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Fuzzy Logic Controller & Filters For Leakage Current Reduction in Solar PV

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Abstract *Leakage currents are small, unwanted currents that flow from solar panels or wiring to the ground due to parasitic capacitance. These currents can reduce efficiency, create safety hazards, and cause interference. To reduce the leakage currents passive filters are used, to improve the power conversion by proper grounding. Passive filters acts like gates, blocking these unwanted currents allowing flow of current in one particular direction. A fuzzy logic controller acts like a smart system, constantly adjusting the solar panels based on conditions like sunlight and temperature to maximize energy production. Fuzzy logic controllers don't directly stop leakage currents, instead optimize the solar panel system's operation to minimize factors that contribute to leakage currents. By intelligently managing the system, they can also lessen the impact of any existing leakage. This smart control optimizes performance even with changing weather conditions, ensuring the system consistently generates as much power as possible. Proper mitigation of leakage currents using of fuzzy logic controller are key to maximizing both the safety and efficiency of a solar PV system.*

Keywords: *FLC,PV,EMI,VSC,SVM*

1. INTRODUCTION

Leakage current in solar PV arrays is a significant issue that can lead to safety hazards, power losses, and reduced system efficiency. To mitigate this problem, passive filters and Fuzzy Logic Controllers (FLC) are effective techniques. Passive filters help in minimizing high- frequency leakage currents by providing a low-impedance path for unwanted signals. Meanwhile, Fuzzy Logic Controllers dynamically adjust system parameters to optimize performance and further reduce leakage currents. Combining these techniques enhances the reliability and efficiency of the PV system, ensuring stable operation and improved power quality.

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2. PROPOSED METHODOLOGY

LEAKAGE CURRENT ANALYSIS

Leakage current in PV systems arises due to parasitic capacitance between the PV panels and the ground. It is primarily influenced by inverter switching, common-mode voltage variations, and grounding configurations. High leakage currents can lead to safety hazards, increased electromagnetic interference (EMI), and efficiency losses. Transformerless inverters are more susceptible to leakage current issues due to the absence of galvanic isolation.

Common-mode voltage fluctuations drive leakage currents through the parasitic capacitance of the system, which can be analyzed using frequency-domain and time-domain methods. Different grounding schemes impact the behavior of leakage current, with floating PV systems generally exhibiting lower leakage current compared to grounded configurations. Proper mitigation strategies are necessary to ensure compliance with safety standards and improve the operational efficiency of PV systems

SCHEMATIC DIAGRAM

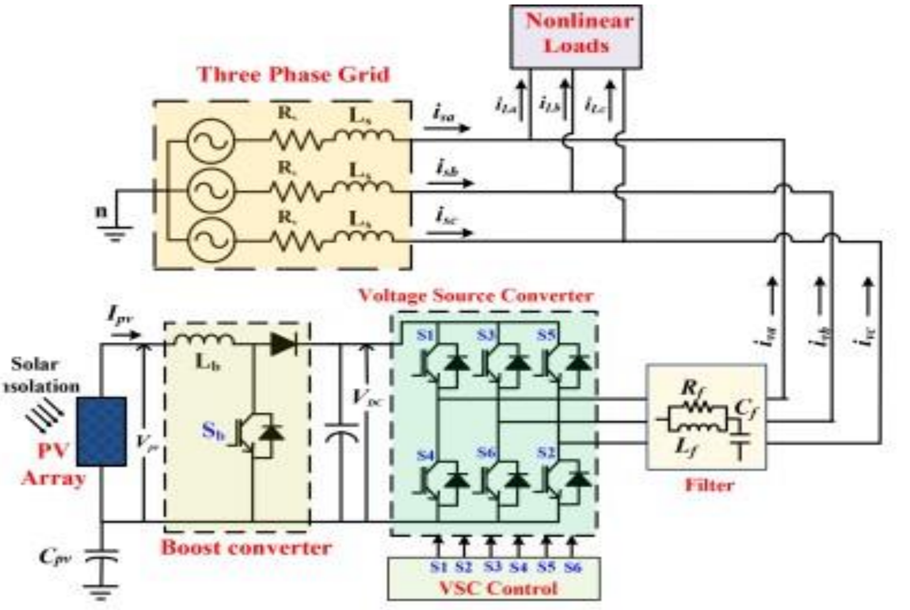
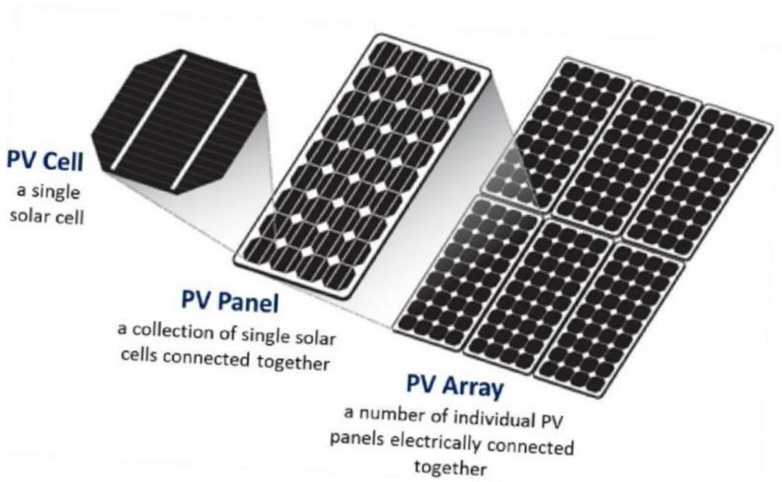


Fig. 1. Schematics of three-phase grid-tied solar energy conversion system.

COMPONENTS

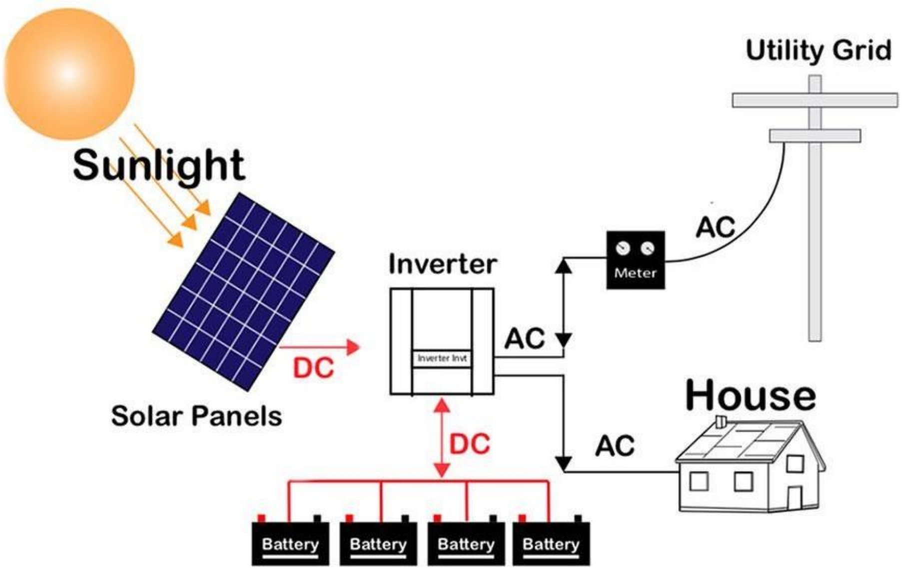
1. **Solar PV Array** : A solar PV array is a combination of multiple photovoltaic (PV) modules that convert solar energy into electrical power. In a transformerless grid- connected system, the PV array plays a critical role in generating DC power while being susceptible to leakage currents due to parasitic capacitance between the PV panels and the ground. The PV array absorbs sunlight and generates DC output power. The generated DC voltage and current depend on irradiance levels and temperature. This DC power is fed into the inverter for conversion into AC.



2. **Boost Converter** : A boost converter is a crucial component in a solar PV system for stepping up the DC voltage from the PV array to the required level for the inverter.It actively minimizes voltage fluctuations that could otherwise induce common-mode voltage variations, a key factor in leakage current formation. By optimizing power transfer, the boost converter reduces sudden voltage transitions, which helps in controlling the parasitic capacitance effect between the PV panels and the ground. Additionally, its ability to regulate the duty cycle dynamically contributes to a more uniform current flow, preventing sharp spikes that could trigger unwanted leakage currents. When integrated with passive filtering techniques and intelligent control methods like Fuzzy Logic Controllers (FLCs), the boost converter aids in achieving a robust and efficient PV system with minimal leakage issues, ensuring enhanced safety and long-term reliability of the system.
3. **Voltage Source Converter** : A Voltage Source Converter (VSC) in a solar PV system serves as the key interface between the DC output of the boost converter and the AC grid, playing a crucial role in both power conversion and leakage current mitigation. Unlike conventional converters, a well-designed VSC actively regulates the

common- mode voltage (CMV) to prevent unnecessary fluctuations that contribute to leakage currents through parasitic capacitance. By implementing advanced pulse-width modulation (PWM) strategies, such as sinusoidal PWM (SPWM) or space vector modulation (SVM), the VSC minimizes high-frequency switching disturbances, which are primary sources of leakage currents. Additionally, when integrated with passive filters and a fuzzy logic controller (FLC), the VSC dynamically adjusts its switching patterns to optimize power transfer while suppressing common-mode disturbances..

4. **Filters** : Filters are mainly used to reduce the harmonics. Filters play a crucial role in reducing leakage currents and improving power quality in transformerless solar PV systems. Due to parasitic capacitance between the PV array and the ground, variations in common-mode voltage (CMV) can lead to unwanted leakage currents. To mitigate this, passive filters such as common-mode (CM) chokes, LCL filters, and RC snubber circuits are used to suppress high-frequency components and provide a low-impedance path for leakage currents.
5. **Fuzzy Logic Controller** : A Fuzzy Logic Controller (FLC) is an effective tool for mitigating leakage current in electrical systems, particularly in power converters, photovoltaic (PV) inverters, and insulation monitoring applications. Leakage current, which can arise due to insulation degradation, stray capacitance, or improper grounding, poses safety risks and affects system performance. Traditional control methods struggle with the uncertainties associated with leakage current variations, making fuzzy logic an ideal choice due to its ability to handle imprecise and nonlinear data
6. **Inverter** : An inverter in a solar PV system is responsible for converting DC power from the PV array into AC power for grid integration while ensuring efficient and stable operation. In transformerless PV systems, the inverter plays a key role in controlling common-mode voltage (CMV) to minimize leakage currents caused by parasitic capacitance between the PV array and the ground.
7. **Grid tied Solar System :** A grid-tied solar system is a renewable energy setup where solar panels generate electricity and directly supply it to the utility grid through an inverter. This system does not require battery storage, as it uses the grid to balance energy supply and demand. When solar power production exceeds consumption, excess energy is sent to the grid, often earning credits through net metering. Conversely, when solar generation is insufficient, the grid supplies the required electricity. A synchronization mechanism ensures seamless operation between the inverter and the grid, maintaining stable voltage and frequency. Grid-tied systems are cost-effective, highly efficient, and contribute to reducing dependence on fossil fuels while promoting clean energy adoption.



Advantages :

- Improved System Efficiency.
- Reduced Electromagnetic Interference.
- Low Maintenance Cost.
- Reliable Operation.
- Better Power Quality.

5. CONCLUSION

Leakage current mitigation in solar PV arrays using passive filters and fuzzy logic controllers (FLC) is a highly effective approach to enhancing the safety, efficiency, and reliability of transformerless grid-connected PV systems. Passive filters efficiently suppress high-frequency leakage currents, while FLC dynamically adjusts system parameters, ensuring optimal performance under varying operating conditions. This combination not only minimizes power losses and electromagnetic interference (EMI) but also extends the lifespan of system components and ensures compliance with international safety standards. By integrating intelligent control with advanced filtering techniques, this approach paves the way for more stable, energy-efficient, and environmentally sustainable solar power systems, contributing to the global transition toward clean and reliable renewable energy solutions.

REFERENCES

[1] A. Molina-Garcia, J. Guerrero-Pérez, M. C. Bueso, M. Kessler, and E. Gómez-Lázaro,"A new solar module modelling for PV applications based on a symmetrized and shifted gompertz model," IEEE Trans. Energy Convers., vol. 30, no. 1, pp. 51–59, Mar. 2015.

[2] R. Panigrahi, S. K. Mishra, S. C. Srivastava, A. K. Srivastava, and N. N. Schulz,"Gridintegrationofsmall-scalephotovoltaicsystemsinsecondary distribution network—A review," IEEE Trans. Ind. Appl., vol. 56, no. 3, pp. 3178–3195, May/Jun. 2020.

[3] Power generation systems connected to the low-voltage distribution network—Technical minimum requirements for the connection to and parallel operation with low-voltage distribution networks, VDE-ARN 4105-2011, 2011.

[4] S. Mishra et al., "Enabling cyber-physical demand response in smart gridsviaconjointcommunicationandcontrollerdesign,"IETCyber-Phys. System: Theory Appl., vol. 4, no. 4, pp. 291–303, Dec. 2019.

[5] N.G.Dhere,N.S.Shiradkar,andE.Schneller,"Evolutionofleakagecurrent paths in MC-Si PV modules from leading manufacturers undergoing high-voltage bias testing," IEEE J. Photovolt., vol. 4, no. 2, pp. 654–658, Mar. 2014.

[6] M. Rabiul Islam, A. M. Mahfuz-Ur-Rahman, K. M. Muttaqi, and D. Sutanto, "State-of-the-art of the medium-voltage power converter technologies for grid integration of solar photovoltaic power plants," IEEE Trans. Energy Convers., vol. 34, no. 1, pp. 372–384, Mar. 2019.

[7] A. Ahmed, M. S. Manoharan, and J. Park, "An efficient single-sourced asymmetrical cascaded multilevel inverter with reduced leakage current suitable for single-stage PV systems," IEEE Trans. Energy Convers., vol. 34, no. 1, pp. 211–220, Mar. 2019.

[8] K. S. Kumar, A. Kirubakaran, and N. Subrahmanyam, "Bidirectional clamping-based H5, HERIC, and H6 transformerless inverter topologies with reactive power capability," IEEE Trans. Ind. Appl., vol. 56, no. 5, pp. 5119–5128, Sep./Oct. 2020.

[9] M. N. H. Khan, M. Forouzesh, Y. P. Siwakoti, L. Li, T. Kerekes, and F. Blaabjerg, "Transformerless inverter topologies for single-phase photovoltaic systems: A comparative review," IEEE Trans. Emerg. Sel. Topics Power Electron., vol. 8, no. 1, pp. 805–835, Mar. 2020.

[10] W. Wu, Y. Sun, Z. Lin, T. Tang, F. Blaabjerg, and H. Shu-Hung Chung, "A new LCL-filter with in-series parallel resonant circuit for singlephase grid-tied inverter," IEEE Trans. Ind. Electron., vol. 61, no. 9, pp. 4640–4644, Sep. 2014.

[11] W. Li, Y. Gu, H. Luo, W. Cui, X. He, and C. Xia, "Topology review and derivation methodology of single-phase transformerless photovoltaic inverters for leakage current suppression," IEEE Trans. Ind. Electron., vol. 62, no. 7, pp. 4537–4551, Jul. 2015.

[12] L. Concari, D. Barater, C. Concari, A. Toscani, G. Buticchi, and M. Liserre, "H8 architecture for reduced common-mode voltage threephase PV converters with silicon and SiC power switches," in Proc. 43rd Annu. Conf. IEEE Ind. Electron. Soc., Beijing, China, 2017, pp. 4227–4232.

[13] X. Guo, R. He, J. Jian, Z. Lu, X. Sun, and J. M. Guerrero, "Leakage current elimination of four-leg inverter for transformerless three-phase PVsystems,"IEEETrans.PowerElectron.,vol.31,no.3,pp. 1841–1846, Mar. 2016.

[14] X. Guo, D. Xu, and B. Wu, "Three-phase seven-switch inverter with commonmodevoltagereductionfortransformerlessphotovoltaicsystem," inProc. IEEE IECON 40th Annu.Conf. IEEE Ind . Electron. Soc.,Dallas, TX, USA, 2014, pp. 2279–2284.

[15] R. Rahimi, S. Farhangi, B. Farhangi, G. R. Moradi, E. Afshari, and F. Blaabjerg, "H8 inverter to reduce leakage current in transformerless three-phase grid-connected photovoltaic systems," IEEE Trans. Emerg. Sel. Topics Power Electron., vol. 6, no. 2, pp. 910–918, Jun. 2018.