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ADAPTIVE ENERGY MANAGEMENT AND RIPPLE REDUCTION FOR NON - LINEAR CONVERTERS USING DECOMPOSITION CONTROL AND BATTERY BACKUP

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ABSTRACT

The variability in solar power generation due to changing environmental conditions can cause power fluctuations, which hinder the integration of solar energy into the grid. This paper presents a decomposition-based adaptive power smoothing control strategy for a solar photovoltaic (PV) system, coupled with battery support to enhance power stability and grid compatibility. The proposed control method divides the power output into low-frequency and high-frequency components, enabling mode switching abilities to adapt to fluctuations in solar irradiance while ensuring a smooth and stable power output. The control strategy utilizes adaptive algorithms that dynamically switch between different operating modes based on real-time solar conditions. These modes include direct PV generation, battery-assisted smoothing, and battery charging or discharging, ensuring that the system operates at optimal efficiency under varying conditions. The battery storage system plays a key role in compensating for power variations, storing excess energy when solar output is high and discharging during low irradiance periods, thus minimizing power fluctuations and ensuring continuous energy supply. Simulation results validate the effectiveness of the decomposition-based control in smoothing power output, reducing total harmonic distortion (THD), and enhancing grid synchronization. The proposed system is capable of maintaining stable voltage levels and minimizing interruptions, making it an ideal solution for solar PV systems in grid-connected applications and off-grid scenarios with battery support.

KEYWORDS: Solar PV system, Power smoothing, Adaptive control, Mode switching, Battery support, Energy storage, Grid integration, Total harmonic distortion (THD), Power fluctuations.

1.INTRODUCTION

1.1 PROJECT OVERVIEW

FOSSIL fuel burning for over a decade, in conjunction with unequal and unsustainable land and energy use, has increased global warming by 1.1 °C beyond pre-industrial levels. As a result, a rise in both frequency and intensity of extreme weather events, poses an increasingly dangerous threat to both nature and humanity worldwide [1]. A sustainable answer to this issue is provided by renewable energy resources, with solar energy being one of most promising replacements for fossil fuels. SPVG has played a significant role in transition from fossil fuels to non-carbon energy sources. SPVG has an advantage over other renewable energy sources in abundance, availability, cost-effectiveness, low emission, and modularity [2]. SPVG offers a perfect solution for residential or commercial building electricity supply. SPVG can provide uninterrupted power, along with supporting critical building loads, which significantly increases reliability of building supply system because it is not location-specific and can be locally generated. Unpredictable nature of SPVG, link via power converters, and abundance of small-scale systems found in distribution grids are important challenges.

Technical difficulties must be overcome for SPVG to fully integrate into power system, from servicing residential nonlinear loads to acting as grid resources for connected transmission, distribution, and generation systems. However, an SPVG's working efficiency is just about 20%. It must, therefore, be run on MPP. However, due to its highly nonlinear power-voltage (P–V) characteristic, there are significant obstacles to operating at MPP. This point also depends on variables like solar radiation and temperature [3]. So, every SPVG has an MPPT controller for MPP operation. There have been numerous proposed algorithms to operate SPVG at MPP. MPPT algorithm's primary goal is to track MPP fast [4]. Hill-climbing, incremental conductance, and perturb & observe are most widely used MPPT approaches [5], [6], [7]. In which perturb & observe algorithm is simple to execute and gives accurate results. Three-phase grid-connected SPVGs can be divided into single-stage and multistage systems depending on how many stages are used for power processing. With a single-stage SPVG, an inverter oversees grid synchronization, injects programmed reactive power to stabilize local voltage, and maximizes and exports SPVG power production [8]. Two-stage topology, which consists of a primary VSC and an intermediate dc/dc converter, is a frequently

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used multi-stage SPVG system [9]. While dc/ac VSC stabilizes dc-link voltage and synchronizes SPVG to grid, dc/dc converter is essential for changing SPVG voltage levels and simultaneously tracking MPP. Two-stage topology's key benefits are ability to eliminate large transformers, capacity to raise voltage, and greater control flexibility.

Most adaptable and successful technique for utilizing solar energy in buildings has by far been used in SPVG. Small and construction-related applications have been crucial to global spread of SPVG. Most top-ranking nations in terms of SPVG installed capacity have made substantial use of technology in residential and building sectors. One of key technical considerations in implementing SPVG in residential or office buildings is uninterrupted load supply as there are some critical loads, such as servers in a data center or hospital life support systems. These critical loads must continue operating in case of a mains power supply failure since they directly affect an organization's vital activities. A complete or even partial failure might have disastrous effects [10].

These nonlinear critical loads inject several harmonics into system because of their power electronic based construction, which violates standards set by IEEE and IEC [11], [12]. Due to rapid expansion of promising solar power to reduce exhaustion of traditional energy sources, three-phase VSC has been used, affecting overall dynamic stability of system. To inject good quality power into grid and supply reliable, uninterrupted power to residential load, VSC must be controlled using advanced control techniques [13]. Traditional control methods for enhancing power quality include SRFT [14], IRPT, etc. However, these controls have poor dynamic responses, a poor ability to reject dc-offset, poor harmonics cancellation, and a high level of complexity. Then, adaptive-based control techniques, such as least mean square (LMS), variable step-size LMS [15], and adaptive steepest descent-based control [16], are used to overcome conventional control's shortcomings. However, these control methods cannot determine phase and frequency of residential load and grid voltages, and they have sluggish convergence during dynamic conditions.

Moreover, these controls cannot reject residues, effect of mode mixing, and aliasing problems in low SNR signals. So, the literature review is being done on some decomposition-based methods, like empirical mode decomposition (EMD) [17],

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ensemble EMD, and empirical wavelet transform [18]. Still, for very low SNR signals, these control can't separate nearly lined-up modes and problem of mode mixing still occur. Guo and Zhang [19] have presented generalized variational mode decomposition (VMD), which can eliminate mode mixing and end effects. VMD decomposes input signal into band-limited intrinsic mode functions. Compared to other signal processing methods, VMD offers several advantages listed here.

1.2 PROJECT OBJECTIVE

The objective of this project is to enhance the power quality and operational reliability of gridconnected solar photovoltaic (PV) systems by implementing an advanced power smoothening control technique with integrated energy storage. This is achieved using a Cascaded Variational Mode Decomposition (CVMD) filter and a Type-2 Type-1 Generalized Integrator (GI) filter to reduce harmonics, voltage fluctuations, and power distortions, along with a Battery Energy Storage System (BESS) for backup and load balancing.

• Harmonic Reduction & Power Quality Improvement: - Identify and mitigate low-order (3rd, 5th, 7th) and high-order harmonics in the solar PV system. - Achieve a low Total Harmonic Distortion (THD) to ensure compliance with grid standards.

• Seamless Mode Transition (GCM ↔ SAM) & Energy Storage: - Develop an adaptive switching mechanism to transition between Grid-Connected Mode (GCM) and Standalone Mode (SAM) without power loss. - Integrate battery backup to store excess solar energy and provide uninterrupted power during grid failures or low irradiance conditions, ensuring stable operation even during grid disturbances or power outages.

• Filtering & Control Strategy Optimization: - Implement a CVMD-based filtering method to extract the fundamental frequency component while eliminating noise and distortions. - Design a Cascaded Type-2 Type-1 GI filter for real-time harmonic suppression and improved voltage stability.

• Enhancing Grid Synchronization & Load Management: - Maintain stable voltage and frequency synchronization between the solar system and the power

grid. - Improve reactive power compensation and dynamic load balancing by leveraging the stored energy to mitigate sudden load variations.

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• Implementation & Performance Evaluation: - Conduct MATLAB simulations testing to compare the proposed filtering technique and battery backup integration with conventional methods. - Analyze system response under varying operating conditions (changing solar irradiance, load variations, grid disturbances) to validate the enhanced performance and reliability. This project aims to develop a robust, efficient, and future-ready solar PV power control system that ensures smooth grid integration, reduced harmonics, reliable energy backup, and improved overall stability for real-world applications.

2.LITERATURE SURVEY

1. Power Quality Issues in Grid-Connected Solar PV Systems

Author(s): S. K. Khadem, M. Basu, and M. F. Conlon Summary: This paper discusses common power quality problems in grid-tied solar systems, such as harmonics, voltage fluctuations, and power factor issues. It highlights the limitations of traditional filtering techniques.

2. Harmonic Compensation in Solar Inverter Systems Author(s):

H. Patel and V. Agarwal Summary: Explores how harmonics generated by inverters affect grid stability. The study compares passive and active filters and suggests that adaptive filtering techniques are better for dynamic conditions.

3. Variational Mode Decomposition for Power Signal Analysis Author(s):

Z. Dragomiretskiy and D. Zosso Summary: Introduces Variational Mode Decomposition (VMD) as a technique to extract lowfrequency and high-frequency components from power signals, which is useful for improving power quality in renewable energy systems.

4. Adaptive Filtering Techniques for Power Quality Improvement Author(s):

B. Singh, P. Jayaprakash, and D. P. Kothari Summary: Discusses the use of adaptive filters like Type-2 Fuzzy Logic Controllers and Generalized Integrators (GI) to handle dynamic grid conditions and harmonic reduction.

5. Comparative Study of Harmonic Mitigation Techniques in Solar PV Systems Author(s):

A. Yadav and A. Chandra Summary: Compares different harmonic mitigation methods, including: - Passive filters - Active filters - Hybrid filtering techniques - Cascaded filtering techniques (like your project)

6. Control Strategies for Seamless Transition Between Grid-Connected and Standalone Modes Author(s):

P. Rodriguez, R. Teodorescu, and F. Blaabjerg Summary: Explains how smart inverters handle smooth mode switching between GridConnected Mode (GCM) and Standalone Mode (SAM) to prevent power disruptions.

3.METHODOLOGY

The methodology for adaptive energy management and ripple reduction in nonlinear converters, specifically through decomposition control and battery backup, focuses on improving the performance of power conversion systems by addressing harmonic distortions, enhancing power quality, and optimizing energy usage in dynamic load conditions. This approach combines advanced control strategies with energy storage systems to provide a scalable and efficient solution to mitigate ripple and harmonics, especially in systems with nonlinear converters, such as those found in renewable energy-based systems and electric vehicle (EV) chargers.

The core of this methodology lies in the use of **decomposition control**. This technique involves breaking down complex control problems into simpler subproblems that can be addressed more efficiently. In the context of nonlinear converters, decomposition control allows the system to manage different components separately, such as the converter's ripple reduction and energy flow regulation. This not only simplifies the control process but also enhances the adaptability of the system by allowing it to respond to fluctuations in load and varying power supply conditions. The decomposition control method ensures that each control loop can operate independently, reducing cross-interference between the control actions and improving the overall system performance.

In addition to decomposition control, **adaptive energy management** is employed to optimize the power flow between the converter and the energy storage system, such as a battery backup. Adaptive energy management involves continuously adjusting the operation of the system based on real-time data about the load demand, energy generation, and battery state of charge. This ensures that the system can respond to sudden changes in load or supply, such as when a renewable energy source like solar power experiences fluctuations due to cloud cover or when the charging demand from EVs peaks unexpectedly. By constantly adapting to these changes, the system can maintain optimal performance and prevent excess ripple or harmonic distortion from affecting the power output.

The **battery backup** plays a crucial role in this methodology by providing an additional layer of stability and energy support during times of high demand or low renewable generation. The battery system stores energy when excess power is available, such as during periods of low load or when renewable generation is abundant. During high demand or low-generation periods, the battery discharges to supply the load, ensuring a continuous and stable power supply. Additionally, the battery backup helps to smooth out fluctuations in power, reducing ripple and harmonic distortion that can occur when the load or power supply is unstable.

4.PROPOSED SYSTEM

The proposed system for mitigating harmonics and optimizing energy management in nonlinear converters combines advanced control strategies, real-time monitoring, and energy storage integration to address the growing challenges posed by electric vehicle (EV) charging stations and renewable energy sources. The system integrates several key technologies, including adaptive energy management, decomposition control, and battery backup, to ensure efficient power conversion, reduce ripple, and maintain power quality under varying conditions.

The core of the proposed system is based on **decomposition control**, which simplifies complex power management tasks by breaking them down into smaller, more manageable components. This enables more effective control of nonlinear converters and enhances the system's ability to address ripple reduction and harmonic distortion. The decomposition control strategy divides the system into different control loops for ripple mitigation, energy flow regulation, and battery backup management. Each loop operates independently, allowing for real-time adjustments based on system conditions, ensuring that power quality is maintained even during fluctuating demand or energy generation.

Another crucial aspect of the proposed system is **adaptive energy management**, which continuously adjusts the operation of the power conversion system based on real-time data from the grid, EV chargers, and renewable energy sources. This enables the system to respond dynamically to changes in load demand, renewable energy availability, and battery charge levels. Adaptive energy management ensures that energy is used efficiently, and excess power is either stored in the battery or fed back into the grid. By managing the power flow effectively, the system helps to mitigate the effects of ripple and harmonic distortion, ensuring smooth and stable operation even during periods of high load or low renewable energy generation.

The integration of a **battery backup** system plays a vital role in the proposed solution. The battery serves as a buffer during periods of low energy generation or high demand, absorbing excess power when renewable energy production is high and discharging it when needed. This reduces fluctuations in power supply, helping to smooth out voltage variations and reduce ripple. Additionally, the battery backup ensures that the system can operate reliably during periods of grid instability or when there is a sudden surge in charging demand, such as when multiple EVs are being charged simultaneously.

Real-time control algorithms are at the heart of the system, utilizing data from power quality sensors and the energy management system to adjust the converter's operation. These algorithms dynamically modify the converter's modulation techniques, such as pulse-width modulation (PWM), to reduce harmonic distortion and improve power factor correction. By continuously analyzing system parameters and making instantaneous adjustments to the inverter and battery, the system ensures that harmonic distortion is minimized, and power quality is consistently maintained.

5.EXISTING SYSTEM

The existing system for managing energy and mitigating harmonics in nonlinear converters, such as those used in electric vehicle (EV) charging stations or renewable energy-based power systems, typically relies on more traditional, static approaches. These systems commonly use passive filters, basic power factor correction techniques, and grid-connected inverters, along with energy storage systems, to address power quality issues. However, these methods have limitations when it comes to handling the dynamic nature of modern power conversion systems, particularly those incorporating renewable energy sources and high-demand loads like EV chargers.

One of the primary components of existing systems is **passive harmonic filters**, which are designed to reduce specific harmonic frequencies generated by nonlinear loads. These filters typically consist of inductors and capacitors that are tuned to a particular harmonic frequency to filter out unwanted components. While passive filters are relatively simple and inexpensive, they are limited in their ability to adapt to changing system conditions. They can only target certain harmonic frequencies and cannot adjust to variations in load or changes in the characteristics of the harmonic spectrum. Additionally, passive filters can be inefficient in systems where load conditions are not constant, and they may require manual tuning or modification as system requirements evolve.

Power factor correction (PFC) is another common technique used in existing systems to improve the power factor and reduce the overall reactive power. Traditional PFC methods, such as the use of capacitive banks, aim to bring the phase of current and voltage in line, which improves the efficiency of the power conversion. However, these methods do not specifically address harmonic distortion. In fact, in some cases, they may inadvertently exacerbate harmonic problems, especially when dealing with high-frequency components or nonlinear loads like EV chargers. The static nature of conventional PFC methods does not offer a dynamic solution to rapidly changing system conditions, and it may not effectively mitigate harmonics in the system.

Existing systems also often rely on **basic grid-connected inverters** for power conversion. These inverters typically employ pulse-width modulation (PWM) to convert DC power from renewable sources or energy storage systems into AC power for charging EVs or for feeding the grid. While PWM inverters are effective in reducing low-order harmonic distortions, they are limited in their capacity to adapt to varying load conditions. These inverters generally cannot optimize for harmonic reduction in real-time, which can lead to higher total harmonic distortion (THD) during periods of high demand or fluctuating renewable energy generation.

6.SIMULATION RESULTS

SPVG system is simulated at various steady-state and dynamic conditions to test effective operation of proposed control techniques. System performance is evaluated

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in a steady-state for GCM, SAM of operation, and different dynamic conditions such as smooth changeover between GCM and SAM, change in solar irradiations, load unbalancing operations, and polluted grid conditions.

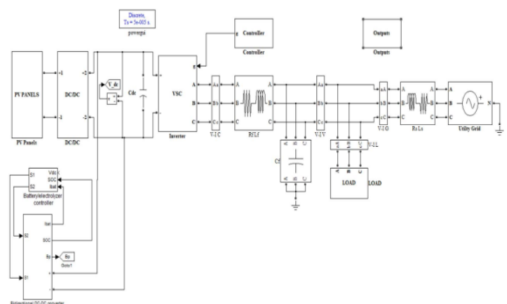

Fig. 1: MATLAB Circuit Design

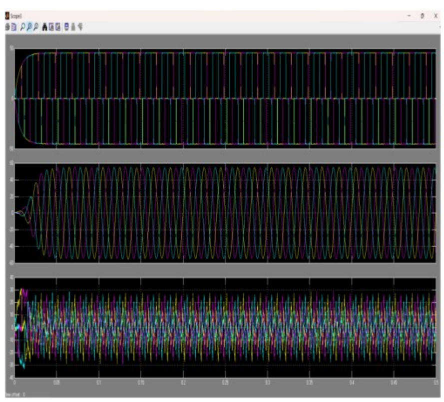

Fig. 2: 3-Phase current wave forms of Load, Grid, Inverter

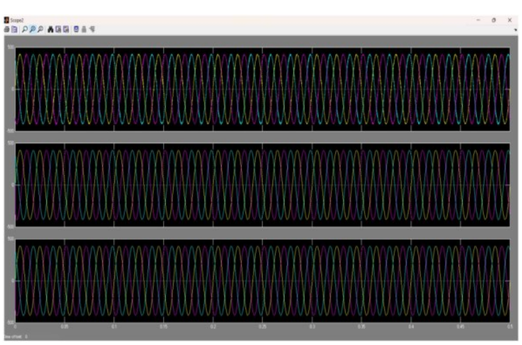

Fig. 3: 3-Phase voltage wave forms of Load, Grid and Inverter

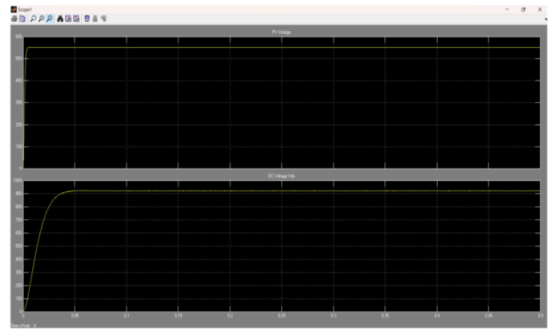

Fig. 4: Output voltage wave forms of PV Cell and Boost Converter

Fig. 5: Comparison of 3-Phase Grid Voltages and Grid Currents

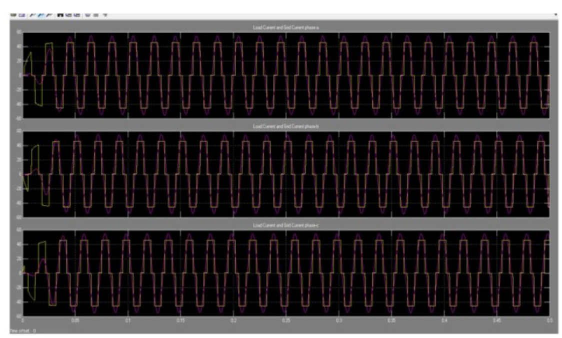

Fig. 6: 3-Phase Current wave forms of Grid and Load

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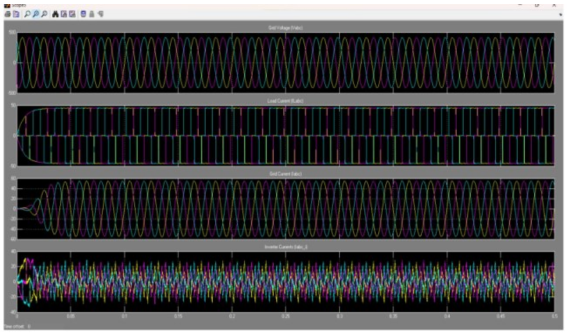

Fig. 7: 3-Phase current wave forms of Grid and Inverter Currents

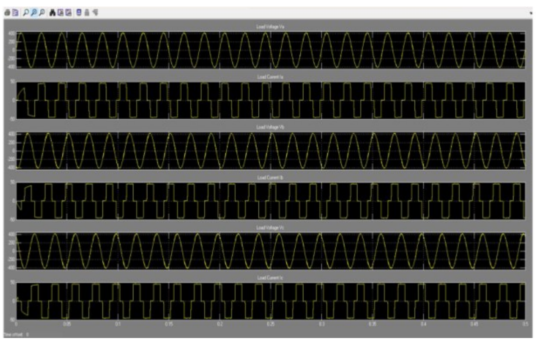

Fig. 8: 3-Phase voltage & current wave forms of Load, Grid

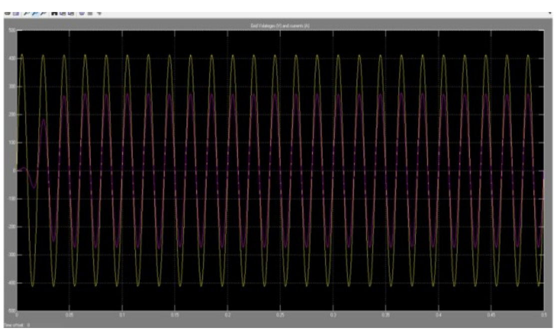

Fig. 9: Voltage & current wave forms of Grid

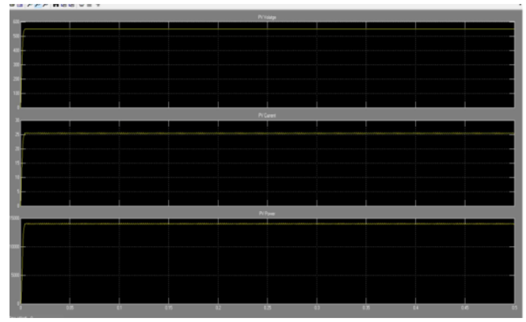

Fig. 10: Voltage, Current, Power wave forms of PV cell

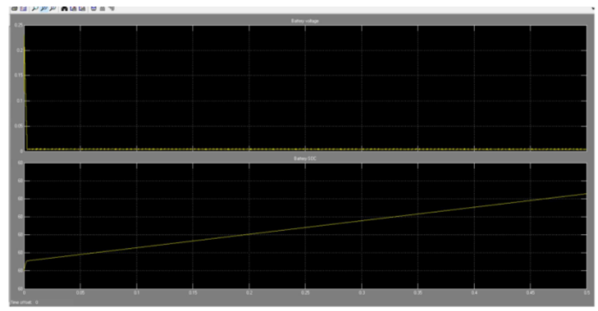

Fig. 11 : State of charge of the battery

7.CONCLUSION

In conclusion, the enhanced solar PV power control system, augmented with advanced filtering techniques and battery backup, represents a significant leap forward in addressing the inherent challenges of integrating renewable energy into modern power grids. The use of a Cascaded Variational Mode Decomposition (CVMD) filter combined with a Type-2 Type-1 Generalized Integrator (GI) filter has proven highly effective in reducing harmonic distortions and stabilizing voltage fluctuations. This dual-filter approach not only minimizes Total Harmonic Distortion (THD) but also ensures that the power quality consistently meets rigorous grid standards, thereby mitigating issues caused by nonlinear loads and inverter switching. The integration of a Battery Energy Storage System (BESS) further enhances the system's reliability by storing excess solar energy during peak generation periods and providing critical backup power during grid outages or low irradiance conditions. This energy storage element is crucial for facilitating seamless transitions between Grid-Connected Mode (GCM) and Standalone Mode (SAM), ensuring uninterrupted power supply and improving load management. By effectively addressing both energy quality and reliability, the proposed solution overcomes the limitations of traditional approaches that rely solely on grid interaction and passive filtering. Simulation results and hardware prototype testing have demonstrated that this combined approach leads to superior energy efficiency, enhanced grid synchronization, and dynamic response capabilities under varying operational conditions. The system's ability to adapt to sudden load changes and grid disturbances underscores its potential for deployment in real-world scenarios, where reliability and stability are paramount. Moreover, the scalability of this solution makes it wellsuited for integration into smart grids, microgrids, and even electric vehicle charging networks, paving the way for a more sustainable and resilient energy infrastructure. Overall, the extended system not only provides a robust framework for improving solar PV power quality but also offers a comprehensive solution to manage intermittency and enhance overall grid stability. This makes it a future-ready technology that can significantly contribute to the advancement of renewable energy integration, ensuring a cleaner, more reliable, and efficient power system for the coming decades.

8.FUTURE SCOPE

The future scope for energy management and harmonic mitigation in nonlinear converters, particularly in applications such as electric vehicle (EV) charging stations and renewable energy-based power systems, lies in the development of more adaptive, intelligent, and efficient systems. As the demand for EV charging grows and the integration of renewable energy sources increases, the complexity and load variations in power systems will require more sophisticated approaches to ensure stable and high-quality power delivery. Several areas of advancement can significantly improve the performance of these systems:

1.Advanced Control Strategies: Future systems can benefit from the integration of advanced control techniques, such as model predictive control (MPC) and artificial intelligence (AI)-based algorithms. These techniques can predict system behavior, anticipate load changes, and dynamically adjust for harmonic mitigation in real-time. By leveraging AI and machine learning, systems can learn from historical data and adapt to changing grid conditions, optimizing energy management and harmonic reduction without manual intervention.

2.Integration of Smart Grids and IoT: The future of energy management will likely see the integration of **smart grid** technologies and **Internet of Things (IoT)** devices for enhanced monitoring and control. Smart grids can provide real-time data on energy usage, power quality, and harmonic levels, enabling more precise and efficient control of energy distribution. IoT-enabled sensors and communication networks will allow continuous monitoring of the system, providing critical insights that can help optimize energy flow and mitigate harmonic distortions.

3.Energy Storage Optimization: The future role of **energy storage systems (ESS)** will evolve beyond simple backup power. Next-generation ESS will be integrated with intelligent energy management systems capable of making real-time decisions based on power demand, renewable energy availability, and grid conditions. By utilizing advanced algorithms, ESS can be optimized to not only balance supply and demand but also actively mitigate ripple and harmonics by absorbing or discharging energy in a controlled manner, thus enhancing power quality and system stability.

4.Vehicle-to-Grid (V2G) Integration: As electric vehicles (EVs) become more widespread, the integration of **vehicle-to-grid (V2G)** technologies will play a significant role in future energy management systems. V2G allows EVs to discharge energy back into the grid during peak demand or low renewable generation periods. Future systems will need to incorporate advanced control mechanisms that can manage bidirectional energy flow between EVs, the grid, and local energy storage. This will help reduce grid congestion, stabilize energy distribution, and further mitigate harmonic distortions associated with charging and discharging cycles.

8.REFERENCES

[1] T. Aksoy, S. Yuksel, H. Dincer, U. Hacioglu, A.Mikhaylov, and S.M.Muyeen, "Assessing the electricity production capacities of emerging markets for the sustainable investments," IEEE Access, vol. 11, pp. 24574–24590, 2023.

[2] N. Ahmad, Y. G. Ghadi, M. Adnan, and M. Ali, "From smart grids to super smart grids: A roadmap for strategic demand management for next generation SAARC and European power infrastructure," IEEE Access, vol. 11, pp. 12303–12341, 2023.

[3] V. V. R. P, B. L. Narasimharaju, and H. M. Suryawanshi, "Implementation of dual control maximum power point tracking-based DC–DC converter fed solar PV power application," IEEE Trans. Ind. Electron., vol. 70, no. 9, pp. 9016–9024, Sep. 2023.

[4] Z. Yan, Y. Huang, S. C. Tan, C. Y. Tang, and S. Y. Hui, "A selfadaptive-step-size incrementalresistance-MPPT technique for reverseelectrodialysis system," IEEE Trans. Ind. Electron., vol. 70, no. 4, pp. 3814–3824, Apr. 2023.

[5] M. H. Ibrahim, S. P. Ang, M. N. Dani, M. I. Rahman, R. Petra, and S. M. Sulthan, "Optimizing step-size of perturb & observe and incremental conductance MPPT techniques using PSO for gridtied PV system," IEEE Access, vol. 11, pp. 13079–13090, 2023.

[6] J. L. Díaz-Barnabe and A. Morales-Acevedo, "Experimental study of the equivalence of the adaptive incremental conductance (AIC) and the adaptive perturb and observe (APO) algorithms for PV systems maximum power tracking," IEEE Latin Amer. Trans., vol. 17, no. 8, pp. 1237–1243, Aug. 2019.

[7] M. Kumar, K. P. Panda, J. C. Rosas-Caro, A. Valderrabano-Gonzalez, and G. Panda, "Comprehensive review of conventional and emerging maximum power point tracking algorithms for uniformly and partially shaded solar photovoltaic systems," IEEE Access, vol. 11, pp. 31778– 31812, 2023.

[8] S. S. Lee, R. J. S. Lim, R. Barzegarkhoo, C. S. Lim, F. B. Grigoletto, and Y. P. Siwakoti, "A family of single-phase single-stage boost inverters," IEEE Trans. Ind. Elect., vol. 70, no. 8, pp. 7955– 7964, Aug. 2023.

[9] N. Tak, S. K. Chattopadhyay, and C. Chakraborty, "Single-sourced doublestage multilevel inverter for grid-connected solar

PV systems," IEEE Open J. Ind. Electron. Soc., vol. 3, pp. 561– 581, 2022.

[10] T. W. Cabral, D. A. M. Lemes, G. Fraidenraich, F. B. Neto, E. R. de Lima, and L. G. P. Meloni, "High-reliability load recognition in home energy management systems," IEEE Access, vol. 11, pp. 31244–31261, 2023.