A NEW INTELLIGENT CONTROLLER BASED SMES/BES HYBRID ENERGY IN PV FED MICROGRID

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ABSTRACT: The power grid's stability is seriously threatened by the intermittent and variable character of renewable energy sources (RESs), which are increasingly being incorporated into the system to fulfill rising power demands. In this research, a novel cooperative control technique for a photovoltaic-based grid-connected system is introduced to solve the unstable output power caused by the intrinsic randomness and fluctuation of RES. Within the scope of a hybrid energy storage system (HESS), this suggested approach makes use of both battery energy storage systems (BESS) and superconducting magnetic energy storage (SMES). The control technique uses a fuzzy control-based low-pass filter (LPF) at top-level control (TLC) to optimize transient power allocation and dynamically control the filtration coefficient. Concurrently, a rapid Model Predictive Control (MPC) technique is used at the under layer level control (ULC) to sustain DC bus voltage using a one-step prediction horizon. The effectiveness of the suggested control technique in improving the stability and performance of the grid-connected system is demonstrated by the methodical validation of its superiority and viability under a variety of operating scenarios.

KEYWORDS: SMES, MPC, BATTERY, TLC, ULC, PV POWER, RES.

I.INTRODUCTION: The increasing integration of renewable energy sources (RES) into the electricity grid has become a focus area in pursuit of the "double carbon" target [1]. Notably, photovoltaic (PV) generating gains popularity since it uses a limitless supply of solar energy and requires little initial investment [2]. However, the power system faces serious difficulties as a result of the shift to a large percentage of renewable energy. The primary cause of the difficulties is the power variations of RES brought on by the erratic and unpredictable nature of new energy sources, which even surpass load fluctuations and serve as the primary source of system uncertainty [3], [4]. This study suggests a hybrid energy storage system (HESS) that combines power-type and energy-type ESSs to improve the stability and dependability of PV grid-connected systems in order to overcome these issues. By combining the high power density and millisecond-level response characteristics of power-type ESSs with the high energy density and long-timescale operation capabilities of energy-type ESSs, the HESS is made to handle the dynamics of multi-time scale energy needs [5]. Slow average power demand changes are strategically compensated for by the energy-type ESS, which is exemplified by a battery energy storage system (BESS) with flexibility features [6]. For transient power correction within the HESS, the power type ESS—best represented by the superconducting magnetic energy storage (SMES) system—becomes the best option due to its low self-discharge rate and high power density [7].

By reducing battery stress and mitigating power fluctuations, this integrated strategy prolongs the BESS's operational lifespan. For the HESS to operate as efficiently as possible in the face of fluctuating load demand and PV generation power, an efficient control technique that can optimize transient power allocation must be developed. Maintaining energy balance among various ESS types and achieving precision power dispatch are the key control goals of the HESS. Several control strategies for RES grid-connected systems have been investigated in the past, including the low pass filter (LPF) for HESS power flow management [8], [9]. Nevertheless, the impact of a fixed cutoff frequency on the HESS's state of charge (SOC) is frequently overlooked in these attempts. In order to forecast the irradiance profile for the following day, Ref [10] uses a clear sky model. It first establishes the initial values of the filter time constants and then adaptively modifies them in response to the current power ramp rate. However, because the approach requires a lot of data storage and computational power during execution, it is challenging to implement.

Furthermore, super capacitors and BESS have been effectively incorporated into DC-DC converters using model predictive control (MPC), a powerful framework for power regulation [11]. In light of the aforementioned issue, this work presents a novel control technique for the control of

HESS in PV grid-connected systems that combines fuzzy LPF (FLPF) with fast MPC. The suggested method makes it easier to optimize the BESS's operation and operating life as well as transient power allocation.

II.LITARATURE SURVEY:

1) Collaborative Optimization of PV Greenhouses and Clean Energy Systems in Rural Areas

An integrated energy system is a crucial piece of infrastructure that supports rural development and is essential to China's rural regeneration policy. One efficient strategy for rural areas to meet double carbon targets and hasten agricultural modernization is the implementation of rural energy projects. The rural energy system with photovoltaic greenhouses is the research object in this work, which is based on the actual rural energy systems in northern China. The weather sensitivity of photovoltaic generating and agricultural productivity is taken into account while creating the agrometeorological and energy meteorological models. We suggest a new approach to maximize the cooperation between rural energy systems and photovoltaic greenhouse load control. Carbon, electrical energy, and thermal energy are all included in the combined coordination model of agriculture and energy networks. The majority of the energy is utilized for supplemental greenhouse lighting and heating, which are meticulously modeled with a particular focus on photosynthesis. Lastly, as an analytical example, three photovoltaic greenhouses in northern China and a real-world 47-bus distribution network are simulated. According to the simulation results, a 3996 m2 greenhouse with a 25% photovoltaic coverage ratio can save 15% on energy expenses by utilizing the suggested optimization technique.

2) Optimal superconducting coil integrated into PV generators for smoothing power and regulating voltage in distribution system with PHEVs

Plug-in hybrid electric vehicles (PHEVs) and solar (PV) generators are becoming increasingly common in power distribution systems. System power and voltage fluctuate as a result of changing PV power and sudden PHEV power charging. In order to address this issue, this work introduces a novel use of the superconducting coil (SC), which is coupled between the dc link of PV generators. The SC can share the inverters with the PV generators by using the dc-to-dc converter as an interfaced circuit.

Furthermore, the PV generators with the common SC can control the system voltage and produce a steady power production. The proportional-integral (PI) controllers regulate the PV inverters and the dc-to-dc converter. In order to minimize power and voltage fluctuations, the PI parameters and SC inductance are optimized. According to simulation data, the superconducting magnetic energy storage (SMES) put at the PV terminal has the same smoothing impact on the PV power fluctuation as do PV generators with the common SC, which has a lower SC inductance. Additionally, they provide the SMES with a better voltage regulation effect.

III.PROPOSED SYSTEM: A detailed representation of the setup of the PV grid-connected system with a HESS is shown in Fig. 3.1. The main RES in the system is a photovoltaic system. This PV system uses a DC-DC boost converter to provide power to the DC bus. Through a two-level voltage source converter, the DC bus then enables effective power transmission to the grid. Bidirectional DC-DC converters are used to connect the BESS and SMES separately to the DC link in order to reduce power fluctuations. There is a maximum power point tracking (MPPT) algorithm that controls the PV converter, which is in charge of effective power extraction. Power transmission optimization under dynamic temperature and irradiance conditions is greatly aided by this approach, which incorporates the perturb and observe (P&O) technique. By detecting current and voltage and comparing them to the PV cell's prior value, the MPPT algorithm, which is based on the P&O control method, calculates the PV panel's output power. Fig. 3.2 displays the MPPT control flow diagram, which clarifies the complexities of this procedure.

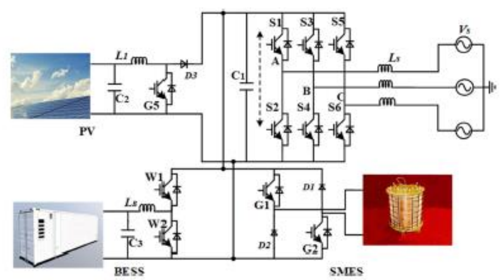


Fig. 3.1. Structure of PV grid-connected system integrated with the HESS.

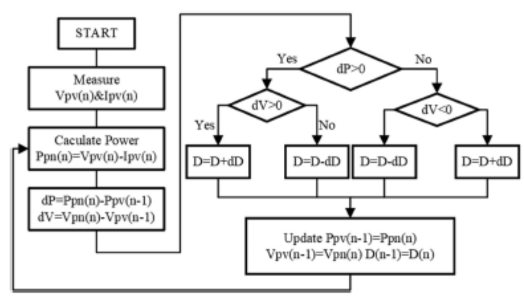


Fig. 3.2. Flow diagram of MPPT algorithm.

Two main functions that are necessary for optimal operation are included in the suggested control method. Optimizing the power distribution between the BESS and the SMES is its primary goal. Second, it highlights the importance of promptly tracking and stabilizing voltage variations brought on by power fluctuations on the DC side.

A. Dynamic Power Assignment Design Fig. 3 displays the block diagram outlining the suggested TLC technique. Based on the control signal S, hysteresis control in the HESS regulates three different operating modes: charging, standby, and discharging. By controlling the DC bus voltage with a proportional-integral (PI) control mechanism, the total reference current for HESS is determined. The low-frequency current is extracted to operate as the reference current for the battery system following processing of the sampled total current signal from the hybrid energy storage through the LPF. The SMES then successfully controls the uncompensated high-frequency current in the BESS. A first-order transfer function (1) defines the LPF, as shown in Fig. 4.3:

$$G(s) = \frac{1}{Ts+1} = k \quad (1)$$

Where T is the predetermined cut-off frequency's time constant. A carefully thought-out set of thresholds for low frequency current operations, managed by the LPF's cut-off frequency, is essential to HESS's efficacy. A fuzzy filtering control mechanism is used to prolong the life cycle of the BESS and prevent overcharge and over discharge of the HESS. Through power balance-based current exchange, this control technique ensures the recovery of a safe SOC for HESS by regulating the LPF's time constant. Table I displays comprehensive fuzzy inference rules, and Fig. 4.4 displays the fuzzy inference surface under charging mode (CM) and discharging mode (DM).

TABLE I
FUZZY RULES OF TIME CONSTANT T UNDER DM AND CM

SOC_BESS \ SOC_SMES (T)	PS	PM	PB	PS	PM	PB
PS	PM	PM	PB	PM	PS	PS
PM	PS	PB	PB	PB	PB	PM
PB	PS	PM	PS	PB	PS	PS
Operation mode	DM			CM		

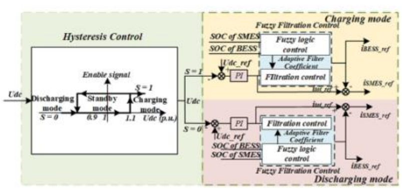


Fig. 4.3. Structure of fuzzy logic control algorithm for the

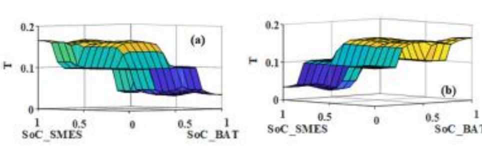


Fig. 4.4. Fuzzy inference surface under (a) discharging m

B. Design of FCS-MPC Controller Two bidirectional DC-DC converters enable the dynamic power exchange between the HESS and DC bus while maintaining the DC bus voltage equilibrium. An efficient controller is necessary to regulate the bidirectional DC-DC converter and react quickly to power conversion instructions because of the high power output and absorption demands associated with HESS. A Finite Control SetMPC (FCS-MPC) approach is suggested in this study to accomplish quick monitoring of bidirectional DCDC converters. Fig. 3.5 displays the ULC approach block diagram. During the SMES's charge mode (CM), as shown in Fig. 3.3, the control signal S is set to 1, and logical AND gating sets G1 and G2 to 1 as well. On the other hand, SMES switch to the discharging mode (DM) when S equals 0 and G1 and G2 are both 0. Similarly, depending on whether S equals 0 or 1, the half-bridge converter operates in either boost or buck modes throughout the BESS's charging and discharging process. W1 controls the charging current, while W2 is set to 0 when the BESS switches to CM. On the other hand, W1 is set to 0 and controls the discharging current when the battery storage system is in DM. Table II provides a detailed overview of the HESS DC-DC converter's switching states. The discrete-time state equations of the HESS converter prediction model in charging and discharging modes can be acquired using the bidirectional DC-DC topology.

TABLE II
SWITCHING STATE OF HESS DC-DC CONVERTER

HESS Mode	W1	W2	G1	G2
CM	1	0	1	1
	0	0	1	1
	0	0	0	1
	1	0	0	1
DM	0	1	0	1
	0	1	0	0
	0	0	0	0
	0	0	0	1

$$\begin{cases} i_{smes}(k+1) = \frac{T}{L_{sc}}(s_1{}^* u_{dc}(k)) + i_{smes}(k) \\ i_b(k+1) = \frac{T}{L_b}(u_b(k) - s_3{}^* u_{dc}(k)) + i_b(k) \\ U_{dc}(k+1) = \frac{T}{C_{dc}}(s_3{}^* i_b(k) \\ -s_1{}^* i_{smes}(k) - i_{dc}(k)) + u_{dc}(k) \end{cases} \quad (2)$$

$$\begin{cases} i_{smes}(k+1) = \frac{T}{L_{sc}}((1-s_2)^* u_{dc}(k)) + i_{smes}(k) \\ i_b(k+1) = \frac{T}{L_b}(u_b(k) - (1-s_4)^* u_{dc}(k)) + i_b(k) \\ U_{dc}(k+1) = \frac{T}{C_{dc}}((1-s_4)^* i_b(k) \\ +(1-s_2)^* i_{smes}(k) - i_{dc}(k)) + u_{dc}(k) \end{cases} \quad (3)$$

Where T is the time step, Lb is the bidirectional DC-DC inductance in the BESS, Lsmes is the superconducting magnet inductance, Cdc is the HESS's DC-link capacitance, and ub is the battery unit is terminal voltage. The DC link voltage at time step k is indicated by udc(k), and the current levels of the SMES and BESS inductors are represented by ismes(k) and ib(k), respectively. The forecast current values of SMES and BESS inductor for the next time step are indicated in (3) by ismes(k+1) and ib(k+1). Stabilization of the DC link voltage is the main goal of MPC. The superconducting coil current is carefully controlled to maintain an ideal level, meeting the urgent need for high power while reducing overreactions from both SMES and BESS. In order to reduce battery current fluctuation, the cost function also takes into account the battery system inductor current's divergence from its reference value. In (4), the cost function is defined,

$$J_{cost} = C_{u_{dc}} + C_{i_b} + \alpha \cdot C_{i_{smes}} \quad (4)$$

$$\alpha = \begin{cases} 0.1e^{|i_{smes}-i_{smes\_ref}| * \frac{ln(20)}{(i_{smes\_crt}-i_{smes\_ref})}}, i_{smes} > i_{smes\_ref} \; |\Delta U_{dc}| > 0.1p.u. \\ 0.1e^{|i_{smes}-i_{smes\_ref}| * \frac{ln(20)}{(i_{smes\_ref}-i_{smes\_min})}}, i_{smes} \leq i_{smes\_ref} \; |\Delta U_{dc}| > 0.1p.u. \\ 1, |\Delta U_{dc}| < 0.1p.u. \end{cases} \quad (5)$$

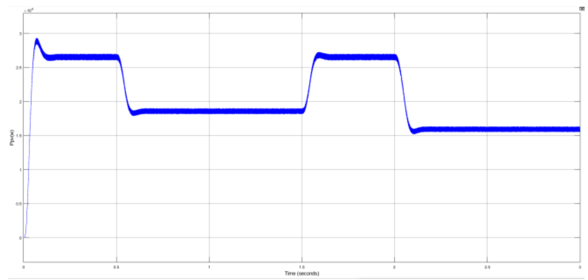
The terms C_{udc}, C_{ib} and C_{ismes} represent constraints related to the DC link voltage, battery current and SMES current, respectively. These constraints are defined as

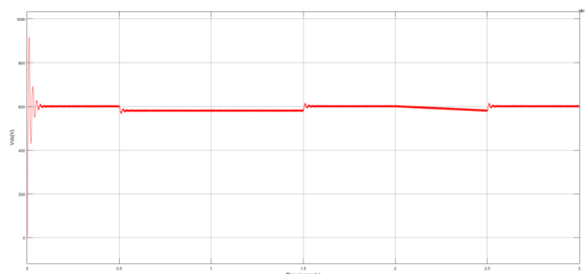
$$\begin{cases} C_{u_{dc}} = (U_{dc}(k+1) - U_{dc\_ref})^2 \\ C_{i_b} = (i_b(k+1) - i_{b\_ref})^2 \\ C_{i_{smes}} = (i_{smes}(k+1) - i_{smes\_ref})^2 \end{cases} \quad (6)$$

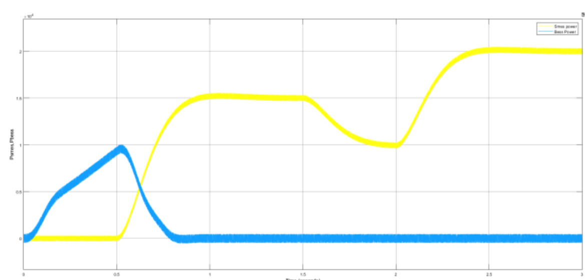
IV.SIMULATION RESULTS:

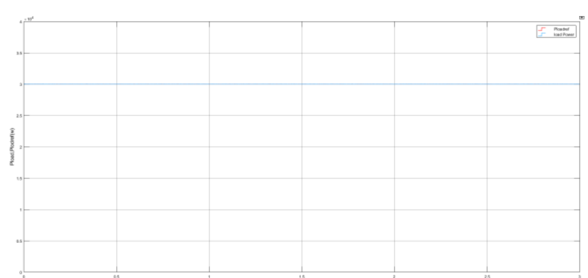
Case1

The dynamics of PV output power and the HESS's performance using the suggested control approach are explained below in the case of PV output power fluctuation. The intrinsic fluctuation of PV output power brought on by shifting environmental factors like temperature and irradiance is depicted in plot (a). It is clear from plots (b) and (c) that the HESS successfully controls the DC bus voltage within the designated reference range and makes up for the power differential between PV generation and load usage. Plot (d) shows a significant decrease in the BESS's charging and discharging activities when the SMES's output power is adequate to fulfill the load demand. As a result, the battery's reactions to transitory high power are much diminished, extending the battery's cycle life.



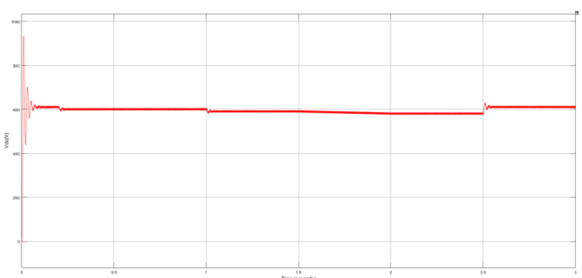


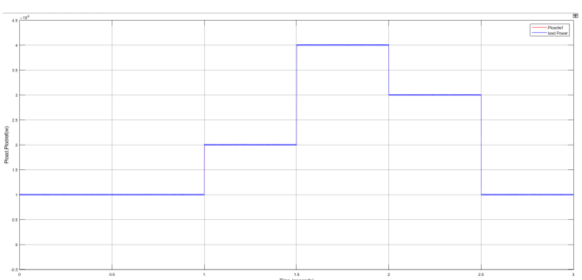




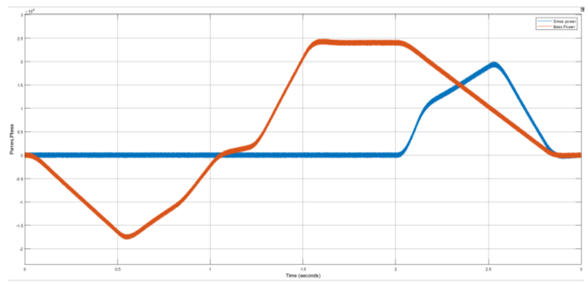
Case2

According to Fig. below, in a load step shift scenario, the grid-connected load demand steps up from 10 kW to 40 kW between 0 and 1.5 s, and then steps down from 40 kW to 10 kW between 2.0 and 3.0 s. The PV grid-connected system integrated with the HESS can smoothly respond to the power step change caused by the sudden change of load, and there is virtually no overshoot in the charge and discharge process, as demonstrated by the noteworthy dynamic changes in PV output power that are analogous to the scenario described.





Using the suggested control approach, the output power characteristics of the different ESSs within the HESS during load step changes are depicted in the figure below. The findings show that the output power trends of the BESS and SMES consistently match the control scheme that was devised. FLPF and MPC controls enable the dynamic modification of power distribution between the battery and superconductor, namely the power charge or discharge in the HESS.



V.CONCLUSION

In order to handle power fluctuations in PV grid-connected systems and preserve the stability of the DC bus voltage, this thesis presents a HESS and a corresponding control mechanism. The BESS and SMES are two energy storage systems that are integrated into the HESS. Based on the SOC scheme, a fuzzy filtration control approach is dynamically controlling the power assignment between the BESS and SMES. Additionally, the HESS can quickly monitor and control the voltage variations of BESS and SMES and preserve load side voltage stability thanks to an incorporated rapid computation FCS MPC algorithm. By utilizing the SMES system's built-in high power capacity to handle disruptions, the control strategy dramatically lowers the

BESS's charge/discharge frequency, extending the HESS's operational lifespan. Lastly, the viability and effectiveness of the suggested control approach are methodically confirmed under a range of operating circumstances, including power variations on both sides of PV generation and load consumption, proving its effectiveness in improving the grid-connected system's stability and performance.

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