

Effect of Solar Thermal and Electric Vehicle on a Three Area Thermal System with MOA Optimized TID Controller

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Abstract- This article delves into the implementation of a cutting-edge tilt integral derivative controller (TID) within a solar thermal power system (STPS) and electric vehicle (EV) integrated three area power system (PS). Through the application of innovative mayfly optimization algorithm (MOA) techniques, the controller and various system parameters have undergone optimization for optimal performance of the suggested system. The distinct advantage of the suggested TID controller is evidenced by its outperformance in terms of settling time (ST), overshoots (POs), and peak undershoots (PUs), when compared to PID and PI controllers. Further, an analysis of the advantages resulting from the incorporation of EVs and STPS into system dynamics has been carried out, yielding some significant improvement found in POs, PUs, and ST. Furthermore, the robustness of the proposed controller has been established by using sensitivity analysis.

Keywords AGC, TID controller, EV, mayfly optimization, STPS.

Nomenclature:

AGC	Automatic Generation Control	POs	Peak Overshoots
ESS	Energy Storage System	PUs	Peak Undershoots
EV	Electric Vehicle	PID	Proportional Integral Derivative
ΔF	Change in frequency	PI	Proportional Integral
ISE	Integral Squared Error	STP	Solar Thermal Power System
MOA	Mayfly Optimization Algorithm	ST	Settling Time
N	Filter coefficient	ΔP_{tie}	Change in tie poer
PS	Power System	TID	Tilt Integral Derivative
TS	Thermal System		

1. Introduction

The modern electricity system has a great deal of intrinsic complexity due to its constant expansion. Consequently, it becomes challenging to keep the frequency of the system within permitted bounds and to determine the proper power balance between generation and demand. By implementing Automatic Generation Control (AGC), these

problems can be resolved. AGC's primary objectives are to provide a dependable control mechanism, ensure a consistent frequency profile throughout all control zones, and support the preservation of the power balance among demand and supply [1]. Further, the energy system depends on AGC to keep the grid stable by modifying the generators' output in response to variations in demand and grid circumstances. While integrating various energy sources into the grid, AGC continuously monitors and controls generation in real-time to assist maintain a dependable and efficient supply of electricity to customers [2-5].

In the past, single-area thermal systems (TS) have been the main focus of AGC research. Nonetheless, there has been a discernible movement in favour of multi-area multi-source systems in recent years. Previous research took into account a variety of non-linearities, including the Governor Dead Band (GDB) and the Generation limit. This is a changing body of knowledge with a wider and more intricate variety of factors to be taken into account when analysing and implementing AGC. The integration of renewable energy sources (RES), such as wind turbine systems and solar thermal power plant (STPS), has been the subject of a small number of studies on AGC [6-7]. In particular, researchers in [8-13] have examined an AGC study that included solar thermal power system (STPS), under the assumption of a constant solar irradiation. It is noted that the output of STPS is sporadic due to the intermittent nature of solar radiation.

The rapid progression of electric vehicle (EV) technology, coupled with distributed energy storage, is expected to significantly enhance emergency reliability services [14-16]. Also, the wide range of EV applications, such as wireless charging systems, high-power applications such as EV charging, energy efficiency, cost savings, etc., has led to adoption in the power system [17-19]. Simultaneously, EVs' increasing appeal is due to their positive environmental effects, which include lowering carbon dioxide emissions and dependency on fossil fuels [20-22]. In low inertia power systems, researchers have investigated EV technology in [23-25], considering Grid-to-Vehicle as well as Vehicle-to-Grid operation. According to this literature, incorporating EVs into multi-area power systems merits in-depth analysis and additional research.

The development of secondary controllers has been the main focus of research on AGC. Historically, a variety of tilt (T) type of controllers have been developed, such as Tilt-Integral-Derivative (TID) [26-27], and I-TD, in addition to simple fractional order [28]. Despite these developments, there is still a significant need for a comparison analysis to assess these controllers' performance in the context of multi-area AGC system integrated with EV and ESS. This insight emphasizes the necessity of additional research to fully comprehend and maximize the effectiveness of the controllers in such intricate systems. There has been a discernible trend in recent AGC research toward the use of different meta heuristic methods to optimize controller parameters. Magnetotactic bacteria [29], butterfly [30], biogeography [31], bird swarm [32], emperor penguin [33],

tunicate swarm [34], black widow [35], crow search [36], artificial rabbit [37], mountain gazelle [38], and hybrid crow search algorithm [39] are a few of these techniques. The Mayfly Optimization Algorithm (MOA) is inspired by the flight patterns and mating behaviors of mayflies is a recent addition to this collection of optimization algorithms. MOA blends evolutionary algorithms and swarm intelligence features [40]. Although MOA has been effectively used in other study fields, the setting of AGC has not yet been used to assess its effectiveness. This emphasizes the necessity of doing a thorough analysis to determine whether MOA is effective in improving controller parameters for AGC. Sensitivity analysis is a widely used technique in the AGC field to assess how resilient controllers are to significant changes in system loading and parameters [22, 41-42]. A new controller called TID has been presented in this work, although its sensitivity analysis has not yet been investigated. This analysis would add significantly to our understanding of the controller's efficacy in AGC applications at variety of loading situation.

Based on the aforementioned considerations, the following objectives are delineated.

- To build a simulation model of a three-area PS consisting of TS, STPS, and EV.
- Implementation of a TID controller as secondary controllers for three area PS and compare the system performance with PID and PI controllers.
- Utilization of a MOA for the optimal performance of multi-area PS.
- Assess the system's performance with the inclusion of STPS.
- Assess the system's performance with the inclusion of EV.
- Assess the resilience of the proposed TID controller under various system load conditions.

2. System Investigated

Fig. 1 shows the simulation model of a three-unequal-area TS comprises of EVs and STPS. The TS is subject to a 3%/min GRC. The appendix contains an outline of the considered parameters for different sub-system [10, 32]. A number of controllers are independently regarded as secondary controllers, including TID, PID, and PI controllers. The system's dynamic responses are thoroughly examined. The MOA, a recently introduced metaheuristic approach, is proposed for optimizing controller and other pertinent parameters. The Integral Squared Error (ISE), as defined in Eq. (1), serves as the performance metric for this optimization endeavor. In evaluating the dynamic responses pertaining to frequency and tie power deviation, we introduce a 0.01 p.u. load disturbance in area-1 as part of our analysis.

$$\eta_{ISE} = \int_0^t \{(\Delta F_m)^2 + (\Delta P_{m-n})^2\}.dt \quad (1)$$

3. Proposed TID Controller

Recently, a unique fractional-order controller known as the Tilt Controller has been presented in [32]. The benefits of non-integer and integer controllers are combined in this controller. With the important exception that the proportional term of PID is multiplied by $1/s_{ni}$, The structure of both the PID controller and the TID controller closely resemble each other. On the other hand, the forward path's introduction of derivative control brings about a phenomenon called derivative kick, which may not be desirable in electronic

circuits. T and D terms are integrated into the forward path, while integral terms are introduced into the feedback loop. [30]. Figures 2 the controller structures used in this investigations, and equations (2) provide the I-TD transfer functions equation.

$$F(s) = \frac{K_T}{1/s^n} + \frac{K_I}{s} + K_D s \quad (2)$$

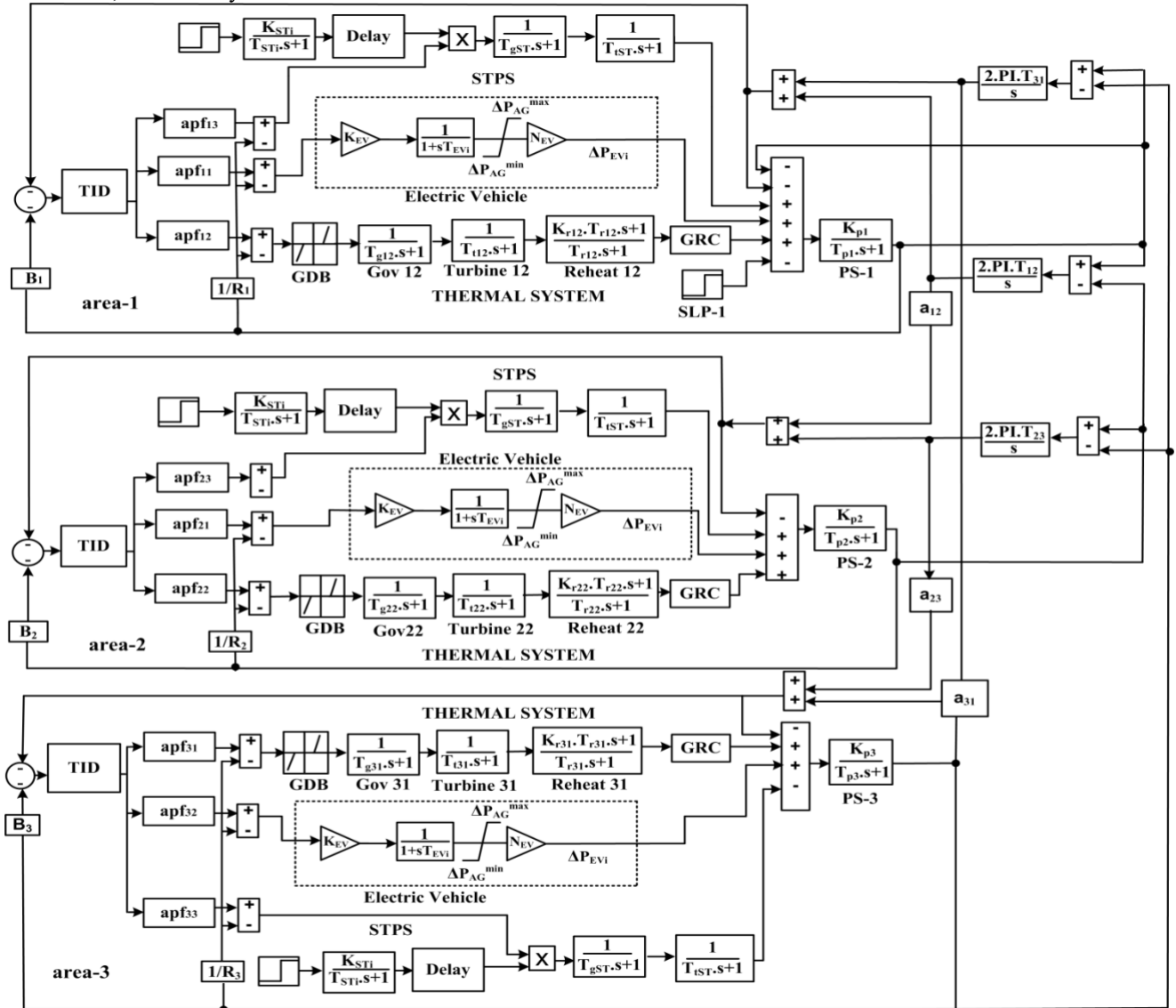


Fig. 1. TF representation of the proposed system model.

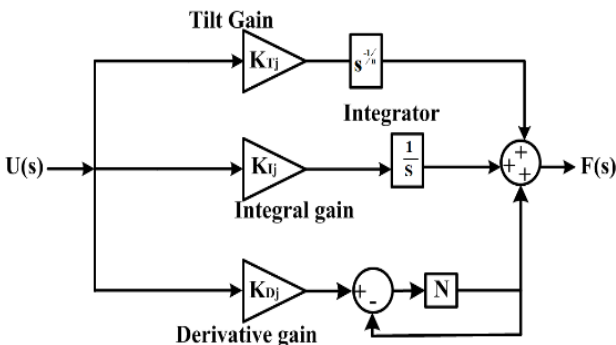


Fig. 2. TID controller.

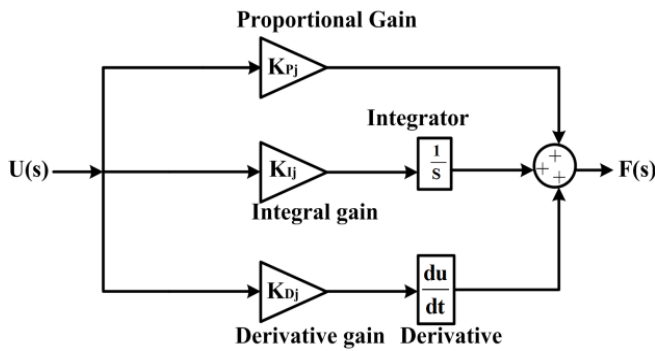


Fig. 3. PID controller.

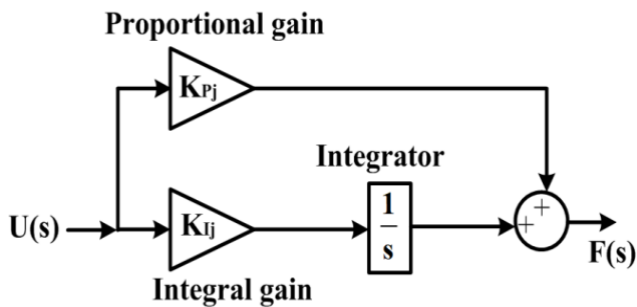


Fig. 4. PI controller.

4. Mayfly Optimization Algorithm

The Mayfly Optimization Algorithm (MOA), a metaheuristic optimization method influenced by mayfly mating behavior, was first presented by Konstantinos et al. [40]. This algorithm uses mayflies, which are renowned for having a one-day lifespan, as its model to solve complicated optimization problems in an efficient manner by imitating their behavior. A population of viable solutions, or a set of candidate solutions, is produced during the execution of MOA. Every contender represents a different potential fix for the current issue. The system mimics the iterative enhancements and modifications seen in mayfly mating behavior. The program updates the population's gender distribution at each iterations. Males are distributed randomly within the search space, while females are attracted to the pheromones they emit. A fitness function that takes into account how much solutions have been improved is used to evaluate the females' level of fitness. The algorithm then proceeds with mating and crossover methods to produce offspring solutions once the females have chosen their spouses. These progeny experience mutation in order to carry over traits from both parents and offer more exploration to the search space. After evaluating the recently created offspring solutions, a selection process determines which individuals will advance to the next iteration, prioritizing those with superior fitness values. For a predetermined number of iterations, the algorithm keeps repeating these stages until a termination requirement is satisfied. A maximum iteration of 100, a population size (males and females) of 30, an inertia weight of 0.8, a personal learning coefficient of 1, a distance sight coefficient of 2, a random flight coefficient of 1, a damping ratio of 0.81, a offspring

size 30, and rate of mutation of 0.01, are the tuned parameters of MOA for this particular work. In Figure 5, the MOA flow chart is displayed.

5. Results of Simulation and Discussion

5.1 Thermal System Dynamics with Various Controllers

Three area thermal system in Fig 1. is provided with various supplementary controllers, namely TID, PID, and PI, are evaluated independently. By employing the MOA, we iteratively fine-tune the controller parameters. Subsequently, we compare the system responses corresponding to considered controller and present them visually in Fig 6. Table 1 extracts key indices parameters such as POs, ST, and PUs from the Fig.6.

The values of indices provided in Table 1 and the dynamic profile shown in Figure 6 are critically evaluated. According to the investigation, systems with PID and PI controllers typically exhibit lower dynamics than the suggested system using TID, especially when it comes to ST, PUs, and POs. Thus, for the next section of the case study, the TID controller will be used.

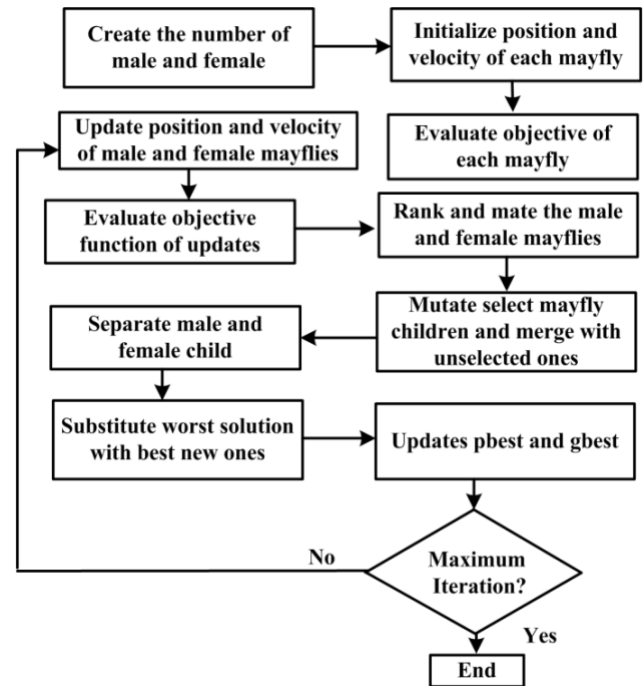


Fig. 5. Flowchart illustrating the operation of MOA.

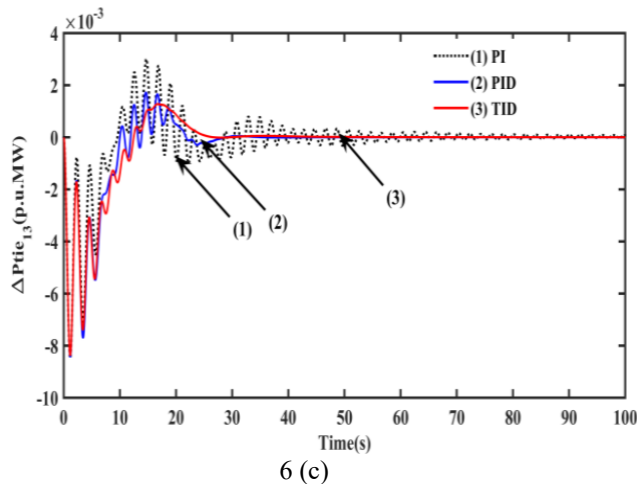
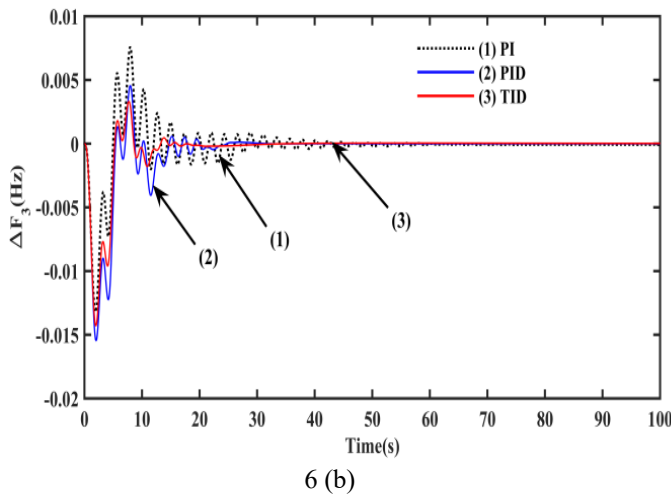
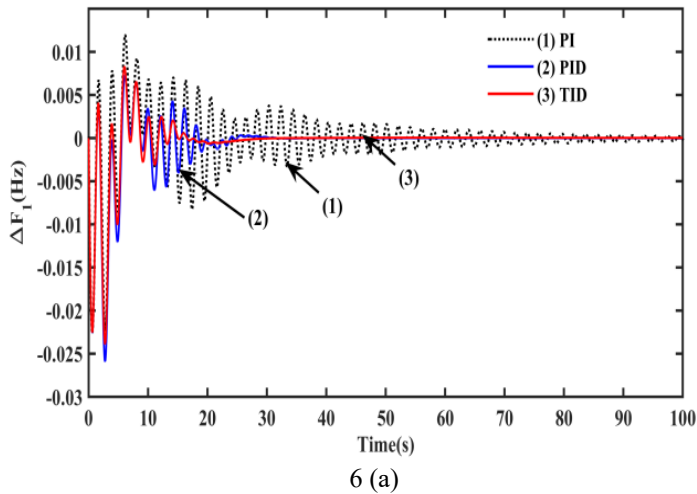


Fig. 6. Comparison of thermal system dynamics among PID, PI and TID, Controllers (a) ΔF_1 , (b) ΔF_3 , (c) ΔP_{tie13} .

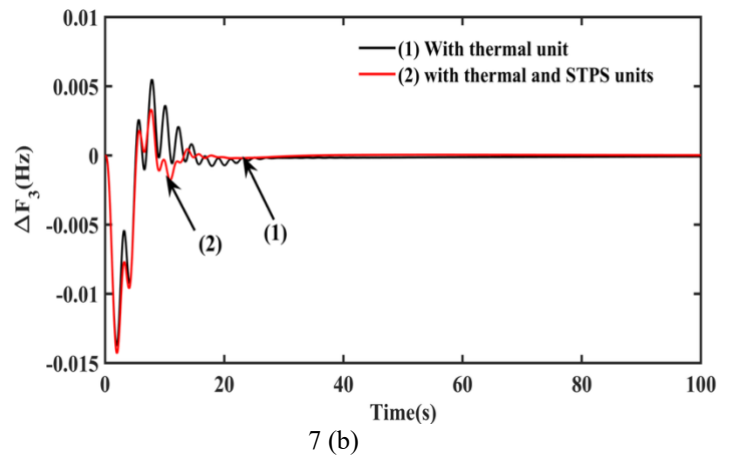
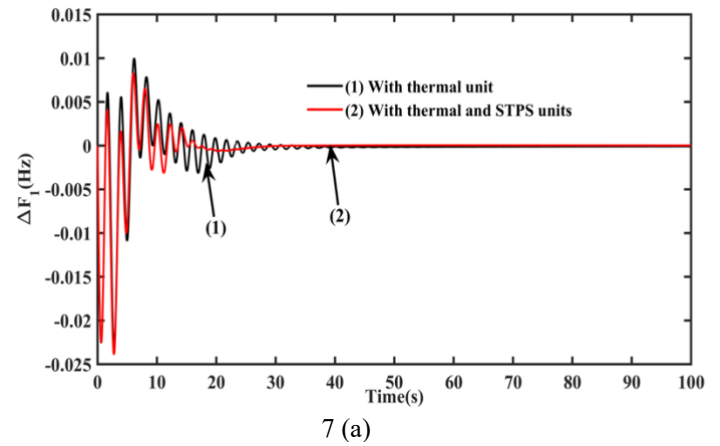
Table 1. Comparison of Indices parameters values for thermal system responses Illustrated in Fig.6

	Indices	TID	PID	PI
ΔF_1	POs	0.0033	0.0042	0.0050
	ST	28.440	34.000	45.120

ΔF_3	PU _s	0.0130	0.0156	0.0280
	PO _s	0.0013	0.0032	0.0040
	ST	35.048	38.340	48.510
	PU _s	0.0050	0.0058	0.0144
ΔP_{tie13}	PO _s	0.0001	0.0010	0.0017
	ST	41.057	43.430	53.240
	PU _s	0.0033	0.0036	0.0077

5.2 Effect of STPS Integration on Thermal System Performance

Here, the STPS unit is integrated in all the three areas. The dynamic profiles are analyzed with the TID controller, and its optimal parameters are determined through MOA. The comparison of the system dynamics with and without STPS units depicted in Fig.7. The obtained dynamic responses indicate a noticeable enhancement in system dynamics with STPS unit.



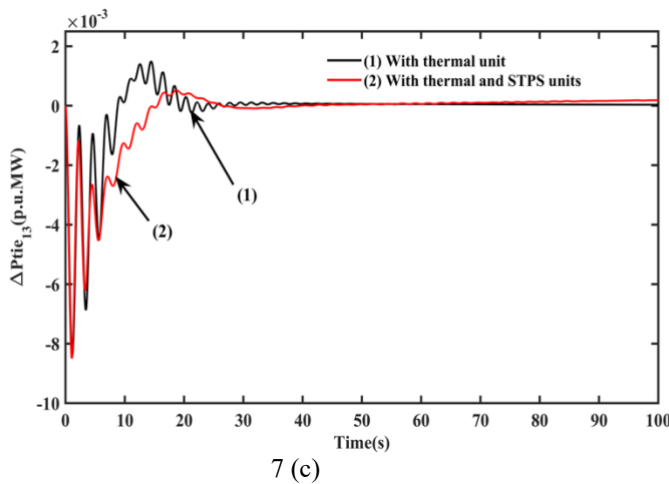


Fig. 7. Comparison of thermal system response with and without STPS unit (a) ΔF_1 , (b) ΔF_3 , (c) ΔP_{tie12} .

5.3 Effect of EV Integration on Thermal-STPS Performance

In scenario 5.2, the system under consideration incorporates EV across all areas. The proposed TID controller parameters are optimized using MOA. The dynamic profile corresponding to with and without EV are compared and illustrated in Fig.8. From the obtained dynamic response, it is evident that when system is integrated with EV unit, the systems dynamic improves in terms of number of oscillation and take very less time to mitigate the steady state error. Also, the POs and POs comparatively low when without EV.

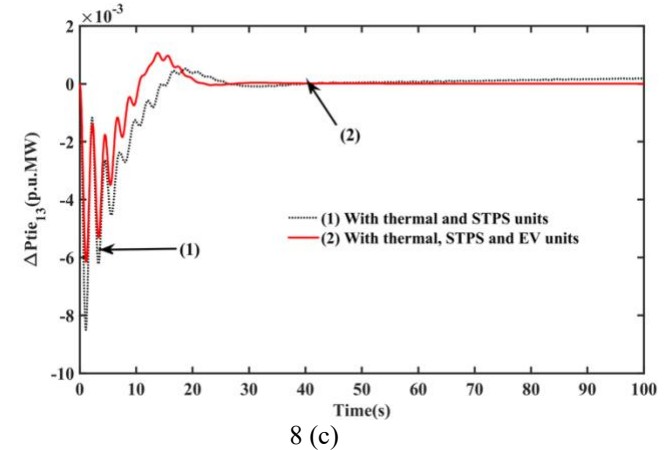
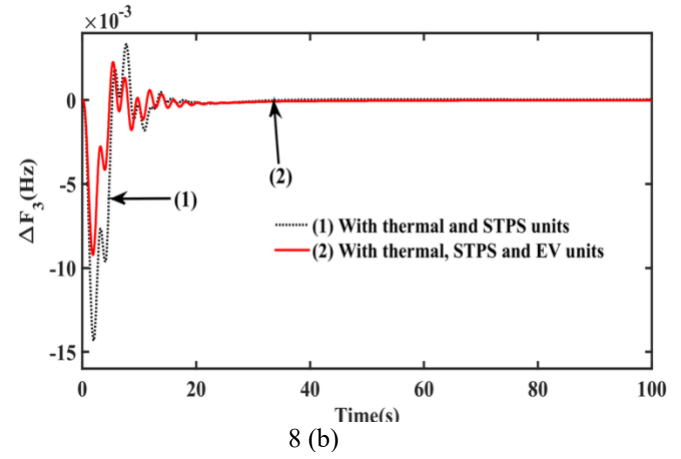
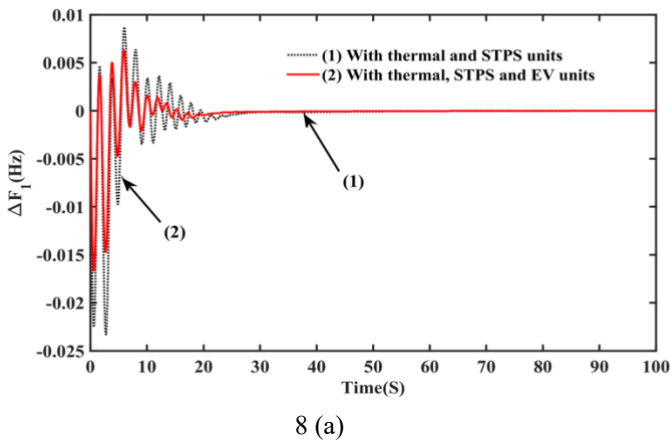
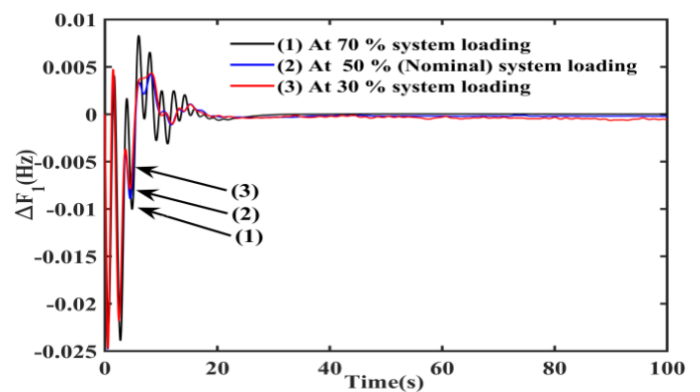


Fig. 8. Comparison of system dynamic responses as depicted in Fig.8 (a) ΔF_1 , (b) ΔF_1 (c) ΔP_{tie12} .



5.4 Assessments of the Resilience of the Proposed Controller

Using a system loading variation from the nominal 50% to $\pm 20\%$, we evaluate the resilience of the optimal TID controller found in case-5.1. Using the MOA approach, the controller parameters are changed through each scenario. Figure 9 compares and illustrates the system dynamics for loadings of 30%, 50%, and 70%. The TID controller's performance stays stable when the system loading varies between $\pm 20\%$ and the nominal value, according to an analysis of the dynamic responses. Thus, it can be observed that the TID controller consistently performs well across a diverse range of system loading conditions.



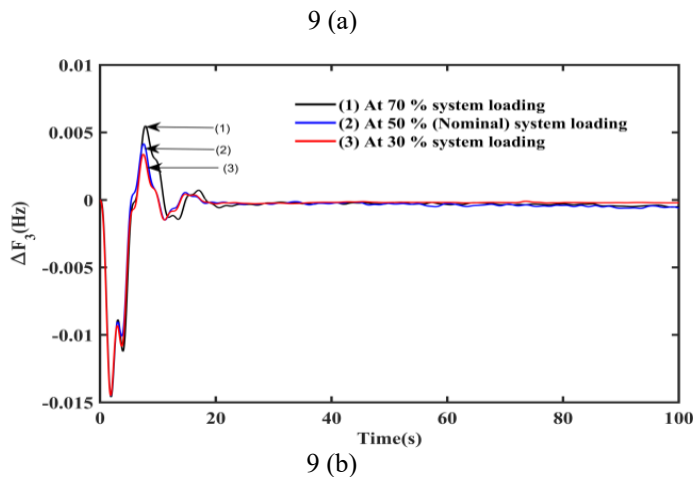


Fig. 9. System performance at different loading scenario.

6. Conclusions

Various types of controllers, including TID, PID, and PI, were successfully utilized as secondary controllers in the study of the three-area AGC system. The tilt controllers' settings were optimized through the application of the MOA techniques. An examination of the system's dynamic responses comparing TID, PID, and PI showed that the TID controller performed better in terms of Pos, ST and PUs. Further, sensitivity analysis showed that the TID controller could work consistently across a broad range of system loading situations without modifications to the default system parameter settings.

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Author Contributions

All authors were responsible for the conceptualization, validation, resources, data curation, software development, and project administration. They jointly contributed to the methodology, formal analysis, investigation, original draft preparation, review and editing, visualization, supervision, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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