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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 14, Issue 1| Pages 56-63|e-ISSN: 2347-470X

Speed Control of a Battery-Less Isolated PV–Diesel Hybrid System Using a Modified MRAC–Fuzzy Controller

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ABSTRACT- This article presents a generic model of the PV- diesel generator system and simulation of speed control of an alternator in isolated network. A diesel generator is a machine that converts diesel fuel into electrical energy. It is typically used as a backup power source or in areas where access to the electrical grid is unavailable. In an insulated network system, a photovoltaic (PV) generator with an inverter interface is employed in parallel using a PI regulator without a battery. The distribution system has one basic purpose: to ensure, a continuous power supply to customers while ensuring that the voltage remains within acceptable limits. The main challenge in maintaining system stability during load operation lies in controlling everything variables. A sudden droplet in solar irradiance will result in an immediate reduction in the PV power output. This causes the voltage to decrease below the essential levels, finally leading to the whole failure of the low-voltage relay in the PV module. The success of any control algorithm depends on the accuracy of its "identifier" in predicting the dynamic behavior of the station. For this reason, a Model Reference Adaptive Control (MRAC) system is used for this purpose. This approach continuously adjusts the controller parameters, forcing the actual station outputs to follow the outputs of an ideal reference model. This paper proposes a modified adaptive control strategy that incorporates a fuzzy search table. This configuration is designed to ensure stable transition performance within an isolated grid. The entire system model is built and tested using MATLAB/Simulink, and results are presented.

Keywords: Energy, Energy management, Battery energy storage system, Renewable energy sources, Adaptive control.

ARTICLE INFORMATION

Author(s): Ekhlas M. Thajeel, Zainab N. Abbas, and Alia J. Mohammed;
Received: 12/11/2025; **Accepted**: 31/01/2026; **Published**: 10/03/2026;
E- ISSN: 2347-470X;
Paper Id: IJEER1211A08
Citation: 10.37391/ijeer.140106
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-14/ijeer-140106.html

1. INTRODUCTION

In power systems, generators supply various loads with active and reactive power *via* transmission and distribution networks. The goal is to maintain a constant frequency during steady-state operation. However, the challenge lies in the fact that a generator's ability to keep pace with load changes is limited by physical and technical constraints. This highlights the concept of speed regulation. This term refers to the amount of speed (or frequency) change required to transform the synchronous generator's output from zero to full capacity [1]. It is important to note that this focuses on the generator's output, distinguishing it from "voltage drop," which is more related to valve positions. In critical loads (such as hospitals, factories, and shopping centers), diesel generator sets are used as backup power systems to maintain power during outages. They are chosen for their reliability, high power output, cost-effectiveness, and ability to operate without a central power supply [2]. In any real-world system, the load is not constant; its variations over time. So, the generator's speed and frequency also alter. Therefore, to improve the dynamic characteristics of the diesel generator set and stabilize the output frequency, a load feed-forward-speed feedback adaptive-fuzzy optimization control algorithm is used to improve the system [3]. Given the wide variety of renewable energy technologies and the high complexity of modern energy systems, accurate modeling of photovoltaic modules is crucial. It is the only way to accurately predict their influence on overall system stability. Therefore, a comprehensive review of research on effective hybridization of renewable energy sources is essential to address the relevant technical and economic subjects necessary to ensure this stability [4]. For example, a sudden drop in solar irradiance will lead to an immediate reduction in PV power output. And that will cause the voltage to fall below standard levels, ultimately tripping the PV module *via* an under-voltage relay.

Hybrid systems are often used in remote areas. Batteries don't like extreme heat or cold. Batteries are usually the most expensive component of a hybrid system; depending on the discharge rate, they typically need to be replaced every 5-10 years. In a hybrid system, this creates a recurring cost "gap." Without batteries, any cloud passing over the solar panels causes a rapid drop in voltage and frequency. This is where the modified MRAC, which replaces the battery with an intelligent digital buffer, comes into play. MRAC allows the system to "adapt" in real time [5]. As daylight increases, the controller detects deviations from a "reference model" and quickly adjusts the diesel generator speed or fuel consumption to compensate. At the same time, fuzzy logic copes with "noise" and uncertainty in weather events, such as early sunset. When the charge reaches a high level, the speed of the diesel generator is rapidly increased to maintain grid stability, and the battery is not needed to absorb large shocks.

The growth of advanced diesel-solar controllers now allows much higher levels of PV deployment. These controllers prioritize available PV power to meet demand, while ensuring that diesel generators keep the minimum required load parameters. They are designed to respond instantly to changes. For example, when grid demand suddenly drops, the controller immediately lessens the PV array's power or shuts it down completely to confirm the generator continues to be properly loaded. On the other hand, if cloud cover affects a sharp drop in PV output, the controller uses the diesel generator's spinning reserve to immediately compensate for the additional load, thus keeping grid stability [6]. MRAC is a popular approach among control system developers for designing controllers that handle systems with unknown dynamics. This method has been studied, and several summaries and disparities of it exist [7-9]. Fuzzy logic has also seen a wide applications range in control systems. The term "fuzzy" refers to its capability to handle concepts that cannot be expressed in simple terms like "true" or "false." Therefore, a fuzzy controller is planned to manage (rather than define) the ambiguity and uncertainty inherent in a control problem. Its main advantage is its ability to appliance actual solutions, often based on "if-then" rules, even in difficult or poorly defined systems [10]. Modified approximation, guaranteed return, and calculation reliability. While previous MRAC–fuzzy controllers, ANN-based MRAC and Gain-scheduled adaptive PI controllers. work to map every possible scenario, Modified Adaptive Control uses appropriate mathematical tools to maintain the stability of the system even if the prediction is not perfect. Thanks to their high operating efficiency, these controllers enable the linking of large, general-purpose PV solar power systems to isolated grids. This allows for maximum deployment of PV solar energy without the need for batteries. As a result, installation costs are significantly reduced, leading to much less energy input to the grid.

2. SYSTEM CONFIGURATION AND MODELING OF NETWORK

Figure 1 illustrates the isolated power grid designed for this paper. The system is configured as a parallel hybrid integrating a diesel generator with a PV power generator that uses a Maximum Power Point Tracking (MPPT) control system. The main assumption is that this service is completely isolated, operating independently and not connected to any external high-power grid. When PV power is available, both the diesel and PV sources meet the load demand. However, in the event of a sudden drop in PV power or a complete power outage, the diesel generator controller responds immediately to pick up the load, maintaining the required parameters on the power bus.

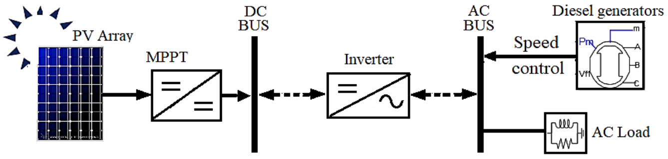

Figure 1. Model of the proposed diesel generator -connected PV system

2.1. Diesel Generator Model

Figure 2 illustrates a standard block diagram model of a diesel generator and its speed regulator. This model perfectly suited to describing the dynamic behaviors of small diesel generator sets. A first-order lag representation is used for both the diesel engine and the valve actuator servomechanism, defined by their respective time constants, T_d and T_{sm} [11]. The speed regulator's behavior is determined by both drop R and integrative control gain K. This integrative control aims to remove steady-state frequency error, although this component may be absent in many small or older units. In this frequency analysis, which uses linear models, the actuator positioner is ignored. "The load demand P_L serves as the primary input to the model, and its main output is the generator speed deviation ω_d. In a per-unit system, this speed deviation is equal to electrical frequency deviation for the system ω_e.

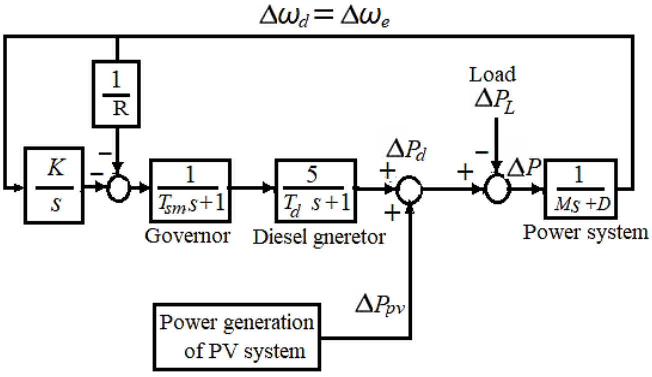

Figure 2. Block diagram of diesel generator and speed governor model

A diesel generator is used as a backup power source (or primary balancing power source), taking over when renewable energy sources are insufficient to meet energy demands. The generator's fuel consumption per hour can be determined using the following equation:

$$F(Di.g) = A \times P_{Di.g}(t) + B \times P_{Di.g}^{rat.} \quad (1)$$

In this equation, $F(Di.g)$ represents the generator's fuel consumption in liters per hour. This consumption is defined by $P_{Di.g}$(t) (actual output power in kilowatts) and $P_{Di.g}^{rat.}$ (the generator's rated output power). The equation depends on two constants, A and B, which denote the slope and intersection coefficients of the fuel curve, respectively.

2.2. PV System Model

PV systems deal multiple advantages: they can develop voltage patterns via feeders, decrease branch loads, and provide environmental benefits by offsetting pollutant emissions. The economic benefits for utilities are also substantial, with reduced losses, cost avoidance (for both power generation and new generation capacity), and mitigation of the risks associated with fluctuating fuel prices [12]. Consequently, a significant number of grids connected PV generators have been connected with distribution systems. The amount of PV power is expected to develop in the future until it becomes comparable to the power supplied by the mains. By using semiconductor materials, a photovoltaic cell array converts sunlight into electricity. Its operating behavior under varying radiation levels and temperatures is characterized by the curves (*I-V*) and (*P-V*). In *Figure 3*, the model used in this study represents each cell using a parallel current source with a diode. This model also contains a series resistor R_S and a switching resistor R_{SH}. According to this model, the output current (*I*) can be formulated as follows [13]:

$$I = I_E - I_0 \left(e^{\frac{q(V+IR_S)}{nkT}} - 1 \right) - \frac{V+IR_S}{R_{SH}} \qquad (2)$$

In this equation, *I* and *V* denote the cell's output current and voltage. The term I_0 denotes to the PV formed by sunlight, while I_E denotes the diode's saturation current. The diode's quality factor *n*, cell temperature *T*, and the physical constants *q* (elementary charge) and *k* (Boltzmann constant) are given.

Where *V* and *I* are represented the output voltage and current of the PV cell, respectively; I_0 is the diode saturation current; I_E is the photocurrent created by sunlight; q is the elementary charge($q = 1.692 \times 10^{-19} C$); n is the quality factor of the diode; *k* is the Boltzmann constant ($k = 1.3806503 \times 10^{-23} J/K$); and *T* is the temperature of the cell.

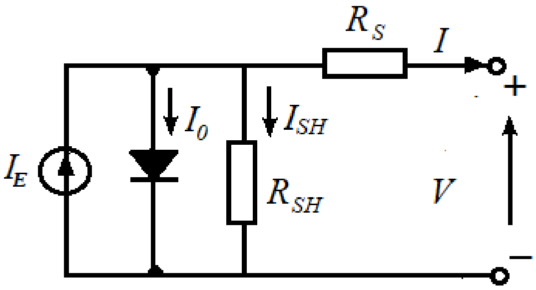

Figure 3. PV Solar equivalent circuit

In *Figure 4*, the photovoltaic generator is linked to the DC bus via a boost converter. The primary function of this converter is to ensure the photovoltaic generator works in MPPT mode. To achieve this, the Perturb and Observe (P&O) algorithm are implemented, which is widely used due to its proven efficiency and simplicity [14]. This method works by measuring only the voltage and current: it introduces a slight perturbation (change) in the voltage, monitors the resulting power output, and then uses this data to define the next control action for the boost converter to maximize the extracted power.

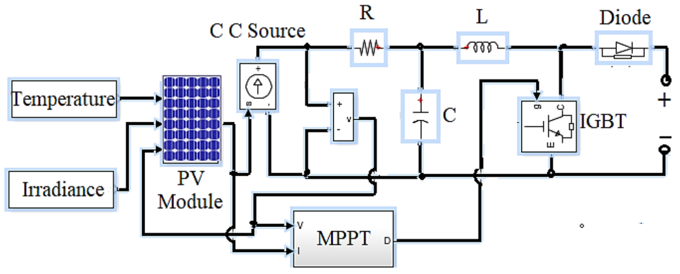

Figure 4. PV generator with boost converter

2.3. Inverter Control Strategy

Grid-compatible inverters operate by monitoring and mimicking the behavior of the installed electrical grid. Instead of establishing their own reference points, they act as controlled current sources based on an external voltage and frequency. To ensure continuous synchronization, these devices utilize a Phase-Locked Loop (*PLL*) converter to match the existing grid signal. A rotating reference frame *dq* is used. The inverter inputs the current vector i_{dq} to correspond to the power setpoints *P** and *Q**. For the grid, a *PLL* is used to determine the phase angle by driving the perpendicular axis voltage component (*q*-axis) to zero [15]:

$$\theta_{PLL} = \int (k_p v_q + k_i \int v_q \, dt) dt \qquad (3)$$

The relationship between current and power is:

$$P = \frac{3}{2}(v_d i_d + v_q i_q) \qquad (4)$$

$$Q = \frac{3}{2}(v_q i_d - v_d i_q) \qquad (5)$$

When the grid frequency changes, the *PLL* adjusts accordingly. If the mains fail, the mathematical operations become corrupted because v_{dq} becomes undefined (which can cause the inverter to trip).

3. PROPOSED REVERSIBLE LOGIC MODULE

Model Reference Adaptive Control works by introducing a visual rule controlled by an adaptation gain, making system's plant consistently conform to a predefined reference model until tracking errors are eliminated. The Massachusetts Institute of Technology (*MIT*) and Lyapunov approaches were used to develop the adaptation mechanism, which is used to adjust the parameters in the control law. In the presence of uncertainties or variations for a reference input by introducing a fractional-order transfer function prefilter. Based on Lyapunov theory, the updating control law minimizes the error between the plant output and the model reference one. [16] used the concept of Lyapunov theory to develop the MRAC system of Linear motor drive.[17] compares the MIT rule and Lyapunov rule for developing the adaptation mechanism on the basis of different time response specifications, the characteristics show that there is very less difference in responses for both the models. So, the physical realization for the system under consideration is comparatively more feasible with Lyapunov theory. But the mathematical modeling of system is simpler for MIT rule. Lyapunov investigated the nonlinear differential equation, this approach is based on finding suitable candidates for Lyapunov functions [18]. For an update law is the "Lyapunov rule" which is given as:

$$\frac{d}{dt}\theta = -\gamma e r \qquad (6)$$

Where r is the reference input signal, in order to derive this formula, the following Lyapunov function is defined:

$$V = \frac{1}{2}\gamma e^2 + \frac{1}{2}b\left(\theta - \frac{b_m}{b}\right)^2 \qquad (7)$$

Adaptive control is a strategy in which a controller automatically alters its control law. It does this to deal with continuous changes in system parameters, which are caused by disturbances such as load variations, generation losses, or faults. This process works by continuously measuring the dynamic behaviors of the station and comparing it to the desired output (often from a reference model). The resulting difference (error) is then added to the "adaptive law." The purpose of this law is to actively search for the correct controller parameters that will force the station's response to match the reference model. The entire design aims to ensure system stability and to keep the tracking error close to zero [19]. The MRAC structure for this study is shown in *figure 5*. It uses a fuzzy system where the inputs are chosen based on the problem dynamics, and the outputs are adjustments to the controller gains (K_P and K_i).

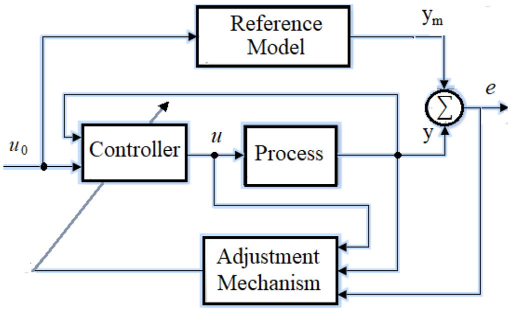

Figure 5. General scheme of MRAC

3.1. The MIT Rule

In a conventional PI controller, achieving the required dynamic response speed using proportional gain K_P alone is difficult. Proportional control only reacts to the current error, thus leaving a fixed error. Therefore, an integration coefficient Ki must be used to eliminate this fixed error. In the early stages of modification, K_I is often reduced to avoid excessive system overshoot; in the middle stages, Ki is increased to improve stability characteristics.

While the regulation of the rotational speed of the diesel generator is closely related to the frequency, the performance of the previous controller showed that the diesel generator was characterized by high torque, slow response and large oscillation errors during system response. The modified MIT Rules approach is frequently used by researchers working with dynamic hybrid models for practical reasons. This preference is often based on the nature of rapidly and randomly changing renewable energy outages due to cloud or wind storms, and the mathematics of the installations. A modified MIT Rule operates more consistently as an efficient system. Instead of adding a fixed point, it is more likely to "track" a movement (e.g., Maximum Power Point)." [20].

The MIT rule, developed at MIT, is a method used to implement the MRAC approach. In this rule, the cost function $F(\theta)$ is defined and minimized [21]:

$$F(\theta) = \frac{e^2}{2} \qquad (8)$$

$$e = y - y_m \qquad (9)$$

where e is the output error, (the difference between the reference model output and actual factory output), and θ is the adjustable control coefficient.

The coefficient θ is adapted in such a way as to minimize this cost function $F(\theta)$. Therefore, the coefficient changes towards the negative gradient of $F(\theta)$. This adaptation rule is expressed as follows: [22]:

$$d\theta/dt = -\gamma(\partial F/\partial\theta) \qquad (10)$$

where γ is the adaptation gain. MIT rule has to be modified by a 'Sign' function defined as:

Sign e = for $e > 0$

= 0 for $e = 0$

= -1 for $e < 0$

A critically damped system takes as the reference model. For first-order system using MIT Rule

$$dy/dt = -ay + bu \qquad (11)$$

Where, u is the control variable, and y is the measure output. Consider the model describes by;

$$dy_m/dt = -a_m y_m + b_m u_c \qquad (12)$$

Let the controller be given:

$$u(t) = \theta_1 u_c\,(t) - \theta_2 y\,(t) \qquad (13)$$

$$\theta_1 = \theta_1^0 = \frac{b_m}{b} \qquad (14)$$

$$\theta_2 = \theta_2^0 = \frac{a_m - a}{b} \qquad (15)$$

Thus, "perfect conformity to the model" is achieved: the system's input-output relationship becomes exactly identical to that of the reference model. The resulting system error e can then be determined from *equation (9)*. The parameter θ uses to describe the control law and its value primarily depends on adaptation gain.

This study applies the MRAC scheme to a first-order system using the MIT rule. The rule applied to the simulation is detailed in *equations (8)* and *(11)*.

Let a=1 and b=1

The controller output is defined as u. The reference model transfer function is given by:

$$\frac{Y(s)}{U(s)} = \frac{1}{s+1} \qquad (16)$$

In this paper, the plant (generator) transfer function can be descripted as:

=1/ (0.004 +1), where s=0.004

3.2. Fuzzy Plus Adaptive Control

Fuzzy plus Adaptive Control is a control strategy that combines fuzzy logic with adaptive mechanisms to handle uncertainties and nonlinearities in dynamic systems. This approach is particularly useful for systems where the exact mathematical model is difficult to obtain or where the system parameters change over time. Fuzzy plus Adaptive Control is designed with adjustable parameters and an embedded mechanism for adjusting them. The basic steps for implementing an adaptive algorithm include: collection of observable data, adjustment of controller parameters and improvement in performance by adjusting the controller parameters to enhance performance. With increasing size and complexity of power systems, and emerging dynamic behavior of synchronous generators, conventional PI controllers often fail to provide adequate performance across a wide range of operating conditions. So, modern control strategies, particularly in areas such as internal combustion engine control, have become heavily reliant on one- and two-dimensional lookup tables [23]. The lookup table defines a relationship between a set of breakpoint data (inputs) and associated table data (outputs). The control output gain can then be used to filter or adjust the table outputs. Lookup tables are highly versatile. As discussed in [24], they can be implemented in various ways, such as storing controller parameters (*e.g.*, gain) that change based on the current operating condition. To achieve better control performance, this work proposes a control design that incorporates a lookup table. The Lookup table (*2-D*) block as shown in *Figure 6* is computed an approximation to a function:

A two-dimensional lookup table functions by mapping its inputs directly to the table's dimensions. The first input *u1* corresponds to the first dimension, and the second input *u2* corresponds to the second dimension. *Fig. 6* shows that in the first input is used to define row break-points; the second input defines column break-points, and so on. When designing such tables, there are two fundamental constraints: memory constraints: the total size of any lookup table is finally limited by the system's available memory.

Memory constraints: The total size of any lookup table is ultimately limited by the system's available memory.
Dimensional consistency: To maintain dimensional consistency, the total size of the table data must be structured to accurately reflect the sizes of the breakpoint data sets.

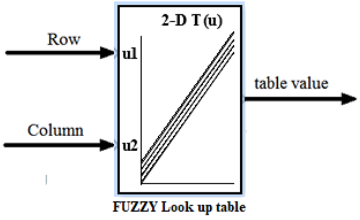

Figure 6. Block diagram of lookup table (2-D)

When implementing lookup table blocks, the dimensions of the breakpoint datasets and their associated table data are governed by two main factors:

- The memory limitations of the system constrain the overall size of a lookup table.
- Lookup tables must use consistent dimensions so that the overall size of the table data reflects the size of each breakpoint data set.

To ensure mathematical integrity, the table data structure must be precisely aligned with the dimensions of its breakpoint sets. For example, the size of the output array must be a direct reflection of the lengths of the input vectors. To illustrate this relationship, consider the following input and output vectors and their corresponding graphical representations:

Vector of input values: {-3 -2 -1 0 1 2 3}

Vector of output values: {-3 -1 0 -1 0 1 3}

The input and output data are of equal size (1x7), allowing for the same scale in a one-dimensional lookup table. The following input and output values define a two-dimensional lookup table.

lookup table and simple estimations for this work and data shown in *Table 1* which can be faster than mathematical function evaluations:

Table 1. Row and column input values

Breakpoint	**Column**	(1)	(2)	(3)	(4)
Row	----------	**0**	**1**	**2**	**3**
(1)	**0**	**11**	**12**	**13**	**14**
(2)	**1**	**21**	**22**	**23**	**24**
(3)	**2**	**31**	**32**	**33**	**34**

4. RESULTS AND DISCUSSION

Figure 7 shows the MATLAB-Simulink diagram of the proposed controller (MRAC modified with the MIT + Fuzzy framework). The diesel engine and the MRAC model were described in previous sections. The solar array is connected to the independent grid *via* an inverter, allowing it to act as a grid-forming source.

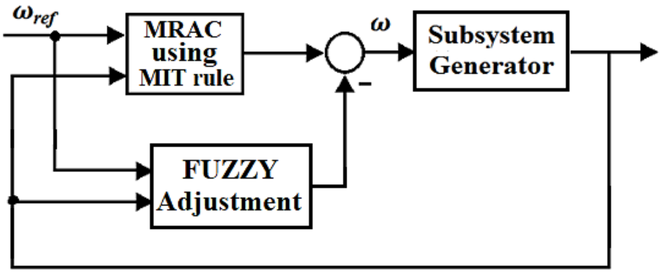

Figure 7. Structure of MRAC based modified MIT rule+ Fuzzy controller

This MRAC approach is applied to a first-order system. It aims to study efficient power sharing and optimize dynamic response, particularly improving tracking performance during variable solar cell output or in complete solar power outages. To assess its effectiveness, the proposed controller is compared to the performance of traditional PI and adaptive PI (API) controllers. In this simulation, the maximum power ratings for the solar array and the diesel generator are 24 k*W* and 88 k*W*, respectively. The parameters of the hybrid System can be shown in *table 2*.

Table 2. Parameters of the Hybrid System

Parameters of Diesel Generator		Parameters of PV Solar	
Nominal power	200 k*W*	Open circuit voltage (VOC)	66 *V*
line-to-line V(rms)	400 *V*	Short circuit current (ISC)	25.44 *A*
Frequency	50 *Hz*	Rated Power	530.5 *W*
Inertia constant, H	0.34 *s*	Voltage at Maximum power (Vmp)	54.2 *V*
Friction factor	0.01(*pu*)	Current at Maximum power (Imp)	23.25 *A*

For the process model due to the fluctuating nature of PV power generation or suddenly drop shuts off the PV power plant totally in the time s=1s and in the same time the load increased 30%. The effectiveness of the proposed method to investigation speed control examines by simulation of three phase fault system model in time from s=1s to s=1.2s when the power is available (PV solar and diesel generator). *Figure 8* shows the response of real and reference model for different values of adaptation gain θ. It is clear from *figure 8*, that, for large values of θ system responses fast, and for small values of θ system responses slow.

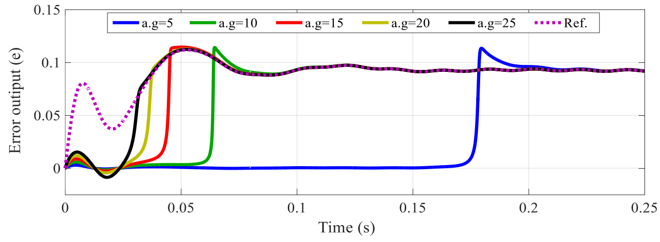

Figure 8. Effect of adaptation gain on output error

Figures 9 and *10* compare the process output against the reference model. The initial response, shown in *figure 9*, has significant oscillations and error. After the Fuzzy regulation (*figure 10*), the system output clearly and closely paths the reference model.

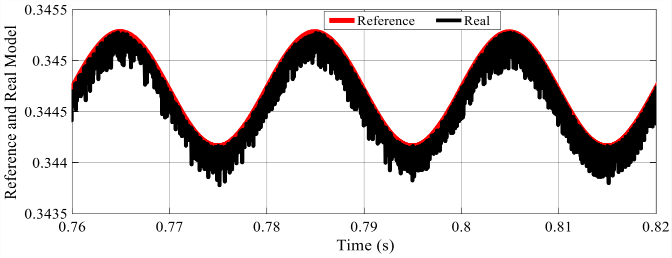

Figure 9. Error comparison of reference and real model by API controller

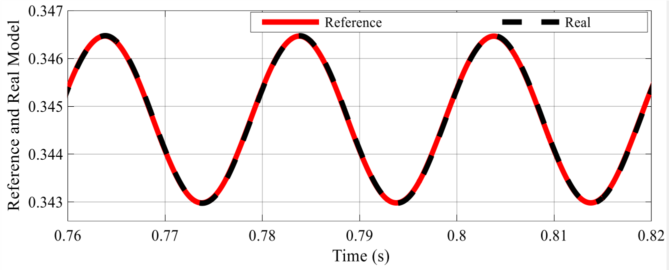

Figure 10. Error comparison of reference and real model by Fuzzy adaptive PI (FAPI) controller

Figure 11 shows the measured response when the non-adaptive PI controller is used with API and FAPI. It is clear that the speed response is different. On the other hand, best control response is with proposed FAPI controller where provides minimum error of overshoots, undershoots and settling time. In the simulation tests a power of PV solar cut off is applied at t =0.1s *Figure 12* illustrates that FAPI control fast response of speed maintain the stability of the network during PV power dropping totally.

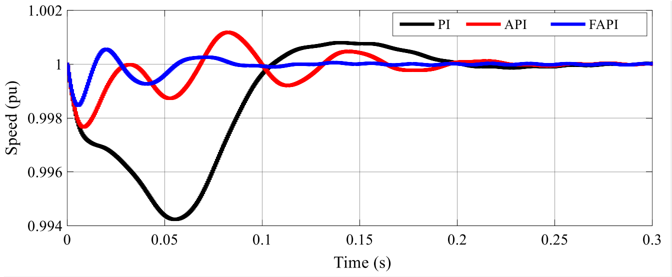

Figure 11. Step response of speed at steady state

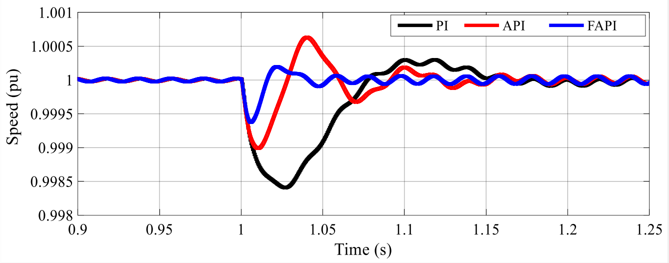

Figure 12. Speed response at PV power shut down

In this work, the ability of the diesel generator to provide an effective control of the active power and power to meet the load requirements is demonstrated. As illustrated in *fig.13* and *figure 14*, the diesel generator provides active power and reactive power after removing synchronization for PV and grid at t=1s. It is shown that each plant (PV, diesel) generates its own energy and the amount of additional energy based on the demand comes from the diesel generator. It was shown that the active energy does not change significantly when the Photovoltaic (PV) system is decoupled from the grid It has been shown that the energy efficiency does not change significantly when the photovoltaic (PV) system is disconnected from the grid. This indicates that a diesel generator has the ability to effectively control the active and reactive power to meet the requirements.

As shown in *figures 13* and *14*, diesel generators supply generation and reaction power after desynchronization to PV and grid at *t*=1s. Individual plants (PV, diesel) are shown to be self-sufficient, and the amount of additional energy depends on the diesel generator according to demand.

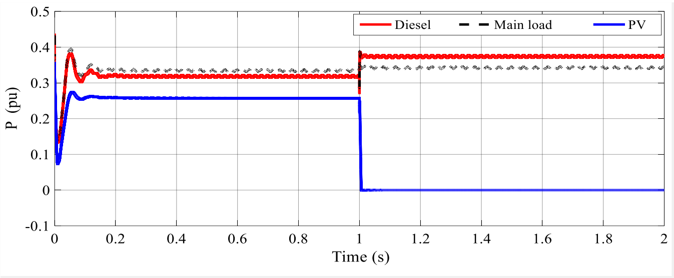

Figure 13. Active power of diesel generator, PV and main load

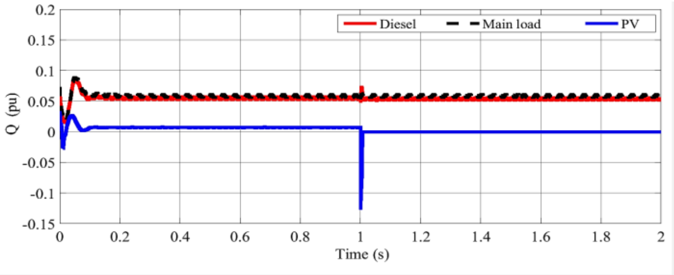

Figure 14. Reactive power of diesel generator, PV and main load

At *t* = 1s, a fall in PV power generation occurs. This causes the inverter voltage to droplet to zero, as showed in *Figure 15*. Simultaneously, *Figure 16* proves an increase in the load current.

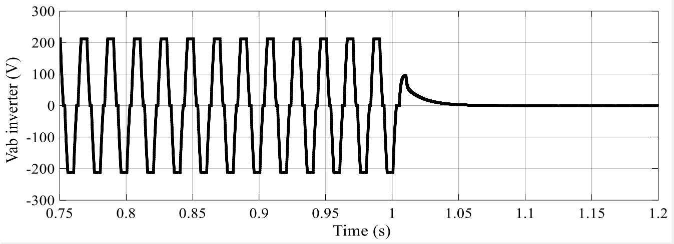

Figure 15. Inverter line voltage

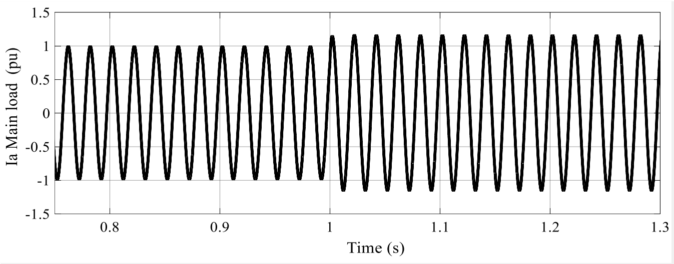

Figure 16. Line current of main load

Figure 17 shows the three-phase temporary fault was applied to load line at *t*=1s and cleared after 20ms. Post fault recovers quickly after clearing the fault due to the proposed FAPI controller support provided by speed control.

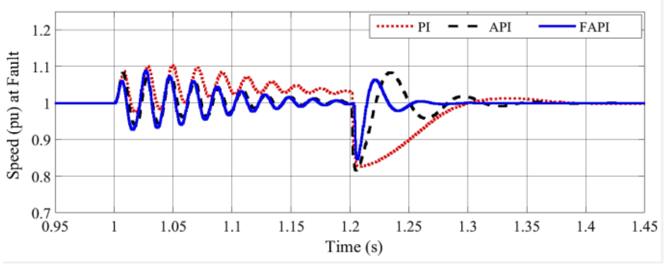

Figure 17. Speed oscillations during three phase faults

The simulation results provide conclusive evidence of the validity of this speed control method, demonstrating its superiority over previous methods to maintain the precision of the adjustment point. The performance comparisons can be seen in *Table 3*.

Table 3. Performance Comparisons

At PV Shut Down	PI	API	FAPI
Overshoots (%)	1.001	1.001	1.000
Undershoots (%)	0.9971	0.9983	0.9991
Settling times (s)	1.176	1.166	1.055

5. CONCLUSION

Hybrid systems, especially those utilizing renewable energy, have proven their efficiency in numerous applications. Furthermore, rapid advancements in grid linked PV technology can be used to isolated power systems of varying scales. The challenge lies in the fact that the performance of a diesel generator can be negatively impacted by changing operating conditions. However, an adaptive controller develops performance by allowing dynamic alteration of its parameters. This research suggests a modified controller based on the MIT + Fuzzy framework, designed to succeed a fast and desirable speed response by adaptive gains. This robust control supports the system to operate without batteries, thus avoiding unnecessary power loss and decreasing energy production costs. This controller used to confirm high speed and optimal response, successful tracking performance during fluctuating PV output or thorough power outages. Simulation results, paralleling the proposed controller with conventional PI and API controllers, clearly show that the MIT + Fuzzy-based controller can effectively keep power balance within the system.

Author Contributions: Ekhlas M. Thajeel: Conceptualization, methodology, and software design. Zainab N. Abbas^2: Data curation, written original draft preparation, interim review, and editing. Alia J. Mohammed: Visualization, investigation, validation, written review, and finalization. All authors have read and agreed to the submitted version of the manuscript.

Funding Source: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Ethical Approval: The material is the author's original work, which has not been previously published.

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