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Robust Frequency Control of an Islanded AC Micro Grid using BDA Optimized 3DOF Controller under Plug in Electric Vehicle

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Abstract: *The article presents the effectiveness of a Binary Dragonfly Algorithm (BDA) based 3-DOF controller for robust frequency control in an islanded AC micro-grid system under different uncertainties. A micro-grid is incorporated with the integration of various renewable energy based distributed generations (DG). The proposed micro-grid system is structured with wind turbine generator (WTG), Photo voltaic (PV) system, Diesel engine generator (DEG), Micro-turbines (MT), Aqua electrolyzer based Fuel Cells(FC) and with few energy storage devices i.e Battery energy storage (BES) and Flywheel energy storage (FES). Moreover a chargeable plug in electric vehicle is effected as load side demand while obtaining frequency control mechanism in micro-grid system. However large dynamics, low inertia and incurred uncertainties of most DG system affects system performance especially on system frequency seriously. In view of this to obtain robust control mechanism in islanded micro-grid system the article proposes a novel Binary Dragonfly Algorithm based 3-DOF controller to ensure servicing of good quality power to remote consumers. The performances of proposed BDA optimized 3-DOF controller is compared with conventional PSO, GA technique based PID and PI controller in order to justify supremacy of proposed approaches. Finally it has been suggested that the proposed BDA optimized 3-DOF controller is more effectiveness over other optimized controllers.*

Keywords *:Micro-grid; Binary Dragonfly Algorithm (BDA); Diesel engine generator (DEG); Micro-turbines (MT); 3-DOF Controller; Plug in Electric Vehicle (EV)*

I. INTRODUCTION

The scarcity of fossil fuels put adverse effect over most of conventional generating stations in the power system. In order to overcome deficiency in electrical power, the concept of micro-grid and renewable energy sources (RES) has been introduced in the power system. Micro-grids are usually small digital grid where verities of distributed generators (DG) are penetrated [1-2]. DG systems are specially referred as micro sources whose power generation mostly depends on renewable energy sources. In economic point of view the distant and remote areas are electrically served by different micro sources but use of combustible fuels emit high CO_2 and furthermore it costs more to transport to the isolated areas. Motivating from these disadvantages the alternative renewable energy sources (RES) are now taken in to consideration for generation of electrical power. The sustainable sources such as wind energy, solar energy, bio mass, tidal energy, geo thermal etc. have been penetrating with micro-grid system for electrifying the system. The considerable advantages like eco-friendly, low transmission losses of this substitutes has been received with growing interest and are favored to be used in power system. Wind and solar are the broadly used power sources and again the entry of fuel cell (FC) in power system ensures a carbon free society [3-4]. Co-ordinate power systems that are in isolated mode can’t supply constant power due to the ever changing parameters and operating condition of wind generator system and photovoltaic cells [5]. This fluctuant sources result instability in power. In a purpose to maintain uninterrupted power supply different energy storage systems (ESS) are acting as power backup sources [6] in the micro grid system. It stores back up of excess generated electricity and supplies it when there is insufficient power. Now-a-days fly wheel (FES) and battery energy storage system (BES) are used as energy storage systems [7-8]. Undesirable supply and demand imbalance is also arisen due to this renewable energy source oscillation, which also causes voltage and frequency to deviate highly. In operational point of view micro-grid structure may be two basic modes i.e. grid-connected mode and off-grid or islanded mode [9-10]. The impact of different uncertainties arisen in micro-grid system does not affect to the micro-grid in grid connected mode, however different uncertainties associated with renewable sources largely affect to the micro-grid control in off-grid or islanded situations. So micro-grid control under islanded condition creates huge challenges for power engineers. Apart from this if micro-grid system is associated with large plug in electric vehicles (EV), such nonlinear electrical load largely affect the system frequency [11-12]. Hence, an effective control scheme is always needed for controlling of the power supplied from the swinging power sources. In this regard the aspects of micro-grid control mechanism have been demonstrated

through different research articles. In view of this Selvam et.al. [13] proposed spider monkey optimization algorithm for frequency control of an islanded micro-grid system. Bevrani et al. [14] proposed PSO based fuzzy controller for secondary frequency control in an AC micro-grid system..

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Conventional controllers are not proved to be the optimal to solve these difficulties. Influenced from these problems, researchers are putting their concerns to robust controller design for frequency balance which in turn will minimize the difference in electrical supply and demand. In view of this to avoid few limitations of above techniques the present article proposes Binary Dragonfly Algorithm (BDA) [15] based 3-degree of freedom based (3-DOF) controller for frequency control of an electric vehicle operated AC off-grid micro-grid system.

II. SYSTEM UNDER STUDY

A. Microgrid Model

The proposed micro-grid system is configured with Diesel engine generator (DEG), Photovoltaic (PV) system, Wind Turbine Generator (WTG), Micro-Turbine(MT) [16] and an Aqua Electrolizer based Fuel Cells (FC). The above micro-sources are primarily responsible for generation of necessary electrical power in micro-grid system. However to improve system response time and to provide uninterrupted power supply some energy storage devices (ESD) like Battery Energy Storage (BES) and Flywheel Energy Storage (FES) devices has been penetrated with micro-grid system. A chargeable Electric Vehicle (EV) is associated with micro-grid system to study frequency control mechanism in micro-grid system. In this regard the configuration of micro-grid system is illustrated in Fig.1 and to examine the system model in MATLAB software the related transfer function model of micro-grid system is depicted in Fig.2. In transfer function model a positive sign (+) is assigned for delivering power to micro-grid and negative sign (-) is associated for receiving power from micro-grid system. In view of this to study dynamic performance especially frequency control in a micro-grid system, both stochastic and random based uncertainties of PV, WTG and applied load are taken in to consideration.

B. Wind Turbine Generator (WTG)

The wind velocity largely affects the output power of a WTG system. The mechanical power available in turbine rotor which has been converted from wind velocity is represented by P_W and is expressed as

$$P_W = \frac{1}{2} \times C_P \times V^3 \times \rho \times A \qquad (1)$$

Here C_P = Co-efficient of aerodynamic power; V = Velocity of wind ; ρ = Density of air; A = Swept area of rotor.

The coefficient C_P is largely influenced by tip-speed ratio (λ) and pitch angle of blade (β) and is illustrated through equation (2) [17]

$$C_P = (0.44 - 0.0167\beta) Sin[\frac{\Pi(\lambda - 3)}{15 - 0.3\beta}] - 0.0184(\lambda - 3)\beta \qquad (2)$$

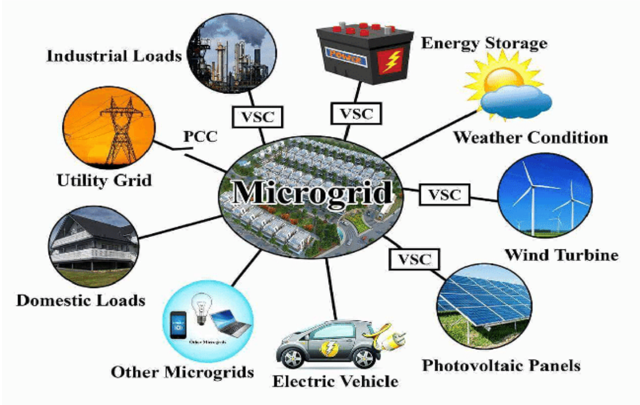

Fig.1 Configuration of an Islanded Micro-grid System

However the tip-speed ratio (λ) may be computed as

$$\lambda = \frac{R \times \omega}{V}$$

Where R = Radius of blades; ω = Angular Velocity.

C. Photo Voltaic (PV) System

The power generated in PV system may be equated as

$$P_{PV} = \eta \times S \times \Phi \times (1 - 0.005(T_a + 25)) \qquad (3)$$

Here, η = Efficiency of array (9%-12%); S = Effective area of array. ϕ = Solar radiation; T_a = Ambient temperature.

Due to wide variation of solar irradiation power (ϕ) the output of PV system largely depends on this factor (ϕ). To conduct realistic simulation in dynamic characteristic of system the integrated micro-sources may be assigned with non-linearity constraints. However to study dynamic performance of complex system the simplified model will be derived which

holds all the dynamic behaviour of system. In regard to this the micro-grid system is represented through first order transfer function model and is illustrated in Fig.2

D. Electric Vehicle (EV)

A chargeable electric vehicle has been connected with the micro-grid system to examine dynamic performance especially frequency control mechanism of an islanded micro-grid system. In this regard the EV system is modelled with its equivalent transfer function and is expressed through equation (4)

$$G_{EV}(s) = \frac{\Delta P_{EV}(s)}{\Delta P_E(s)} = \frac{K}{1 + s.T_{EV}} \qquad (4)$$

E. Deviations in Power and Frequency

The output power of weather dependent micro-sources like PV and WTG are fluctuated with the variation of solar irradiation power (ϕ) and wind velocity (V_W) respectively. In view of this to maintain stable operation of micro-grid system, it is required to control generation irrespective of load demand. So the net supply error (ΔPe) which comes whenever a mismatch occurs between generation and demand and may be controlled to keep system stable.

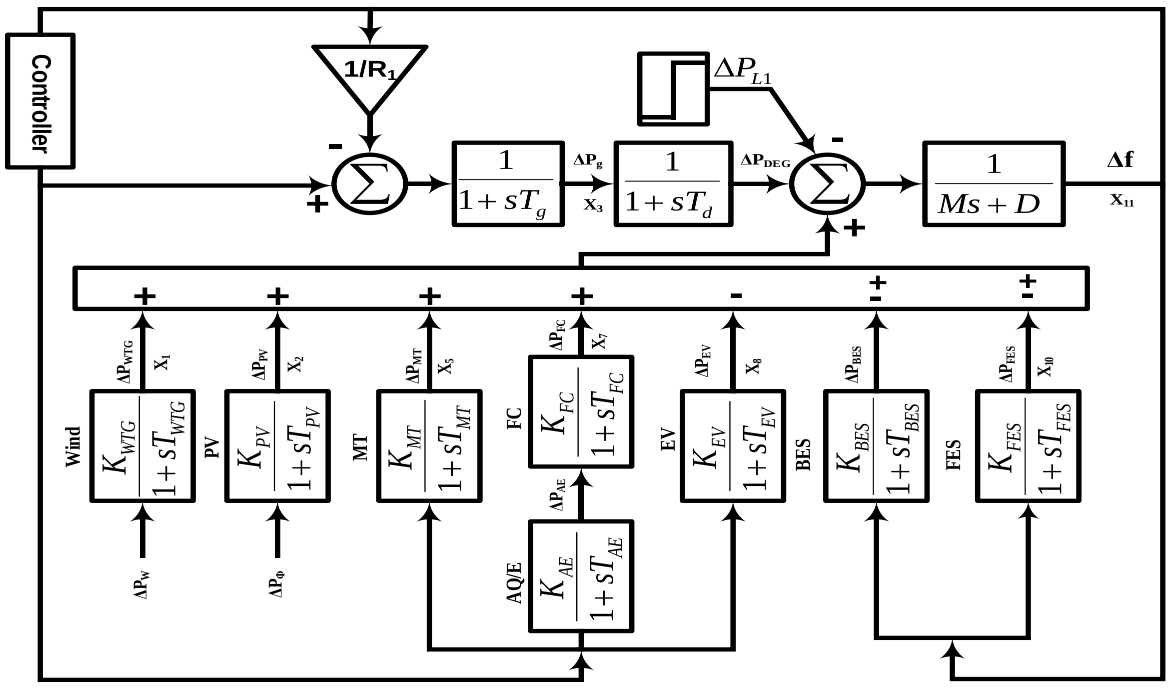

Fig.2 Transfer function Model of Islanded Micro-grid System

ΔPe is expressed through equation (5)

$$\Delta Pe = P_{DEG} + P_{WTG} + P_{\Phi} + P_{MT} + P_{FC} \pm P_{BES} \pm P_{FES} - P_L - P_{EV} \quad (5)$$

In micro-grid system variation in generated power results fluctuations in system frequency and is expressed as

$$\Delta F = \frac{\Delta Pe}{K_f}$$, where K_f is a constant.

However the actual time delay between power variation and frequency deviation creates modification in the frequency deviation expression and is expressed through equation (6)

$$\Delta F = \frac{\Delta Pe}{K_f(1+T_S)} = \frac{\Delta Pe}{M_S + D} \quad (6)$$

Here T = Frequency characteristic time constant; M = Inertia constant; D = Damping Constant.

Apart from this a set of state-space equations are required to model dynamic behaviour of system.

$$\dot{X} = AX + Bu \, ; \quad Y = CX + Du$$

Here X = state (indicated in the model), u = input vector ; Y = output vector ; A, B, C,& D = Constant matrices.

u = [ϕ P_W P_L], Y = [ΔF]

III. PROPOSED STATEMENT

A. Three Degree of Freedom (3-DOF) PID Controller

It has been suggested through different literature article that most of conventional controllers exhibit poor performance under large variation of system parametric conditions especially in complex non-linear power system. These conventional controllers are able to be activated only when the system controlled variables are diverted from their reference value significantly. This drawback creates to sense the error signals with respective plants before sensing by the proposed controller. In this regard the degree of freedom concept has been introduced in control scenario which makes independent adjust of different control variables [18]. Based upon the concept of degree of freedom, the present article has proposed a three degree of freedom (3-DOF) controller for necessary control action in frequency control of islanded micro-grid system. The internal structure and block diagram of proposed 3-DOF controller is depicted in Fig.3 (a) and Fig.3(b) respectively. The improved design of 3-DOF controller gracefully satisfies

(i) Ability to reject large disturbance.

(ii) Ability to perform closed-loop stability

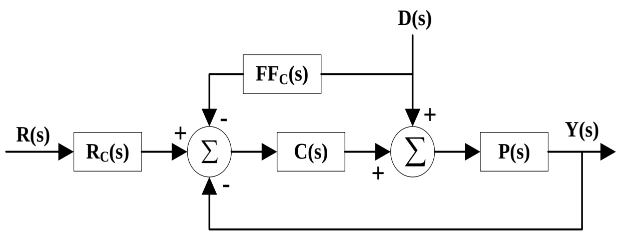

Fig.3(a)3DOF-PID Controller Structure

The different notations associated with 3-DOF controller are described as

R(s) = Input reference value

Y(s) = Output response of plant.

D(s) = Outer disturbance signal.

$G_{RC}(s)$ = Transfer function of reference controller.

$G_C(s)$ = Transfer function of single degree of freedom controller.

$G_{FF}(s)$ = Transfer function of feed-forward controller.

$G_P(s)$ = Transfer function of whole plant.

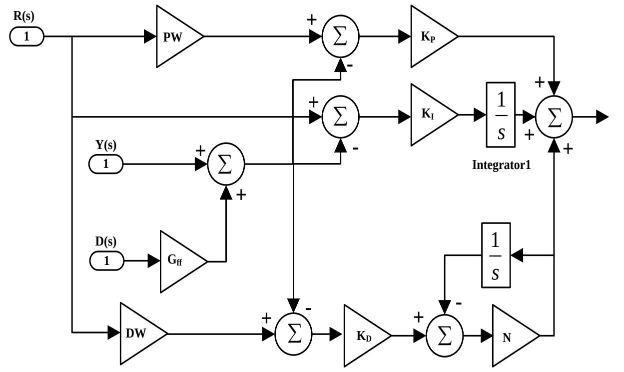

Fig.3(b) 3DOF-PID Controller Block diagram

The output of plant is computed by Fig.3(a). and is expressed through equation (7)

$$Y(s)=G_{RC}\frac{G_C(s).G_P(s)}{1+G_C(s).G_P(s)}R(s) + \frac{G_P(s)-G_P(s).G_{FF}(s).G_C(s)}{1+G_C(s).G_P(s)}D(s) \qquad (7)$$

The basic structural diagram of 3-DOF controller is illustrated in Fig.3 (a).The important variables associated with 3-DOF controller structure are

PW = Proportional weight.

DW = Derivative weight.

N = Filter co-efficient.

$$G_C(s)=\frac{U(s)}{R(s)}=K_P.P_W+\frac{K_I}{s}+K_D.DW(\frac{N.S}{N+S})$$
$$=\frac{s^2(NK_DDW+K_PPW)+s(NK_ePW+K_I)+K_IN}{s(N+S)} \qquad (8)$$

$$G_{RC}(s)=\frac{U(s)}{Y(s)}=-[K_P+\frac{K_I}{s}+K_D(\frac{N.S}{N+S})]$$
$$=-[\frac{s^2(NK_D+K_P)+s(NK_P+K_I)+K_IN}{s(N+S)}]$$

$$G_{FF}(s)=\frac{U(s)}{D(s)}=-K_{FF}(K_P+\frac{K_I}{s}+K_D(\frac{N.S}{N+S}))$$
$$=-K_{FF}[\frac{s^2(NK_D+K_P)+s(NK_P+K_I)+K_IN}{s(N+S)}]$$

B. Basic Dragonfly algorithm (DA)

This algorithm is originated from the concept of swarming feature of dragonflies in nature. The special static and dynamic swarming nature of dragonflies helps to achieve the exploration and exploitation phases of optimization. Artificial dragonflies are modelled by sayedali mirjaili which is used for optimization [19]. The process of navigation, searching for food and distraction from enemy are modelled in this algorithm. Random solution is created by dragonflies to initialize the optimization. Two vectors are used to upgrade the position and displacement of the insects. These vectors are step (Δx), position (x). Step vector is similar to the velocity vector of algorithm PSO. Δx indicates the alignment of motion of the insects. The position is renewed in each iteration and it continues till the objective is not achieved. The iteration process increases the position of dragonflies to get converged to the optimal point. Dragonflies do optimization by covering five stages i.e separation, alignment, cohesion, attraction to food and distraction from enemy. This concept makes DA differ from PSO. The step vector and positions are started with any random values and are expressed within lower and upper bounds. In this regard equations (9), (10) and (11) are utilized to update the step of each dragonfly.

$$\Delta X_{t+1}=(sS_i+aA_i+cC_i+fF_i+eE_i)+\omega\Delta X_t \qquad (9)$$

Here, s = Separation weight, S_i = Separation of i^{th} individual

a = Alignment weight, A_i = Alignment of i^{th} individual

c = Cohension weight, Ci= Cohension of i^{th} individual.

F = Food factor ,F_i= Food source of i^{th} individual.

e = Enemy factor ,E_i = Position of enemy of i^{th} individual.

ω = Inertia weight, t = iteration counter

$$X_{t+1}=X_t+\Delta X_{t+1} \qquad (10)$$

$$X_{t+1}=X_t+Le'vy(d)\times X_t \qquad (11)$$

Where t = Current iteration, d = dimension of position vector.

C. Binary Dragonfly Algorithm (BDA)

This binary dragonfly algorithm is different from the ordinary DA. Unlike continuous dragonfly algorithm the binary dragonfly algorithm does not add step vector to position vectors to update the search agent position because the position vector value is either 0 or 1[20]. A transfer function is used to convert SI techniques to binary technique. The function of transfer function is to receive step value and in return it gives either 0 or 1. It indicates the probability of changing position. It is proportional to the velocity vector. If the velocity vector value of search agent is large then the position gets updated. The sudden changes in particles are simulated by this technique with the help of large velocity vector value. The transfer functions used are of two types. These are s-shaped and v-shaped. In regard to the concept of Sharmi, v-shaped is more helpful than the other. V shaped has advantages that it doesn't force particles to receive values either 0 or 1.

The transfer function generally used to solve BDA is

$$T(\Delta x)=\left|\frac{\Delta x}{\sqrt{\Delta x^2+1}}\right| \qquad (12)$$

This transfer function first does counting of the probability of changing position of all dragonflies.

$$X_{t+1}=\{-X_t, r\le T(\Delta X_{t+1}) \qquad (13)$$

$$X_{t+1}=\{X_t, r\ge T(\Delta X_{t+1}) \qquad (14)$$

The above two formulas are used to update the position of search agent in binary search space. Here 'r' is the number in binary interval. With the help of the transfer function as well as position updating formula binary problems are solved by BDA efficiently.

Table.1 Pseudo-code of Binary Dragonfly Algorithm.

Initialization of Population X_i (i=1, 2, 3........n)
Initialization of ΔX_i (i=1, 2, 3......n)
While final criteria is not satisfied
Estimate objective values if each individual dragonfly
Modify food source and enemy
Modify a, c, e, f, s and w
Estimate A, C, E, F and S
Modify step vector (ΔX) by equation (9)
Estimate Probabilities by equation (12)
Modify position vector by equation (13-14)

IV. RESULTS AND ANALYSIS

A. Stochastic analysis to generate solar and wind power Fluctuations

The dynamic behavior of the proposed model has been studied under stochastic method generated load demand, wind power and solar irradiation power. The generated power responses of applied load, wind power and solar irradiation power are demonstrated through Fig.4(a), 5(a) and 6(a) respectively using under empirical equation.

$$P = ((\phi\eta\sqrt{\beta}(1-G(s)+\beta)\,{}^{\delta}\!/_{\beta})\Gamma = \xi.\Gamma \qquad (15)$$

Here P =Output power in wind, solar or load system

ϕ =Stochastic component of power

β =Mean value of power

$G(s)$ = Low pass transfer function

η , δ = Constants help to normalize power

ξ = Factor to match p.u

Γ = Switching signal helps to dictate quick fluctuation of power.

In this regard due to variation in applied load the deviation in system frequency is depicted in Fig.4(b). Like this deviation in frequency response due to fluctuation in wind power and solar power are depicted in Fig.5(b) and Fig.6(b) respectively. All the simulated dynamic responses are obtained due to proposed Binary Dragonfly algorithm (BDA) based 3-DOF, 2-DOF and PID controllers.

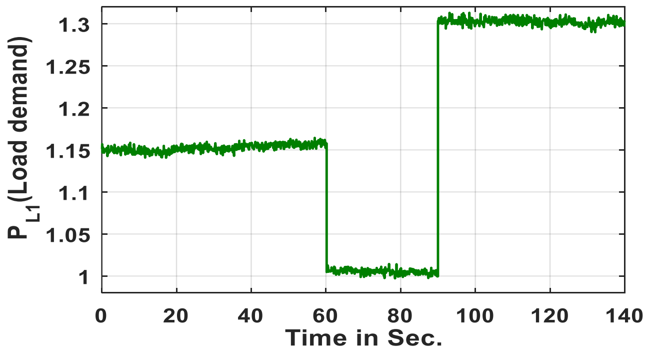

Fig.4(a) Variation of load (ΔP_L)

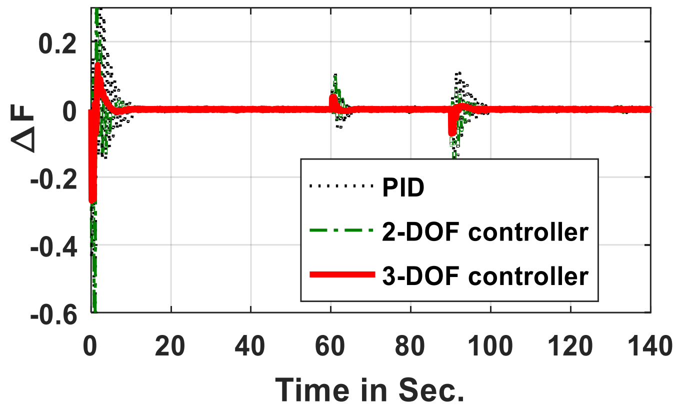

Fig. 4(b) Variation of frequency due to ΔP_L

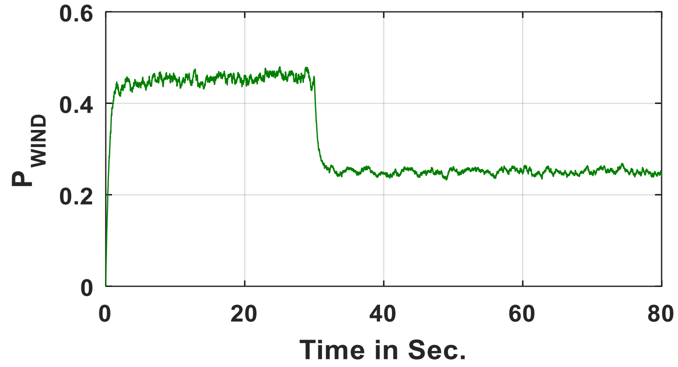

Fig. 5(a) Variation of wind power (ΔP_{WIND})

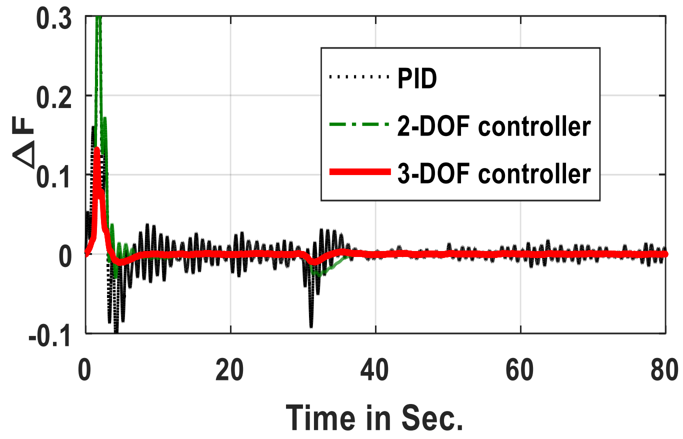

Fig. 5(b) Variation of frequency due to ΔP_W

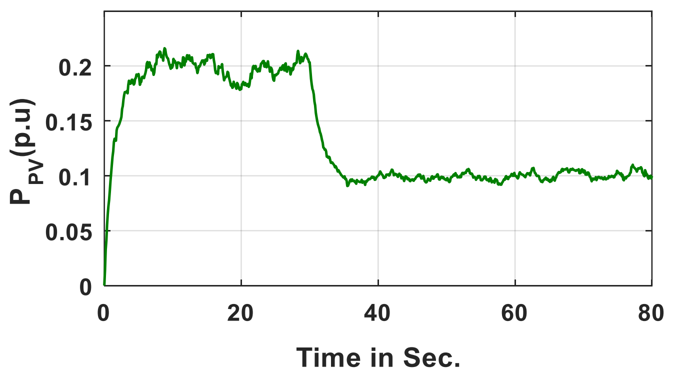

Fig. 6(a) Variation of solar irradiation power (ΔP_Φ)

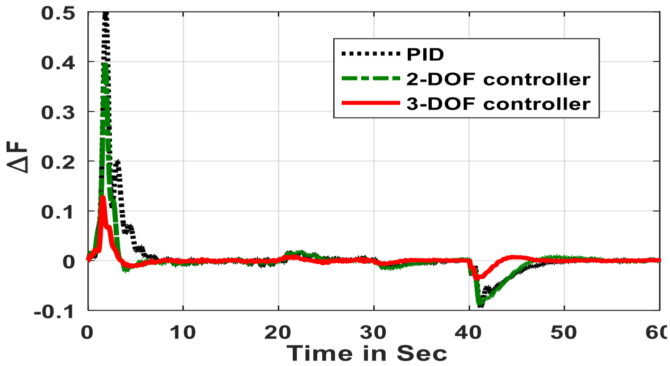

Fig. 6(b) Variation of frequency due to ΔP_{Φ}

Finally it has been noticed that our proposed BDA optimized3-DOF controller significantly improves all dynamic responses in regards to peak overshoot, peak undershoot and settling time of the resulted dynamic responses.

B. Controller Level

The dynamic behavior of an electric vehicle operated off-grid AC micro-grid system has been demonstrated under stochastic generated different uncertainty responses as well as generalized randomly generated uncertainty signals. This section specially highlights to the proposed optimal 3-DOF controller for micro-grid frequency control under randomly generated different uncertainty responses (**ΔP_L, ΔP_W and P_{Φ}**)

***Scenario-1*: Variation of only load (ΔP_L)**

To begin with the system performance is studied under randomly generated load perturbation which is shown in Fig.7(a). In this regard he deviation in frequency response of micro-grid system due to BDA optimized all three implemented controllers under such random load is depicted in Fig.7 (b) which reveals more effectiveness of proposed 3-DOF controller over 2-DOF and PID controllers.

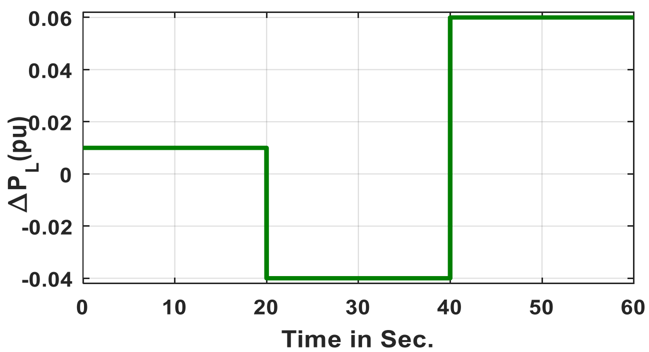

Fig.7(a) Variation of load (ΔP_L)

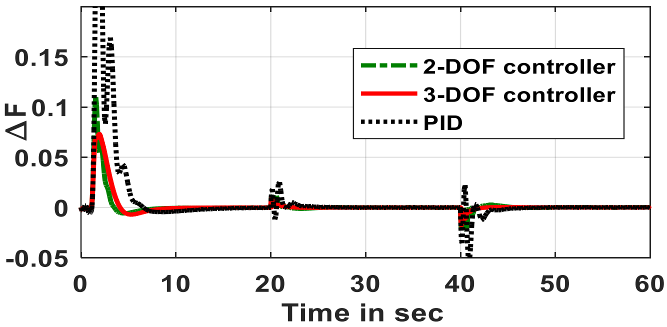

Fig. 7(b) Variation of frequency due to ΔP_L

***Scenario-2*: Fluctuation in wind power only (ΔP_W), ΔP_L=0, ΔP_{Φ}=0**

A randomly generated wind power shown in Fig.8 (a) is effected in micro-grid system to investigate frequency response of an islanded micro-grid system. In this regard the deviation in frequency response due to BDA optimized all implemented controllers under such uncertainty is illustrated in Fig.8 (b). The frequency response depicts improved performance of BDA optimized 3-DOF controller over 2-DOF and PID controllers.

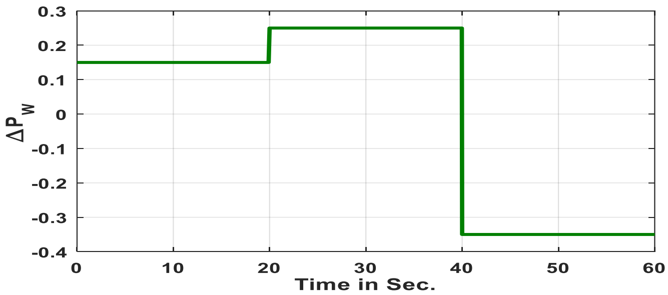

Fig. 8(a) Variation of wind power (ΔP_W)

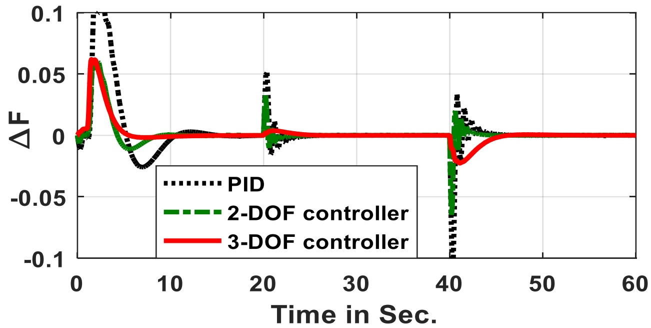

Fig. 8(b) Variation of frequency due to ΔP_W

The performance index values like peak overshoot, peak undershoot and settling time of dynamic frequency response shown in Fig.8(b) are gathered in table.3 along with respective ITAE values. A significant improvement in all performance values due to BAD optimized 3-DOF controller has been noticed in the table.3.

***Scenario-3*: Fluctuation in solar irradiation power only (ΔP_{Φ}), ΔP_L=0, ΔP_L=0**

This section specially aims to justify the viability of optimal 3-DOF controller over 2-DOF and PID controllers under variation of solar irradiation power which is depicted in Fig.9 (a). The time domain simulated frequency response is depicted in Fig.9 (b) which reveals supremacy of proposed BDA optimized 3-DOF controller.

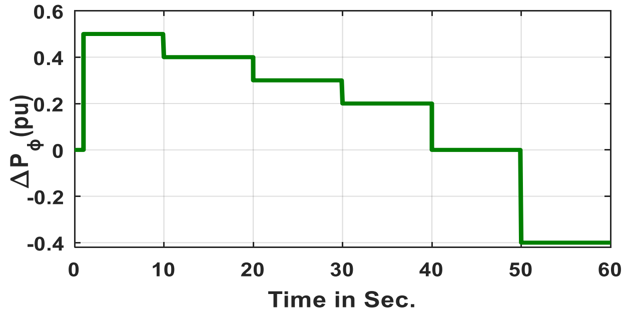

Fig. 9(a) Variation of solar irradiation power (ΔP_{Φ})

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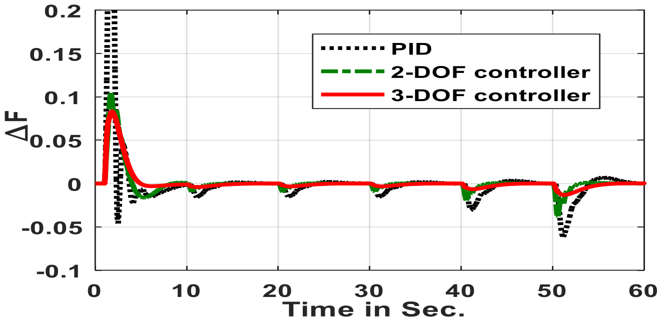

Fig. 9(b) Variation of frequency due to ΔP_{ϕ}

***Scenario-4*: Effectiveness of all three uncertainties simultaneously ($\Delta P_L + \Delta P_{W+}\, \Delta P_{\phi}$)**

Finally the dynamic performance of system is investigated under effectiveness of all three uncertainties i.e. ΔP_L, ΔP_W and ΔP_{ϕ} simultaneously and the combined response is illustrated in Fig.10 (a). Under such uncertainties the resulted deviation in frequency response is depicted in Fig.10 (b) which again confers supremacy of proposed 3-DOF controller in response to frequency control of an islanded micro-grid system

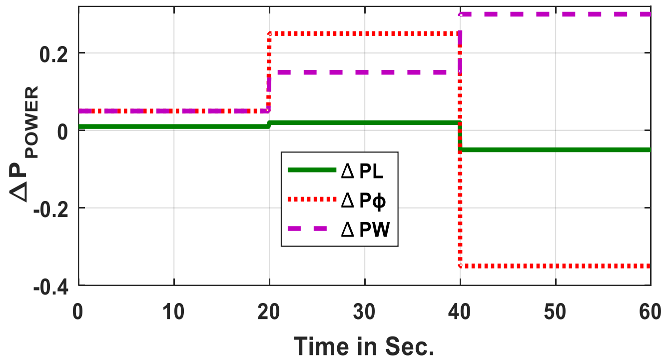

Fig. 10(a) Variation of three uncertainties ($\Delta P_L + \Delta P_{W+}$ ΔP_{ϕ})

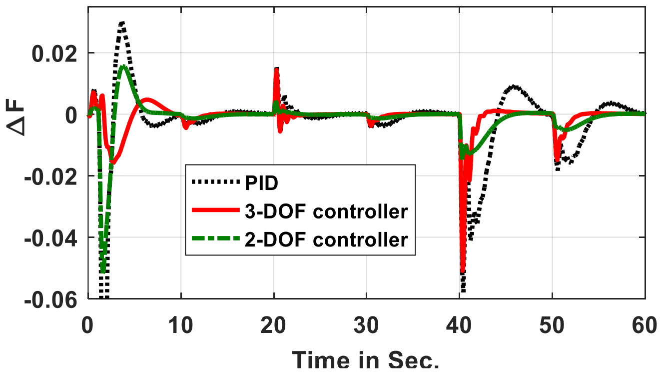

Fig. 10(b) frequency deviation

C. Technique Level

The viability of proposed Binary Dragonfly Algorithm (BDA) is justified through suitable comparative study among all implemented algorithms for this study. So this section specially focuses the effectiveness of proposed BDA technique over conventional PSO and GA techniques through simulated dynamic responses. In this regard for micro-grid control only proposed 3-DOF controller has been implemented to obtain respective dynamic responses of the system. To begin with all the three uncertainties i.e. variation in load (ΔP_L), fluctuation in wind power (ΔP_W) and solar power ($\Delta P\phi$) shown in Fig.7(a), Fig.8(a), and Fig.9(a) respectively are effected individually to investigate dynamic behaviour of an islanded AC micro-grid system.

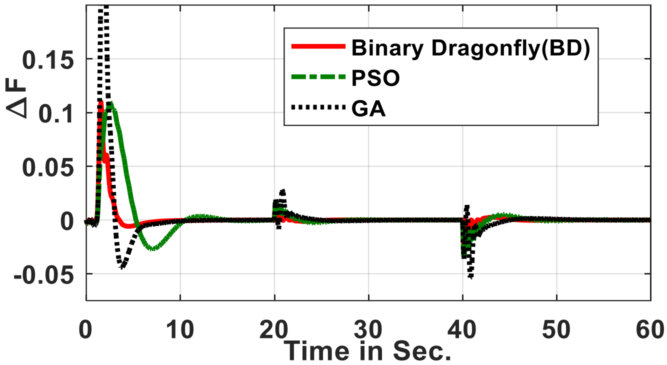

Fig. 11(a) Variation of frequency due to ΔP_L

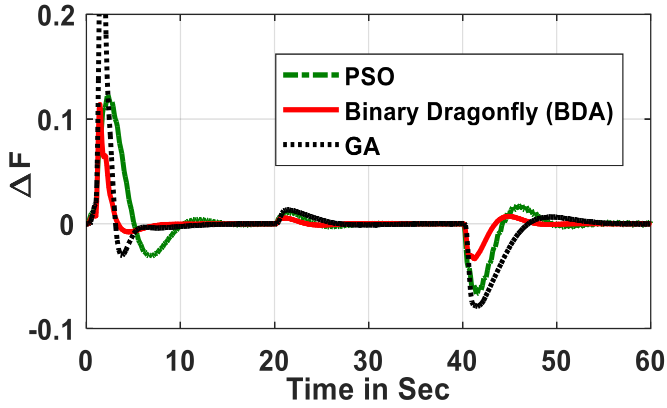

Fig. 11(b) Variation of frequency due to ΔP_W

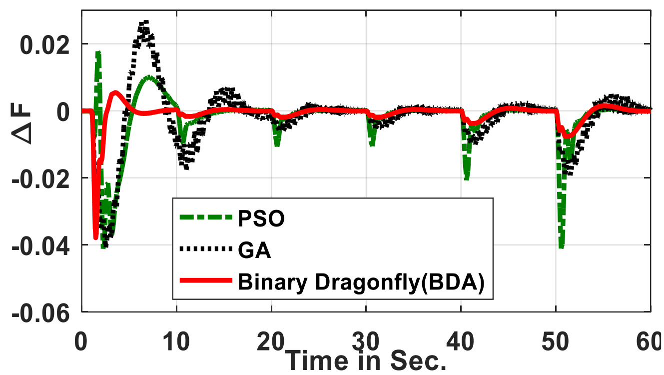

Fig. 12(a) Variation of tie-line power due to ΔP_{ϕ}

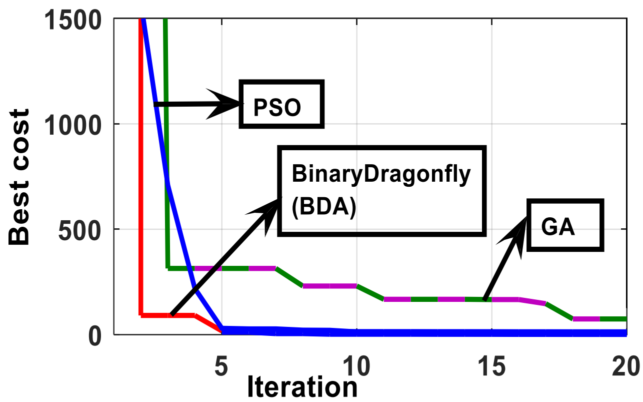

Fig. 12(b) Convergence curve

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Table.2 Optimal gain values of BDA optimized 3-DOF controller under different uncertainties

Area	Uncertainties	Proposed 3-DOF controller.						
		K_P	K_I	K_D	N	P_W	D_W	G_{FF}
EV based micro-grid area	ΔP_L	-1.9516	-0.9692	-1.9922	86.0808	0.0868	1.0832	0.0322
	ΔP_W	-1.9822	-1.7758	0.6898	91.1264	-1.2218	0.9864	0.0606
	ΔP_Φ	-1.6892	-1.9022	-1.1502	67.9934	0.9868	1.1122	0.9212
	$\Delta P_L+\Delta P_W+\Delta P_\Phi$	-1.8964	-1.9696	-1.7786	42.5454	1.2288	1.7842	0.0112

Table.3 Performance indices of different responses due to I-SSO optimized controllers

Controller/ Performance	3-DOF controller			2-DOF controller			PID Controller		
	Over shoot in Pu	Under shoot in Pu	Settling Time (Sec)	Over shoot in Pu	Under shoot in Pu	Settling Time (Sec)	Over shoot in Pu	Under shoot in Pu	Settling Time (Sec)
ΔF	0.06	-0.001	6.80	0.06	-0.01	7.92	0.12	-0.024	12.60
ITAE	8.8312			22.0652			32.1088		

Table.4 Optimal gain parameters of 3-DOF controller due to different techniques with respective ITAE values

Area	Technique	ITAE	3-DOF controller						
			K_P	K_I	K_D	N	P_W	D_W	G_{FF}
Microgrid with EV	GA	31.0158	-1.9988	-1.9696	-1.9902	92.0288	1.0212	0.9424	0.0628
	PSO	23.6332	-1.7978	-1.9498	-1.9822	76.1856	1.8018	1.2034	0.0956
	BDA	20.9682	-1.9706	-1.8568	-1.9814	88.0212	1.4514	1,0828	0.0212

In view of above responses, deviation in frequency response due to variation of applied load demand and fluctuation in wind power are depicted in Fig.11 (a) and Fig.11 (b) respectively however frequency deviation due to fluctuation in solar irradiation power and convergence curve of different implemented algorithms are depicted through Fig.12(a-b) respectively. The optimized gain parameters of proposed 3-DOF controller due to different techniques i.e proposed BDA, PSO and GA along with respective ITAE values are gathered in table.4. Finally critical analysis over different dynamic responses depicted in Fig.(11-12) and table.4 reveals more effectiveness of proposed BDA optimized 3-DOF controller over other approaches for micro-grid control under different uncertainties.

V. CONCLUSION

The research article has well addressed on frequency control of an electric vehicle operated off-grid micro-grid system with proposing a degree of freedom based optimal 3-DOF controller. The micro-grid system has been well organised with some distribution generation (DG) system to support reliable operation of power system. In this regard a novel Binary Dragonfly algorithm (BDA) has been proposed to optimize the gain parameters of proposed 3DOF-PID controller. The system dynamic performance has been examined by proposed BDA optimized 3DOF-PID controller under certain uncertainties like variation in applied load, fluctuation in wind and solar irradiation power. The performance of proposed optimal 3DOF-PID controller has been compared with 2DOF-PID and PID controllers to show effectiveness of proposed controller. Again the viability of proposed BDA technique has been observed with suitable comparative analysis over PSO and GA algorithm for micro-grid control mechanism. Overall analysis and critical discussion on different numerical results and dynamic responses confers supremacy of proposed BDA optimized 3-DOF controller for frequency control of an islanded micro-grid system.

Appendix

D_i = damping coefficient i^{th} area = 0,012 (pu/Hz); M_i = Inertia constant of i^{th}area = 0.2 (pu/s); i= 1,2;T_{FC} = Fuel Cell time constant = 4s; K_{FC} =1/5; T_{BES} = Battery energy time constant = 0.1s; K_{BES} = 1/300; T_{FES} = Flywheel energy storage time constant =0.1s; K_{FES} =1/100; T_d = Diesel engine generator time constant = 2s; T_{MT} = Micro-turbine time constant = 2s; K_{MT} =1 ; T_{WTG} = Wind turbine generator time constant = 1.5s; K_{WTG} = 1; T_{PV} = Photo Voltaic cell time constant = 1.8s ;K_{PV} = 1; T_{EV} = Time constant of Electric Vehicle =0.2s; K_{EV} =1/100; T_{AE} = Time constant of Aqua electrolyser = 0.5s; K_{AE} =1/25; R = Regulation =2.4 Hz/Mw

REFERENCES

1. A. M. Bouzid , J. M. Guerrero , A. Cheriti , M. Bouhamida , P. Sicard , and M. Benghanem, "A survey on control of electric power distributed generation systems for micro grid applications", Renewable and Sustainable Energy Reviews, vol.44, pp. 751-766, 2015.
2. Z. Wang, and M. Lemmon,"Stability analysis of weak rural electrification microgrids with droop-controlled rotational and electronic distributed generators" In Power & Energy Society General Meeting, IEEE, pp. 1-5, 2015.
3. U. R. Prasanna , and K. Rajashekara, "Fuel cell based hybrid power generation strategies for microgrid applications", In Industry Applications Society Annual Meeting, IEEE, pp. 1-7, 2015.

4. M. Patterson , N. F. Macia , and A. M. Kannan, "Hybrid microgrid model based on solar photovoltaic battery fuel cell system for intermittent load applications" IEEE Transactions on Energy Conversion, vol.30, No.1, pp. 359-366, 2015.
5. A. Merabet , K. T. Ahmed , H. Ibrahim , R. Beguenane , and A. M. Ghias, 'Energy management and control system for laboratory scale microgrid based wind-PV-battery', IEEE transactions on sustainable energy, vol.8, No.1, pp. 145-154, 2017
6. M. J. Hossain, , H. R. Pota , M. A. Mahmud , and M. Aldeen, "Robust control for power sharing in microgrids with low-inertia wind and PV generators", IEEE Transactions on Sustainable Energy, Vol.6, No.3, 1067-1077, 2015.
7. A. K. Arani , H. Karami , G. B. Gharehpetian , and M. S. A. Hejazi, "Review of Flywheel Energy Storage Systems structures and applications in power systems and micro grids", Renewable and Sustainable Energy Reviews, vol. 69, 9-18, 2017.
8. T. T. Nguyen, H. J. Yoo , and H. M. Kim, "A flywheel energy storage system based on a doubly fed induction machine and battery for micro grid control", Energies, Vol.8, No.6, 5074-5089, 2015.
9. J. Li , Y. Liu , and L. Wu, 'Optimal operation for community-based multi-party micro grid in grid-connected and islanded modes', IEEE Transactions on Smart Grid, vol.9, No.2, 756-765, 2018.
10. Z. Wang , B. Chen, and J. Wang, 'Decentralized energy management system for networked micro grids in grid-connected and islanded modes', IEEE Transactions on Smart Grid, vol.7, No.2, 1097-1105, 2016.
11. Y. Guo, J. Xiong , S. Xu, and W. Su, "Two-stage economic operation of microgrid-like electric vehicle parking deck", IEEE Transactions on Smart Grid, vol.7, No.3, pp.1703-1712, 2016.
12. J. M. Clairand, M. Arriaga, C. A. Canizares, and C. Alvarez, "Power Generation Planning of Galapagos' Microgrid Considering Electric Vehicles and Induction Stoves", IEEE Transactions on Sustainable Energy,2018
13. K. Selvam , and D. V. Kumar, "Frequency control of micro grid with wind perturbations using levy walks with spider monkey optimization algorithm", International Journal of Renewable Energy Research (IJRER), vol.7, No.1, pp.146-156, 2017.
14. H. Bevrani, F. Habibi , P. Babahajyani , M. Watanabe , and Y. Mitani, "Intelligent frequency control in an AC microgrid: Online PSO-based fuzzy tuning approach", IEEE transactions on smart grid, vol.3(4), pp.1935-1944. (2012)
15. M. M. Mafarja, D. Eleyan, I. Jaber , A. Hammouri, and S. Mirjalili, 'Binary dragonfly algorithm for feature selection', In New Trends in Computing Sciences (ICTCS), 2017 International Conference , pp. 12-17. IEEE, 2017.
16. S. Mohammadi , S. Soleymani , and B. Mozafari, "Scenario-based stochastic operation management of microgrid including wind, photovoltaic, micro-turbine, fuel cell and energy storage devices", International Journal of Electrical Power & Energy Systems, vol.54, 525-535, 2014.
17. D. J. Lee, and L. Wang, "Small-signal stability analysis of an autonomous hybrid renewable energy power generation/energy storage system part I: Time-domain simulations", IEEE Transactions on Energy Conversion, vol.23, No.1, pp.311-320, 2008.
18. A. Rahman, L. C. Saikia, and N. Sinha, "Load frequency control of a hydro-thermal system under deregulated environment using biogeography-based optimised three- degree-of-freedom integral-derivative controller", IET Generation, Transmission & Distribution, vol.9, No.15, pp. 2284-2293, 2015.
19. S. Mirjalili, "Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems", Neural Computing and Applications, vol.27(4), pp.1053-1073, 2016.
20. M. Mafarja, I. Aljarah , A. A. Heidari, H. Faris, P. Fournier-Viger , X. Li, and S. Mirjalili, "Binary dragonfly optimization for feature selection using time-varying transfer functions", Knowledge-Based Systems, 2018.

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