LEAKAGE CURRENT MITIGATION TECHINIQUE IN SOLAR PV ARRAY USING PASSIVE FILTERS.

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ABSTRACT: In transformer-less solar photovoltaic (PV) systems, high-frequency capacitance between system components can create unintended pathways that lead to leakage current flow. These leakage currents negatively impact system performance, causing electromagnetic interference and reducing the lifespan of PV panels. To address this issue, this study proposes a passive filter designed specifically to suppress leakage currents during PV array operation. An analytical optimization approach based on frequency-domain analysis is used to determine optimal filter parameters, ensuring efficient performance. Unlike conventional techniques, this method does not require additional semiconductor switches, thereby simplifying the system design and improving reliability. An adaptive control mechanism is incorporated to extract fundamental load current components and effectively reduce harmonic distortion. Simulation results demonstrate that the proposed filter maintains leakage current levels within the limits specified by DIN and NB/T grid standards. Furthermore, comparative analysis highlights the practicality and superior performance of the approach. Real-time Hardware-in-the-Loop (HIL) testing under various operating conditions confirms that the grid current Total Harmonic Distortion (THD) remains below 5%, complying with IEEE 519 and IEC 61727 standards. Overall, the proposed system offers an efficient and reliable solution for improving the performance and longevity of transformer-less PV systems.

KEYWORDS: DC-DC converter, DC-AC converter, DSTATCOM, grid-tied solar array, harmonic analysis, MPPT, power quality, solar power generation, voltage control, voltage source converter.

I. INTRODUCTION

The widespread use of Solar Energy Conversion Systems (SECS) occurs because these systems offer minimal maintenance requirements as well as zero emissions alongside silent operational characteristics. The price decline of solar PV installations because of technological progress remains unable to surmount grid-connected system problems with ride-through stability, leakage current generation, inertia management, inter-harmonic generation and synchronization difficulties which have prompted updated international grid regulations.

The main cause of leakage current originates from parasitic capacitances which range from 50 to 150 nF/kW between PV layers and their proximate surroundings. This isolation method confronts these challenges but adds system cost and bulk elements together with complexity. Alternative configurations using H5, H6 together with optimized H5 (oH5) minimize leakage currents but these improvements demand supplementary semiconductors that boost system complexity and losses.

The three-phase H7, H8 and H9 converters enhance common-mode voltage and leakage current stabilization while their additional semiconductor components author increased complexity in system design. These topologies face significant challenges when trying to compensate harmonics because they cannot reach the required standards set by IEEE 519 and IEC 61727. Advanced controllers including both adaptive model predictive and proportional-resonant (PR) help the system however these controllers function at specific frequencies .Generalized integrators use more computational power to enhance harmonic correction. Modified LCL filters function as filter-based methods to suppress leakage current and maintain operation efficiency.

II. LITERATURE

The paper presents an innovative method to model PV solar modules by using symmetric-shifted Gompertz functions. The proposed technique achieves two major benefits by simplifying fitting parameter count and improving model convergence efficiency and lowering computational resources compared to traditional modelling procedures. The research establishes both the entire I-V curve derivation and multiple nonlinear relationships between electrical and environmental conditions. The new approach shows superiority through comparison with existing modelling frameworks. Research performed on real power systems from CdTe thin-film and silicon-based PV power plants proves the model achieves accurate results. Through this method manufacturers can verify PV module active power generation by using their provided datasheet values without requiring laboratory testing of single modules.

Research shows that solar energy systems became popular because solar panel costs decreased and power electronics improved meaning widespread rooftop installations for smaller systems occurred under favorable subsidy programs. Grid codes have experienced revisions for accommodating PV along with distributed generation (DG) systems into electric power networks. Power converter topologies with various control methods have been created for grid synchronization since the introduction of regulations. This paper examines recent developments in grid-connected PV systems and explains useful information to assist new researchers who face system integration challenges.

This work creates an user-oriented cyber-physical system which manages Distributed Demand Response (DDR) controls in power distribution networks. The model deploys Local Schedulers (LS) across multiple bus locations for decreasing the peaks of sparse communication network usage. The COMDES methodology provides network topologies with security through its application of bandwidth with stability assessments for voltage along with load cycle considerations. The system achieves optimal voltage control by applying Lyapunov stability principles combined with Linear Matrix Inequalities (LMI) for producing efficient load scheduling. Three scheduling protocols namely Earliest Deadline First, Least Laxity First and Dynamic Rate Priority enable peak shaving operations. The methodology performs its validation through tests conducted on both IEEE 4-bus and IEEE 14-bus network systems.

This study investigates the impact of environmental factors—such as temperature, humidity, and wet conditions—on leakage currents in PV modules. Research results show that PV module assembly structures together with their material make-up control the way leakage currents operate. The experimental measured data undergoes Arrhenius model analysis for determining activation energies throughout different humidity conditions. Research examines how rain and dew moisture affects glass surfaces located at the front section of PV installations. The increase in leakage currents reaches ten times its original value when modules become wet thus requiring testing protocols to include both moisture-free and saturated environments.

An analysis reviews modern medium-voltage converter technology development as a solution to lower costs when integrating solar PV power plants into power grids. Current research focuses on developing new solutions which will optimize the efficiency and decrease the expenses associated with massive solar plants.

The proposed nearest level modulation (NLM) technique develops a switching plan that allows complete power flow through the primary H-bridge. This method functions without requiring high-voltage switches since it lets power move from one auxiliary H-bridge to another. A single-input-single-output auxiliary converter rated at 5% of total power capacity powers the proposed design which creates a compact and efficient yet cost-effective inverter structure. This design matches perfectly with applications that require high power and high voltages. Programable firing angles control the device switching and MPPT regulates the main DC-link while an isolated DC/DC converter operates on the auxiliary DC-links. Experimental testing of the topology proves successful through hardware prototype validation at 1.5 kW power capacity.

This research work combines the BDC-based H5 Heric H6 TLI inverter topologies with upgraded PWM methods. During freewheeling mode the BDC branch sustains the inverter terminal voltages at half the DC-link voltage for leakage current reduction. The modified PWM methods support reverse current transmission across all power regions. Experimentation together with MATLAB simulations demonstrate that the proposed topologies attain superior performance than standard configurations.

2.1. Photovoltaic (PV) Module Modelling

[1] A. Molina-Garcia, J. Guerrero-Pérez, M. C. Bueso, M. Kessler, and E. Gómez-Lázaro proposed a new approach to model photovoltaic (PV) solar modules using symmetric-shifted Gompertz functions. This method significantly reduces the number of fitting parameters, convergence issues, and computational costs compared to previous models. It provides the entire I-V curve and describes nonlinear relationships between environmental and electrical variables. The proposed model is validated with real data from CdTe thin-film and Si PV power plants. Additionally, it can be used to verify active power generation based on manufacturer datasheets without requiring laboratory analysis.

2.2 Grid-Integrated PV Systems

[2] R. Panigrahi, S. K. Mishra, S. C. Srivastava, A. K. Srivastava, and N. N. Schulz reviewed the cost reduction, efficiency improvements, and advancements in power electronics associated with solar panels. The study highlights the rapid growth of small-scale rooftop PV installations due to governmental incentives and direct user benefits. The paper discusses grid integration standards, power converter topologies, grid synchronization methods, and control strategies. It provides a comprehensive overview for new researchers on grid-integrated PV systems and key challenges in the field.

2.3 Demand Response in Smart Grids

[3] S. Mishra et al. introduced a novel user-centric cyber-physical framework for distributed demand response (DDR) in power distribution systems. The framework employs a Conjoint Methodology for communication and controller design (COMDES) to optimize communication topology considering smart grid cyber-physical properties such as bandwidth, load profile, and voltage stability. The study utilizes IEEE 4-bus and 14-bus models to demonstrate the framework's effectiveness. Established scheduling algorithms such as Earliest Deadline First, Least Laxity First, and Dynamic Rate Priority are used to achieve peak shaving.

2.4 Leakage Current Analysis in PV Modules

[4] N. G. Dhere, N. S. Shiradkar, and E. Schneller analyzed module leakage currents under different environmental conditions, including temperature, humidity, rain, and wetness. The study used the Arrhenius model to fit experimental data and compute activation energies for different humidity levels. The effects of dew and rain on module front glass were investigated, showing a tenfold increase in leakage currents under wet conditions. The findings suggest that accelerated testing should include wet conditions rather than being limited to non-condensing environments.

2.5 Medium-Voltage Converter Technologies for Grid Integration

[5] M. Rabiul Islam, A. M. Mahfuz-Ur-Rahman, K. M. Muttaqi, and D. Sutanto reviewed research activities and future directions in medium-voltage converter technologies for cost-effective solar PV grid integration. The paper highlights advancements in power electronics and control strategies for efficient energy conversion and integration.

2.6 High-Power Inverter Switching Strategies

[6] A. Ahmed, M. S. Manoharan, and J. Park proposed a switching pattern based on the nearest level modulation method to improve power transfer efficiency in H-bridge inverters. The technique minimizes high-voltage switches by utilizing a single-input single-output auxiliary converter, reducing cost and size while enhancing efficiency. The inverter architecture is suitable for high-power, high-voltage applications, with verification through simulation and experimental testing on a 1.5 kW hardware prototype.

2.7 Leakage Current Reduction in Transformer-less Inverters

[7] K. S. Kumar, A. Kirubakaran, and N. Subrahmanyam proposed bidirectional clamping (BDC)-based H5, Heric, and H6 transformer-less inverter (TLI) topologies with improved PWM schemes. The BDC branch reduces leakage current by clamping inverter terminal voltages to half the DC-link voltage during freewheeling periods. The proposed PWM schemes ensure a bidirectional current path in the negative power region. MATLAB simulations and experimental results validate the improved performance compared to traditional topologies.

III. METHODOLOGY

The proposed method designs a leakage current reducing technique built with passive filters for transformer-less solar photovoltaic systems. The first step uses frequency-domain analysis* to locate resonance frequencies that cause leakage current formation.

A passive filter built with resistors and inductors and capacitors has been designed according to the analysis results to establish a high-impedance path at resonance frequencies which effectively minimizes leakage current.

The system performance reaches maximum potential through an adaptive control system which removes fundamental load current elements while filtering harmonics to maintain THD at less than 5% following IEEE 519 and IEC 61727 requirements.

The systematic design undergoes simulation testing across different operating situations involving modifications of irradiation levels and loading patterns to determine how well it functions. A real-time hardware-in-loop (HIL) validation system exists for substantiating the practical applicability of the proposed methodology.

A comparative study of the proposed approach compares existing leakage mitigation techniques through evaluations of power quality facets and leakage current reduction and system performance efficiency.

The systematic approach guarantees that the proposed passive filter method enhances safety while increasing reliability while maintaining grid standards and energy efficiency for broad implementation in smart grids and modern solar PV installations.

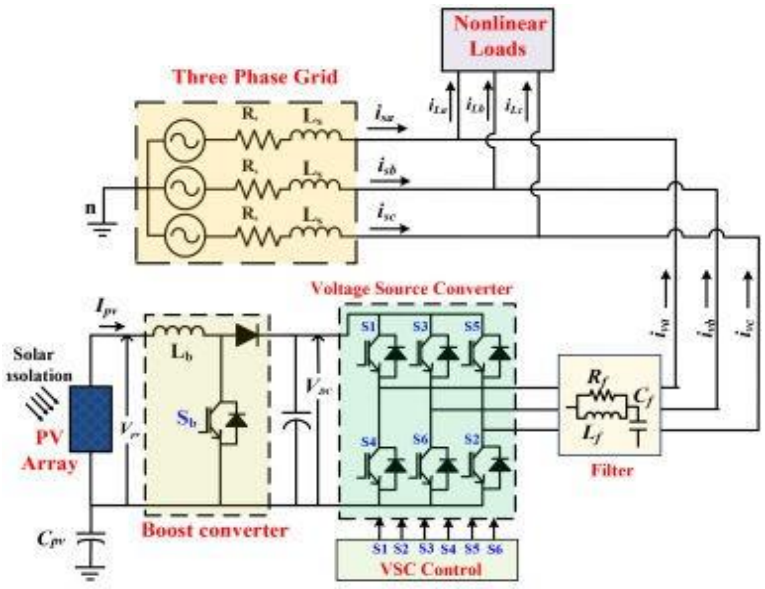

Fig 3.1 Schematic of three-phase grid –tied solar energy conversion system

IV. CONCLUSION

The passive filter design is presented for solar PV array systems to alleviate the leakage current enabling power quality improvement features. The novel passive filter design technique is studied and analyzed the dynamics under various operating scenarios. The distinct advantages of the presented work are summarized as follows. The novel passive filter

design has been presented to suppress the leakage current and improves the system dynamics even under wide variation of the solar power generation.

The leakage current is restricted in the range of 195 mA as per the prescribed limits of DIN standard VDE00126-1-1 and NB/T standard 32004, without any additional semiconductor devices or topology reconfiguration, unlike stateof-art systems,The balanced and sinusoidal grid currents are attained even under unbalanced load currents and its THD values are also accomplished in the range of 2.5% as per the recommended IEEE standard 519 and IEC standard 61727; and The adaptive controller effectively compensate the harmonics and provides robust operation even under abnormal grid scenarios. The stability and convergence analysis of the adaptive controller has been demonstrated to evince the robustness property and the boundedness of estimated harmonic components respectively.

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