Influence of Ultracapacitor and Plug-In Electric Vehicle for Frequency Regulation of Hybrid Power System Utilizing Artificial Gorilla Troops Optimizer Algorithm

Smruti Ranjan Nayak, Rajendra Kumar Khadanga, Deepa Das, Yogendra Arya, Sidhartha Panda, and Preeti Ranjan Sahu

1Department of Electrical and Electronics Engineering, Centurion University of Technology and Management, Bhubaneswar 752050, Odisha, India
2Department of Electrical Engineering, Government College of Engineering, Kalahandi, 766002 Odisha, India
3Department of Electrical Engineering, J.C. Bose University of Science and Technology, YMCA, Faridabad, Haryana 121006, India
4Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla 768018, Odisha, India
5Department of Electrical and Electronics Engineering, NIST Institute of Science and Technology, Berhampur 761008, Odisha, India

Correspondence should be addressed to Yogendra Arya; yarya@jcboseust.ac.in

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The proposed research work considers the effect of ultracapacitor (UC) and plug-in electric vehicle (PEV) inside a distributed energy sources based on three-area hybrid power system. Recently developed artificial gorilla troops optimizer (GTO) algorithm-based fractional order tilt integral derivative (FOTID) controller is suggested for load frequency control (LFC) of a three-area hybrid power system. By setting up a TID controller for the hybrid system’s frequency regulation, the algorithms’ realistic use is attempted via showcasing its immense potential. The results of the GTO-based TID regulator are observed better over GTO-based PID. Next, by considering a modification of system settings and under existence of intermittent behavior of renewable energy sources, it is evident that the influence of UC and PEV is more ethical compared to the conventional regulator-based frequency control. Additionally, it is seen that the suggested GTO-based FOTID controller along with the UC and PEV outperforms GTO-based TID controller in terms of lesser overshoots/settling times and fast responses.

1. Introduction

Load frequency control (LFC) is a mission which is to confirm frequency anomalies within a specified range that goes beyond what many people would think is feasible [1]. To keep the frequency within a reasonable range, a comprehensive planned power system must address this crucial issue discovered with LFC [2]. The review of the literature shows that the LFC problem has been the subject of numerous prior analyses. The majority of LFC and flow research on LFC focuses on the frequency regulation of a two-area linked power system.

The effect of an electric vehicle on the LFC application is explained in [3]. In [4], the utilization of different distributed energy sources for the LFC application is explained. The application of static synchronous series compensator (SSSC) and capacitive energy storage (CES) inside the LFC is explained in [5]. Surprisingly, few people have analysed traditional energy sources, and even fewer have thought about how distributed sources may affect the LFC strategy. A two-area LFC with a two-degree freedom TID controller is explained in [6]. A robust conditional value at risk (CVaR) tuning method is proposed in [7] to make the day ahead home energy management system (HEMS) protective alongside the
uncertainty in solar power generation and energy price volatility. Arya [8] depicts the expansion from the two to the five-area LFC. Once more, [9] explains the implementation of a few renewable energy-based single-/multisource two-area interconnected systems. Next, [10] explains how the energy storage technology is applied to a three-area LFC. The incorporation of renewable energy sources in a three-area power system, however, has not received considerable research [11]. Again, [2] shows the impact of ultracapacitors in LFC. In addition, the LFC problem does not take the impact of ultracapacitors and plug-in electric vehicles (PEV) into account combinedly. As a result, a three-area power system is considered in this work, with diverse distributed energy sources such as wind generators, solar generators, fuel cells, microturbines, and diesel engine generators along with a plug-in electric vehicle and an ultracapacitor in each area taken into consideration.

The LFC problem has been resolved by many controllers like the proportional integral, and derivative application has also been used for these issues [12], and researchers have also used types 1 and 2 fuzzy PID controllers [13], tilt integral derivative remote controls [14], cascade tilt-integral-tilt-derivative controllers [15], $(1 + PD)$-PID cascade controller [16], etc. In contrast, the use of a fractional order tilt integral derivative (FOTID) controller for AGC applications has not been studied by any of the researchers in the literature.

One of the typical methods to resolve the problem regarding LFC is known to be the utilization of an evolutionary algorithm (EA). The ability to manage nonlinear functions is the major aim of EA [17]. Other few observations of the EA application are GA [18], PSO [19], equilibrium optimization technique [20], artificial bee colony optimization [21], GWO [22], cuckoo search algorithm [22], adaptive cuckoo search algorithm [23], bat algorithm [24], water cycle algorithm [25], African vulture optimization algorithm [26], parasitism predation algorithm [27], wild horse optimizer [28], dingo optimization algorithm [29], etc. EA has been employed to successfully implement the LFC design. Although these methods offer a strong execution, their rate of convergence is slow and they commonly become stuck in global optimization.

The GTO algorithm has been intensively used in numerous optimization problems [30, 31]. The previously described GTO calculation, the mathematical formulation of the daily relationships of gorillas, and the development of novel mechanisms for exploration and exploitation are all examples of this [32, 33]. Now that the other points have just been considered, a novel approach has been made by including a UC and a PEV in each area of the AGC system. Again, for the load frequency regulation of the said hybrid power system, a GTO algorithm based on the FOTID controller has also been created.

2. Research Gap and Contribution

2.1. Research Gap. The following are the research gaps identified by the literature review:

(1) The effects of UC and PEV integration into the three-area AGC operation have seldom ever been studied

(2) According to the author's knowledge, there is no execution of a fractional order TID controller in the LFC applications based on distributed power generation

(3) In the existing investigations, comprehensive analysis considering several worthwhile analyses has not been possible
2.2. Contribution. The following are briefly displayed as the paper’s main contributions:

(i) The effects of integrating an ultracapacitor (UC) and a plug-in electric vehicle (PEV) with various distributed energy sources are investigated within a three-area hybrid power system.

(ii) Using the newly established GTO computation, a FOTID controller is constructed for the hybrid system, and it has been shown that it offers better frequency regulation than certain other current regulators and controllers.

(iii) In terms of operation time, the advantages of the provided algorithm over a few different tactics are analysed.

3. Proposed Hybrid Power System

Figure 1 shows the line diagram of the proposed three-area power system, and Figure 2(a) shows the detailed structure of the said hybrid three-area hybrid power system which is interconnected with each other. Distributed energy sources (DER) are shown in Figure 2(b). For the three-area system mentioned earlier, several system parameters are shown in Table 1 [34].

3.1. Component Modelling of the Hybrid System

(A) Thermal power system: for generating power in a thermal power plant, we use a turbine \((G_T(s))\), generator \((G_{PS}(s))\), governor \((G_{TG}(s))\), and reheater \((G_{RH}(s))\). The transfer functions (TF) for this system are given as follows [6]:

![Figure 2: (a) Structure of three-area hybrid power system and (b) distributed energy sources (DER).]
Table 1: Nominal parameters of hybrid power system.

<table>
<thead>
<tr>
<th>Components</th>
<th>Gain (K)</th>
<th>Time constant (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbine generator (WTG)</td>
<td>$K_{WTG} = 1$</td>
<td>$T_{WTG} = 1.5 \text{ s}$</td>
</tr>
<tr>
<td>Hydroaqua electrolyzer (HAE)</td>
<td>$K_{HAE} = 0.02$</td>
<td>$T_{HAE} = 0.5 \text{ s}$</td>
</tr>
<tr>
<td>Fuel cell (FC)</td>
<td>$K_{FC} = 0.01$</td>
<td>$T_{FC} = 4 \text{ s}$</td>
</tr>
<tr>
<td>Diesel engine generator (DEG)</td>
<td>$K_{DEG} = 0.03$</td>
<td>$T_{DEG} = 2 \text{ s}$</td>
</tr>
<tr>
<td>Microturbine generator (MTG)</td>
<td>$K_{MTG} = 1$</td>
<td>$T_{MTG} = 1.5 \text{ s}$</td>
</tr>
<tr>
<td>Thermal power station</td>
<td>$K_{ri} = 0.5, T_{ri} = 10.0, 2\pi T_{ij} = 0.545 \text{ puMW/Hz}, \beta_{i} = 0.425, T_{Gi} = 0.08, T_{Ri} = 0.3$</td>
<td></td>
</tr>
<tr>
<td>Hydropower station</td>
<td>$R_{i} = 2.4 \text{ Hz/puMW}, K_{PS} = 120 \text{ puMW/Hz}, T_{PS} = 20 \text{ s}, T_{Rhi} = 0.513 \text{ s}, T_{Rhi} = 5 \text{ s}, T_{Gi} = 48.7 \text{ s}, T_{Wi} = 1 \text{ s}$</td>
<td></td>
</tr>
</tbody>
</table>

(B) Hydropower plant modelling: the hydropower plant’s key components are mainly a hydraulic governor ($G_{HG}(s)$) and a hydroturbine ($G_{HT}(s)$) expressed as below [13]:

\[
G_{HG}(s) = \frac{1}{1 + sT_{Gh}},
\]

\[
G_{HT}(s) = \frac{1 + sK_{T}T_{R}}{1 + sT_{Ri}}.
\]

(C) Wind turbine generator (WTG) system: the TF of WTG can be defined as [17]

\[
G_{WTG}(s) = \frac{K_{WTG}}{1 + sT_{WTG}}.
\]

(D) Photo voltaic (PV) system: this system comprises a panel, MPPT charge controller, boost converter, and one filter circuit. Its TF can be defined as [17]

\[
G_{PV}(s) = \frac{K_{PV}}{1 + sT_{PV}}.
\]

(E) Microturbine generator (MTG) system: the MTG, usually referred to as miniature turbines, can produce both heat and power as [22]

\[
G_{MTG}(s) = \frac{K_{MTG}}{1 + sT_{MTG}}.
\]
Initialize the gorillas in problem and specify N, T, β and p

Calculate the fitness of gorilla

$t = 1$

$t < T$

$i = 1$

$i < t$

$t = t + 1$

Update the position of the gorilla via Eq. 22

Apply Eq. 20 to evaluate the fitness and if new solution is better than the previous one then replace it

Yes

$i = i + 1$

No

Set the best solutions as the location of silverback

Update the L, C according to Eq. 23 & 24

Update the gorilla position via Eq. 26

Apply Eq. 20 to evaluate the fitness and if new solution is better than the previous one then replace it

Yes

$i < N$

No

Set the best result as the location of silverback.

$T = t + 1$

$t = 1$

$i = i + 1$

Figure 4: Flow chart of the GTO algorithm.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Proposed GTO-tuned FOTID controller with UC and PEV</th>
<th>GTO-tuned TID controller with UC and PEV</th>
<th>GTO-tuned TID controller with UC</th>
<th>GTO-tuned TID controller</th>
<th>GTO-tuned PID controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller-1</td>
<td>$K_p = 2.0000, K_i = 0.2160, K_d = 2.0000$</td>
<td>$K_p = 2.0000, K_i = 0.0288, K_d = 2.0000$</td>
<td>$K_p = 1.9968, K_i = 1.6153, K_d = 1.9966$</td>
<td>$K_p = 1.9869, K_i = 0.0288, K_d = 1.9865$</td>
<td>$K_p = 1.9869, K_i = 1.8965, K_d = 1.8965$</td>
</tr>
<tr>
<td>Controller-2</td>
<td>$K_p = 1.9979, K_i = 2.0000, K_d = 1.9948$</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 2.0000$</td>
<td>$K_p = 2.0000, K_i = 1.9974, K_d = 1.6856$</td>
<td>$K_p = 1.9865, K_i = 1.9898, K_d = 1.9896$</td>
<td>$K_p = 1.9865, K_i = 1.9789, K_d = 1.8965$</td>
</tr>
<tr>
<td>Controller-3</td>
<td>$K_p = 1.9995, K_i = 0.0937, K_d = 1.0915$</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 2.0000$</td>
<td>$K_p = 2.0000, K_i = 1.9865, K_d = 0.1712$</td>
<td>$K_p = 1.9865, K_i = 1.9896, K_d = 1.9859$</td>
<td>$K_p = 1.9856, K_i = 1.9785, K_d = 1.9856$</td>
</tr>
<tr>
<td>Controller-4</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 2.0000$</td>
<td>$K_p = 1.9997, K_i = 2.0000, K_d = 2.0000$</td>
<td>$K_p = 1.9882, K_i = 1.9865, K_d = 1.4482$</td>
<td>$K_p = 1.9997, K_i = 1.9986, K_d = 1.9985$</td>
<td>$K_p = 1.9989, K_i = 1.9858, K_d = 1.9865$</td>
</tr>
<tr>
<td>Controller-5</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 1.9898$</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 2.0000$</td>
<td>$K_p = 1.6411, K_i = 1.8075, K_d = 1.9865$</td>
<td>$K_p = 1.9989, K_i = 1.9974, K_d = 1.9989$</td>
<td>$K_p = 1.9998, K_i = 1.7965, K_d = 1.9202$</td>
</tr>
<tr>
<td>Controller-6</td>
<td>$K_p = 2.0000, K_i = 1.8420, K_d = 2.0000$</td>
<td>$K_p = 2.0000, K_i = 2.0000, K_d = 1.9558$</td>
<td>$K_p = 2.0000, K_i = 0.9984, K_d = 1.9558$</td>
<td>$K_p = 1.9865, K_i = 1.9986, K_d = 1.9558$</td>
<td>$K_p = 1.9879, K_i = 1.9965, K_d = 1.5714$</td>
</tr>
<tr>
<td>Constant Parameters</td>
<td>$n = 25.0187, \lambda = 0.2354, \mu = 0.1552$</td>
<td>$n = 39.895$</td>
<td>$n = 14.4180$</td>
<td>$n = 39.965$</td>
<td>$-$</td>
</tr>
<tr>
<td>ITAE</td>
<td>163.7</td>
<td>169.6</td>
<td>198</td>
<td>244</td>
<td>327.7</td>
</tr>
</tbody>
</table>

Table 2: Optimized controller parameters.
(F) Fuel cell (FC) system: the FC is an integral part owing to its increased production and lower pollution, which are expressed as [22]

\[ G_{\text{FC}}(s) = \frac{K_{\text{FC}}}{1 + sT_{\text{FC}}} \]  

(9)

(G) Diesel engine generator (DEG) system: the DEG can deliver dependable power whenever and wherever it is needed, which can be expressed as [26]

\[ G_{\text{DEG}}(s) = \frac{K_{\text{DEG}}}{1 + sT_{\text{DEG}}} \]  

(10)

(H) Hydroaqua electrolyzer (HAE) system: in a typical operation, the HAE is utilised to produce hydrogen (H\(_2\)) by electrolyzing water with electricity and then storing the hydrogen in a tank after compression which can be expressed as [30]

\[ G_{\text{HAE}}(s) = \frac{K_{\text{HAE}}}{1 + sT_{\text{HAE}}} \]  

(11)

(I) Power system and load modelling: by 1st-order TF, we can model the load expressed as power system (Eq. (2)) and again given by

\[ G_{\text{PS}}(s) = \frac{K_{\text{PS}}}{1 + sT_{\text{PS}}} \]  

(12)

(J) Plug-in electric vehicle (PEV): a PEV is a vehicle that has an externally rechargeable battery with a maximum capacity of about 4 kilowatts per hour, as shown in [26]

\[ G_{\text{PEV}}(s) = \frac{K_{\text{PEV}}}{1 + sT_{\text{PEV}}} \Delta F_i(s) \]  

(13)

(K) Ultracapacitor (UC): a UC has a high value of capacitance when contrasted with an ordinary electrolytic capacitor. The enormous number of attributes of UC like modest in size, ability to store huge proportions of energy, etc. makes it sensible for an updated AGC in an interconnected power system. Mathematically, the UC can be shown as

\[ \text{Figure 5: Convergence profile for GTO algorithm.} \]
\[ \Delta P_{\text{UCI}}(s) = \frac{K_{\text{UCI}}}{1 + s T_{\text{UCI}}} \Delta F_1(s). \]  
\[ \Delta P_C(s) = \frac{K_p}{s^{\lambda}} \text{ACE}(s) + \frac{K_I}{s^\mu} \text{ACE}(s) + s^\mu K_D \text{ACE}(s). \]  

4. Fractional Order Tilt Integral Derivative Controller

As shown in Figure 3, a FOTID controller structure is like a FOPID controller with a fractional order integrator and differentiator. ACE is input to the controller and output is \( \Delta P_C(s) \). This can be written via the following equations [35]:

\[ T_{\text{FOTID}}(s) = \frac{K_p}{s^{\lambda\mu}} + \frac{K_I}{s^\lambda} + s^\mu K_D. \]  

4.1. Optimization Problem. The goal of the current investigation is to minimize frequency deviation by considering an ITAE objective function, which is represented as [36]

\[ J = \text{ITAE} = \int_0^{t_{\text{sim}}} (|\Delta F_1| + |\Delta \text{Ptie}_{12}|) \cdot t \cdot dt, \]  

where \( \Delta F_1 \) shows the change in frequency and the \( \Delta \text{Ptie}_{12} \) shows the tie-line power deviation. The tie-line power deviation equation between areas 1 and 2 is given by

\[ \Delta \text{Ptie}_{12} = 2\pi T_{12} \left( \int \Delta F_1 dt - \int \Delta F_2 dt \right), \]  

where \( T_{12} \) is synchronizing power coefficient and \( \Delta F_1 \) and \( \Delta F_2 \) are incremental frequency changes of areas 1 and 2, respectively.
Figure 7: Continued.
For the problem, an optimization problem can be formulated as

$$\text{Minimize } J$$

Subject to

$$K_p^{\text{Min}} \leq K_P \leq K_p^{\text{Max}},$$

$$K_i^{\text{Min}} \leq K_I \leq K_i^{\text{Max}},$$

$$K_d^{\text{Min}} \leq K_D \leq K_d^{\text{Max}}.$$  

\(K_P, K_I,\) and \(K_D\) stands for the proportional, integral, and derivative parameters of the controller with their minimum (Min) and maximum (Max) ranges. However, \(n\) is kept between 1 and 50, and \(\lambda\) and \(\mu\) are the range of the controller parameters (Min and Max) between \(-2\) and \(+2\).

5. Artificial Gorilla Troops Optimizer (GTO)

The collective activities of the gorillas inspired the development of an intelligent algorithm namely GTO. It requires a few parameters to be optimized for obtaining the global solution which makes it simple for the implementation in engineering applications. The three important parts in GTO such as initialization, exploration, and exploitation are based on the different strategies of gorillas which include movement to the unknown area, migrating to known locations, moving to the other gorillas, following the decisions of the silverback, and competing for the adult female gorillas. Once the initialization phase is over, the exploration phase depends on the three behaviors including migrating to the unknown area, migrating to the identified locations, and moving to other gorillas. Similarly, the exploitation phase in GTO is designed by employing two behaviors of gorillas [29] as shown in Figure 4. The three phases of GTO are described as follows.

5.1. Initialization Phase. The position of the \(n^{\text{th}}\) gorilla is defined as

$$X_n = \text{rand}(1, D) \times (u_b - l_b) + l_b,$$  

where \(n \in N\) is the number of gorillas present in \(D\) dimensional search space. The position vector of gorillas can be written as \(X = \{X_1, X_1, \ldots, X_n, \ldots, X_n\}\).

5.2. Exploration Phase. At each stage, all \(N\) gorillas are considered as candidate solutions and the best solution is supposed to be the silverback. Migration to unknown locations enhances the exploration in GTO, whereas the balance between exploitation and exploration is obtained by following the strategy such as moving to the other gorillas. Migrating to the identified position implies a diverse optimization search space. Based on those three strategies, the exploration phase is mathematically formulated as

\[ G_n(it + 1) = \begin{cases} 
(u_b - l_b) \times r_2 \times l_b, & r_1 < a, \\
(r_3 - C) \times X_A(it) + P \times Q \times X_n(it), & r_1 \geq 0.5, \\
X_A(it) - P \times (P \times X_n(it) - X_B(it)) + r_4 \times X_n(it) - X_B(it), & r_1 < 0.5,
\end{cases} \]  

\(r_1, r_2, r_3, r_4\) are the random numbers generated between 0 and 1.
Figure 8: Continued.
where it represents the current iteration; $X_n(it)$ is the current position vector of the $n^{th}$ gorilla; $G_n(it + 1)$ is the candidate gorilla position in next iteration; $r_1, r_2, r_3,$ and $r_4$ are the random values ranging from 0 to 1; and $X_A(it)$ and $X_B(it)$ represent the randomly selected position vector at $it^{th}$ iteration. The parameter $a$ is also a random number between 0 and 1. The variables $C, P,$ and $Q$ can be mathematically computed as

\[
C = (\cos (2 \times r_5)) \times \left(1 - \frac{it}{it_{\max}}\right),
\]

\[
P = C \times y, \quad y \in [-1, 1],
\]

\[
Q = Y \times X_n(it), \quad y \in [-C, C],
\]

where $\cos(\cdot)$ denotes the cosine function, $r_5$ is the random number ranging from 0 to 1, and $it_{\max}$ represents the maximum iteration taken in the optimization algorithm. Similarly, the candidate solution $G_n(it + 1)$ is evaluated for all $N$. After the completion of an exploration phase, fitness functions obtained from $G_n(it + 1)$ and $G_n(it)$ are evaluated. If $F(G_n(it + 1)) < F(X_n(it))$, then the fitness function obtained from $G_n(it + 1)$ is better than the fitness function obtained from $G_n(it)$. Hence, $G_n(it + 1)$ replaces the original vector $G_n(it)$. The optimal solution obtained from the above computation is referred to as the silverback, i.e., $X_{silverback}$.

5.3. Exploitation Phase. This phase is based on two strategies; those are following the silverback and competition for adult females. Let $z$ be the constant parameter which decides to switch between these two strategies. The silverback gorilla’s decision is followed if $C \geq z$. The mathematical expression representing the above behavior can be shown as

\[
G_n(it + 1) = P \times M \times (G_n(it) - X_{silverback}) + G_n(it), \quad (23)
\]

where $X_{silverback}$ is the best solution obtained so far. The parameter $M$ is calculated as

\[
M = \left(\frac{\sum_{n=1}^{N}X_n(it)}{N}\right)^{2/L} \quad (24)
\]

The second strategy is chosen if $C < Z$ which is represented as

\[
G_n(it + 1) = X_{silverback} - (X_{silverback} \times I - X_n(it) \times I) \times J, \quad (25)
\]

\[
l = 2 \times r_6 - 1, \quad (26a)
\]

\[
j = \varphi \times W, \quad (26b)
\]

\[
W = \begin{cases} 
N_1, & r_7 \geq 0.5, \\
N_2, & r_7 < 0.5.
\end{cases} \quad (26c)
\]

The behavior of young gorillas competing violently over selecting the adult female gorillas is represented in equations (26a), (26b), and (26c). $I$ signify the impact force, where $r_6$ is a random value, $j$ represents the violence intensity, and $\varphi$ is a constant. $r_7$ is a random value between 0 and 1.

After the completion of the exploitation phase, the fitness functions are evaluated. If $F(G_n(it + 1)) < F(G_n(it + 1))$, $G_n(it + 1)$ replaces the original vector $X_n(it)$. The best solution is referred to as the $X_{silverback}$. 

![Figure 8: (a–c) System response for condition 2.](image-url)
Figure 9: Continued.
6. Result and Discussion

6.1. Implementation of GTO Algorithm. By running the simulation and using Eq. (18) to get the TID, PIDF, and PID regulator limitations, it is possible to design the hybrid power system’s objective function and the regulatory parameters are shown in Table 2.

A conclusion can be drawn from Table 2 that in comparison to GTO-based TID with UC and PEV, GTO-based TID with UC, and a standard GTO-based PID, the rate improvement in $J$ with the GTO-based FOTID with the effect of UC and PEV controller is 3.47%, 17.32%, 32.91%, and 50.07%, respectively. This data supports the usage of the suggested methodology.

The convergence characteristic for the GTO algorithm along with some other existing algorithms like grey wolf optimizer (GWO) and whale optimization algorithm (WOA) for the Schwefel multimodal standard benchmark function is shown in Figure 5. The suggested GTO algorithm performs significantly better than previous algorithms, which supports the use of GTO approach. The following disturbances are now considered in a three-area power system:

6.2. Condition 1: Wind and Solar Disturbances in Areas 1 and 2, Respectively. Both regions of the system exposed to self-assuredly varying loading designs as stated in Figures 6(a) and 6(b) were done to demonstrate the effectiveness of the suggested regulator against variety in electrical power interest. These signals were generated randomly by considering a particular disturbance. By considering the nominal parameters shown in Table 1, this simulation is performed. When analyzing the preceding aggravation, the three-area power system’s response is depicted in Figures 7(a)–7(c). The proposed GTO-based FOTID regulator for the UC- and PEV-based hybrid power system exhibits stable operation under dynamically varying wind and sun patterns, as shown in Figure 7.

6.3. Condition 2: Area 1 Is Disturbed by Wind Disturbance. At a later stage, a wind-unsettling influence in region 1 is applied to test the proposed UC- and PEV-based hybrid three-area hybrid power system Figure 6(a). The frequency response of regions 1 and 2 ($\Delta F_1$ and $\Delta F_2$) and the change of tie-line power ($P_{tie_{ij}}$) after experiencing annoyance with various proposed controllers are shown in Figures 8(a)–8(c). It is frequently noticed that the proposed GTO-based FOTID regulator for the said UC- and PEV-based hybrid power system stands in calculable in contrast to the other approaches.

6.4. Condition 3: Area 2 Is Disturbed by Solar Disturbance. The penetration of solar energy in zone 2 varies at that precise moment, as depicted in Figure 6(b). Figures 9(a)–9(c) show the response in areas 2 and 3 and the tie-line power change for the three-area system ($\Delta P_{tie_{23}}$) in response to the same incident. It can be said that using the GTO-based FOTID controller with UC and PEV will significantly reduce the oscillation of the system after a perturbation.
Figure 10: Continued.
6.5. **Condition 4: Sensitivity Analysis.** Eventually, a sensitivity study is finished to show the unrivalled excellence of the suggested technique. By altering the system limits as shown in Table 3, the abovementioned examination is carried out [37]. Figures 10(a)–10(c) illustrate how the sources of RESs were changed effectively during the action. The remark made it clear that real frequency discrepancies could undoubtedly be noted. It indicates robustness and superior behavior of the suggested method.

7. **Conclusions and Future Work**

This finding indicates the application of an ultracapacitor and plug-in electric vehicle and a FOTID controller for frequency regulation in a hybrid three-area hybrid power system that uses the GTO algorithm. The correlation chart typically demonstrates that the performance index value of the system with GTO algorithm rapidly declines in comparison to the existing algorithms. This justifies the use of the suggested technique. Further, FOTID controller boundaries are then designed for a UC- and PEV-based power system for frequency regulation using the GTO technique. The simulation output shows that the application of a GTO-based FOTID regulator for a UC- and PEV-based hybrid power system is more successful in controlling the system frequency compared to PID and TID regulators. Future work on the distributed system may focus on testing the use of several other sources with numerous other controllers and new algorithms.

**Data Availability**

No underlying data was collected or produced in this study.

**Conflicts of Interest**

The authors of this paper have no known conflict or any other financial interest that could affect the outcome of this paper.

**Authors’ Contributions**

The authors confirm the final authorship for this manuscript. All the authors have equally contributed to this manuscript.

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