A modified differential evolution algorithm for frequency management of interconnected hybrid renewable system

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ABSTRACT

In recent decades, the insufficiency in power production has led to the incorporation of renewable energy sources into microgrid systems. However, ambiguity in the generation of renewable sources and load variation impacts on the system frequency influencing the stable operation of microgrid system. To augment the stable operation of the system an intelligent controller is required for continuous electric power. The implementation of a modified differential evolution (MDE)-based cascaded proportional integral derivative fractional filter (PIDFN) controller using integral of time-weighted absolute error (ITAE) is proposed in this work. In order to demonstrate the robustness and efficacy of the proposed MDE optimization technique is compared with differential evolution (DE), teaching learning-based optimization (TLBO), invasive weed optimization (IWO) and particle swarm optimization (PSO). MDE-based cascaded PIDFN controller is implemented for governing the frequency in two-area interconnected microgrid system. The system is substantiated over load perturbations, system uncertainties, communication delay and real time data of solar irradiance and wind speed and action of unified power flow controller (UPFC) in MATLAB®/Simulink environment.

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1. INTRODUCTION

Under the notion of sustainable development, the production of renewable energy sources (RESs) like wind, hydro, and solar has expanded significantly in recent years replacing the traditional thermal power. The day by day increase in load demand is managed by the power generation from the renewable sources. The ability of the central grid is strengthened by lowering the peak loads due to evolution of the idea of decentralization in power generation. In light of this, renewable energy sources are utilized and the concept of microgrid is implemented. Micrograds are an amalgamation of renewable source, storage units and loads. The intermittent nature of low inertia renewable sources creates a disparity between generation and demand which impelled the formation of interconnected microgrid system. Interconnection of microgrid enables the sharing of surplus power but makes the system more difficult to govern. The frequency change and power flow in the interconnected tie line gradually deviates from their nominal value when the load changes dynamically in the interconnected microgrid system. This intensifies severe frequency deviations which further deteriorates the power quality and hence impacts the microgrid efficiency. In order to balance the power transmission across the various power system to maintain a steady grid frequency, load frequency control is used in micro grids with multiple generating units.

Recent advances in contemporary power networks have necessitated the use of decentralized control methods rather than centralized control schemes to ameliorate unreliable and inefficient power system control. The power system frequency was controlled by robust optimal [1], stochastic optimal [2], and secondary loop frequency control methods [3] in literature. In order to get an enhanced LFC response the controller parameters need to be tuned rapidly and precisely. In this context, various meta-heuristic optimization techniques like firefly algorithm [4], ant lion optimizer (ALO) [5], grey wolf optimization [6] and differential evolution [7] have been proposed in literature. An integrated multi-source, multi-area power system's voltage and frequency are controlled by a model predictive controller (MPC), whose parameters are tuned via salp swarm algorithm [8], model predictive controller [9] and using intelligent techniques for energy storage devices [10]. Harris hawk optimization (HHO) based model predictive controller (MPC) has been implemented for regulating the voltage and frequency and validated under different conditions in three area hybrid power system as shown in [11] and [12]. Leader Harris hawk optimization (LHHO) based MPC has been proposed for controlling voltage and frequency of the system. A hybrid interconnected power system comprising of thermal, wind, diesel, photovoltaic (PV) and hydrogen units in [13] has been designed. The algorithm was tested in conjunction with capacitive energy storage units and virtual inertia units. The work in [14] explain an intelligent fuzzy logic controller was implemented for a multi-area interconnected power system further the controller was compared with PI and PID subjected to minimization of integral of time-weighted absolute error (ITAE) function. However, these optimization techniques do not offer exceptional performance in terms of settling time, peak overshoot or undershoot. Differential evolution (DE) search strategy proposed in [15] was capable to address optimization problems effectively. In a specific procedure DE performance is dependent on the selection of values of crossover constant and scaling factor. In this paper modified differential evolution (MDE) technique is suggested which will overcome the drawback of DE.

From literature it has been studied that the performance of load frequency control (LFC) system does not depend on the optimization strategy but also rely on the controller design. Different controller such as adaptive control [16], [17] model predictive control [18] have been proposed to control the frequency in isolated MG system. These conventional controllers fail to work effectively under various operating conditions due to aberrant nature of RESs. In contrast, fractional order controllers which improves the stability of an interconnected MG system have gained a great deal of interest in recent years due to its versatile structure and has a greater number of tuning parameters. In recent years cascaded controller have been employed in interconnected power system as it can withstand diverse disturbances effectively. In this context, a cascaded proportional integral derivative fractional filter (PIDFN) controller is suggested for an interconnected microgrid system for diminishing the frequency disruption in this paper. The, classical controller like P, PI and PID works effectively for hybrid MG system. These controllers are sluggish in event of rapid load disturbance in terms of parameter adjustments. Further sliding mode controllers, fractional order PI and PID controllers have structural issues and incur more cost. These findings encourage the development of a cascaded PIDFN controller [19]. The suggested controller has a better performance for abating the deviations of frequency in the system. Inspired by the research works, this paper suggests a MDE algorithm for tuning the parameter of the cascaded-PIDFN controller. The suggested optimization techniques surmount other optimization algorithms in terms of ITAE and convergence.

The contributions and features of the proposed work are as follows: i) A novel modified differential (MDE) algorithm is used to adjust the parameter of the cascaded PIDFN controller, ii) The supremacy of the MDE has been established by comparing with other optimization techniques such as differential evolution (DE), particle swarm optimization (PSO), teaching learning-based optimization (TLBO) and invasive weed optimization (IWO), iii) The proposed cascaded PIDFN controller performance is studied under various situations such as variable load disturbance, system uncertainties, communication delay and real time data of solar irradiance and measurement of wind speed. The actions of unified power flow controller (UPFC) are also tested on the two-area interconnected microgrid system in MATLAB/Simulink environment, and iv) The efficacy of optimization technique MDE is verified for different performance parameters.

The article is established as follows: the hybrid renewable energy system (HRES) model is described in section 2, and the proposed cascaded PIDFN controller is covered in section 3. The performance of the MDE is discussed in section 4 and simulation results are presented in section 5. Finally, the conclusion is presented in section 6.

2. MODELLING OF THE PROPOSED SYSTEM

A two-area interconnected microgrid system is designed for analysis of frequency deviation of the system. The area 1 of the microgrid comprises of a wind turbine generator (WTG), diesel generator (DEG) and ultracapacitor (ULC) whereas area 2 comprises of a photovoltaic cell (PV), DEG, battery storage as shown in Figure 1. When the MG system is exposed to load perturbations and the intermittent nature of RES generation introduces ambiguity in the system which leads to instability. Hence each area required to monitor and control for proper operation of power system. In this paper a cascaded-PIDFN controller is used, whose parameters are tuned by MDE algorithm to minimize the frequency deviation and oscillations in each area and tie line. Additionally, the performance of MDE-PIDFN controller is compared with DE, PSO, TLBO and IWO. The various components of the proposed MG system are briefly illustrated in the following subsections.

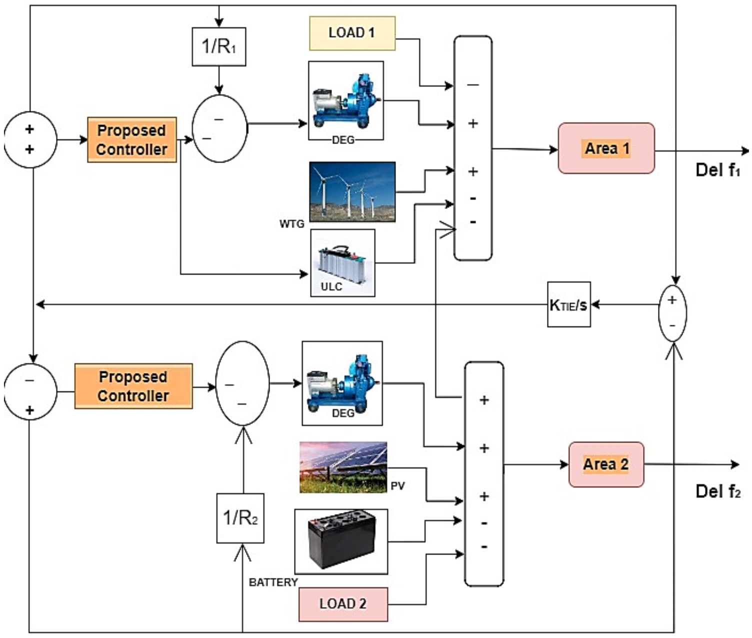


Figure 1. Proposed microgrid system

2.1. Modelling of PV units

The PV system provides fluctuating power due to erratic nature of solar radiation and temperature. The extracted power from the PV cell is determined using:

$$P_{PV} = \eta S\phi(1 - 0.005(T_a + 25)) \quad (1)$$

where η= effectiveness of PV array, S = PV surface area, ϕ = intensity of solar radiation, T_a = surrounding temperature.

2.2. Modelling of wind turbine system

The wind turbine's output power is irregular owing to varying wind speed. The WTG is characterized as a combination of power coefficient ‘C_p’ and other physical factors tip speed ratio ′λ′ and blade pitch angle ‘β’ are the fundamental components of ‘C_p’. The output mechanical power of the WTG is expressed as:

$$P_{WTG} = \frac{1}{2}\rho A C_P V_W \quad (2)$$

where ρ = is the density of air in kg/m^3 and A = is the region swept by the turbine blades in m^3.

2.3. Modelling of diesel engine generator units

Typically, a diesel generator (DG) is installed in places where there is no grid connection, or it is utilized as an alternate emergency power source when there are grid outages. DG are not only deployed for backup or emergency units, but they also have auxiliary purposes to offset the intermittent nature of RESs in remote MG. The diesel engine generator (DEG) is well known in the MG system as an efficient source of power which acts during load augmentation with great durability and efficiency. The, parameter in the figure

Δf, T_{GOV}, T_{GE}, T_{DE} and R corresponds to the frequency deviation, governor's time constant, generator time constant, delay time constant and speed regulation of governor respectively.

2.4. Modelling of battery energy system

The DEG sources inhibits poor response time so they are supplemented by energy storage devices for improved frequency management. The battery energy system (BES) acts like storage units and frequency fluctuations are maintained via power exchange with the MG. The transfer function model of BES system is given by (3).

$$G_{BES}(s) = \frac{K_{BES}}{1+sT_{BES}} \tag{3}$$

2.5. Modelling of ultracapacitor

It is an electrostatically charged component. Unlike batteries, it can withstand thousands of cycles. The charging and discharging times of the storage units are significantly faster. It has low resistance and responds quickly to power fluctuation. The transfer function is described as (4).

$$G_{ULC}(s) = \frac{1}{1+sT_{ULC}} \tag{4}$$

2.6. Modelling of the microgrid system

MGs consists of distributed energy resources, storage devices, and configurable load blocks to allow distant grid operations with sufficient control capabilities. In recent years, substantial study has been undertaken in order to confirm the microgrid's (MG) stability and dependability. Here, in this work, an isolated MG is analyzed to validate the performance of various frequency regulator controllers. Power, is supplied by all sources, and a relationship between frequency change and power consumption is established. The transfer function model is represented as (5).

$$\frac{\Delta f}{\Delta P} = \frac{K_{PS}}{1+sT_{PS}} \tag{5}$$

3. CONTROLLER DESIGN

To reduce the frequency variation in the MG, a cascaded-PIDFN controller is implemented [19]. The performance of the controller is also compared to that of other controllers under various scenarios. The suggested controller is a cascaded design of PIDN and PIDFN based on fractional calculus, with differentiators and integrators. The PIDN controller comprises of P, I, D controller with a derivative filter coefficient N and the PIDFN controllers is of the form of $PI^{\lambda}D^{\mu}$ and a derivative filter coefficient N. λ and μ are the order of integrators and differentiators respectively. With the inclusion of a fractional order PIDN controller, the integer order PIDN controller may be extended from point to plane, making the PIDN control method more adaptable and robust [20], [21].The scaling parameters provided by the advanced control optimization, the gain parameters of a cascaded PIDFN controller becomes more flexible [22], [23] and by implementing a fuzzy PID filter [24].

4. MDE STRATEGIES

A DE algorithm is proposed which was found to be superior in reference to other evolutionary algorithm simplicity, ease of implementation, and fewer variables [25]. The operation of DE algorithm follows four steps: i) initialization, ii) mutation, iii) crossover, and iv) selection. In the first step, it starts with n numbers of population size and number of decision vectors distributed randomly as, $\overrightarrow{X_k^l} = (X_1^l, X_2^l, \ldots, X_D^l)$ over D-dimensional search space. In second step, a mutant vector $(\overrightarrow{M_k^l})$ is generated by applying the mutation operator any of the following:

$$\text{DE/rand/1: } \overrightarrow{M_k^l} = \overrightarrow{X_{k_1}^l} + f\left(\overrightarrow{X_{k_2}^l} - \overrightarrow{X_{k_3}^l}\right) \tag{6}$$

$$\text{DE/best/1: } \overrightarrow{M_k^l} = \overrightarrow{X_{best}^l} + f\left(\overrightarrow{X_{k_1}^l} - \overrightarrow{X_{k_2}^l}\right) \tag{7}$$

$$\text{DE/rand/2: } \overrightarrow{M_k^l} = \overrightarrow{X_{k_5}^l} + f\left(\overrightarrow{X_{k_1}^l} - \overrightarrow{X_{k_2}^l}\right) + f\left(\overrightarrow{X_{k_3}^l} - \overrightarrow{X_{k_4}^l}\right) \tag{8}$$

$$\text{DE/best/2: } \overrightarrow{M_k^l} = \overrightarrow{X_{best}^l} + f\left(\overrightarrow{X_{k_1}^l} - \overrightarrow{X_{k_2}^l}\right) + f\left(\overrightarrow{X_{k_3}^l} - \overrightarrow{X_{k_4}^l}\right) \tag{9}$$

DE/current-to-best/1: $\overrightarrow{M_k^l} = \overrightarrow{X_k^l} + f\left(\overrightarrow{X_{best}^l} - \overrightarrow{X_k^l}\right) + f\left(\overrightarrow{X_{best}^l} - \overrightarrow{X_{k_2}^l}\right)$ (10)

In third step, the decision vector ($\overrightarrow{X_k^l}$) and mutant vector ($\overrightarrow{M_k^l}$) undergo crossover operation to form a trial vector (V_{ij}^l), expressed as (11):

$$V_{kj}^l = \begin{cases} M_{kj}^l & if\ rand(0,1) < Cr \\ X_{kj}^l & otherwise. \end{cases} \quad for\ j = 1,2,\dots,D \tag{11}$$

in last step, the vector for the next generation is selected as per the (12):

$$X_k^{l+1} = \begin{cases} V_k^l & if\ fitness\ of\ V_k^l\ is\ better\ than\ X_k^l \\ X_k^l & otherwise \end{cases} \tag{12}$$

where, $\overrightarrow{X_k^l}$ is the kth decision vector of lth generation; $\overrightarrow{M_k^l}$ is the kth mutant vector of lth generation; $\overrightarrow{X_k^l}$ and $\overrightarrow{X_{best}^l}$ are the lth generation's randomly chosen decision vector and best solution vector, respectively where f is the scale factor and Cr is the crossover rate having value between 0 to 1.

The mutation operator like DE/rand mutation operator has more exploration feature than exploitation which also takes more time to attain optimal solution. Similarly, the DE/best mutation operator has more exploitation feature than exploration and takes less time to obtain optimal solution. This approach, however, suffers from early convergence and being stuck in local optima. A novel mutation operator is presented in the MDE algorithm to prevent the above difficulty and maintain a balance between exploitation and exploration. Here, six best solutions from the current generation are chosen to find three mutant vectors in (13) to (15). The final mutant vector ($\vec{M}_k^l$) is then determined by taking the average of these three mutant vectors. In crossover step, a new trial vector is obtained as (16). Finally, in selection step, the decision vector for next generation is obtained as expressed in (17).

$$\overrightarrow{M_1} = \overrightarrow{X_k^l} + f\left(\overrightarrow{X_{best1}^l} - \overrightarrow{X_k^l}\right) + f\left(\overrightarrow{X_{best2}^l} - \overrightarrow{X_k^l}\right) \tag{13}$$

$$\overrightarrow{M_2} = \overrightarrow{X_k^l} + f\left(\overrightarrow{X_{best3}^l} - \overrightarrow{X_k^l}\right) + f\left(\overrightarrow{X_{best4}^l} - \overrightarrow{X_k^l}\right) \tag{14}$$

$$\overrightarrow{M_3} = \overrightarrow{X_k^l} + f\left(\overrightarrow{X_{best5}^l} - \overrightarrow{X_k^l}\right) + f\left(\overrightarrow{X_{best6}^l} - \overrightarrow{X_k^l}\right) \tag{15}$$

$$\vec{M}_k^l = Mean\left(\vec{M}_1, \vec{M}_2, \vec{M}_3\right) \tag{16}$$

$$f = 2 \times \left(1 - \frac{l}{L_{max}}\right) \tag{17}$$

Where, $\vec{X}_{best1}^l, \vec{X}_{best2}^l, \vec{X}_{best3}^l, \vec{X}_{best4}^l, \vec{X}_{best5}^l$ and $\vec{X}_{best6}^i$ are the six best decision vectors chosen from lth generation. l and L_{max} are the current and maximum generation respectively.

5. RESULTS AND DISCUSSION

The proposed MDE algorithm based cascaded-PIDFN controller is tested for frequency management in a hybrid microgrid system. The robustness of the controller is tested under various condition which includes arbitrary load disturbances, incorporation of FACTs devices in the hybrid system with real-time solar irradiance and wind speed data, the effect of communication latency, and parameter variations in the system.

In each case, the cascaded PIDFN controller parameters are tuned by modified differential evolution (MDE) and the performance is compared with DE, TLBO, PSO and IWO techniques. The comparison is based on ITAE and dynamic values of ΔF_1, ΔF_2 and ΔP_{tie}. The population size, swarm size, and number of search agents in all meta-heuristic algorithms is set at 20 and executed up to 100 iterations. The optimization algorithms being meta-heuristic in nature so the process has been repeated 10 times independently and ITAE is measured.

5.1. Effect of variable load performance

The effect of frequency on the variation of load in any area are considered in this case. In this case a random step load variation in Area 1 as shown in Figure 2 is implemented to test the robustness of the proposed controller. The, above load profile is applied to the system and the parameters for ITAE are calculated using different optimization techniques. The different ITAE values obtained from the optimization techniques are listed in Table 1.

Figures 3(a)-(c) represents the dynamic performance of ΔF_1, ΔF_2 and ΔP_{tie} respectively under random load perturbations. From Figure 3(a) it is observed that the transient response of the variation of frequency (ΔF_1) in area 1 has better response using the MDE-PIDFN controller compare to another controller. Similarly in Figures 3(b) and 3(c) the MDE-PIDFN controller provide better transient response for the variation of frequency (ΔF_2) in area 2 and change in tie line power (ΔP_{tie}) respectively as compared to other controllers which is shown in the zoom portion of the figure. From Table 2 it is observed that the MDE-PIDFN controller has a better fitness as compared to other controllers. The transient specification of the system with respect to peak undershoot (PUS) and settling time (TS) is represented in Table 2. The MDE algorithm offers improved dynamic responsiveness in terms of settling time as compare to other optimization techniques.

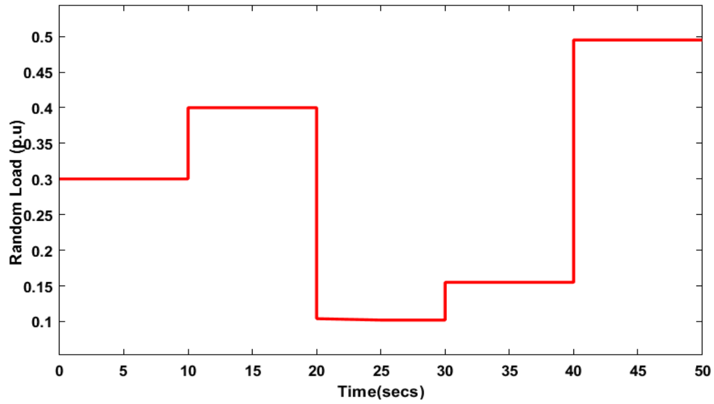
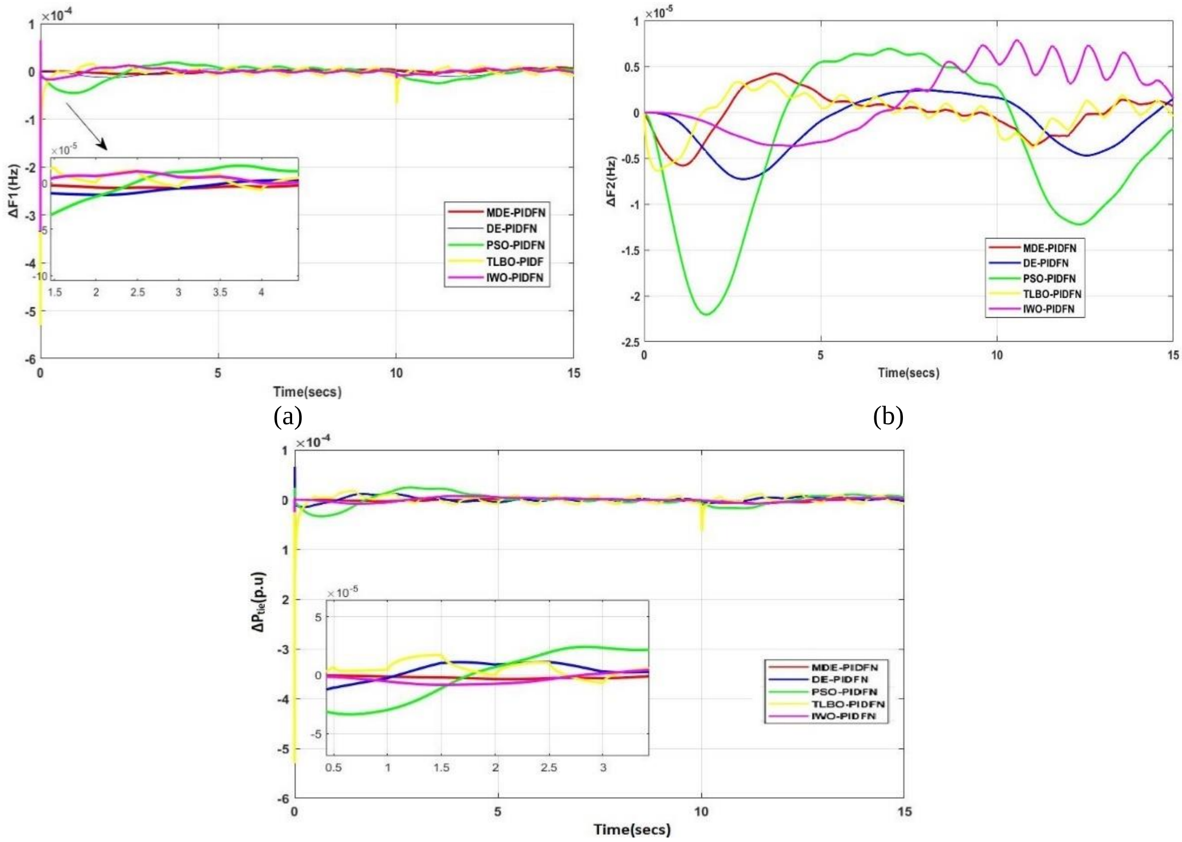


Figure 2. Random load profile



(a) (b)

(c)

Figure 3. Frequency fluctuations a random load perturbation (a) ΔF_1, (b) ΔF_2, and (c) ΔP_{tie}

Table 1. Comparisons of ITAE value for load fluctuations in Area 1

Controller	IWO-PIDFN	PSO-PIDFN	TLBO-PIDFN	DE-PIDFN	MDE-PIDFN
ITAE	0.0023	0.0034	0.0022	0.0020	0.00191

Table 2. System specifications under variable load disturbance in Area 1

Controller	ΔF_1 (Hz)		ΔF_2 (Hz)		ΔP_{tie} (p.u)	
	PUS (Hz) × 10^{-4}	TS (sec)	PUS (Hz) × 10^{-5}	TS (sec)	PUS (Hz) × 10^{-4}	TS (sec)
IWO-PIDFN	-	4.7	-0.478	Unstable		2.79
TLBO-PIDFN	-	5.6	-0.687	Unstable		3.95
PSO-PIDFN	-0.48	5.1	-2.25	Unstable	-3.15	Unstable
DE-PIDFN	-0.1	3.5	-0.756	Unstable	-0.12	2.9
MDE-PIDFN	-	1.5	-0.65	5	-	0.05

5.2. Effect of the UPFC in the HRES

In this scenario, UPFC is implemented in the system and the microgrid is subjected to real time data of variation of PV irradiance and wind speed on a particular day which are represented in Figure 4 and Figure 5. The different ITAE values implementing an UPFC in the HRES is obtained from various optimization techniques are listed in Table 3.

According to Table 4, the MDE-PIDFN controller has superior fitness compared to other controllers. The dynamic performance of ΔF_1, ΔF_2, and ΔP_{tie} under random load perturbations is depicted in Figures 6(a)-(c). Figure 6(a) demonstrates that the MDE-PIDFN controller provides a superior transient response to the frequency fluctuation (F_1) in region 1 compared to other controllers. Similarly, in Figures 6(b) and 6(c), the MDE-PIDFN controller provides a better transient response for the frequency variation (F_2) in area 2 and the change in tie line power (ΔP_{tie}) than other controllers, as indicated in the zoom region of Figure 6. Table 4 displays the transient specifications of the system in terms of peak undershoot (PUS) and settling time (TS). As comparison to other optimization techniques, the MDE method offers higher dynamic responsiveness in terms of settling time.

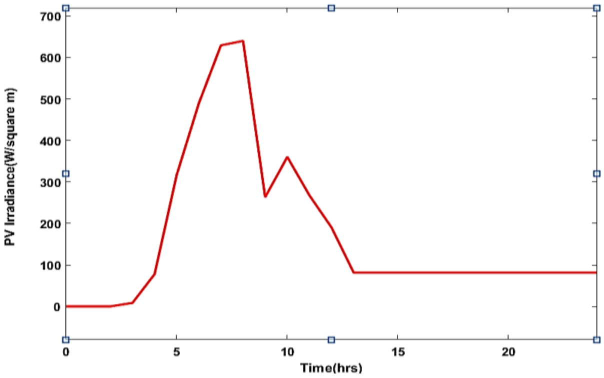


Figure 4. Variation in PV irradiance

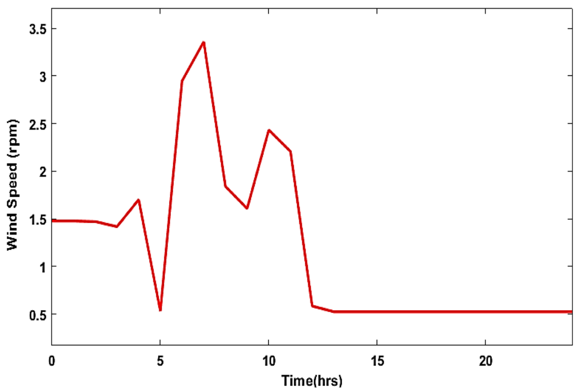


Figure 5. Variation in wind speed data

Table 3. Different optimization techniques under action of UPFC

Controller	IWO-PIDFN	PSO-PIDFN	TLBO-PIDFN	DE-PIDFN	MDE-PIDFN
ITAE	0.000007	0.000004	0.0000038	0.0000034	0.0000003

Table 4. System specifications under action of UPFC and random load disturbance in Area 1 and Area 2

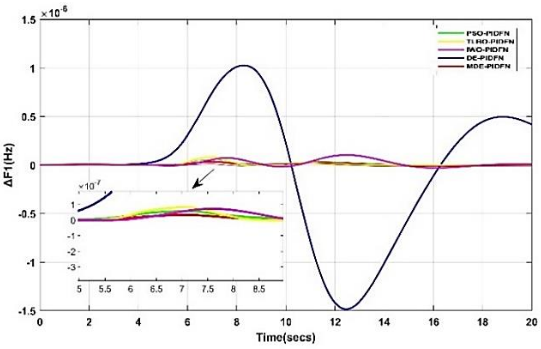
Controller	ΔF_1 (Hz)		ΔF_2 (Hz)		ΔP_{tie} (p.u)	
	PUS (Hz) × 10^{-4}	TS (sec)	PUS (Hz) × 10^{-6}	TS (sec)	PUS (Hz) × 10^{-6}	TS (sec)
IWO-PIDFN	-	9.65		5.5	-	17.2
TLBO-PIDFN	-	7.87		6.78	-0.02	11.6
PSO-PIDFN	-	8.23		8.9	-	12.2
DE-PIDFN	-1.5	Unstable	-2.5	Unstable	-0.68	Unstable
MDE-PIDFN	-	6.35		4.88	-	9.3

5.3. Robustness of the proposed controller

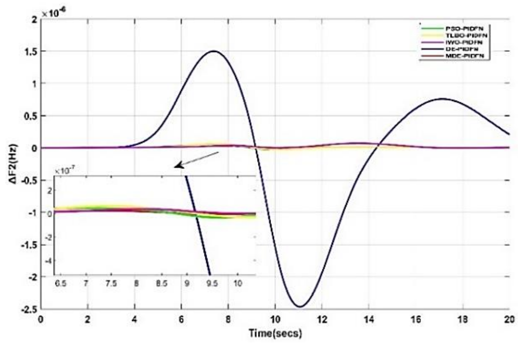
In order to test the robustness of the proposed controller the HRES is tested under parameters variations of the power system gain (K_{ps}), power system time constant (T_{ps}) and regulation of the governor (R) as represented in Table 5 and communication time delay (CTD) of 0.1 secs is implemented at the input of the controller. The change in operational set point of the generating points may be delayed which impacts on system stability due to mismatch between generation and demand. CTDs minimizes the system instability so the influence of CTDs on frequency stability of the HRES is examined here. Furthermore, area 1 is subjected to a step load change at 30 seconds and area 2 at 20 seconds.

Table 5. Parameter variation

Parameter	R	K_{ps}	T_{ps}
Variation (%) in Area 1	+5	-20	+25
Variation (%) in Area 2	-5	+20	-25



(a)



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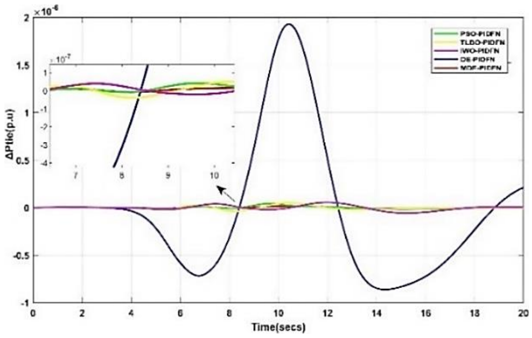

(c)

Figure 6. Dynamic response under UPFC (a) ΔF_1, (b) ΔF_2, and (c) ΔP_{tie}

When the HRES system is exposed to variation in parameters and CTD the system ITAE values is represented in Table 5 for various controllers. From Table 6 it is observed that the ITAE value of the proposed controller has a better value as compared to other optimization methods. Figures 7(a)-(c) depict the dynamic response of frequency deviations F_1 and F_2 in each location, as well as the tie line power variation of ΔP_{tie} in Areas 1 and 2 respectively. Figure 7(a) demonstrates that the MDE-PIDFN controller provides a superior transient response to conventional controllers for the frequency fluctuation (F1) in region 1. Similarly, in Figures 7(b) and 7(c), the MDE-PIDFN controller provides a better transient response for the frequency variation (F_2) in area 2 and the change in tie line power (P_{tie}) than other controllers, as seen in the zoomed region. The transient specification of the HRES under this scenario is represented in Table 7. From Table 7 it is examined that the MDE method provides enhanced dynamic responsiveness in terms of settling time in comparison to other optimization strategies.

Table 6. ITAE values of different optimization techniques under action of CTD and variation in parameters

Controller	IWO-PIDFN	PSO-PIDFN	TLBO-PIDFN	DE-PIDFN	MDE-PIDFN
ITAE	0.005945	0.004812	0.004218	0.002984	0.002105

Table 7. System specifications under parameter variation and CTD

Controller	ΔF_1 (Hz)		ΔF_2 (Hz)		ΔP_{tie} (p.u)	
	PUS (Hz) × 10^{-3}	TS (sec)	PUS (Hz)	TS (sec)	PUS (Hz) × 10^{-3}	TS (sec)
IWO-PIDFN	-0.5	7.8	-0.5	4.97	-0.12	3.85
TLBO-PIDFN	-2.12	9.6	-2.12	4.32	-0.62	9.91
PSO-PIDFN	-0.8	Unstable	-0.8	3.7	-	Unstable
DE-PIDFN	-0.41	14.98	-0.034	3.8	-0.1	16.3
MDE-PIDFN	-1	2.98	-	2.91	-	2.68

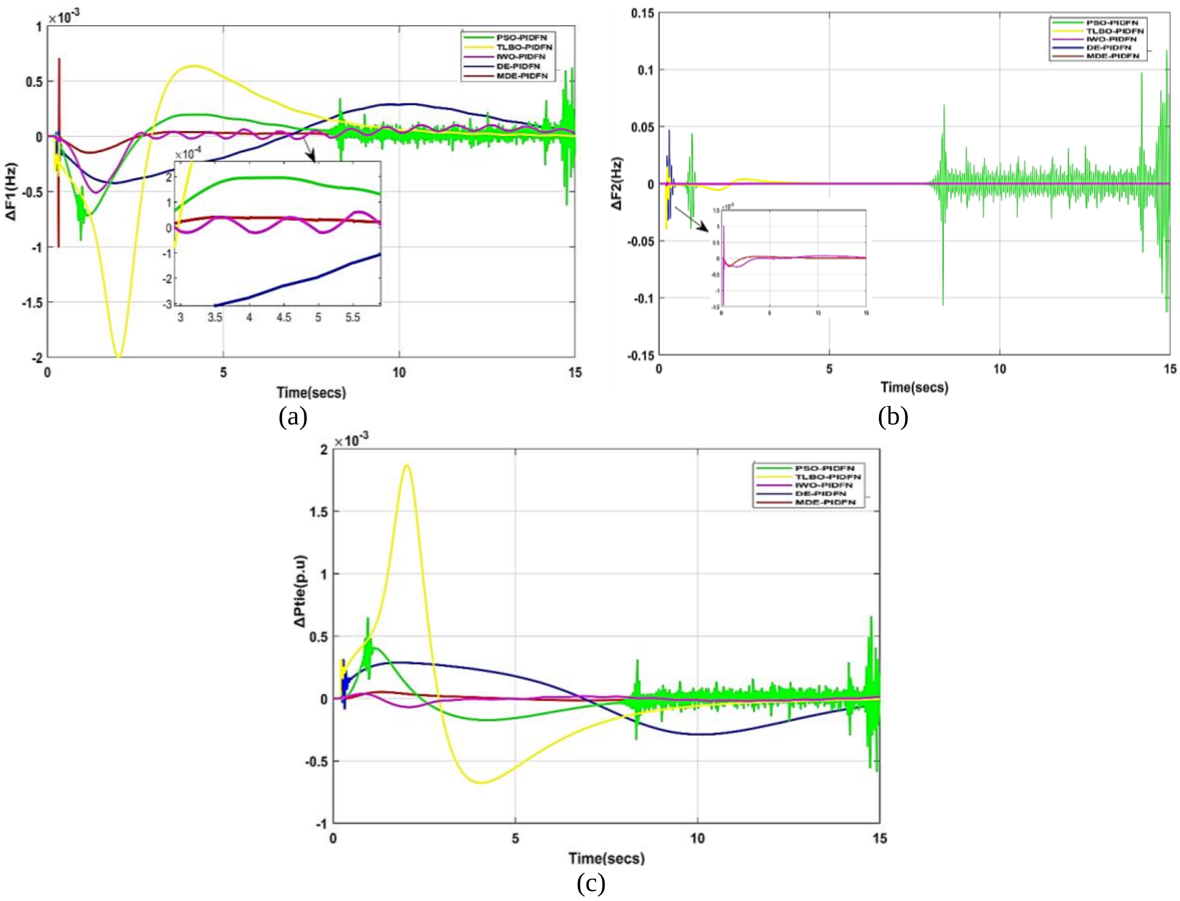

Figure 7. Dynamic response under CTD and parameter variation (a) ΔF_1, (b) ΔF_2 and (c) ΔP_{tie}

6. CONCLUSION

An interconnected microgrid system constituting wind generator, photovoltaic, diesel engine generator, battery and capacitor is modelled in this paper. The HRES comprising of nature dependent sources results in frequency perturbations in the system which can be ameliorated by using a controller. In this paper a MDE technique is suggested to tune the parameters of the cascaded-PIDFN controller of two area MG system. To assess the effectiveness of the proposed controller the microgrid is subjected to load perturbation, parametric variations, effect of CTD and UPFC in the system. The dynamic behavior of the MG system is analyzed and compared with the results of DE, PSO, TLBO and IWO tuned cascaded-PIDFN controller. In Area 1 the proposed controller improves the settling time by 80.10%, 68.95%, 61.79% as compared to DE-PIDFN, TLBO-PIDFN and IWO-PIDFN controller. Similarly in Area 2, the settling time is improved by 23.42%, 21.29%, 32.63% and 41.44% in contrast with DE-PIDFN, PSO-PIDFN, TLBO-PIDFN and IWO-PIDFN controller. The settling time in the tie line is also improved by 83.55%, 72.95% and 30.38% as compared to DE-PIDFN, TLBO-PIDFN and IWO-PIDFN controller. The proposed controller is accountable for maintaining frequency fluctuation and making the power system more stable with reduced peak overshoot, undershoot, and muted oscillations.

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