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Enhancing Control of Solar and Wind Power Fluctuations via Battery Energy Storage Station (BESS)

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ABSTRACT

The Battery Energy Storage Station (BESS) plays a crucial role in addressing variations in the output of wind or solar power generation. The challenges associated with mitigating these fluctuations are analysed based on the power fluctuation rate, which serves as a key performance metric for photovoltaic (PV) and wind power (WP) generation equipment connected to the power grid. Achieving optimal regulation of power output levels and the state of charge (SOC) of the battery is vital for the effective functioning of BESS, necessitating the implementation of an appropriate control strategy. This paper presents an innovative control strategy that involves tuning the controller and integrating a Battery Energy Storage System (BESS) with a large wind farm. The goal is to efficiently smooth out intermittent power fluctuations originating from the wind farm.

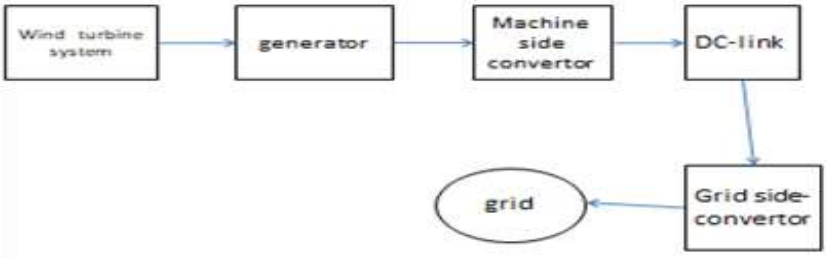
Keywords: Adaptive smoothing control, Battery Energy Storage Station (BESS), solar power generation, State of Charge (SOC), wind power generation

Main text

In recent times, there has been a significant increase in the widespread adoption of Battery Energy Storage Stations (BESS). These stations are being established globally to meet the growing demand for power generated from wind and solar sources. With a primary goal of enhancing power quality, these Battery Energy Storage Stations incorporate cutting-edge technologies, including superconducting magnetic energy storage systems. Their applications are diverse, covering areas such as grid stabilization, backup power, electric vehicle charging, and frequency regulation.

Battery energy storage plays a crucial role, especially in microgrid applications associated with wind, photovoltaic (PV), and hybrid power generation stations. In these systems, the State of Charge (SOC) is a key component, significantly contributing to the management and control of fluctuations in wind and solar generation. The instability resulting from these fluctuations poses a potential threat to microgrid stability. Therefore, the integration of Photovoltaic Generating Stations (PVGS) and Wind Power Generating Stations (WPGS) with Battery Energy Storage Stations (BESS) becomes essential to tackle this challenge.

Mathematical modeling of a (WPGS)



Mathematical modelling of a (PVGS):

Systems (BESS) to manage fluctuations in photovoltaic (PV) and wind power. Precisely, the battery can be deployed in instances where a less seamless output is acceptable. Despite the presence of several effective BESS-based techniques for mitigating power fluctuations in renewable energy systems, as detailed in [2], [3], control strategies outlined in [1]-[5] predominantly focus on small-scale BESS applications, aiming to promptly smooth out variations in wind power (WP) and PV.

Notably, both a Wind/PV/BESS hybrid power generating system and a State of Charge (SOC)-based smoothing control approach have been implemented. These strategies contribute to the immediate alleviation of fluctuations. It is emphasized that a thoughtfully designed control strategy plays a pivotal role in determining the appropriate BESS size needed to minimize power fluctuations effectively.

Specifically, the integration of a hybrid power generating system combining Wind/PV/BESS and a smoothing control approach based on State of Charge (SOC) contributes to the prompt mitigation of fluctuations. It is highlighted that a meticulously designed control strategy is crucial in determining the optimal BESS size required for effectively minimizing power fluctuations.

WIND POWER ENERGY STORAGE

Despite the manifold benefits of wind energy, its widespread integration can give rise to technological challenges and issues pertaining to grid interconnection, electricity quality, reliability, and protection

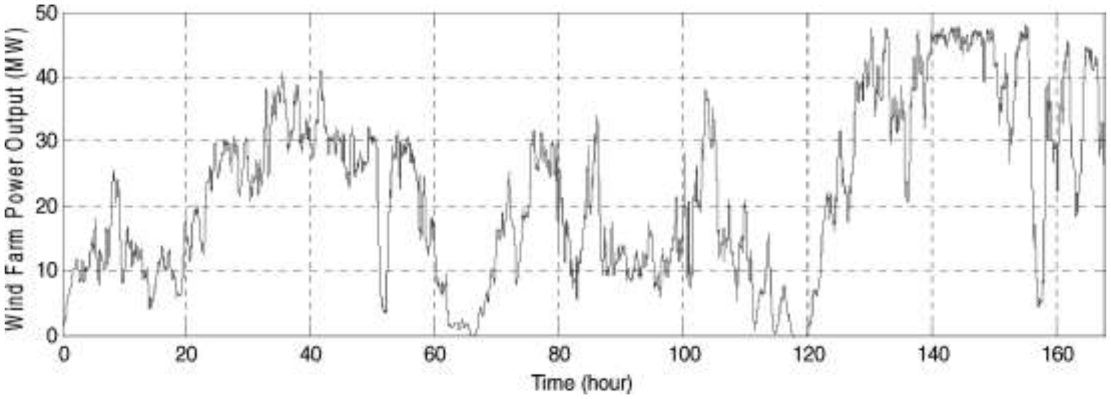


Fig.1.wind farm output power.[1]

The graph illustrates the power output patterns of a sizable 50MW wind farm. The power generation experiences fluctuations throughout the day, presenting a considerable challenge when integrating such a highly variable energy source into a power grid, particularly in areas prone to vulnerability. Integrating a power source characterized by significant discontinuities poses a substantial risk, giving rise to serious problems. The primary challenges associated with these wind farm discontinuities and energy storage can be outlined as follows:

1.Discontinuity: Economic dispatch relies on a utility's capacity to adjust a generating unit's power production in sync with fluctuations in the load [9]. To align a wind farm with the characteristics of traditional generation units, its output must be controlled to achieve the desired dispatchability.

2.Rate of change: The rapid and substantial fluctuations in wind farm production [1]-[10], both positive and negative, present a challenge due to the substantial amount of wind generation [10]. It is crucial to limit such swift changes to facilitate the smooth integration of vast generation into the grid, thereby reducing the need for costly ancillary services. This approach aims to alleviate strain on the system and comply with service requirements.

3.Regulating wind farm output power: The integration of large-scale wind power, such as a significant wind farm, may strain the transmission lines responsible for transporting wind energy. This could potentially overload a vulnerable component of the system [1]. Consequently, it might be necessary to curtail the wind farm's power output to prevent overloading and associated issues.

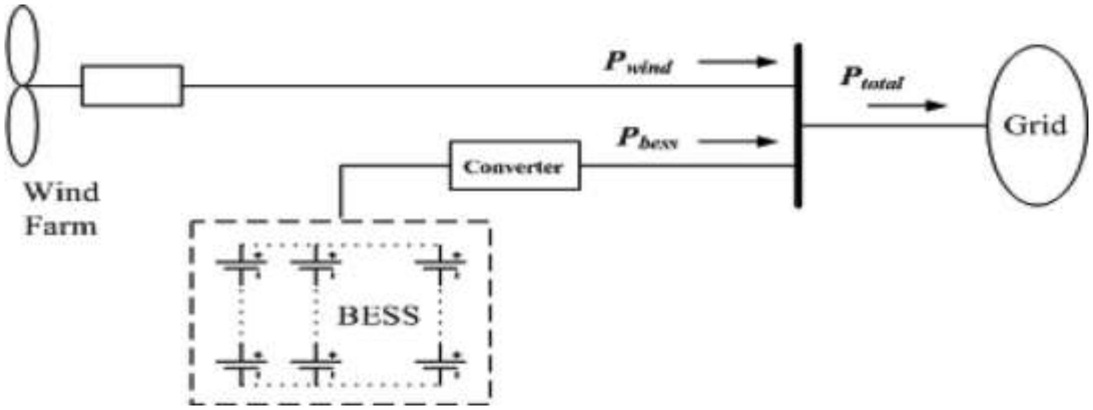


Fig.2.BESS integration at a wind farm.[1].

Control strategy:

A novel control scheme is imperative in our pursuit of optimizing the utilization of the Battery Energy Storage System (BESS) to smooth the net power supplied to the system over a defined time period, such as an hour for hourly dispatch. The developed control strategy is built upon the controller architecture delineated in [2], where the State of Charge (SOC) acts as a feedback signal, ensuring the battery's SOC remains within acceptable ranges in response to changing conditions or setpoint adjustments.

It's crucial to note that the power generated by the wind farm may fluctuate during the dispatching period. Consequently, we anticipate the controller to function as a regulator, dynamically adjusting the Battery Energy Storage System (BESS) [11]-[21]. The targeted set point, denoted as Pset, serves as the primary input for the controller to achieve the desired level of electricity dispatch within the specified hour. A judicious selection for Pset involves utilizing the hourly average of the expected wind farm output for the upcoming hour. Recent advancements in wind forecasting offer a precise estimate of Pset, with an approximately 10% root mean square error.

Controller tuning:

- Initial Configuration: Upon the installation of a Battery energy Storage System (BESS), the controller undergoes setup with a fundamental set of control parameters. These attributes are defined based on the system specifications and expected operating conditions. Nevertheless, it is important to note that these default settings may not be optimal in certain situation.
- Collecting Data: The system controller consistently monitors the system's performance, collecting data on various factors such as the battery's state of charge, the system's voltage, current, and temperature, along with the grid's frequency and load demand. This information plays a crucial role in the tuning procedure.
- Assessment: Examining the data obtained allows for a comprehensive understanding of how the Battery Energy Storage System (BESS) reacts to different inputs and environmental conditions. This evaluation is instrumental in identifying any deficiencies or deviations from the set performance goals.
- Adjusted Parameters: After analysing [2] the collected data the tuning parameters of the controller, including gains in a PID controller or weights in a Model Predictive Control (MPC) algorithm, undergo modification. These variables govern the response of the Battery Energy Storage System (BESS) to fluctuations in load demand and grid conditions.
- Modelling: Utilizing simulations allows for the assessment of the Battery Energy Storage System's (BESS) performance under diverse conditions and the testing of adjusted settings. This stage is instrumental in forecasting the behaviour of the modified controller in real-world scenarios.
- Feedback Loop: Continuous data collection and monitoring provide feedback on the performance of the Battery Energy Storage System (BESS). If the system fails to meet its objectives or experiences issues such as excessive charging, overheating, or inefficiency, additional adjustments to the controller parameters are implemented.t.
- Iterative Process: The tuning of a controller often involves repetition, with variables potentially needing multiple adjustments to achieve the desired operational objectives. This iterative procedure may continue throughout the lifespan of the Battery Energy Storage System (BESS) to adapt to changing conditions and accommodate the effects of aging batteries.
- Optimization: The goal of tuning the controller is to enhance the efficiency of the Battery Energy Storage System (BESS). This may involve improving overall system effectiveness, ensuring grid reliability, extending the lifespan of batteries, or achieving various specific objectives.

Fine-tuning a system's controllers can lead to a substantial enhancement in performance. This improvement involves increased effectiveness, productivity, and overall system efficiency, as it enables the system to respond more rapidly and precisely

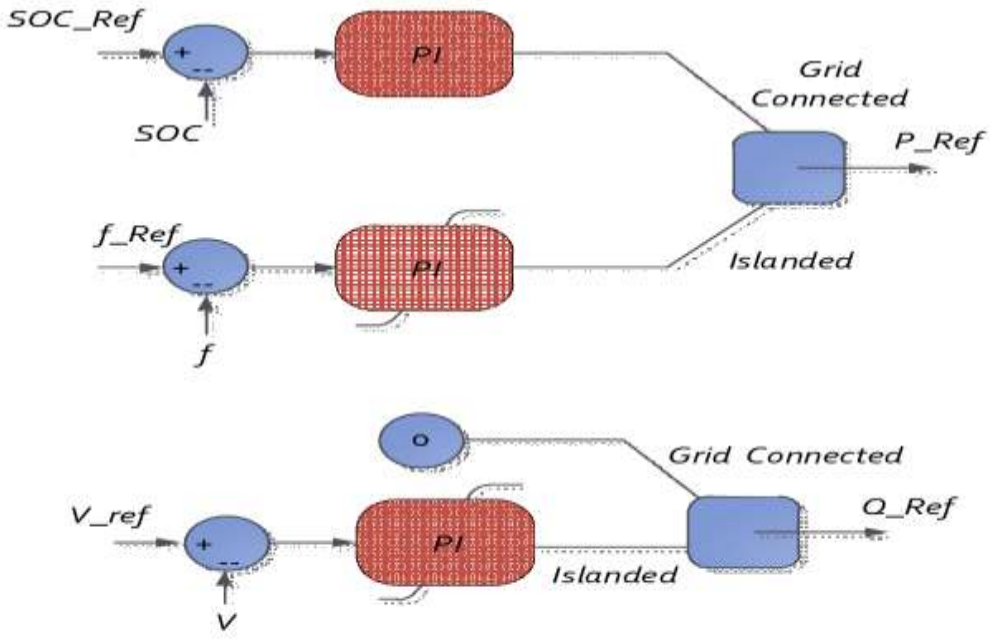


Fig.3.BESS controller system.

Fussy Wavelet Filtering Method:

This research introduces an innovative fuzzy wavelet filtering technique designed to enhance the stability of output power fluctuations in a hybrid system comprising Wind Power Generating Stations (WPGS) and Photovoltaic Generating Stations (PVGS). As a result, the output power variations in these hybrid systems can be effectively balanced, enabling a rapid response from Battery Energy Storage Systems (BESS) during charge/discharge operations.

The wavelet transform process can be succinctly summarized as follows:

Step 1: Utilizing wavelet scale decomposition, the original data is separated into low and high-frequency values through low and high pass filters

. Step 2: The low and high-frequency decomposition values are then reconstructed to reveal their respective high and low-frequency components.

The low-frequency component of the wind/photovoltaic hybrid power output is utilized to calculate the target smoothing power, while the high-frequency component of the BESS determines the same

As illustrated in Fig. 4, an adaptive smoothing control method based on fuzzy logic and wavelet transform is propose

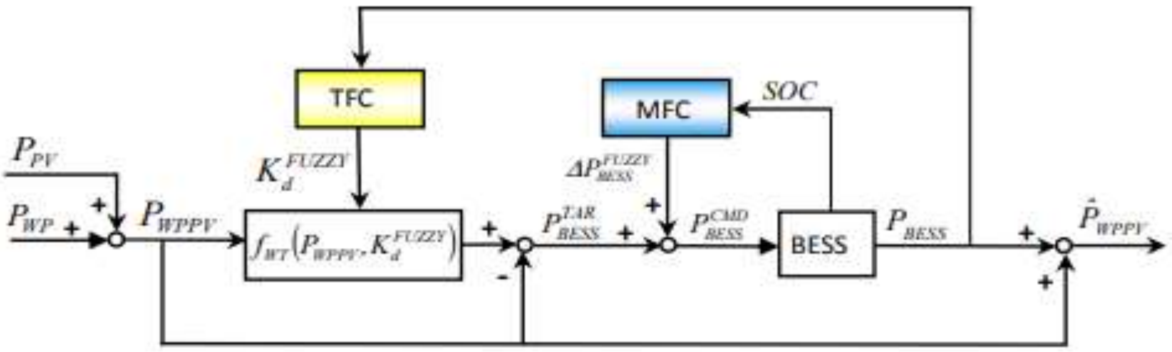


Fig.4. power smoothing control strategy based on fuzzy wavelet transform.[2]

The suggested strategy for power smoothing control is predicated on These equations can be used to formulate the fuzzy wavelet transform.

$$\hat{p}_{WPPV}=P_{WPPV}+P_{BESS} \qquad 1 \longrightarrow$$

$$P_{BESS}^{CMD} = P_{BESS}^{TAR}+\Delta P_{BESS}^{FUZZY} \qquad 2 \longrightarrow$$

$$P_{BESS}^{TAR} = P_{WPPV}^{WT} - P_{WPPV} \qquad 3 \longrightarrow$$

$$P_{WPPV}^{WT} = f_{WT}(P_{WPPT}, K_d^{FUZZY}) \qquad 4 \longrightarrow$$

$$P_{BESS}^{min} \leq P_{BESS} \leq P_{BESS}^{Max} \qquad 5 \longrightarrow$$

$$SOC^{min} \leq \text{SOC} \leq SOC^{max} \qquad 6 \longrightarrow$$

$$\Delta P_{BESS}^{FUZZY} = f_{MFC}^{(SOC)} \qquad 7 \longrightarrow$$

$$K_d^{FUZZY} = f_{TFC} P_{BESS} \qquad 8 \longrightarrow$$

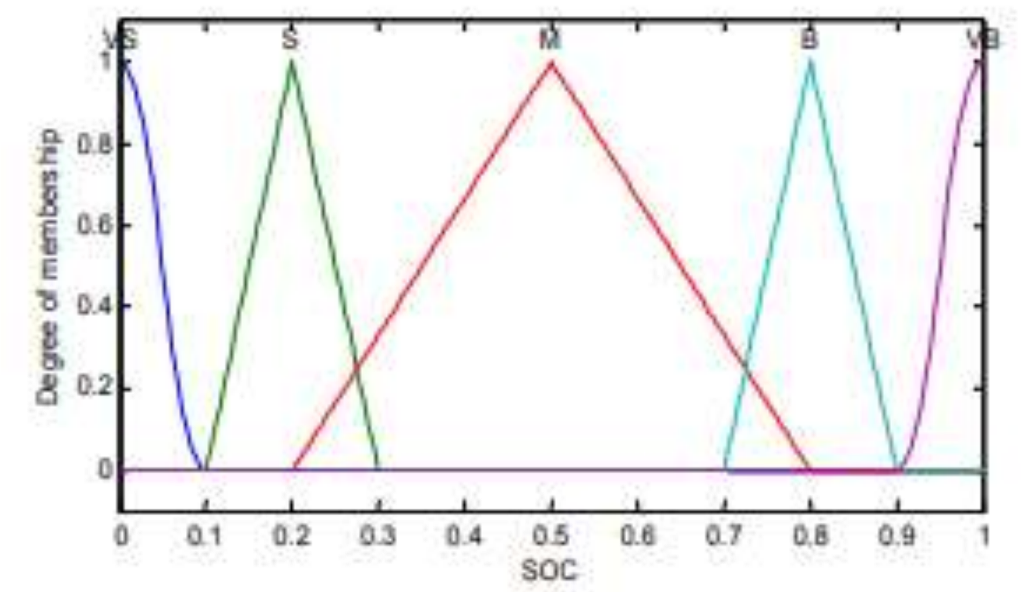


Fig.5.Membership function for SOC.[2].

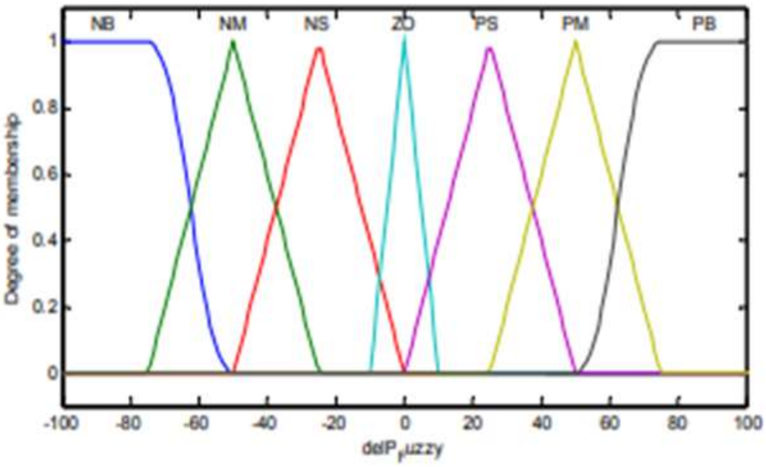


Fig.6.Membership function for ΔP_{BESS}^{FUZZY}[2].

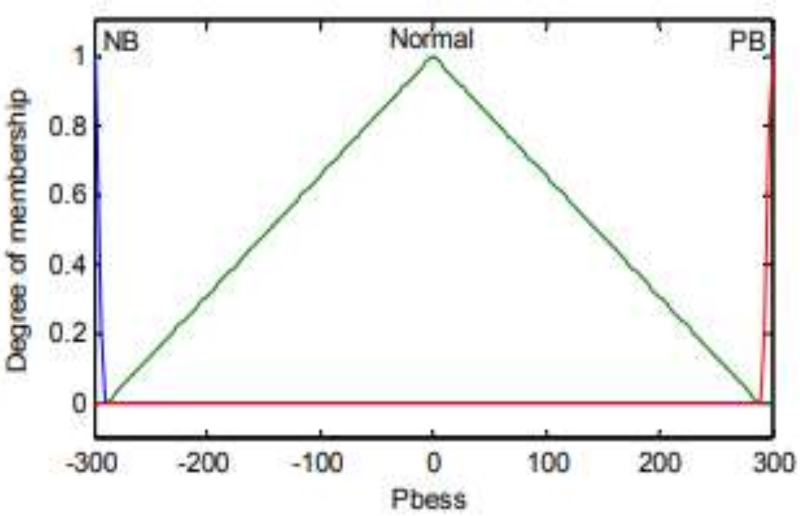


Fig.7.Membership function for P_{BES}[2].

Controlled by state-of-charge feedback:

The adjustment of Battery Energy Storage System (BESS) output allows for the implementation of a smoothing control mechanism, stabilizing the variable power production of a wind farm [6]. This control system, configured in a hybrid manner, demonstrates a crucial outcome. The system generates a pivotal result by employing a time constant (T) derived from a first-order lagging filter. The total output of the wind farm, collectively referred to as WF output, integrates outputs from multiple wind generators. The "smoothing time constant," a constant value, plays a key role. Any disparity between the WF output and the desired output serves as a reference signal for the BESS charging or discharging process. This discrepancy stems from the outcomes produced by the BESS, considering the inherent regulatory latency associated with its operations

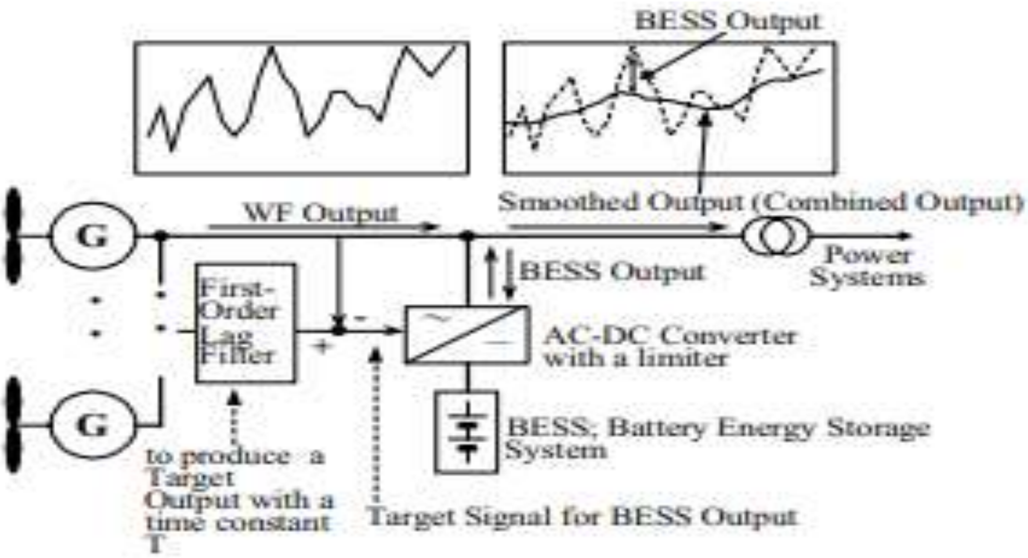


Fig. 7 presents an overview of the hybrid system [3]. Figure 6 provides a simplified block diagram representing the condensed model, while Figure 5 depicts the 'basic smoothing control' of the hybrid system. In Fig. 7, a lengthier smoothing time constant, indicated as T (T=1,800 seconds), illustrates an amplified smoothing effect. As a result, this leads to more noticeable fluctuations in the output of the Battery Energy Storage System (BESS) and the State of Charge (SOC) of the power source.

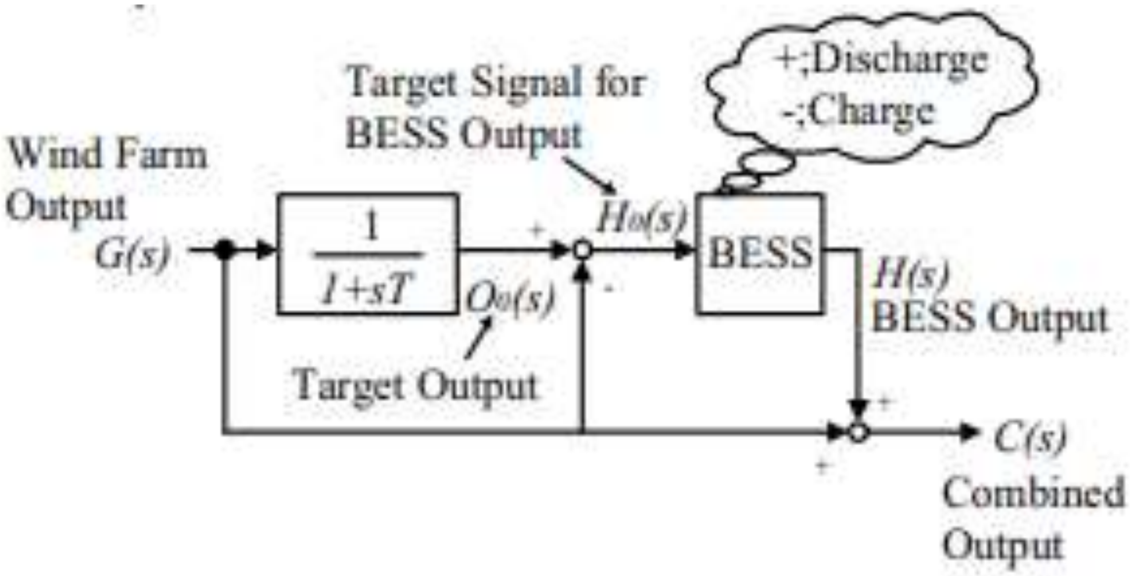


Fig. 8 depicts a block diagram representing a simplified model for the basic smoothing control model [3]. Meanwhile, Fig. 3 presents the Remaining Energy Level (REL), indicating the battery's State of Charge (SOC) as a percentage of its rated capacity. This REL range is determined by integrating the output of the Battery Energy Storage System (BESS) within the SOC. However, Fig. 3 does not incorporate losses, such as conversion losses in AC-DC converters, internal battery resistance, or self-discharge losses. If the model were to account for these losses, the RELs depicted in Figure 3 would eventually deteriorate to an unusable state.

In cases where these losses are not considered, a longer smoothing time constant might cause the REL shown in Figure 3 to increase until it reaches an unsustainable level. This is particularly true when the actions of the BESS counteract a significant fluctuation in the Wind Farm (WF) output.

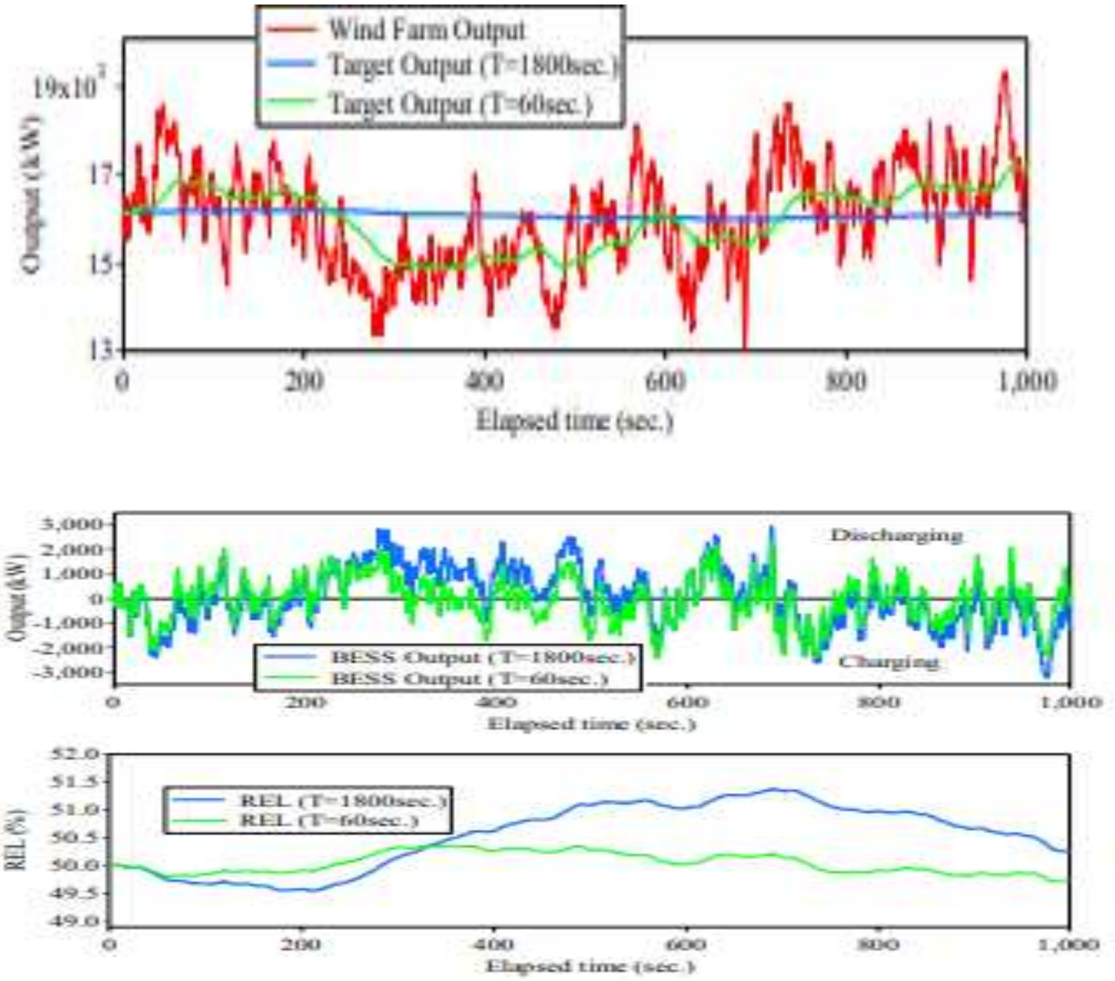


Fig.10**.** Typical output in the basic smoothing control.[3]

Energy Storage Technologies:

Current energy storage technologies are founded on potential, electromagnetic, chemical, or kinetic energy principles. Each method possesses distinct characteristics that influence factors such as power capacity, costs, and energy storage density. Although there are comprehensive insights available on various technologies and their attributes, transitioning to a commercial system often presents challenges in aligning with intended objectives.

The selection of appropriate technologies for specific applications is primarily based on the energy storage rating and the associated time constant governing the rate of power delivery. Long-term storage devices can accommodate larger energy quantities but are limited in their response time. On the other hand, short-term devices can respond swiftly to sudden signal changes but are impractical for storing substantial energy quantities. Presently, no single technology comprehensively addresses both concerns in an economically viable manner [10]. For example, lead-acid batteries are a cost-effective solution for long-term power storage, but factors such as temperature, age, storage capacity, state of charge, and charge/discharge rate impact their dynamic response. Combining lead-acid batteries with complementary instant devices like supercapacitors, capable of managing rapid transients, is a prudent approach to ensure a more effective strategy.

Conclusion:

The variability in solar and wind power generation output presents challenges that can impact utility and micro-grid operations. Integrating Battery Energy Storage Systems (BESS) with Photovoltaic Generation Systems (PVGS) and Wind Power Generation Systems (WPGS) is one approach to mitigate this issue. Efficient control schemes are crucial for power management and dispatch in these hybrid systems.

This study proposes a novel State of Charge (SOC)-based control methodology to minimize output fluctuations in a hybrid generation system that combines Wind Power (WP) and Photovoltaic (PV) sources. The approach involves real-time power allocation techniques and SOC feedback management strategies to regulate battery power and energy in a timely manner. The suggested control strategy demonstrates that the SOC of each battery energy storage unit can gradually converge towards 50%, regardless of their initial SOC differences. Despite varying initial SOC levels, the control time tends to increase. Additionally, this control strategy is expected to promote an equitable distribution of the load across storage units, enhancing the service life of the energy storage system and delaying the accelerated degradation of batteries.

Moreover, the implementation of a power fluctuation rate constraint as part of the smoothing control mechanism has successfully achieved the filtering of BESS charge and discharge power.

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