Artificial raindrop algorithm for control of frequency in a networked power system

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ABSTRACT

Load frequency control (LFC) evaluates the net changes in generation by continuously monitoring tie-line flows and system frequency required relying on load changes. It adjusts generator set points to minimize the area control error's (ACE) time-averaged value. ACE is regarded as a controlled output of LFC. Previous research focused on customary power systems like hydro-hydro, thermal-thermal, and hydro-thermal configurations. This current development study introduces the hybrid PV and dual thermal system interconnected systems for LFC analysis. The research evaluates LFC performance with different controllers, considering parameters such as maximum peak overshoot (Mp), maximum undershoot (Mu), settling time (Ts), and peak time (Tp). Controllers, including proportional integral (PI), anti-windup PI, fuzzy gain scheduling PI, and A cutting-edge algorithm generating fake raindrops are used for minimize ACE. The analysis introduces various load perturbations to observe controller performance in interconnected power systems. Both PV-thermal-thermal and thermal-thermal-thermal systems exemplify innovative approaches to energy management that bolster energy efficiency and sustainability. By integrating these advanced systems, we can make significant strides towards achieving global sustainability goals and promoting a cleaner and support energy efficiency for the future.

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1. INTRODUCTION

The incorporation of sustainable energy into conventional electricity systems has grown dramatically in the last ten years, partly because of reduced distributed energy prices, environmental concerns, and legislative support for renewable energy sources. However, because renewable energy is intermittent and affects grid frequency by reducing system inertia, this integration presents a threat to grid stability. It is still very important to handle load-frequency management, which is usually done with classic controllers like proportional integral (PI) and proportional integral derivative (PID), and is frequently optimized with strategies like particle swarm optimization (PSO) and genetic algorithm (GA) [1]-[5].

Newer methods that show promise in resolving these issues in multi-machine power systems include fuzzy-based PID controllers and contemporary strategies like optimum control and model predictive control (MPC). Research has looked into a number of techniques, including generalized Hopfield neural network

(GHNN) for self-adaptive PID tuning and adaptive neuro-fuzzy inference system (ANFIS) for adaptive control, which have shown benefits over conventional techniques in simulations [6]-[10]. New developments in smart generation control include the proportional-derivative win or learn fast-policy hill climbing (κ) (PDWoLF-PHC(κ)) technique, which emphasizes flexibility and resilience in intricate multi-area power systems. Further investigation is being conducted into algorithmic enhancements like as BFOA and genetic algorithms, which optimize control parameters for improved load frequency control (LFC) performance in a variety of power system setups [11]-[15].

2. GRID-BASED SOLAR ENERGY SYSTEM

Due to the inherently low PV panel conversion efficiency and the application of the maximum power point tracking (MPPT) method becomes crucial [16], [17]. This algorithm enhances the PV system's tracking efficiency guarantees steady load voltage maintenance in spite of temperature and irradiance fluctuations [18]. An inverter is then used to convert the PV system's DC output to AC, as seen in Figure 1.

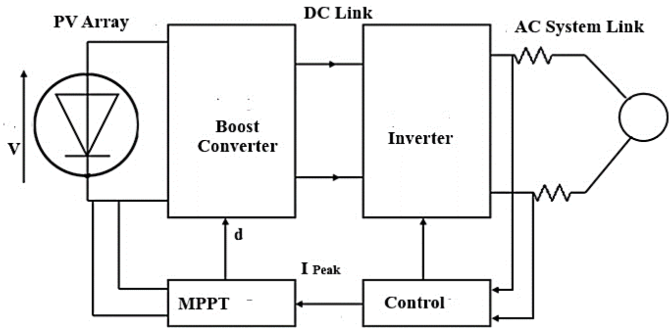


Figure 1. PV cell equivalent circuit

2.1. Photovoltaic (PV) panel

Photovoltaic (PV) diodes make up a solar cell panel, which uses the photovoltaic effect to function. The PV cell produces electricity when it is exposed to sunlight. The voltage that the PV cell normally generates ranges from 0.3 to 0.6 V, depending on the technology. Figure 1 depicts the PV cell's comparable circuit. Modeling the solar panel is done using (1) and (2).

$$I = I_1 - I_{o1}(exp(q(V - IR_e)/BkT) - 1) - (V - IR_e)/R_{sh} \quad (1)$$

$$I_A = (\lambda_1/1000)[I_{sc} + K.(T - 25)] \quad (2)$$

In the given context, I_{sc} represents the current in a short circuit, I signifies the generated current of the photovoltaic array, I_A stands for the photo current, I_{o1} denotes the reverse saturation current, V represents the voltage produced by the solar cell. The Boltzmann constant is denoted by k., T signifies the Kelvin temperature, q represents the electron charge, λ_1 represents the irradiance, and B is the diode's quality factor. Temperature and illumination play a crucial role in determining power generation in the cell, with this generation being connected directly to irradiance and inversely to temperature [19]-[22].

2.2. Integrated PV-thermal-hydro power system

A three-area interconnected system's block diagram is shown in Figure 2. The three areas' frequency deviations (Δf1-Δf3) are displayed [23], [24]. To examine the differences in frequency and tie-line power, equal load disturbances are introduced to each of the three systems. The system's performance is evaluated by evaluating different load perturbations. This system's main goal is the same as a three-area thermal system's [25].

Manual regulation is replaced by a closed-loop control method called load frequency control, or LFC. Eliminating frequency variations brought on by load disturbances in the tie lines and throughout the three zones is the primary goal of LFC. Every system controls its own oscillations and makes up for those in regions where deviations are uncontrollable [26]. The three-area block schematic of a networked system is shown in Figure 2.

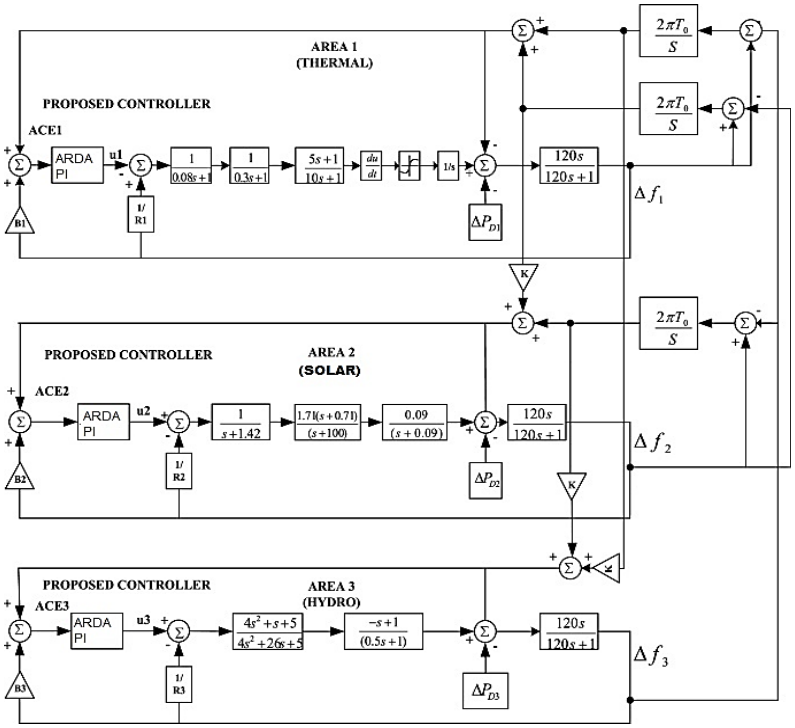


Figure 2. Diagrammatic representation of an integrated three-zone system

3. ARTIFICIAL RAINDROP ALGORITHM (ARDA)

A signal produced by the LFC regulates frequency and establishes generation. The LFC's ARDA modifies the PI controller's gains. This is the definition of the general optimization problem, where x is an n-dimensional vector and S is a set of finite measure. This optimization problem is intended to be solved by the raindrop algorithm.

At first, N raindrops fall on the "ground," where S stands for the "ground". The notation "$xi \in S$ x i ∈ S" indicates the location of the i-th raindrop. The raindrop will migrate during each period after it has fallen. The ideal values for the PI controller are ascertained by means of the six phases of ARDA: raindrop production, raindrop descent, raindrop collision, raindrop flow, RP updating, and vapor updating. If there's still duplicate vapor in Figure 3, which shows the process diagram of the artificial rain drop algorithm.

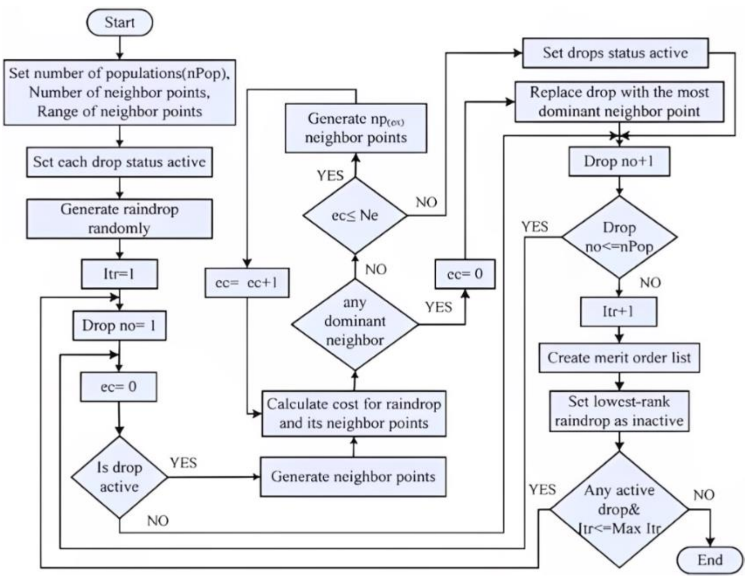


Figure 3. Displays the flow diagram of the artificial rain drop algorithm

4. RESULT AND DISCUSSION

The momentary reaction evaluation with reference to the islanded microgrid (MG) system was conducted with the aid of MATLAB/Simulink 2018a. To ensure a fair and comprehensive assessment of optimization of particle swarms (PSO), the grey wolf algorithm for optimization (GOA), and artificial rain drop algorithm (ARDA), identical system parameters were employed in both simulations.

4.1. Controlling voltage and frequency during load variation and DG integration

In an islanded microgrid, frequency, voltage, and regulation are critical due to the lack of main grid support. To optimize stability after DG insertion and load changes, three metaheuristic techniques (PSO, GOA, ARDA) were employed to fine-tune the capacitance of the DC-link and PI controller parameters. ARDA iteratively searched for optimal values by minimizing the FF parameter during simulation. At 0.05 seconds, photovoltaic (PV) modules powered by solar were activated, causing voltage overshoots (Figure 4).

The optimized PI gains and capacitance values obtained through these techniques ensure minimal overshoot and settling time, ensuring optimal dynamic behavior in the MG model behavior. Figure 4 illustrates voltage overshoot at 0.05 seconds in the DG integration process, influenced by DG rating and controller parameters. To ensure a fair comparison between PSO, GOA, and ARDA, the same system settings were maintained. Load changes at 0.25 s (addition) and 0.55 s (disconnection) caused corresponding voltage fluctuations.

Figure 5 depicts responses during DG insertion, load addition, and disconnection of load [20]-[22]. Optimal parameters from ARDA outperform PSO and GOA in Figures 5(a) and 5(b), evident in lower overshoot and settling times across conditions. In islanded MG operations, addressing system frequency is crucial. Figure 5(c) shows ARDA's superior frequency regulation compared to PSO and GOA, emphasizing ARDA's effectiveness in enhancing overall MG system performance. Figure 6 depicts MG system frequency response for three optimization methods, indicating stable responses within ±1% deviation. Notably, ARDA exhibits superior dynamic.

Table 1 presents a comparative analysis of control of frequency and voltage in the islanded microgrid setup (MG) under study, highlighting the superior effectiveness of ARDA compared to its competitors. The results shown in Table 1 show that the ARDA controller worked better than both PSO and GOA. This meant that the studied MG system had better dynamic response indicators and stable operation. It maintained voltage within ±5% and frequency within ±1%, meeting IEEE standards. Notably, the settling time for frequency wasn't calculated due to the curve staying within ±2% of the rated value.

Table 1. Summarizes comparative analyses for control of frequency and voltage in the examined islanded microgrid emphasizing ARDA's efficacy over competitors

Examined scenario		Approach	MOS/MUS (%)	Peak period (milliseconds)	Settling time (ms)
Voltage	MG insertion	PSO	5.86	27.2	37.7
		GOA	4.68	36.3	64.5
		ARDA	1.45	26.2	26.36
	Load injection	PSO	16.45	4.00	94.21
		GOA	16.00	4.70	94.20
		ARDA	15.04	3.90	94.19
	Load detachment	PSO	16.41	7.70	73.50
		GOA	15.59	7.50	78.50
		ARDA	14.77	7.80	77.40
Frequency	MG injection	PSO	0.44	2.05	-
		GOA	0.54	5.58	-
		ARDA	0.46	2.30	-
	Load injection	PSO	0.66	35.2	-
		GOA	0.50	34.8	-
		ARDA	0.46	35.0	-
	Load detachment	PSO	0.50	36.4	-
		GOA	0.48	36.7	-
		ARDA	0.46	36.8	-

4.2. Evaluation of the analyzed optimization algorithms effectiveness

This segment presents results from evaluating three optimization algorithms (PSO, GOA, ARDA) under identical conditions. All algorithms underwent 50 iterations with 50 search agents in a fair comparison. Over 20 simulation runs, ARDA achieved the minimum fitness function value (0.5841) in the seventeenth cycle, outperforming PSO (0.9211586 at 21st iteration) and GOA (0.8748774 at 25th iteration). ARDA exhibited faster convergence and superior solution quality. Figure 7 shows the PSO, GOA, and ARDA convergence curve.

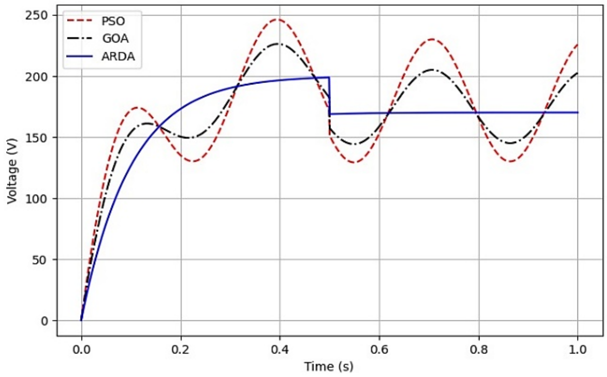
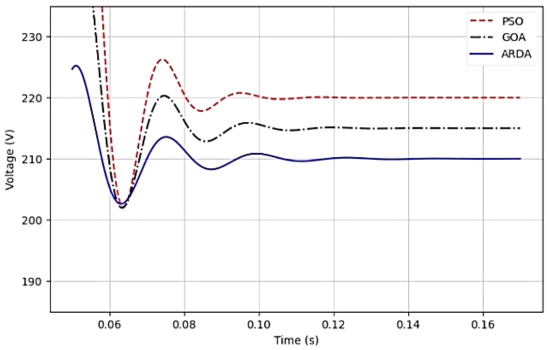
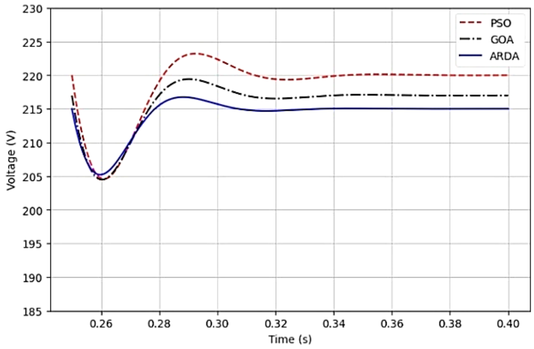


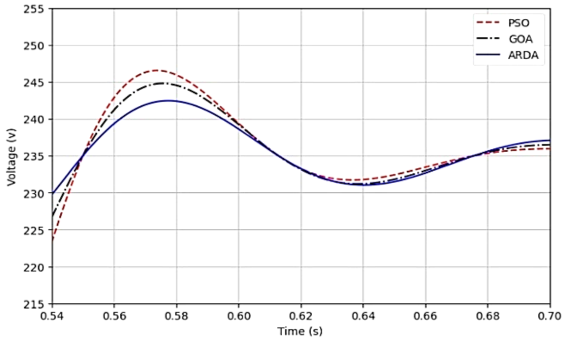
Figure 4. Response of the system's voltage under load variation and DG integration



(a)



(b)



(c)

Figure 5. Profile of voltage at (a) DG integration, (b) abrupt load increase, and (c) abrupt load drop

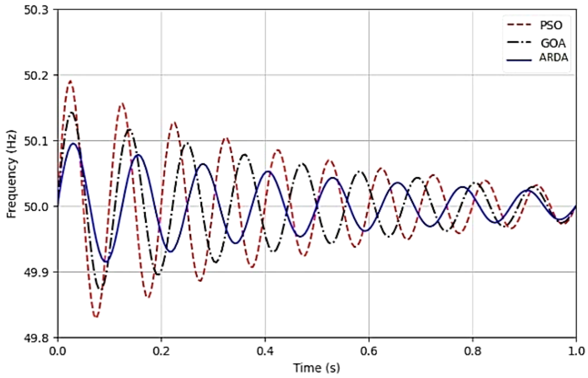


Figure 6. The microgrid system's frequency response for the explored optimization methods

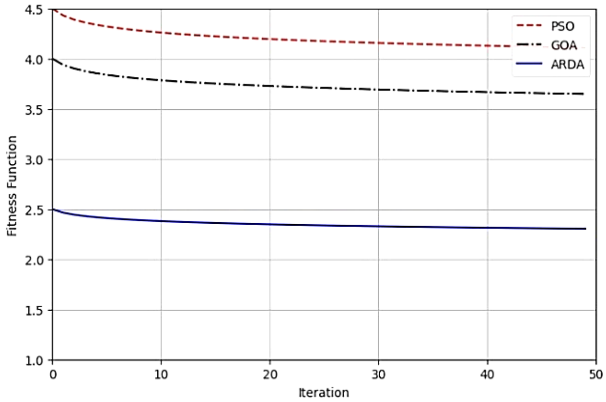


Figure 7. The convergence profile for GOA, PSO, and ARDA

5. CONCLUSION

This paper presents the successful development of an optimal controller for an islanded microgrid (MG) utilizing the adaptive randomized differential algorithm (ARDA). The designed controller effectively regulates voltage and frequency during load variation and microgrid integration, minimizing overshoot and settling time scenarios. Comparative analysis of optimization algorithms demonstrates that ARDA exhibits superior convergence behavior, offering higher quality solutions and faster optimization capabilities compared to alternative algorithms.

The implemented controller provides remarkable power quality by ensuring virtually perfect sinusoidal waveforms for both voltage and current, according to the power quality analysis. Under the identical operating conditions and system settings, a thorough comparison with controllers that use particle swarm optimization (PSO) and genetic optimization algorithm (GOA) highlights the ARDA-based controller's superior performance. The results show that in every studied case, the ARDA-based parameter selection produces the best dynamic responses, outperforming alternative approaches. Furthermore, there may be future uses for this strategy that try to increase energy efficiency.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Lakshmi Dhandapani	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Pushpa Sreenivasan		✓				✓		✓	✓	✓	✓	✓		
Malathy Batumalay	✓		✓	✓		✓			✓		✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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