Frequency regulation by fuzzy and binary control in a hybrid islanded microgrid

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Abstract Islanded microgrids must be self-sufficient in terms of frequency and voltage control due to their islanded operation. A control strategy for frequency regulation by combining the operation of a wind generator, a diesel generator, a battery energy storage system and a dump load in a microgrid is proposed in this paper. In the proposed strategy, the control task is partitioned into two subtasks: 1) choosing the appropriate element to be used for regulation, and 2) providing frequency regulation. A global controller chooses the element to operate. Then, the frequency regulation is provided by separate individual controllers. The proposed control strategy is tested on a microgrid with mixed types of generation and modeled on Simulink. By monitoring the power of individual elements and system frequency, it is shown that the proposed control strategy operates efficiently. The proposed strategy facilitates the integration of renewable energy sources and enhances frequency regulation.

Keywords Frequency regulation, Fuzzy control, Hybrid microgrid, Automatic operation

1 Introduction

Integration of renewable energy sources into power systems is a crucial step in reducing the environmental

impact of electric power generation. Renewable energy can substitute the usual fuel-based sources of energy resulting in environmentally friendly power systems. However, renewable energy sources, such as wind power, being intermittent can be unreliable. As a result, weather dependent sources cannot be used alone to efficiently supply a load.

Microgrids with a variety of power generation sources tackle the unreliability issue by combining renewable energy sources with controllable fuel-based generation. The fuel-based generation provides reliable power while the renewable energy reduces the environmental impact of generating electric power.

As these systems, often referred to as microgrids, may sometimes operate in an islanded mode, a control approach is required to maintain frequency and voltage regulation. Control of system frequency only is considered in this paper.

Frequency is dependent on the real power balance in the system. Hence, balancing mechanisms can be introduced to the system with the purpose of offsetting the intermittent power generation of a renewable energy.

Various energy sources have been used to provide frequency regulation in islanded hybrid microgrids. In [1] and [2], frequency is regulated through dump loads (DL), while a battery energy storage system (BESS) is used as the main frequency regulator in [3] and [4].

Operational requirements demand that the BESS operation be maintained between the State of Charge (SOC) limits and instantaneous power limits. Very few studies have considered the SOC when operating a BESS as a balancing mechanism in a hybrid power system, as it has been done in study [5]. This constraint is considered in this paper.

Using a single balancing mechanism for frequency regulation is a common topic in the literature. On the other hand, the combination of multiple balancing mechanism is a less visited topic. In this study, a power system that

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combines a diesel generator set (DG), a battery energy storage system (BESS) and a dump load (DL) as balancing mechanisms has been chosen. A wind generator (WG) is used as the renewable source of energy. The system schematic is shown in Fig. 1.

The use of multiple balancing mechanisms raises the need for coordination between the balancing mechanisms. Three balancing mechanisms are chosen in this study as were also used in [6] and [7]. A pre-set step signal can be used to initiate the change of operation mode. Although a pre-set signal is not used in the simulation studies in [6], it is shown by the same author in study [7] that this pre-set signal is required to commit the DG when preventing the discharge of the BESS. Thus, the strategy implemented in [6] and [7] is not completely automatic.

Other studies in the literature opted for calculating the system real power mismatch [5, 8–10]. The power mismatch estimates the difference between wind power production and load consumption. In [8] the power mismatch is used to generate an ON signal to commission the DG.

Studies in [9] and [10] balanced the power mismatch in order to extract maximum power from the wind turbine. However, the power mismatch calculation is again required to decide whether the DL is committed. In study [5] the power mismatch is used as an input of a fuzzy inference engine.

A control strategy that needs neither the load consumption nor the wind power production to operate the system is proposed in this paper. The coordination of balancing mechanisms is achieved by means of a inference engine that mimics a human operator decision. The proposed strategy divides the regulation task in two parts: 1) selecting a balancing mechanism and 2) providing frequency regulation.

A global controller has been designed using an IF–THEN inference engine that allows the coordination of balancing mechanisms without power mismatch calculation. Then, individual fuzzy controllers operate each balancing mechanism. High-order mathematical models are used to test the proposed control strategy.

Fig. 1 Hybrid power system schematic

To enhance the frequency regulation, a fuzzy control is proposed to prepare the DG for commissioning. In previous studies, the diesel engine was operated only in two states: 1) rest, and 2) nominal speed. That approach results in a large frequency deviation as seen in [6]. Here, an engine controller has been designed to regulate the diesel engine speed according to the system needs.

The paper is organized as follows. The hybrid power system structure and mathematical model are discussed in Sect. 2. The hybrid power system operational guidelines are briefly described in Sect. 3. The overall control strategy is detailed in Sect. 4 and the global controller that allows the automatic operation of the system is described in Sect. 5. Details of the frequency and operational controllers are given in Sect. 6 and simulation results are given in Sect. 7. Finally, the conclusions and findings of this study are given in Sect. 8.

2 Microgrid model

The microgrid under study comprises a DG rated 300 kVA, a WG rated 275 kVA, a BESS and a DL. The BESS instantaneous absorption and supply are limited between -150 and $+150$ kW, respectively. The DL maximum consumption is 200 kW. All system elements are connected at $480 V_{\text{rms}}$.

High-order mathematical models have been used to represent the microgrid in Simulink. The microgrid elements were modeled separately and then combined to form the microgrid under study.

The DG model consists of a diesel engine, a synchronous machine and a clutch. The diesel engine model is represented by separate high-order transfer functions as in [11]. The engine parameters were extracted from [12].

The synchronous machine model and parameters can be found in the Simulink SimPowerSystems library and follows the model in [13]. The clutch modifies the torque transmitted to the synchronous machine [6, 8] and the diesel engine speed [8]. When locking the clutch, a maximum speed difference of 10^{-5} is acceptable. Similar to the studies in [6, 7], the diesel engine cranking dynamics are avoided. To avoid the unnecessary diesel engine cranking dynamics, the engine rest state is simulated at a speed of 0.3 p.u. Thus, although the engine is considered stopped, the simulated value would remain at 0.3 p.u. Since the cranking delay will affect the readiness of the DG to provide frequency regulation, a 0.5 s delay is added as cranking time to the DG model [6, 7]. Thus, the diesel engine start will be delayed by 0.5 s when the speed increases from 0.3 p.u.

The WG model comprises a wind turbine and an asynchronous generator. The wind turbine model follows a

cubic relationship between wind speed and the harnessed mechanical power. The wind turbine mathematical model can be found in [14]. According to the power rating, a wind turbine radius of 20 m was chosen [15]. The asynchronous generator was implemented using high-order mathematical models for both electrical and mechanical parts. The mathematical model can be found in the Simulink SimPowerSystems library and follows the model in [13]. The asynchronous generator has a voltage and power rating of 480 V_{rms} and 275 kVA, respectively.

The BESS mathematical model follows [16]. In order to comply with power and voltage system requirements, a capacity of 117 Ah and a voltage of 1,000 V_{DC} were chosen. A Nickel Metal Hydride (NiMH) type of battery is used due to its environmental-friendly aspect [17]. The parameters of a single cell NiMH battery were extracted from study [16].

In addition, the SOC calculation has been modified to account for the Peukert effect. Based on study [18], a Peukert coefficient of 1.024 was selected. The SOC calculation follows [19]. To control the BESS power output, a current injection control is used similar to studies [20] and [21].

The DL comprises 8 electrical resistors that are switched to obtain the required power consumption. The model was developed following study [22]. The DL resistors presented the values of 230.4, 115.2, 57.6, 28.8, 14.4, 7.2, 3.6 and 1.8 Ω . Ideal switches were used to connect the resistors comprising the DL. To control the DL switches, a look-up table has been implemented as in study [22].

Voltage regulation is provided by the DG. The DG synchronous generator uses its excitation system to maintain the system's voltage between standards, as seen in [6]. The excitation system was modeled according to the IEEE Recommended Practice [23] for a DC1A Type Excitation System. In addition, a capacitor bank is implemented at the WG terminals to offset the asynchronous generator reactive power consumption.

3 Microgrid operational guidelines

In this study, the microgrid is operated according to an environmentally friendly dispatch. The environmentally friendly dispatch reduces the use of fuel-based generation and maximizes the use of renewable energy.

BESS allows the system to increase the use of renewable energy by absorbing power during high wind conditions and using the stored power later, when wind power generation is low. In this study, the BESS can only be charged from renewable energy. Hence, the BESS functions as the system's primary balancing mechanism.

However, operational guidelines state that the BESS can only actuate as long as its SOC is between limits.

Following [24], the SOC limits have been established at 30 % and 70 % for empty and full, respectively.

In addition, the BESS instantaneous power output must also be restricted due to the battery's charge and discharge rate limits. As a result, the instantaneous supply and absorption has been limited between +150 and -150 kW, respectively.

If the BESS operational limits are surpassed, the DG or DL must replace the BESS as frequency regulators. The DG and DL are considered secondary balancing mechanisms.

4 Overall control strategy

The proposed control strategy divides the control task into two subtasks: 1) choosing the balancing mechanism to operate, 2) providing frequency regulation with the chosen balancing mechanism. Hence, the system's operation is managed by a layered control strategy.

The first layer consists of a global controller that chooses the balancing mechanism to operate according to the system conditions. When a balancing mechanism is chosen, the global controller outputs ON/OFF status, in the binary form of 1 and 0, respectively. The running status is then given to the second control layer.

An ON status signal allows for the chosen frequency controller to be connected to the balancing mechanism; hence, the balancing mechanism is able to provide frequency regulation. An OFF status disconnects the frequency controller from the balancing mechanism. When OFF, the balancing mechanism remains at its last operational set point.

Four controllers are used in the second control layer to operate the balancing mechanisms. If the BESS or DL are committed to operation, the frequency controllers modify the BESS and DL power output.

If the SOC limits are reached, a BESS unload controller reduces the BESS power output to zero in order to prevent the SOC limits from being surpassed.

In contrast to the BESS and DL, the DG possesses a built-in frequency regulator. The speed governor of the diesel engine is able to provide frequency regulation by maintaining the diesel engine speed at nominal [25]. Hence, the design of a frequency controller for the DG is not required. However, in order to improve the system performance, an engine controller has been designed to operate the diesel engine according to the system needs.

Outputs of the second control layer are the operational set points of each balancing mechanism. The operational set points are then given to individual operational controllers. Once the new operating points are reached, the control task is completed. A graphical representation of the

Fig. 2 Graphic representation of the hierarchical relationship among system controllers

hierarchical relationship between the control layers is depicted in Fig. 2.

5 Global controller

The global controller has been designed using knowledge based rules that allow the system to operate automatically. The rules are designed in an IF–THEN format, where the system conditions allow the IF clause to decide which balancing mechanism to operate.

The global controller monitors the BESS power output (P_{BESS}), the DG power output (P_{DG}), the DL power output (P_{DL}), the system frequency deviation (Δf) and the SOC. As in fuzzy control, the crisp value of each input is transformed into a state. The input state is then used to choose the balancing mechanism to operate.

As the outputs of the global controller are binary, this controller functions as a binary control. Hence, the input states are also divided in a binary fashion. The control inputs and their states are summarized in Table 1.

As long as P_{BESS} is within Limits (i.e. $-150 \text{ kW} < P_{\text{BESS}} < 150 \text{ kW}$) and SOC is Normal (i.e. $30.15 \% < \text{SOC} < 69.85 \%$), the BESS is committed to frequency regulation, as shown in the control surface in Fig. 3. The control surface depicts the actuation of the global controller to a set of inputs. When the global controller output is ON, the surface presents a value of 1. When the output is OFF, the surface presents a value of 0.

The global controller considers the SOC is empty or full 0.15 % before the actual SOC operating limits (i.e. 30 % and 70 %). This is to allow for the BESS power output to be gradually reduced without surpassing the SOC operating limits.

Table 1 Global controller inputs

Input	States
P_{BESS}	Negative Limit [$P_{\text{BESS}} \leq -150 \text{ kW}$] Negative Normal [$-150 \text{ kW} < P_{\text{BESS}} \leq -1 \text{ kW}$] Zero [$-1 \text{ kW} < P_{\text{BESS}} < +1 \text{ kW}$] Positive Normal [$+1 \text{ kW} \leq P_{\text{BESS}} < +150 \text{ kW}$] Positive Limit [$P_{\text{BESS}} \geq +150 \text{ kW}$]
P_{DL}	Zero [$P_{\text{DL}} < +1 \text{ kW}$] Positive [$P_{\text{DL}} \geq +1 \text{ kW}$]
P_{DG}	Zero [$P_{\text{DG}} < 100 \text{ W}$] Positive [$P_{\text{DG}} \geq 100 \text{ W}$]
Δf	Negative [$\Delta f \leq -0.005 \text{ Hz}$] Zero [$-0.005 \text{ Hz} < \Delta f < +0.005 \text{ Hz}$] Positive [$\Delta f \geq +0.005 \text{ Hz}$]
SOC	Empty [$\text{SOC} \leq 30.15 \%$] Normal [$30.15 \% < \text{SOC} < 69.85 \%$] Full [$\text{SOC} \geq 69.85 \%$]

If the BESS operational limits are reached, the global controller commits a secondary balancing mechanism to frequency regulation.

If the SOC limits are reached, the unload controller is used to reduce P_{BESS} to zero. Similarly, the commissioning of the secondary balancing mechanisms also depends on the SOC state. The DL is committed if SOC is Full. The DG is committed if SOC is Empty. It is noticed from Fig. 3 that the global controller allows the BESS to charge if SOC is Empty and to supply if SOC is Full.

If the BESS instantaneous power limits are surpassed, the global controller uses Δf , P_{DG} and P_{DL} as decision variables. The frequency deviation (Δf) allows the global controller to recognize between power surplus and shortage. A negative Δf suggests the system presents a real power shortage, while a positive Δf suggests that a real power surplus exists.

For example, if P_{BESS} is at maximum absorption (i.e. $P_{\text{BESS}} \leq -150 \text{ kW}$) and a power surplus exists (i.e. $\Delta f > 0$), the DL is committed to frequency regulation, as seen in Fig. 4. Similarly, If P_{BESS} is at maximum supply (i.e. $P_{\text{BESS}} \geq 150 \text{ kW}$) and a power shortage exists (i.e. $\Delta f < 0$), the DG is committed to frequency regulation. Once a secondary balancing mechanism is committed, it will remain as the actuating balancing mechanism until its power output is reduced to zero.

6 Frequency and operational controllers

Four controllers have been designed to operate the balancing mechanisms according to the system needs. The following subsections detail the second layer controllers.

Fig. 3 Global controller control surface, BESS status at varying P_{BESS} and SOC

Fig. 4 Global controller, DL status at varying Δf and P_{BESS}

6.1 DL frequency control

Fuzzy frequency controllers have been proposed in the literature. In [1], a fuzzy logic control was designed to modify the DL consumption according to the system Δf and its rate of change ($d\Delta f/dt$).

The fuzzy frequency control designed in this paper follows the same structure as the control in [1]; however, the membership functions designed here present different widths. The controller design is based on the results of a previously used PID controller. The PID controller was recreated from study [7].

The output membership functions of the proposed fuzzy frequency controller are shown in Fig. 5. The control surface is depicted in Fig. 6. It can be seen from Fig. 5 that the large membership functions are wider and output large ΔP variations, thus providing rapid control action. In contrast, the narrow shaped ΔP membership functions prevent oscillations around the settling point.

Fig. 5 DL frequency controller output membership functions

Fig. 6 DL frequency controller control surface

Fig. 7 Graphic representation of BESS frequency control

6.2 BESS frequency control

The BESS and DL share the same fuzzy inference engine for frequency control. Hence, the BESS power reference also uses the control surface in Fig. 6. However, the BESS frequency controller has been modified by introducing a controlled attenuation. The attenuation prevents undershoots and overshoots when P_{BESS} is close to instantaneous power limits, thereby preventing unnecessarily reaching the BESS operational limits and unnecessarily committing the secondary balancing mechanisms.

The attenuation is provided by a gain control. The gain control operates according to P_{BESS} and uses fuzzy logic to calculate the required attenuation. A graphic representation of the BESS frequency control is given in Fig. 7.

Fig. 8 Gain control, control surface

The gain control, control surface, is depicted in Fig. 8. The control surface was designed by testing different attenuation levels for a given scenario. The lowest attenuations that prevented the commissioning of the secondary balancing mechanisms were chosen. The gain control effectiveness is discussed later in Sect. 7.

The attenuated ΔP is then used to calculate the BESS power reference (P_{BESS}^*) using the previous state of P_{BESS}^* . Then, a current injection control [20, 21] transforms P_{BESS}^* into a voltage reference for the BESS PWM.

6.3 BESS unload controller

The unload controller is used to reduced P_{BESS} to 0 when the SOC limits are likely to be surpassed. The unload controller consists of a fuzzy inference engine that reduces the BESS absorption or consumption through ΔP variations according to the actual value of P_{BESS} . The control surface is shown in Fig. 9.

6.4 Engine controller

The diesel engine provides frequency regulation through the speed governor. Thus, in this study a controller has been designed to operate the diesel engine reference speed according to the system needs. The designed engine controller anticipates the commissioning of the DG and prepares the diesel engine for commissioning by running in stand-by mode. The diesel engine runs in stand-by mode if: 1) the SOC is close to the empty limit, 2) P_{BESS} is close to the instantaneous supply limit.

6.4.1 SOC close to the empty limit

When the SOC is close to being empty, the diesel engine is commanded to run close to nominal speed. It was

Fig. 9 BESS unload controller, control surface

concluded through simulations that the studied diesel engine requires 3.1 s to reach operational speed. Thus, the diesel engine must start its preparation 3.1 s before the SOC is empty.

To calculate the time left before the SOC is empty, the Peukert time capacity, T_p (hour), is calculated as in (1) [26]; then, the discharge speed v_d (%/s) is calculated using (2).

$$T_p = \frac{R_{\text{rating}}}{\left(\frac{i_{\text{batt}} R_{\text{rating}}}{Q}\right)^n} \quad (1)$$

$$v_d = \frac{100\%}{T_p 3600} \quad (2)$$

where Q is the battery capacity; R_{rating} is the time rating of Q ; n is the battery Peukert coefficient, and i_{batt} is the battery current.

Using the discharge speed from (2), the time left before the SOC is empty, t_{SOC} , is calculated through (3). The diesel engine reference speed, ω_d^* , is modified according to (4). As stated in Sect. 2, the diesel engine rest state is simulated at a 0.3 p.u. speed. A stand-by speed of 0.97 p.u. has been chosen to anticipate the commissioning of the DG under this scenario.

$$t_{\text{SOC}}(s) = \frac{(\text{SOC} - \text{empty limit})}{\text{discharge speed}} \quad (3)$$

$$\begin{cases} t_{\text{SOC}} \text{ is less } 3s (t_{\text{SOC}} \leq 3.1) & \omega_d^* = 0.97 \text{ p.u.} \\ t_{\text{SOC}} \text{ is more } 3s (t_{\text{SOC}} > 3.1) & \omega_d^* = 0.30 \text{ p.u.} \end{cases} \quad (4)$$

6.4.2 P_{BESS} close to the instantaneous supply limit

Since it is not possible to estimate when the maximum instantaneous supply will be met, a fuzzy approach is used to modify ω_d^* according to P_{BESS} . As P_{BESS} gets closer to the instantaneous supply limit, it is more probable that a

Fig. 10 Engine controller, control surface for the anticipation of the instantaneous supply limit

variation in the wind production or load consumption will drive P_{BESS} to the +150 kW limit. Therefore, as P_{BESS} gets closer to the instantaneous supply limit, the diesel engine is run closer to the operational speed. The engine controller control surface for this scenario is shown in Fig. 10.

A final consideration is made for the control of the diesel engine speed. In order for the clutch to be locked, it is mandatory that the diesel engine and synchronous machine speed be almost equal. Hence, the engine control is prepared for the scenario where the diesel engine speed (ω_d) may be largely greater than synchronous machine speed (ω_s). If this scenario were to happen, ω_d^* will be set at the current ω_s through a switch. A control signal named ω_{syn} has been created for this purpose and follows (5).

$$\begin{cases} \omega_d > \omega_s = \omega_{\text{syn}} \text{ is ON(1)} & \omega_d^* = \omega_s \\ \omega_d < \omega_s = \omega_{\text{syn}} \text{ is OFF(0)} & \omega_d^* = \omega_{\text{fuzzy}} \end{cases} \quad (5)$$

A graphic representation of the engine controller is presented in Fig. 11. The final output of the engine controller is ω_d^* , which is then used as the speed reference for the diesel engine governor. When the engine controller outputs $\omega_{\text{syn}} = 1$, the governor's reference speed is equal to ω_s . When the engine

Fig. 11 Engine controller graphic representation

controller outputs $\omega_{\text{syn}} = 0$, the governor's reference speed is calculated by the engine controller.

7 Simulation studies

The proposed control strategy has been tested in Simulink. The first two scenarios test the control response to the BESS operational limits. Then, the BESS gain controller is discussed.

7.1 Global control at SOC limits

During initial conditions, the BESS provides frequency regulation by supplying power to the system. However, the BESS SOC approaches the empty limit and the DG must replace the BESS as frequency controller. The global controller actuation and the system response are shown in Fig. 12.

It is seen in Fig. 12b that t_{SOC} reaches the 3.1 s limit at $t = 4.33$ s. As this occurs, the engine controller modifies ω_d^* to stand-by operation. Due to the engine's cranking delay [6], it is at $t = 4.86$ s that the diesel engine speed starts to increase, as seen in Fig. 12d. It should also be noticed from Fig. 12d that when the engine controller is not used, the engine speed is not increased until the SOC empty limit has been reached at $t = 7.44$ s.

Once the SOC empty limit has been reached, the DG replaces the BESS as frequency regulator (Figs. 12g and e). Simultaneously, the unload controller is committed to reduce the BESS supply to 0 kW (Fig. 12f).

When the engine control is used, the proposed control strategy maintains the frequency close to the reference, 60 Hz, with a maximum Δf of -0.23 %. It is seen in Fig. 12h that when the engine controller is used, the maximum Δf can be reduced by 2.07 %.

7.2 Global control at the instantaneous power absorption limit

Due to a large power surplus, the DL starts this scenario providing frequency regulation. When a load disturbance occurs, the power surplus decreases and the BESS can alone provide frequency regulation. Simulation results are shown in Fig. 13.

During initial conditions, the BESS is absorbing at the instantaneous power limit and the DL is providing frequency regulation by absorbing the remaining power surplus (Fig. 13a). At $t = 5$ s, the load consumption increases and thus the power surplus reduces.

As a result, the DL consumption reaches 0 kW at $t = 5.05$ s. As shown in Figs. 13b and c, the global controller decommissions the DL and commits the BESS to

Fig. 12 Simulation results at SOC limits

Fig. 13 Simulation results at the instantaneous power absorption limit

Fig. 14 Gain control performance

frequency regulation. The system frequency during the load disturbance can be observed in Fig. 13d. The maximum Δf is -0.32% .

7.3 BESS frequency controller

In this scenario, the BESS consumption increases from 50.9 to 125.9 kW. The BESS performance with and without the gain control can be seen in Fig. 14.

It is seen from Fig. 14b that the maximum Δf is equal with and without gain control. However, due to slower frequency control, the overshoot is enlarged when the gain control is used. Simulation results show that the gain control effectively prevents the BESS power output from reaching the instantaneous supply limit; thus, preventing the unnecessary commissioning of the DG and improving the system power management.

8 Conclusions

A control strategy for automatic frequency regulation in an islanded microgrid is proposed. The proposed strategy

does not require the wind power or load consumption measurements.

Wind turbines are usually located away from loads. In order to calculate the system's power mismatch, wind power and load consumption measurements may be required to be transmitted over a long distance that can increase the risk of failure on the transmission channel, causing the disruption of the power system operation. By avoiding the power mismatch calculation, the proposed control strategy can reduce the risk of operation disruption due to transmission failure.

In a power mismatch coordination approach, new measurement equipment is required as new loads or renewable sources are added to the system. As a result, the coordination approach proposed in the literature will require additional cost as the system increases in size, or as distributed loads appear across the system. In contrast, the control strategy proposed here will not require additional measurement equipment as new renewable sources or loads are introduced to the system. Hence, the proposed strategy can facilitate the introduction of other renewable energy sources.

Simulation studies show that the proposed control strategy efficiently operates the system according to the dispatch and operational guidelines. Hence, the automatic operation of the islanded microgrid is achieved. Using high-order mathematical models it is shown that the frequency is efficiently regulated with a maximum deviation observed of 0.32 %.

Individual controllers are also designed to operate the balancing mechanisms. The proposed engine controller greatly improves the system frequency by anticipating the SOC empty limit and preparing the DG for commissioning. A reduction of 2.7 % on the frequency deviation is observed when the proposed engine controller is used. Ultimately, the proposed gain controller improves the system performance by preventing the unnecessary commissioning of secondary balancing mechanisms.

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