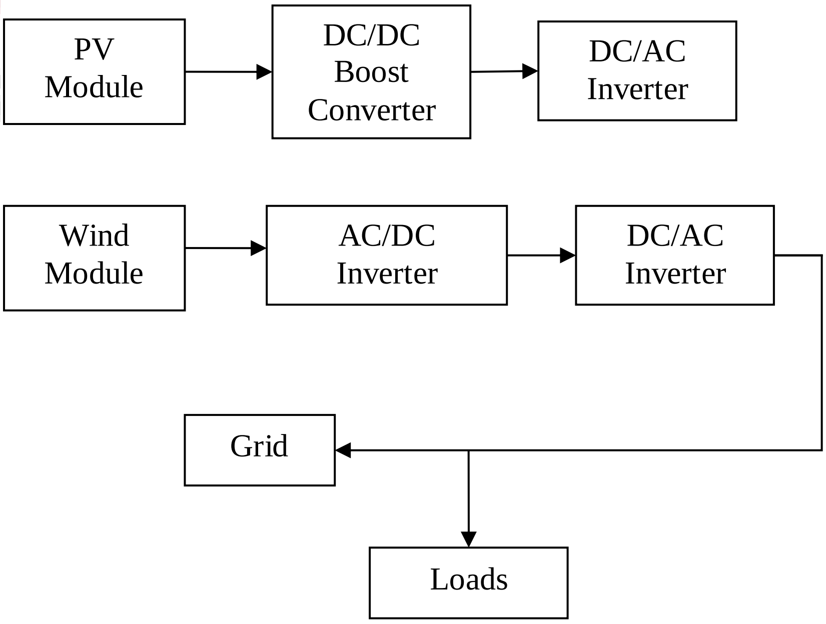

Figure 3 Hybrid energy system topology

In summary, designing a solar-wind hybrid system with a common AC line is important for optimizing the use of renewable energy, improving cost-effectiveness, and ensuring a stable and efficient power supply. However, the challenges of variability, control complexity, energy storage, and grid integration must be addressed to ensure successful implementation

Solar system simulation in MATLAB/SIMULINK

The hybrid PV system comprises photovoltaic (PV) generators, distributed generation (DG), and inverters, showcasing a versatile renewable energy solution. PV cells exhibit a singular operating point where the interplay of current (I) and voltage (V) defines peak power output, corresponding to a specific resistance (V / I). This system presents an effective means to harness solar energy, offering sustainability and environmental benefits while reducing reliance on fossil fuels [4]. The accompanying schematic in Figure 4.2 visually outlines the hybrid PV generation unit, while a PV cell's simplified equivalent circuit diagram has been depicted in Figure 4.3, illustrating key operational principles.

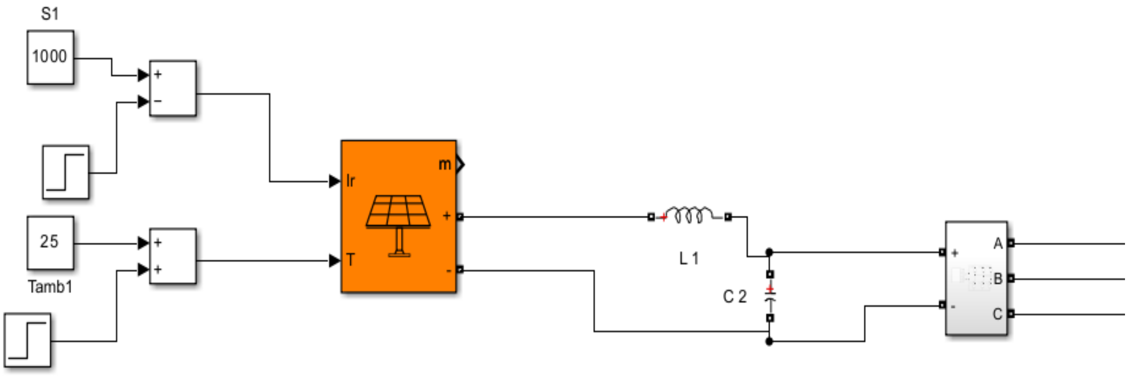

Figure 4 Modeling a Solar System in a Hybrid System

In the circuit configuration, a cell series resistance (Rs) is interconnected with a parallel arrangement consisting of the cell photocurrent (I_{ph}), exponential diode (D), and shunt resistance (R_{sh}). The current (Ipv) flowing through the cell and the voltage (Vpv) across it can be mathematically represented as follows:

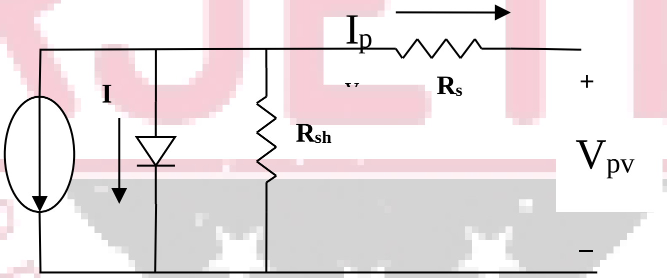

Figure 5 Solar PV Cell Equivalent Circuit

A photovoltaic (PV) cell exhibits an exponential relationship between its current and voltage. The maximum power point (MPP) is situated at the bend or knee of the curve, as depicted in Figure 4.4.

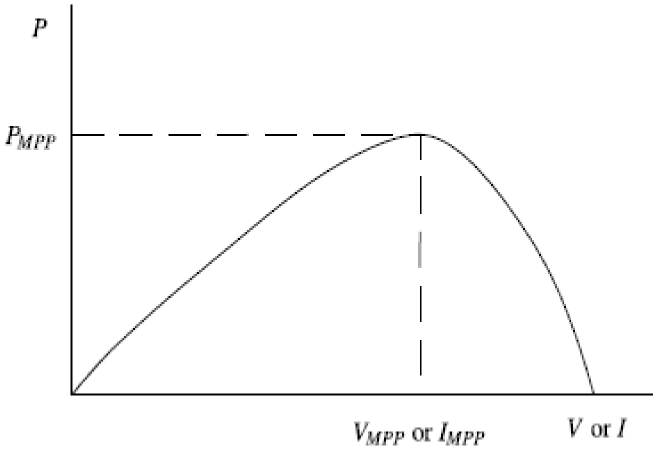

Figure 6 Characteristic PV array power curve

MATLAB/SMILULINK Description of Wind energy system

The wind turbine model featuring a Permanent Magnet Synchronous Generator (PMSG) aims to represent the wind turbine components accurately. The equations describing these components are as follows:
The aerodynamic power output of the wind turbine is expressed by:
In the given equation, the variable ρ symbolizes the air density, which is typically around 1.225 kg/m³. *A* represents the area swept by the rotor blades, measured in square meters (m²). C_P denotes the coefficient of power conversion, and *v* stands for the wind speed, expressed in meters per second (m/s).
The tip-speed ratio is defined as follows:
In the provided equation, ρ represents the air density (typically around 1.225 kg/m³), *A* denotes the area swept by the rotor blades measured in square meters (m²), C_P signifies the coefficient of power conversion, and *v* stands for the wind speed expressed in meters per second (m/s).
The tip-speed ratio is defined as follows:

$$\lambda = \frac{\omega_m R}{v}$$

The wind turbine's mechanical torque output, denoted as *m T*, is determined as follows, where ω_m represents the rotor's angular velocity in radians per second (rad/s), and *R* denotes the rotor radius in meters (m):

$$T_m = \frac{1}{2}\rho A C_p(\lambda, \beta) v^3 \frac{1}{\omega_m}$$

The power coefficient is a non-linear function determined by the tip speed ratio (λ) and the blade pitch angle (β) measured in degrees. The power output can be expressed as follows:

$$P_{Turbine} = \frac{1}{2}\rho A C_{p_{max}} v^3$$

A generic equation is used to model the power coefficient C_P based on the modeling turbine characteristics is defined as:

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

At different wind speeds, a wind turbine operates most efficiently at a specific point along its power curve, known as the Maximum Power Point (MPP). This is where the turbine generates the maximum amount of power. To ensure optimal performance, the load of the Wind Energy Conversion System (WECS) is controlled, allowing for variable-speed operation of the turbine rotor. This control mechanism enables the continuous extraction of maximum power from the wind, enhancing the overall efficiency of the system.

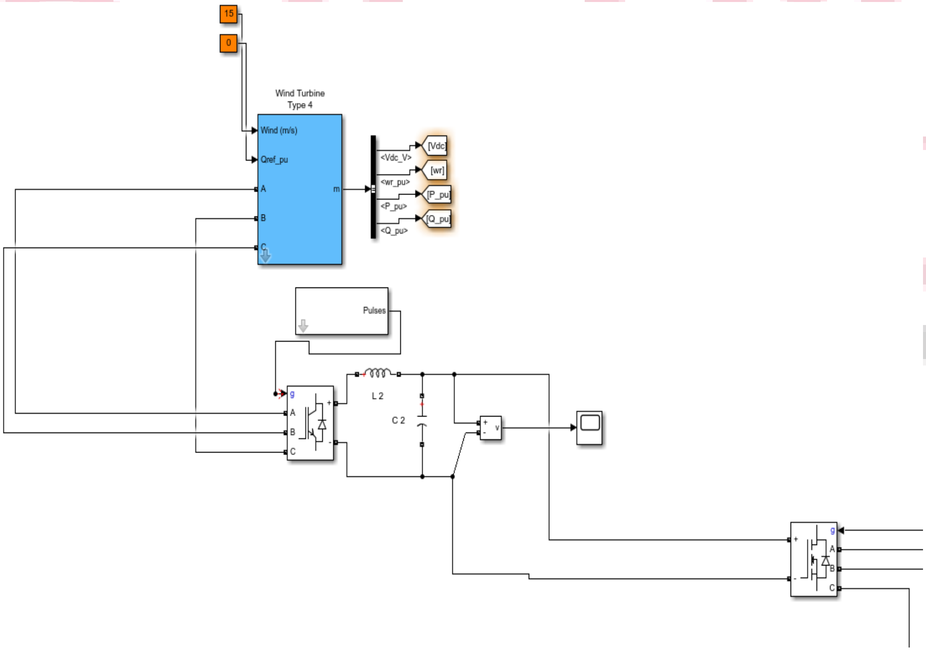

Figure 7 Modeled Wind system

This mechanism utilizes the variable torque output, denoted as w_m, to optimize the waveform of both the output current and voltage, aiming to reach their peak values.

B. Converter System Modelling and Control System

A. Principle of Pulse Width Modulation (PWM)

The circuit model of a single-phase inverter with a center-tapped grounded DC bus, showcasing its components and connections. Meanwhile, Figure 4.7 provides an illustration of the pulse width modulation principle, demonstrating how it controls the width of pulses to regulate the output voltage.

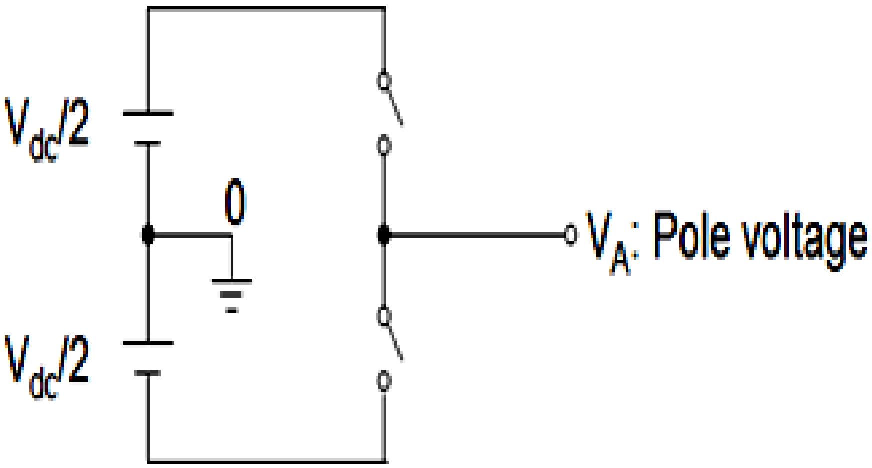

Figure 8 Circuit model of a single-phase inverter

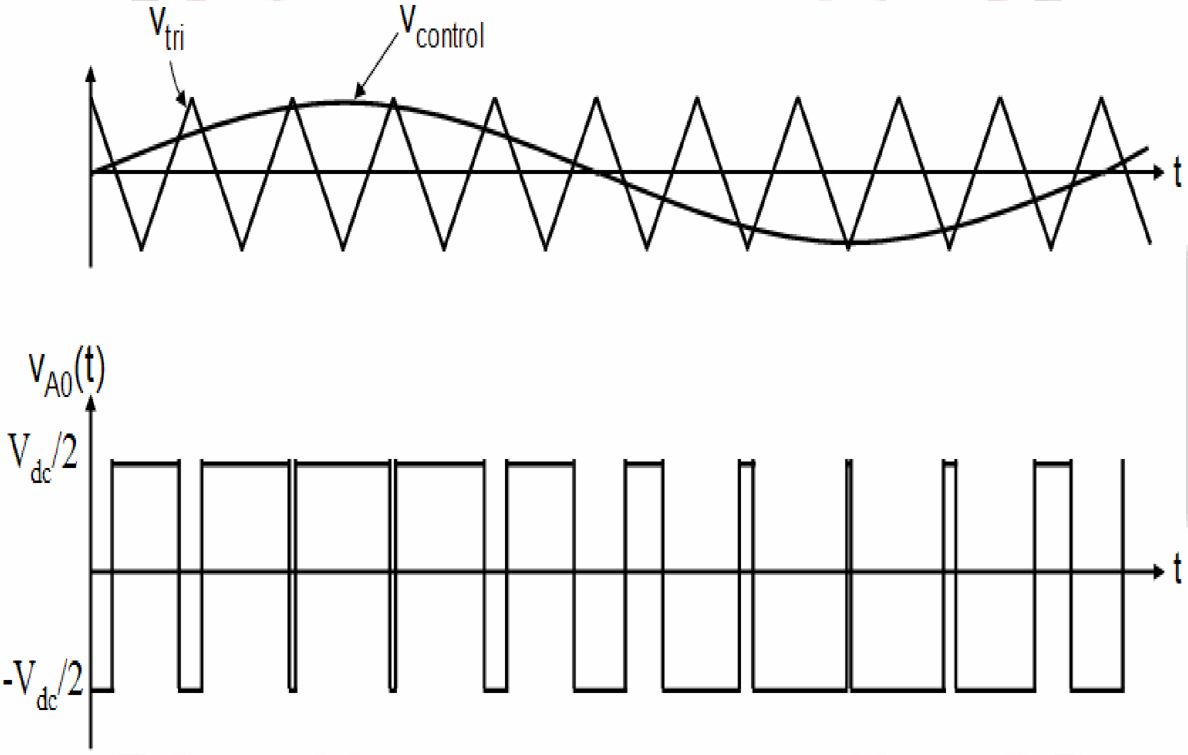

Figure 9 Pulse width modulation.

As depicted in Fig 4.7, the inverter output voltage is determined in the following

- When $V_{control} > V_{tri}$, $V_{A0} = V_{dc}/2$
- When $V_{control} < V_{tri}$, $V_{A0} = -V_{dc}/2$

Also, the inverter output voltage has the following features:

- PWM frequency is the same as the frequency of V_{tri}
- Amplitude is controlled by the peak value of $V_{control}$
- Fundamental frequency is controlled by the frequency of $V_{control}$

B. Principle of Sinusoidal PWM

In Figure 4.8, we observe the circuit model of a three-phase PWM inverter, which showcases the configuration and interconnections of its components. This model offers insights into how the inverter operates and how different elements contribute to its functionality. Meanwhile, Figure 4.9 presents the waveforms of the carrier wave signal (V_{tri}) and the control signal ($V_{control}$). These waveforms provide a visual representation of how the pulse width modulation (PWM) technique regulates the output voltage of the inverter. The inverter's output line-to-neutral voltages are indicated as V_{A0}, V_{B0}, V_{C0}, while the line-to-line voltages are represented as V_{AB}, V_{BC}, V_{CA}, respectively. These voltage measurements are crucial for understanding the performance and behavior of the three-phase PWM inverter under different operating conditions.

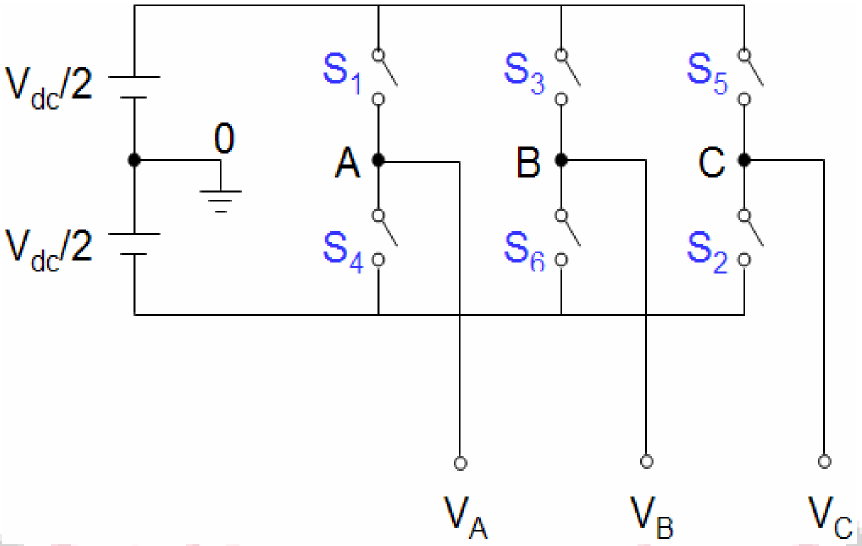

Figure 10 Three-phase PWM Inverter of general three-phase sine-PWM inverter

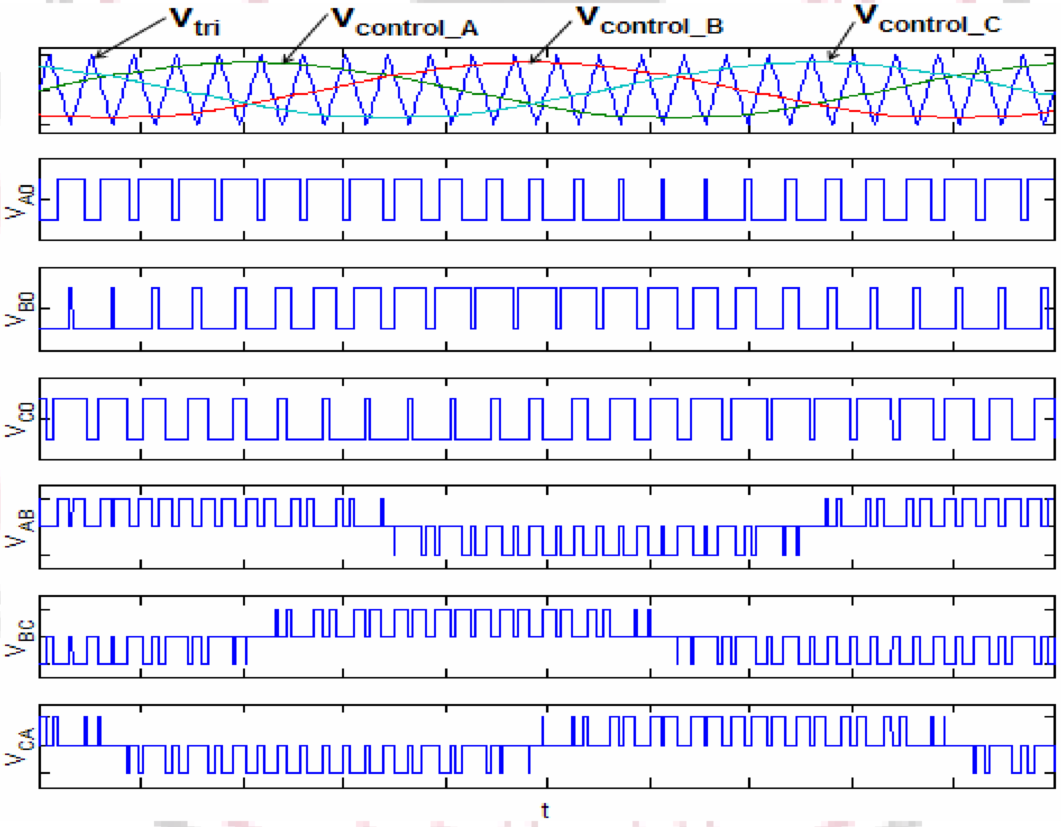

Figure 11 waveforms of carrier wave signal

Algorithms are used to generate reference signal for the PWM generator which thereby is used to produces pulses in the system to fire the inverter circuit.

The inverter system discussed herein pertains to a three-phase, grid-connected configuration employing a three-branch IGBT setup, typically utilized in distributed generation interfaces. A PI current controller with a synchronous frame has been chosen for inverter control.

When it comes to transmitting electricity generated by photovoltaic systems to the grid or AC consumers, the use of DC-AC converters, also known as inverters, is essential. These inverters play a crucial role in converting the direct current (DC) output of solar panels into alternating current (AC) suitable for grid integration or consumption by AC devices. They come in various configurations, with single-phase and three-phase outputs being the most common options.

There are four primary types of grid-integrated inverters commonly used in photovoltaic systems:

- Central System Inverter: This type of inverter is typically employed in large-scale solar installations where multiple solar panels are connected to a centralized inverter. It converts the combined DC power from several solar arrays into AC power for grid connection.

- String Inverter: In contrast to central system inverters, string inverters are installed at the string level, meaning each string of solar panels has its own dedicated inverter. This configuration offers flexibility and scalability, allowing for easier monitoring and maintenance of individual strings.
- Multi-String Inverter: Multi-string inverters are similar to string inverters but are capable of handling multiple strings of solar panels simultaneously. They provide a balance between the central system and string inverter designs, offering both scalability and efficiency.
- Microgrid Inverter (AC Modules): Microgrid inverters, also known as AC modules, are integrated into individual solar panels or modules. They convert the DC output of each panel into AC power directly at the module level, enabling greater energy harvesting efficiency and system flexibility. Each type of grid-integrated inverter has its own advantages and suitability depending on the specific requirements of the solar installation, such as size, location, and expected power output. Understanding the characteristics and applications of these inverters is crucial for designing and implementing effective photovoltaic systems.

The central inverter, an older technology, integrates numerous photovoltaic modules connected to the grid through a centralized unit. These modules are typically arranged in series, forming chains, and are then linked in parallel using string diodes to optimize performance. In contrast, string inverters, representing current technology, consist of smaller-scale plant inverters where each string connects directly to its own inverter. Multi-string inverters incorporate multiple strings, linking them to a shared DC-AC inverter alongside individual DC-DC converters. String inverters offer superior individual controllability compared to central system inverters. The block diagram depicting the three-phase DC-AC inverter connected to the grid is illustrated in Figure 4.8.

The design of the inverter control aims to enhance system parameters. It is carried out in the dq0 reference frame to simplify the analysis of individual components and their respective variations. The system consistently monitors variable parameters and updates them as necessary.

Control system development using the Power Drien Vector modulation control (PVMC)

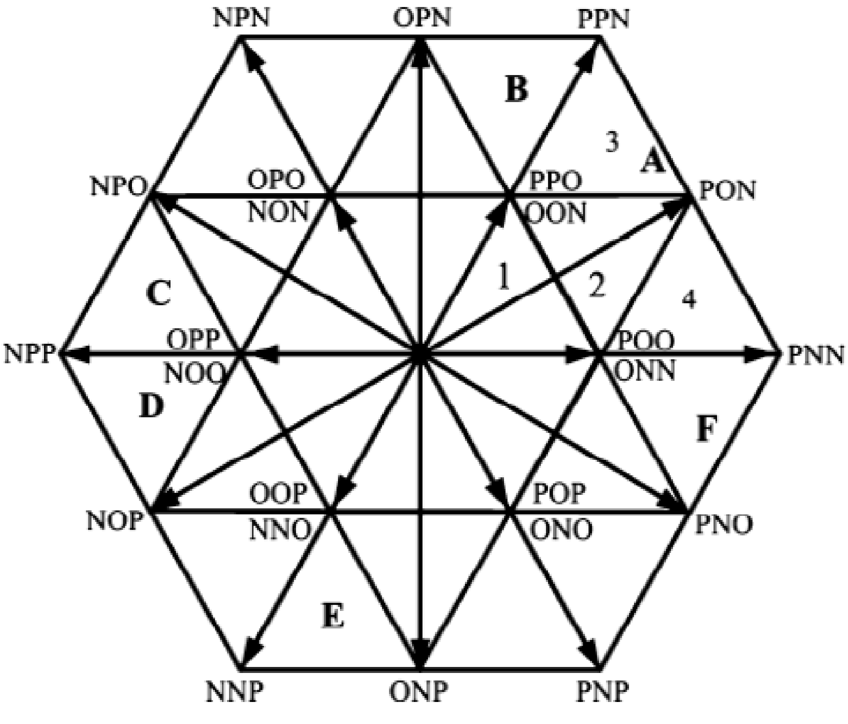

Figure 12 Space-vector diagram of the three-level converter

The simplified algorithm streamlines the Calculation Flow by utilizing only one sector instead of the traditional six, as depicted in Fig. 4.10. This optimization involves strategic Dwell Time calculations and switch configurations within the first sector compared to the others. The algorithm initializes necessary parameters and identifies the sector based on input voltage and current values. Instead of computing Dwell Times for all six sectors, it calculates Dwell Time solely for the identified sector, reducing computational complexity. With the calculated Dwell Time and sector information, the algorithm determines the optimal switch configuration to generate the desired output waveform. By focusing on a single sector and optimizing the calculation process, the algorithm enhances the efficiency and performance of the pulse width modulation (PWM) controller while maintaining accuracy and reliability in waveform generation.

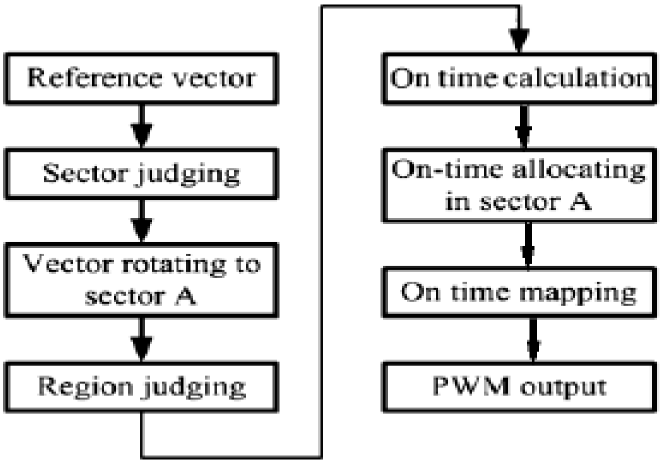

Figure 13 Calculation flow for the three-level SVPWM Simplified calculation

Suppose a scenario where reference vector A remains within region 2 of sector A, depicted in Fig 4.10. In this context, reference vector B is derived by rotating vector A counterclockwise by an angle of 60°. This geometric configuration illustrates the relationship between the two reference vectors within the sector, demonstrating how they are positioned relative to each other.

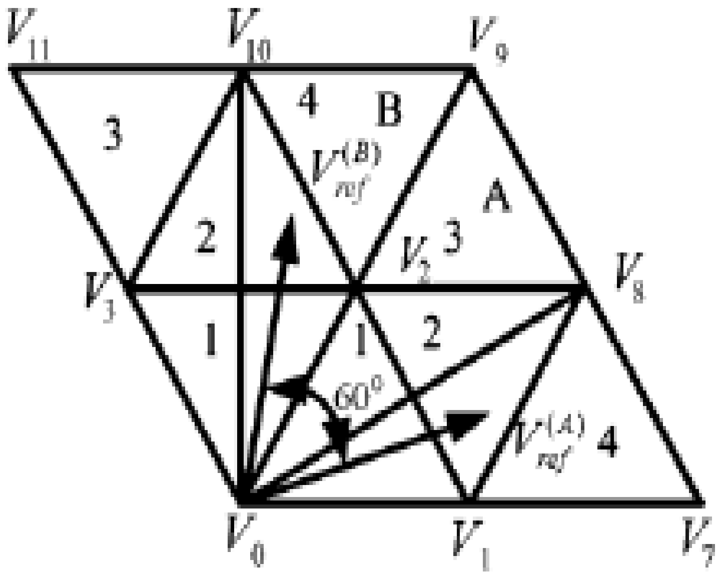

Figure 14 Two vectors with 60° shifting in the sector A and B.

Furthermore, when the reference vector resides in sectors other than sector A, it will undergo rotation to align with sector A, with each rotation occurring at intervals of $n\pi/3$, where n equals 1, 2, 3, 4, or 5. This rotation mechanism ensures that the reference vector consistently corresponds to the appropriate sector. Table 4.1 provides a comprehensive guide detailing the construction of the corresponding reference vector in each of the sectors, facilitating a systematic approach to vector alignment across different sector configurations.

Table 1 Relationships Of Voltages Constructing The ReferenceVectors In Six Sectors.

Sectors	Phase Voltage A	Phase Voltage B	Phase Voltage C
A	U_a	U_b	U_c
B	$-U_b$	$-U_c$	$-U_a$
C	U_c	U_a	U_b
D	$-U_a$	$-U_b$	$-U_c$
E	U_b	U_c	U_a
F	$-U_c$	$-U_a$	$-U_b$

Control system development using Genetic algorithm in hybridization with PQ control (HPQ_GA)

In traditional approaches, controller parameters remain static, which may not be suitable for dynamic references, potentially leading to system instability. Hence, it is crucial to choose appropriate parameters for the scheme. Artificial intelligence-based optimization algorithms are extensively employed to address such optimal problems due to their efficient optimization capabilities and global search abilities. These algorithms emulate nature's selection process and leverage bio-inspired operators to obtain optimal solutions.

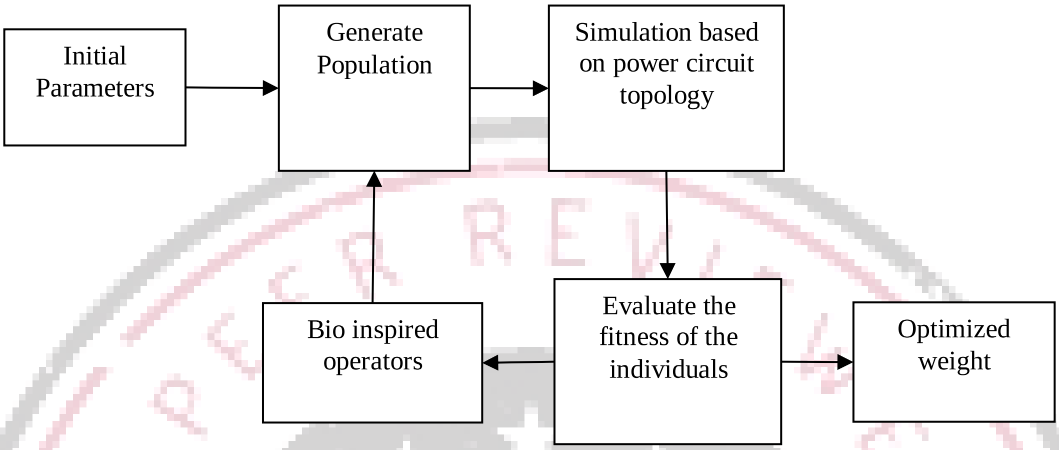

Figure 15 Operation of the optimization scheme

After iterative calculations, the optimal solution can be achieved. The objective of the optimization problem is to identify a set of initial weights that minimize both the suppression/evaluation time and overshoot. This entails reducing the suppression time as much as possible while limiting the overshoot amplitude. Enhancing the converter's performance can be achieved by selecting an optimal PID gain, ensuring improved dynamic and steady-state responses. To optimize the system's dynamic and steady-state behavior during disturbances, an objective function is chosen for minimization, and the PID gains are adjusted to minimize/maximize this objective function, thereby ensuring the desired dynamic performance.

The Fourier coefficients of the PWM-SHE switching pattern for the line-to-neutral voltages of a three-phase system can be expressed using equation (2).

Equation (2) encompasses N variables denoted as α_1 to α_n, and the solution set is derived by setting (N-1) harmonics to zero and assigning a predetermined value to the fundamental amplitude, denoted as α_1, as outlined in equation (3). This approach enables the systematic calculation of solutions by fixing the fundamental amplitude and iteratively determining the values of the remaining harmonics, ensuring a comprehensive evaluation of the equation's variables and constraints.

Where, M represents the modulation index, while the variables ε_1 to ε_n denote the normalized amplitude of the harmonics targeted for elimination. The primary goal of the PWM-SHE technique is to reduce the harmonic content present in the inverter line voltage, formulated as an objective function in equation (4). By minimizing this function, the technique aims to achieve improved waveform quality and reduced distortion in the output voltage, enhancing the overall performance and efficiency of the power conversion process.

For Quarter-wave symmetric pulse pattern. In this method, , , andα α α α α1 2 3 4 5 solutions are expected with elimination of 5th, 7th, 11th and 13th harmonics.

Genetic Algorithms (GA) are optimization algorithms rooted in the principles observed in genetic and evolutionary mechanisms found in natural systems and populations. In binary encoding Genetic Algorithms (GAs), genetic information is represented using binary strings, where each string represents the genes of an individual chromosome, and the population comprises multiple such individuals. Parameters are encoded as fixed-length symbols, usually binary bits, which are concatenated to form a complete chromosome. Specific substrings are then extracted from this concatenated string, decoded, and translated into corresponding values within the search space. The GA process typically involves generating an initial population, evaluating the fitness of each individual, and performing genetic operations such as selection, crossover, and mutation. This study seeks to identify the most effective switching pattern for minimizing lower-order line voltage harmonics in Voltage Source Inverters by employing GA methodology.

- Initialization: The initial population (Pi) is created by ensuring compliance with equation (5), which entails randomly selecting initial individual switching angles. These generated switching angles are uniformly distributed between their minimum and maximum limits, satisfying equation (5).
- Fitness of the candidate solutions: In this case, the Fitness Value (FV) aims to minimize the objective function utilizing equation (6).

The alpha limit violation can be dealt with the violation coefficient value using equation (7).

In such cases, the objective function is determined by multiplying the Vio_coeff value. After computing the fitness of each individual, the parent individuals undergo genetic operations, which include selection, crossover, and mutation. These operations result in each pair of parents producing a child. This iterative process of selecting and mating individuals continues until a new generation is created.

- Selection: After evaluating the initially generated population, the Genetic Algorithm (GA) proceeds to generate a new generation. Chromosomes from the parent population are paired and selected with a predetermined probability.
- Within the Genetic Algorithm framework, the crossover operator is deployed with a set probability to amalgamate parent genotypes, generating two fresh genotypes that inherit traits from both parents. Although crossover serves as the primary exploration mechanism, it lacks the ability to introduce entirely new information beyond what exists in the population. Our method entails merging parameter values from parent genotypes using a single-point crossover technique to create offspring with novel parameter values. Moreover, the mutation operator is applied with a low probability, randomly altering bits of the offspring genotype to introduce characteristics not present in the parent population. Generally regarded as a secondary mechanism, mutation assigns a nonzero probability to each solution for assessment, aiding in the avoidance of local minima and facilitating exploration within the solution space. The decision on which genes undergo mutation is determined using a coin-toss mechanism, with genes being mutated if the randomly generated number falls below the mutation rate. This stochastic process may lead to the discovery of superior solutions but also risks generating weaker individuals.
- Elitism: The crossover and mutation processes are executed iteratively for each pair of chromosomes until all chromosomes from the parent generation are replaced by the newly formed chromosomes. Furthermore, both the finest chromosome from the parent generation and the most superior chromosome identified in all previous generations are duplicated without modification in the subsequent generation. This precaution ensures that they are not inadvertently lost through genetic operations.
- Termination criterion for GA: The procedure delineated in sections [B-E] is repeated until the maximum iteration count is reached. This entails the cyclic execution of the primary stages and functions of the Genetic Algorithm approach, including initialization, selection, crossover, and mutation.

The Genetic Algorithm (GA) concludes its operation upon reaching a predetermined maximum number of generations or when the objective function value remains consistently below a specified threshold for a set number of iterations. The upper-level optimization detects concurrent outages within the power system, taking into account both frequency and Total Harmonic Distortion (THD) levels. Simultaneously, the lower-level optimization simulates the system operator's response to these outages, establishing the most effective power system operation during contingency situations. The converter's architecture remains unchanged, with only the control mechanism for the device being varied.

V. RESULTS AND DISCUSSION

The integration of solar panels and wind turbines was successfully modeled in MATLAB's Simulink environment. The simulation results indicated effective energy capture from both solar and wind sources, demonstrating the potential for a reliable and consistent energy supply. The control algorithms based on the artificial intelligence, designed to optimize power generation and distribution, showed promising efficiency. The system was able to dynamically adjust to varying weather conditions and energy demands, ensuring optimal operation of the hybrid system. In this research work focus on designing a common AC solar-wind hybrid system using MATLAB is done and several significant results are generated throughout the different stages of operation of hybrid system.

The final assessment of the system performance under various operational scenarios was done which indicated that the AC solar-wind hybrid system could meet the expected energy production targets, with high reliability and efficiency. The analysis was done using Power targeted vector modulation control (PVMC) for the hybrid system where the controller was invented for DC/AC converters before integration to the grid. The controller was then modified by hybrid approach for controlling output of DC/Ac inverters having hybridized PQ control with genetic algorithm in the system (HPQ_GA). The results discusses the outcomes from the two algorithms and their efficiency in handling the load changes and load power quality.

The analysis has been done by using two algorithms in hybris solar wind energy system having common AC line. All the fluctuations are being analysed and discussed in detail in this chapter in the following two cases:

Case 1: Active and Reactive Power Quality assessment at the loading points

Case 2: Analysis when the system is subjected to voltage Sag and swell conditions in hybrid system.

The goal here is to compare and contrast the capability of each system to mitigate or manage these harmonic distortions during such transient events. The analysis is comprehensive, covering both the overall quality of the power delivered by the systems under normal conditions (Case 1) and their proficiency in handling specific power quality issues like harmonics during sag/swell conditions (Case 2).

Table 2 Comparative outcomes when hybrid system is subjected to voltage swell conditions

Systems	Parameters	Values
Hybrid solar wind system with DC/AC inverter controlled by PVMC	THD% Voltage	3.76
	THD% Current	4.26
Hybrid solar wind system with DC/AC inverter controlled by HPQ_GA	THD% Voltage	3.75
	THD% current	3.83

In table 5.3, both systems show similar THD values for voltage, with the system controlled by HPQ_GA having a marginally lower THD% in voltage (3.75%) compared to the PVMC-controlled system (3.76%). However, a more noticeable difference is seen in the THD% in current, where the HPQ_GA-controlled system demonstrates better performance (3.83%) compared to the PVMC-controlled system (4.26%). This indicates that the HPQ_GA control method might be more efficient in alleviating harmonic distortion in current within this hybrid system configuration subjected to voltage well conditions.

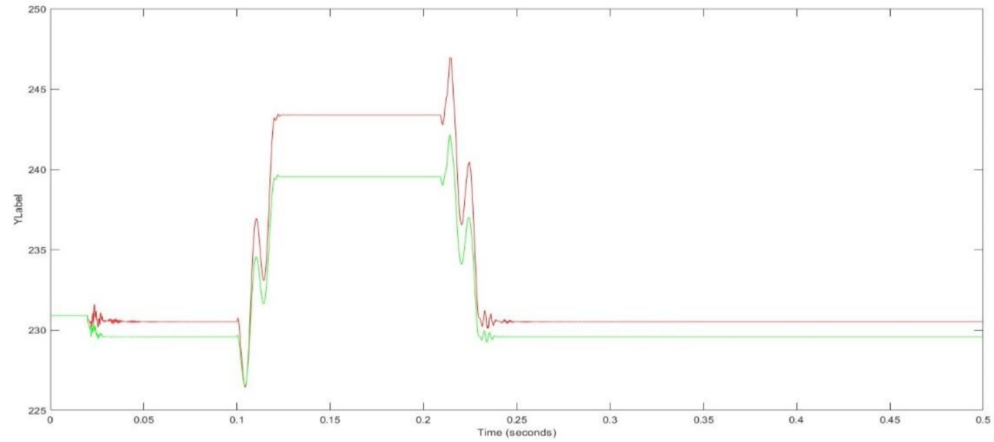

Figure 16 Comparative analysis of phase C voltage subjected to swell conditions

Red graph represents the phase C voltage in system where the common AC line converters are driven by PVMC and green graph represents the voltage graph of phase C in hybrid system driven by HPQ_GA controller. The figure 5.37 represents that the converter control proposed in this work limits the voltage rise to a certain limit safeguarding the loads in the system. In response to a voltage swell, the converter can adjust the duty cycle of its switches to absorb the excess voltage and prevent it from reaching the load.

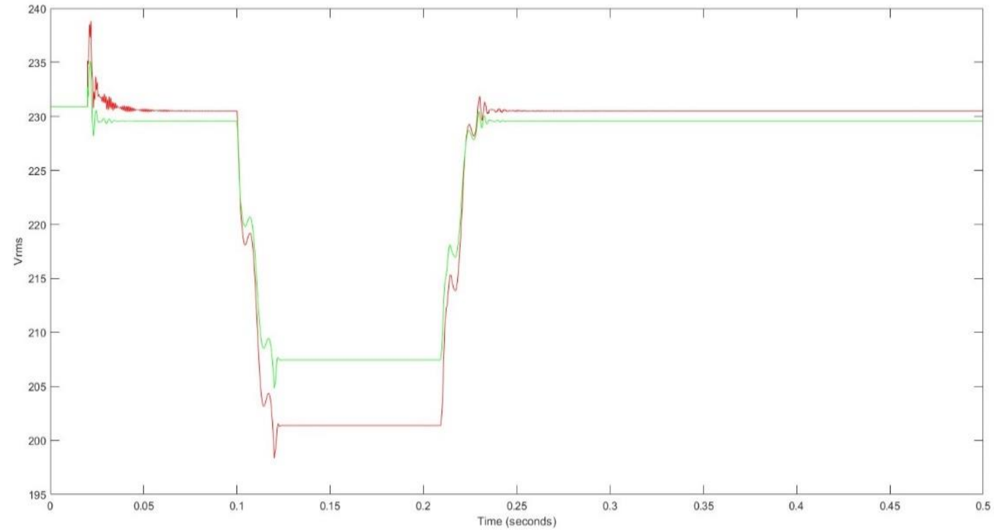

Figure 17 Comparative analysis of phase A voltage subjected to sag conditions

Red graph represents the phase A voltage in system where the common AC line converters are driven by PVMC and green graph represents the voltage graph of phase A in hybrid system driven by HPQ_GA controller. The figure 5.38 represents that the converter control proposed in this work limits the sudden voltage drop to a certain limit and has more efficient performance.

V. CONCLUSION

The research presented highlights the significance of microgrids in the global transition towards sustainable energy sources. By addressing challenges associated with renewable energy integration, such as intermittency and power quality issues, innovative solutions have been proposed. Optimization algorithms for solar PV efficiency and wind turbine operations, coupled with advanced control system development using genetic algorithms, offer promising avenues for enhancing the performance and reliability of microgrid systems. Through simulation and analysis of hybrid solar-wind systems with common AC lines, the study demonstrates the effectiveness of these solutions in mitigating power fluctuations and improving energy quality. Moving forward, continued research and development in microgrid technology and renewable energy integration are crucial for realizing a resilient, efficient, and sustainable energy future.

REFERENCES

[1] Badal, F.R., Das, P., Sarker, S.K. et al. A survey on control issues in renewable energy integration and microgrid. Prot Control Mod Power Syst 4, 8 (2019). https://doi.org/10.1186/s41601-019-0122-8

[2] X. Liu, T. Zhao, H. Deng, P. Wang, J. Liu and F. Blaabjerg, "Microgrid Energy Management with Energy Storage Systems: A Review," in CSEE Journal of Power and Energy Systems, vol. 9, no. 2, pp. 483-504, March 2023, doi: 10.17775/CSEEJPES.2022.04290.

[3] Sheta, A.N., Abdulsalam, G.M., Sedhom, B.E. et al. Comparative framework for AC-microgrid protection schemes: challenges, solutions, real applications, and future trends. Prot Control Mod Power Syst 8, 24 (2023). https://doi.org/10.1186/s41601-023-00296-9

[4] Qinghui Li, Zhigao Cui, Yanping Cai, Yanzhao Su, Bo Wang, Renewable-based microgrids' energy management using smart deep learning techniques: Realistic digital twin case, Solar Energy, Volume 250, 2023, Pages 128-138, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2022.12.030.

[5] Zhifei Zhang, Cai Zhao, Danfeng Chen, An Wen, "Research on Microgrid Scheduling Based on Improved Crow Search Algorithm", International Transactions on Electrical Energy Systems, vol. 2022, Article ID 4662760, 21 pages, 2022. https://doi.org/10.1155/2022/4662760

[6] Dar'enkov, A., Sokolov, V., Sluzov, A., Berdnikov, I., & Shalukho, A. (2022). Research and Development of Adjustable Discontinuous Pulse Width Modulation Method for Three-Phase Voltage Source Inverter. Energies, 15(20), 7463.

[7] Jin, X., Liu, J., Chen, W., & Shi, T. (2023). Optimized Synchronous Pulse Width Modulation Strategy Based on Discontinuous Carriers. Energies, 16(5), 2401.

[8] Amarnath Yalavarthi, Akbar Ahmad, "Analytical Modelling and Verification of Bus-Clamping Modulation Technique for Switched-Capacitor Converter", Modelling and Simulation in Engineering, vol. 2017, Article ID 6261404, 10 pages, 2017. https://doi.org/10.1155/2017/6261404

[9] Gendrin, M., Gauthier, J. Y., & Lin-Shi, X. (2016). A predictive hybrid pulse-width-modulation technique for active-front-end rectifiers. IEEE Transactions on Power Electronics, 32(7), 5487-5496.

[10] Gudipati, K., Maramreddy, H. V. R., Kolli, S. G., Anantha Lakshmi, V., & Sreenivasa Reddy, G. (2023). Comparison of Pulse Width Modulation Techniques for Diode-Clamped and Cascaded Multilevel Inverters. Engineering, Technology & Applied Science Research, 13(4), 11078–11084. https://doi.org/10.48084/etasr.5939

[11] Das, S., Hari, V. P. K., Kumar, A., & Narayanan, G. (2019). Analysis of generalized continual-clamp and split-clamp PWM schemes for induction motor drive. Sādhanā, 44(2), 36.