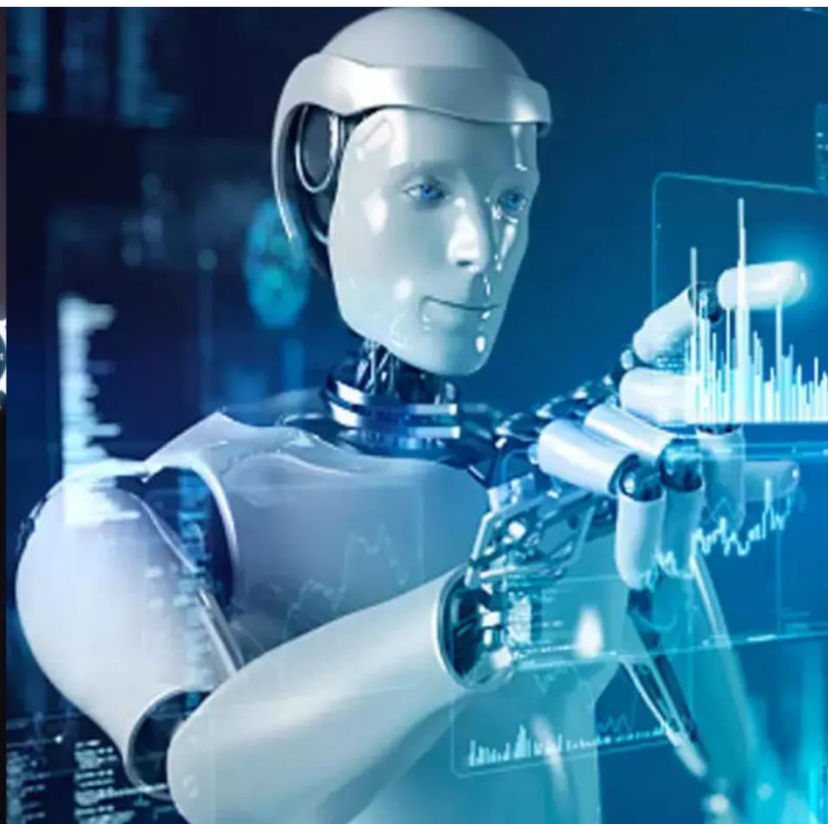




International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 11, November 2025

Hybrid Energy Storage Control Strategy for Stabilizing Wind–Photovoltaic Hybrid Power Generation

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ABSTRACT: In this paper, only the improvement effect of energy storage and VSGs on the system steady-state transient stability are separately investigated, and the problems of how energy storage can effectively coordinate and cooperate with VSGs on the inverter side under the fault condition to further improve the system stability and power quality still need to be studied in depth. By adjusting the command value of active and reactive power, introducing a differential link in the power ring, and adjusting the operating state of the VSG rotor, the VSG has dynamic reactive power support capability while ensuring its synchronization and stability. It injects the corresponding size of reactive current into the grid side in the specified time, so as to improve the frequency regulation and voltage support capability in the event of system failure, and realize the low voltage ride-through.

KEYWORDS: Hybrid Energy, Storage Control Strategy, Wind–Photovoltaic Hybrid Power Generation

I. INTRODUCTION

With the introduction of the National “14th Five-Year Plan” and the proposal of the “dual carbon” target, a novel power system primarily utilizing alternative energy sources will be developed, and the new energy sources are becoming more prevalent in the grid. It is crucial to boost the low voltage ride-through (LVRT) capability during fault conditions and improve the grid-side frequency regulation capacity as the use of wind power and photovoltaic systems grows. Thus, today’s power systems are placing significant emphasis on the advancement of a co-generation system that integrates wind, solar, and storage technologies, and key areas of focus include analyzing power output variations, evaluating LVRT capability, and assessing frequency stabilization and control.

The development of power grids has resulted in shorter and shorter electrical distances between grids, which makes wind and solar energy storage, which have less inertia on the generation side and the grid side, more susceptible to LVRT from short-circuit faults. The research has indicated that wind power and photovoltaic power generation are important factors in the LVRT process of energy storage systems, as extensively discussed in the relevant literature. However, there is a scarcity of research on the LVRT approach for a grid-connected system that integrates wind, solar, and storage technologies. In [8], an enhanced self-regulating VSG control system was introduced for doubly fed induction generator wind farms. This system enhanced the overall system by providing frequency support through supplementary control at the grid-side converter, while still maintaining LVRT capability during transient situations; a new and user-friendly overcurrent suppression control method for voltage-controlled VSGs was introduced by the authors of to efficiently mitigate overcurrent issues caused by symmetrical/asymmetrical voltage fluctuations. Yet, there is no improvement in the system’s ability to support reactive power during voltage decreases. In, an adaptive LVRT method was proposed. In the compensation voltage control circuit, if the reference value does not match the actual value, the angle output of the active power circuit will be adjusted according to the phase change in the VSG’s active power output. In this way, it is possible to transition smoothly between the normal state and the LVRT state.

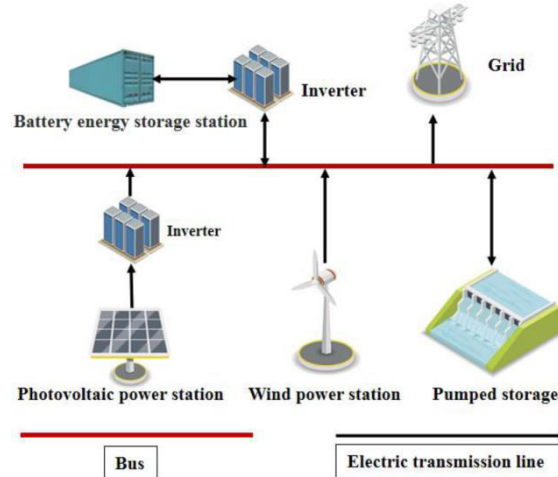


Fig 1: Optimal Scheduling of the Wind-Photovoltaic-Energy

However, in the joint grid-connected wind–PV energy storage, for the power generation system that cannot adjust the frequency and voltage well due to low inertia, any of the above measures cannot thoroughly solve the problem, and for this kind of high proportion of new energy grids, the LVRT requirements are more stringent, and more rapid and effective reactive power compensation is needed. Therefore, the typical approaches to solving this issue usually involve utilizing grid-connected inverters controlled by a VSG. However, in the operation process of traditional VSGs, there are a series of overcurrent problems, which can cause system fluctuations and make it difficult to maintain synchronization during grid voltage dips. In, the respective authors improved the conventional VSG by introducing virtual impedance and proposing an adaptive reference voltage correction method based on virtual impedance for fault current limitation. In addition, an adaptive term is added to the virtual impedance part, which makes the current limiting method applicable to different operation modes of the microgrid, including grid-connected and islanded modes. In, the authors used a virtual impedance quantization design approach to achieve overcurrent suppression, but locked the power loop of the VSG, making it difficult to keep the VSG synchronized.

In, an all-pass filter was employed to precisely synchronize the frequency and phase data during grid faults and incorporated damping effects to restrict the magnitude of short-circuit currents, but suffered from power oscillations, poor dynamic stability, and the inability to provide the grid with a given reactive current based on the voltage dip magnitude. In, a new control technique for VSGs was introduced, which maintained the power loop to enable the VSGs to operate continuously while also offering improved control of reactive currents, However, the equation of motion of the VSG rotor changes and the process was ignored, which is prone to cause it to disconnect from the grid. In a study detailed in, a more advanced dynamic control scheme was suggested for the VSG. This scheme incorporates feedback of the virtual active power at the point of common coupling into the control loop, enhancing the transient stability through the utilization of virtual resistance. Obviously, the control strategies for converters proposed by the majority of researchers have corresponding problems in various aspects and need to be improved.

II. LITERATURE REVIEW

The load frequency control (LFC) is considered the most common solution to maintain the frequency at nominal standards. In this regard, different control methods have been performed in LFC to maintain a frequency stable at nominal standards. These methods involve optimal control techniques such as sliding mode control, artificial neural network, model predictive control (MPC) robust control techniques, fuzzy control techniques hybrid controllers that consist of more than one controller as fuzzy based fractional order control, and freedom degree fractional order control with MPC. These strategies effectively addressed LFC problems, however relied on the developer's expertise and experimentation methods. Additionally, these strategies estimated long time to define their parameters.

Despite significant advances in the development of advanced controllers in the past few decades, PID controllers remain a popular engineering choice due to their easy design and cheap prices. In the presence of system imperfections and nonlinearities (i.e., RESs penetration and load perturbations), the PID controller faces challenges due to the complexity of selecting its parameters, especially with high RESs penetration. In this regard, several researchers applied different structures of improvement to the traditional PID controller such as cascaded controller arrangement (CCA), a feed forward-feedback arrangement, combination arrangement and increasing the degree of freedom. Among these methods the CCA is distinguished by simple construction and easy to implement. The reason for applying to the CCA is due to its ability to enhance the outcomes through more tuning parameters.

With the increasing concentration of RESs in the power system, LFCs that rely on diverse control techniques are unable to deal with the nonlinearities caused by high RESs. So, it is essential to install different systems to enhance the system performance and eliminate the RESs bad effects. In this regard, energy storage schemes (ESSs) play a crucial role in increasing the efficiency and effectiveness of power systems during high RESs penetrations. As a result, different ESSs have been employed to enhance power system execution like fuel cells, super capacitor (SC), plug electric vehicles (PEVs), super magnetic energy storage system (SMES), capacitive energy systems, redox flow batteries (RFBs). As the RESs penetration increases, significant efforts have been made to utilize the different advantages of these ESSs. In this regard, different studies considered hybrid ESSs (HESSs) to enhance the performance of the power grids during high RESs penetration. The HESSs which applied to enhance the performance of the power grids are EVs and SC, Vanadium- RFBs and SMES, PEVs and FCs. However, these ESSs improved the power grid during high RESs penetration, they have significant limitations. As, it requires a controller to control the power injected or absorbed by the ESSs. Building on the benefits of the HESSs, the authors aim to apply HESSs as RESs penetration increased

In addressing frequency stability challenges, conventional controllers like the I, PI, and PID controllers encounter difficulties in parameter tuning and lack deliberation for doubt, averting system stability. Additionally, other non-cascaded controllers have enabled LFC of power systems; nevertheless, high performance with heavy penetration of RESs was not permitted by these controllers. On the other hand, few studies applied CCA to maintain frequency stability, but their arrangement uses more parameters, and the used optimization techniques cannot select the parameters with precision. Also, the developed algorithms have drawbacks like sluggish convergence during the iterative process, trapping in local optima, and adjustment of governing parameters. In addition, only an insufficient study has observed the influence of high RESs diffusion. Consistently, limited reviews consider the use of the EESSs without their hold controllers in power grids with excessive RESs penetration. Nevertheless, these ESSs enhance the power grid performance, but they do not proposal superior solutions for improving the frequency fluctuations. Also, several previously used approaches use traditional ESSs without any control to enhance the performance of their considered systems. This administration highlights the need for a more inclusive analysis of the integration of advanced ESSs alongside robust control strategies to mitigate frequency variations through high RESs penetrations.

III. METHODS

The above studies explore the capability of energy storage systems in grid frequency regulation but present the following issues: (1) When selecting a BESS as the FR target, the droop coefficient's adaptive capability is insufficient, and the SOC tracking ability is inadequate. (2) While the literature considers switching between virtual inertia and droop control, it fails to address the system oscillations caused by the switching process and the adaptive behavior of the virtual inertia coefficient during different FR phases. (3) The SOC recovery strategy does not take into account adaptability, and SOC recovery during the FR period is likely to cause a secondary drop in system frequency. (4) There is no discussion on how to efficiently combine HESSs.

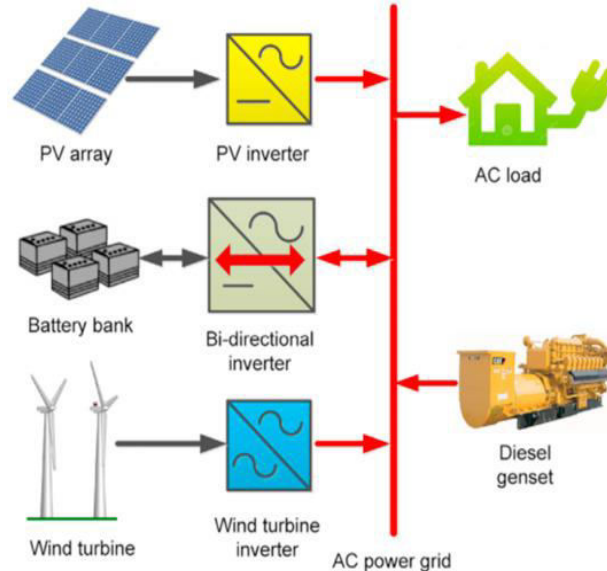


Fig 2: Multi-energy complementary power systems based on solar energy

To address the issue of frequency fluctuations caused by the integration of large-scale RESs into regional power grids through high-voltage RES gathering stations, this paper proposes an integrated control strategy for HESSs to participate in PFR. This strategy not only enhances grid frequency stability but also enables coordinated operation among different ESS. First, a frequency division device is used to allocate the high- and low-frequency components of grid frequency fluctuations to the BESS and PHES, respectively. To enhance the FR performance of the BESS, adaptive droop control and positive/negative virtual inertia control are integrated into the FR phase. Additionally, an SOC self-recovery strategy is introduced within the DB of the HESS to improve the long-term FR capability of the BESS. An HESS-based FR model for the regional power grid was established within the real-time simulation system RT-1000. This paper considers the FR of the system under the uncertainty of RES generation, focusing only on the participation of the BESS, PHES, and CGU. Using the proposed regional power grid FR model, the impact of the integrated strategy on frequency stability is validated under three scenarios: step disturbances, short-term continuous disturbances, and long-term RES disturbances. Experiments under various disturbance scenarios demonstrate that the proposed integrated strategy, which considers the rational allocation of HESSs, not only significantly improved system frequency stability but also improves the FR capability of the BESS.

IV. RESULT ANALYSIS

The impact of the DB on the FR performance of an HESS is considered in full. Moreover, by using frequency division control, the high-frequency and low-frequency components of frequency fluctuations are, respectively, allocated to the BESS and PHES, thereby better utilizing the respective advantages of the HESS. Based on the impact on SOC and frequency, the BESS incorporates positive/negative virtual inertia control. Taking into account the SOC and the degree of frequency variation, this approach simultaneously enhances the inertia level of the system. We propose an adaptive droop control that enables the droop control to not only respond quickly to FR demands but also effectively maintains the SOC of the BESS. In addition, when the frequency of the power grid is within the DB, a method is proposed to construct the SOC recovery coefficient to enhance the ability of the BESS to participate in the PFR over extended periods.

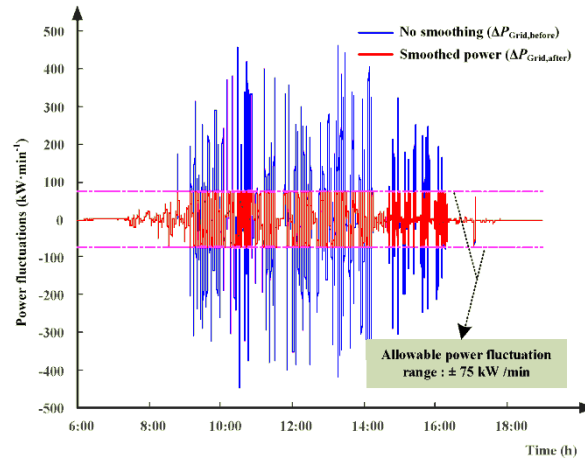


Fig 3: Control Strategy of a Hybrid Energy Storage System

SOC recovery control using nonlinear functions to represent the SOC recovery demand coefficient and the SOC recovery constraint coefficient has the following benefits: Nonlinear functions can dynamically adjust the recovery coefficients based on SOC variations. For example, when the SOC deviates significantly from the ideal state, the recovery demand coefficient can increase rapidly. Conversely, as the SoC approaches the ideal state, the coefficient stabilizes, preventing excessive recovery actions and reducing unnecessary adjustments; nonlinear functions feature smooth transitions, avoiding abrupt changes in recovery demand or constraints, which could destabilize the system. When the SoC moves from one range to another, the nonlinear function ensures that the output changes continuously and gradually, enhancing control strategy stability.

V. CONCLUSION

Wind power and photovoltaic systems both employ a dual-loop control strategy consisting of outer-loop power control and inner-loop current control. This approach enables easy parameter adjustment and offers strong dynamic characteristics and robustness. The energy storage system utilizes a constant voltage and frequency control strategy to regulate the power output. This strategy involves adjusting the voltage and frequency of the grid connection point to manage the energy storage's power output. It also helps in handling fluctuations in the output of the wind power system and providing support for transient voltage during wind power system failures. Testing various configurations of wind and solar storage systems, along with operation during fault conditions, confirms that the integrated control method effectively mitigates power fluctuations in the wind and solar system. This enhancement in LVRT capability is beneficial for maintaining the secure and steady operation of both the wind and solar storage system and the power grid. To address the response of the virtual synchronous machine to a short-circuit fault in the grid, we suggest a thorough current-limiting approach that aims to prevent excessive current flow and oscillation. This technique is designed to uphold the VSG's dynamic performance under both normal and faulty operating conditions. This paper focuses solely on basic studies related to fault current limitations. However, there is still significant work to be accomplished regarding the operation and control of VSGs during grid fault conditions, including developing standards and understanding the interaction between VSGs and traditional power systems.

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