Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

Regulation of frequency by DBOA tuned PID controller in an interconnected hybrid microgrid

Vishwas.B
Department of Electrical and Electronics Engineering
Global Academy of Technology
Bengaluru, India
Vishwasb1ga19ee052@gmail.com

Darshan S
Department of Electrical and Electronics Engineering
Global Academy of Technology
Bengaluru, India
daaarshan62@gmail.com

Sunil P
Department of Electrical and Electronics Engineering
Global Academy of Technology
Bengaluru, India
sunilp1ga20ee408@gmail.com

Nihaarika D
Department of Electrical and Electronics Engineering
Global Academy of Technology
Bengaluru, India
nihaa01@gmail.com

Mausri Bhuyan
Department of Electrical and Electronics Engineering
Global Academy of Technology
Bengaluru, India
mausri@gmail.com

Smriti Jaiswal
Department of Electrical Engineering
NIT Silchar
Silchar, India
smriti_rs@ee.nits.ac.in

***Abstract*— Hybrid microgrid system powered by renewable energy has significant impact on production of electricity. It keeps varying with changing weather condition which makes the system unstable. To deal with this issue the proposed work investigates coordinated frequency control using an appropriate control approach. The interconnected hybrid system is modelled using a combined solar gas turbine, solar photovoltaic and biodiesel energized generator, together with refrigerator as the thermostatic load. Dynamic Butterfly Optimization Algorithm (DBOA) is applied to optimize the controller gains for effective frequency control. With PID controllers and other well-known optimization techniques, the frequency responses of the proposed microgrid are compared using MATLAB/Simulink. Finally, DBOA tuned PID controller is preferred to carry out three case reports. Finally, sensitivity analysis is performed to validate the system robustness.**

Keywords—Solar thermal system, solar photovoltaic, combined solar gas turbine, storage devices, optimization technique, Dynamic butterfly optimization

I. INTRODUCTION

The Renewable energy sources (RES) are the primary substitute in power sector unit for all countries of the world. The year 2021 was another record-breaking year for renewable energy, with an increase in installed power capacity of over 314 gigawatts (GW) [1].

The emission of harmful CO2 and greenhouses gases is the main reason for minimizing the usage of traditional power plants. Non-conventional energy sources (NCES) were developed as a remedy for the drawback of the traditional system. The concept of “generate locally, consume locally” is used to provide electricity to remote locations where it is impossible to generate it [2]. Microgrids can employ a variety of NCES. The most efficient for large scale production is solar thermal technology [3]. Many solar thermal systems have already been taken into consideration for microgrid studies, including the dish-Stirling [3], parabolic trough collector [4], linear Fresnel system [5], and solar tower [6]. But, use of such components in microgrid system has its own drawbacks that need to be dealt with. The output power is not always consistent and the frequency of the grid may significantly change in response to shifts in the supply and demand for power. To resolve such issue, load frequency control (LFC) and power regulation are therefore necessary [11]. LFC's primary objective is to keep the system's frequency stable.

Many scholars around the world have worked on LFC. For the LFC of an isolated system in paper [2] discusses the application of the chaotic crow search algorithm with an improved hybrid PD-TID fuzzy controller. Tuning the gains of PID controller using genetic algorithm isolated systems based on solar thermal energy are discussed [3]. In [4], an isolated hybrid microgrid system based on a parabolic trough solar thermal, wind energy, diesel set, and battery storage unit is proposed. [5,6] comprises of solar tower system along with bio renewable components for an interconnected system using Quasi-oppositional selfish-herd algorithm in [5] to optimize controllers and BOA optimized PFOID controller in [6]. [7] Discusses how to manage frequency in a unconnected hybrid system that uses wind, solar energy, microturbines, and fuel cells. The author of [8] has addressed an isolated hybrid system that uses solar, wind, diesel, rechargeable batteries, generators, and super magnetic energy storage (SMES). The authors in [9] consists of several planning, control, and operating approaches, each with benefits and drawbacks. Energy management control,

Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

operation and planning for both grid and isolated mode is portrayed [9]. The expression and evaluation of hierarchical control systems. Using microgrid primary control is crucial for comparing different control schemes, as well as for microgrid performance and system dependability [10]. The dependability and steadiness of power flow between sources and consumers are examined in [11], with a focus on local power distribution systems, particularly on RE resources and energy storage techniques. Systems using hybrid RE storage use software tools. An isolated system is modelled using solar PV biodiesel and biogas generator. Grasshopper optimization algorithm GOA is used to fine tune the PID controller, system response is studied by randomly changing the source and load condition [12].

For LFC analysis in single and multi-microgrid systems, a number of standard controllers have been studied, including PI[3], PID[8], PFOID [6], and 2DOF-PID[17] controllers. The hybrid fuzzy PD-TID and TID controllers are two recently created controllers for LFC of microgrid. The microgrid mainly depends on the performance of controllers. It's crucial to choose the right optimization tools while adjusting the controller's parameters. A few examples of the various metaheuristic algorithms are the genetic algorithm [3], mine blast algorithm [MBA] [4], quasi-oppositional selfish herd optimization (SHO) [5], butterfly optimization algorithm (BOA) [6], flower pollination algorithm (FPA) [8], and grasshopper optimization algorithm [12].The work discussed here relies on frequency regulation using a PID controller, and, as mentioned in the previous paragraph, the controller's parameters are tuned using PSO. The battery storage unit, BDEG, BGTG, and solar PV are the parts of microgrid system. The main goal of this research are:

- To study the system response of an interconnected microgrid tuned by DBOA algorithm.
- The use of DBOA to PID controller in an interconnected system is a novel technique.
- The system response is studied under varying source and load condition.
- Sensitivity analysis is performed to study the robustness of the system.

Table 1- Specification of the terms used

Specifications	Symbol	Standards
Time and gain quantity of SPV unit, respectively	K_{SPV},T_{SPV}	1.8,1
Lead time, lag time, valve actuator	X_C,Y_C,b_B ,	0.6,1s,0.05
Combustion reaction delay, biogas reaction delay, and BGTG unit discharge time constants	T_{CR}, T_{BG}, T_{BT}	0.01s,0.23s, 0.2s
Valve gain, valve actuator delay, engine gain and time constants of BDEG unit, correspondingly	K_{VA}, T_{VA}, K_{BE}, T_{BE}	1, 0.05 s, 1, 0.5 s
Gain and time quantity of BESS unit, respectively	K_{BESS}, T_{BESS}	0.0033, 0.1s
Gain of steam turbine, time quantity of steam turbine	K_{ST}, T_{ST}	1,0.3
Time and Gain quantity of receiver	T_{RV}, K_{RV}	1,4
Time and Gain quantity of heat exchanger	T_X, K_X	1,1
Time and Gain quantity of valve positioner	T_{VP}, K_{VP}	1,0.05
Time and Gain quantity of speed governor	T_{SG}, K_{SG}	0.6,1
Time and Gain quantity of fuel cell	T_{FC}, K_{FC}	0.01,0.23
Time and Gain quantity of SMESU	T_{SMESU}, K_{SMESU}	0.3, 0.12
Time and Gain quantity of RG	T_{RG}, K_{RG}	0.2456, -1
Damping factor and the system's inertia constant	D, M_{eq}	0.012, 0.2s

II. SYSTEM UNDER STUDY

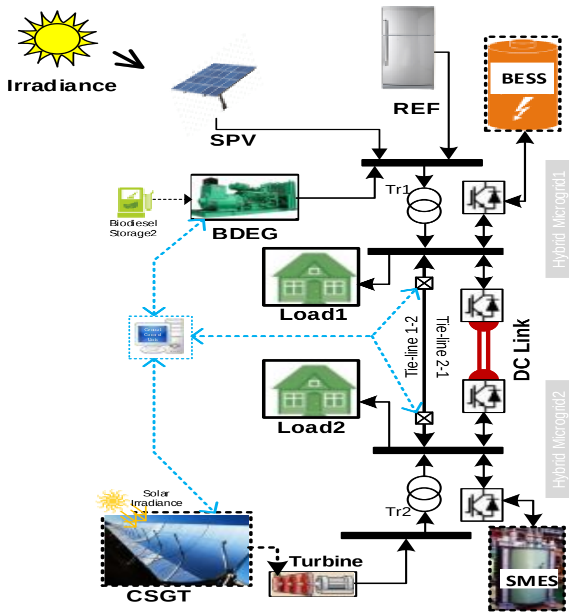


Fig.1: Proposed schematic diagram

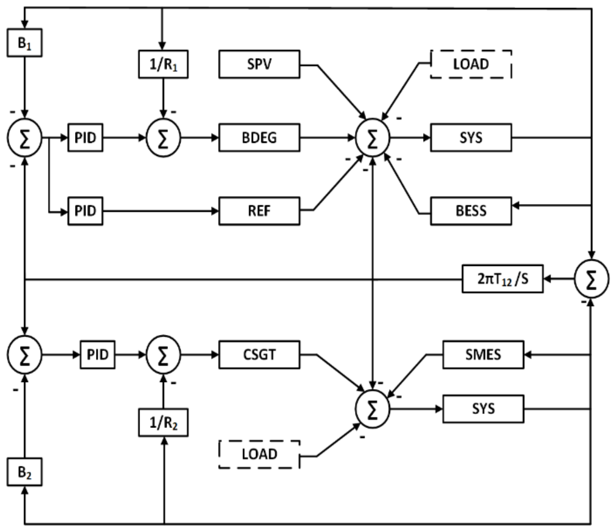


Fig 2: Linearized model of the system

Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

The analysis uses solar PV, a combined solar gas turbine (CSGT), a biogas turbine generator (BGTG), a biodiesel energized generator (BDEG), battery energy storage system (BESS) and super magnetic energy storage system (SMES). The specifications of the system used is given in Table 1. Figures 1 and 2 depict the proposed system's schematic model and linearized transfer function model, respectively.

A. Solar PV array (SPV)

Solar panels are constructed from solar cells, also known as photovoltaic cells, which are grounded together. Arrays [18] is the term used for such collection of panels. The arrays of solar PV panels are the majorly used solar photovoltaic system with maximum power point tracker [MPPT] [2]. For low frequency domain analysis, the SPV system's linearized transfer function model may be written as:

$$G_{SPV}(s) = \frac{K_{SPV}}{1+sT_{SPV}} \quad (1)$$

B. Biodiesel Energized Generator (BDEG)

From vegetable and animal fats, the biodiesel is extracted. Diesel-like characteristics can be found in this extracted biodiesel [12]. It can be used in conventional DEG in purified or blended form [12].The model of its linearized transfer function may be estimated as follows:

$$G_{BDEG}(s) = \left(\frac{K_{VA}}{1+sT_{VA}}\right)\left(\frac{K_{BE}}{1+sT_{BE}}\right) \quad (2)$$

C. Battery Energy Storage System (BESS)

The power vacillation is sometimes caused due to partially shaded SPV array by floating clouds, it results in frequency fluctuation and undesired switching of other linked devices in the microgrid [12]. In order to overcome this situation, BESS is used to manage short-time power fluctuation [12]. It can supply for a longer amount of time and has storage with a better energy density [3]. The BESS linearized transfer function model is written as follows:

$$G_{BESS}(s) = \frac{K_{BESS}}{1+sT_{BESS}} \quad (3)$$

D. Superconducting Magnetic Energy Storage Unit (SMESU)

A super conducting magnetic energy storage unit (SMESU) is a device that stores energy in a magnetic field created by a superconducting coil. It consists of a coil of superconducting material that is cooled to a very low temperature, usually with the help of liquid helium. When the coil is charged, it creates a magnetic field that stores energy. When the energy is needed, the magnetic field is discharged, and the stored energy is released. They have very high energy densities, meaning they can store a large amount of energy in a small volume. They also have very high efficiency, with charge/discharge losses typically less than 5%. They are also very fast, with charge/discharge times of less than a second. The transfer function of SMESU is as shown below

$$G_{SMESU} = \frac{K_{SMESU}}{1+sT_{SMESU}} \quad (4)$$

E. Refrigerator (RG)

The ability for quick withdrawal and the storage capacity of refrigerators makes them friendly, simple-to-use manageable loads. As they may be turned on when generation upsurges to absorb the extra energy and off when generation declines to maintain the microgrid frequency, RGs connected to RE significantly contribute to the system's stability. The transfer function is represented by the next expression.

$$G_{RG}(s) = \frac{K_{RG}}{1+sT_{RG}} \quad (5)$$

F. Combined Solar Gas Turbine (CSGT)

It comprises of solar thermal operation along with gas turbine. Fig 3, shows the CSGT serial scheme layout. Owing to the lack of heat exchange, thermal energy is delivered, the solar thermal system uses the air that is pumped into it from the compressor to heat it to the proper temperature. Less fuel is required to maintain the correct temperature for the operation of the turbine since this warm air is introduced into the combustion chamber. Such type of power plant meets the required load demand [18]. The following is an expression for the CSGT's transfer function:

$$G_{CSGT} = (G_{ST} + G_{BG})\left(\frac{K_{ST}}{sT_{ST}+1}\right) \quad (6)$$

Besides this, G_{ST} is the solar tower transfer function and G_{BG} is the bio gas turbine transfer function.

$$G_{ST}(s) = \left(\frac{K_{ST}}{1+sT_{RV}}\right)\left(\frac{K_{RV}}{1+sT_{RV}}\right)\left(\frac{K_X}{1+sT_X}\right) \quad (7)$$

$$G_{BG}(s) = \left(\frac{K_{VP}}{1+sT_{VP}}\right)\left(\frac{1+sK_{SG}}{1+sT_{SG}}\right)\left(\frac{1+sK_{FC}}{1+sT_{FC}}\right) \quad (8)$$

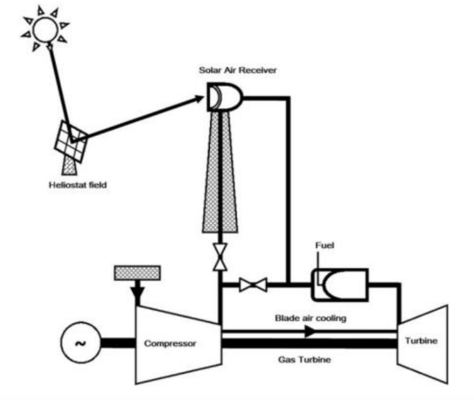


Fig 3. Serial scheme layout of CSGT

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

F. *System Dynamics Model*

The non-conventional power producers based on renewable resources are included in the proposed system, along with battery storage and power electronic converters. The difference between net generation and load demand, defined as the net change in power of the system at each time of area 1(P_{G1}) and area (P_{G2}), can be

$$P_{G1} = P_{SPV} + P_{BDEG} \pm P_{BESU} - P_{L1} - P_{T12} + P_{REF} \quad (9)$$

$$P_{G2} = P_{CGST} \pm P_{SMESU} - P_{L2} - P_{T21} \quad (10)$$

The overall transfer function of the system (G_{SYS}) is written as [19]

$$G_{SYS} = \frac{\Delta F_i}{\Delta P_E} = \frac{1}{D+sM_{eq}} \text{ ; i=1,2} \quad (11)$$

III. PROPOSED METHODOLOGY

A. *Formulation Of Objective Function*

In order to solve optimization problems, the objective function is essential, and the choice of the error function is crucial. The integral square error (ISE) of variation in frequency in both areas and tie-line power is chosen as the objective function whose equation is represented as

$$J_{ISE} = \int_0^T [(\Delta F_1)^2 + (\Delta F_2)^2 + (\Delta P_{tie})^2]dt \quad (12)$$

Where, J_{ISE} =Objective function minimized ΔF_1 & ΔF_2 = changes in frequency of area 1 and 2. ΔP_{tie}= Tie power change.

$$s.t.\ K_{C\,min} \le K_C \le K_{C\,max}$$

where, $K_{C\,min}$= lb and $K_{C\,max}$= ub

$$K_{P\,min} \le K_P \le K_{P\,max}$$
$$K_{I\,min} \le K_I \le K_{I\,max}$$
$$K_{D\,min} \le K_D \le K_{D\,max}$$

where K_P K_I, K_D are the least and greatest gain constants of the PID controller [19].

B. *Selection Of Optimization Algorithm*

Optimization algorithms are used to find the optimal solution to a wide range of problems in various fields. This hybrid model is optimized using PSO,BOA and DBOA for a PID controller. Fig 4 shows the convergence curve for these algorithms and DBOA is found to be superior amongst them.Fig 5 and 6 shows the frequency response of area 1 and area 2 whereas fig 7 shows the tie line power change. The overshoot, undershoot and settling time of the system is shown in Table 2. Table 3 shows the operating condition of proposed system, while table 4 shows the parameters of different algorithms and table 5 shows the optimized values of the controller.

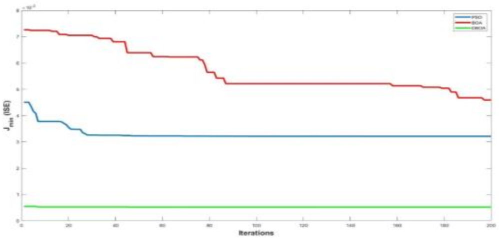


Fig 4. Convergence curve

Table 2: Parameters of PID controllers optimized by different algorithms

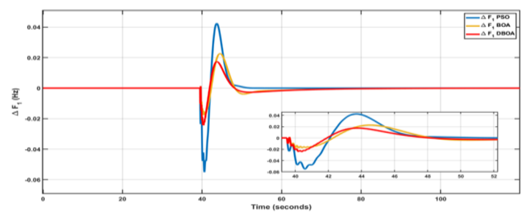
Algorithm		O_{SH} (Overshoot)	U_{SH} (Undershoot)	Settling time (T_{ST})
PSO	Area 1	0.0424	-0.0547	51.6
	Area 2	0.0418	-0.051	51.32
BOA	Area 1	0.0226	-0.172	76.34
	Area 2	0.0226	-0.0162	110.2
DBOA	Area 1	0.0173	-0.0234	77.03
	Area 2	0.0172	-0.0227	109.6

Table 3: Operating conditions of the proposed system

	Area 1	Area 2
System Component	Biodiesel engine generator, Refrigerator, Battery Energy Storage System, Solar Photo Voltaic	Combined Solar Thermal Gas Turbine, Super magnetic energy storage system.
Δ_{PL}	0.00,0s<t<40s 0.06,40s<t<120s	0.00,0s<t<40s 0.01,40s<t<120s
Δ_{PSPV}	0.00,0s<t<40s 0.01,40s<t<120s	-
Δ_{PCGST}	-	0.00,0s<t<40s 0.01,40s<t<120s

Table 4: Parameters for different algorithm

Algorithms	Year	Parameters
PSO (Latif et al. 2018)	1995	w=1, w_d=0.99, c_1=1.5, c_2=2.0
BOA (Latif et al. 2018)	2017	D=0.8, Y=0.1, M_s=0.1
DBOA (Tubishat et al. 2020)	2020	p=0.8, power exponent=0.1



Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

Fig 5: Frequency curve of Area 1

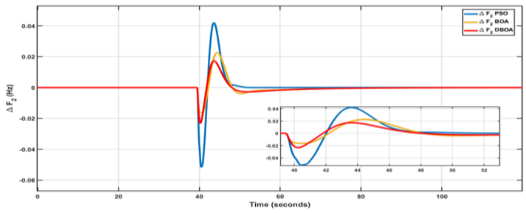


Fig 6: Frequency curve of Area 2

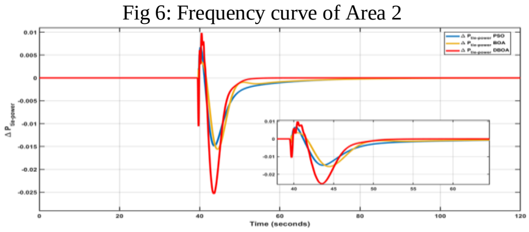


Fig 7: Tie power change

IV. DYNAMIC BUTTERFLY OPTIMIZATION

The Dynamic Butterfly Optimization Algorithm (DBOA) is a metaheuristic optimization algorithm inspired by the foraging behavior of butterflies. The flowchart of DBOA algorithm is shown in Fig 8.

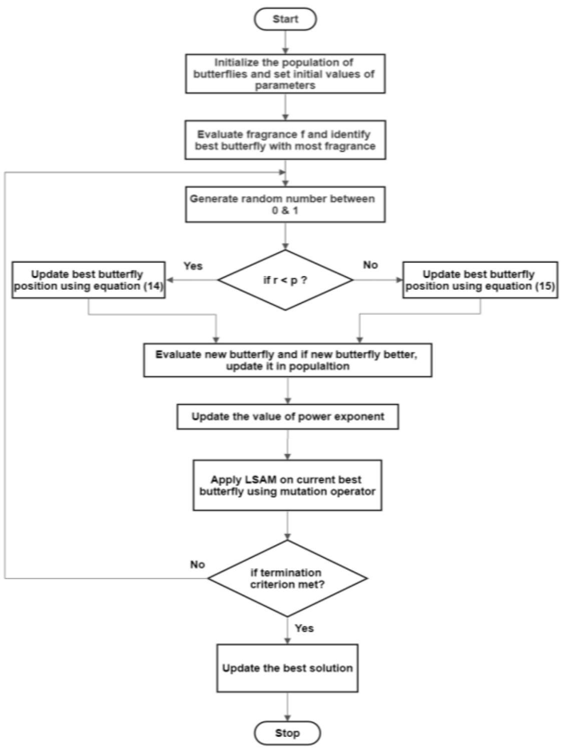


Fig 8: Flowchart algorithm of DBOA

The algorithm is based on the social foraging behavior of butterflies, which involves the coordination of individual movements to find food sources. The algorithm simulates this behavior by using a population of virtual butterflies, each representing a potential solution to the optimization problem.

In the DBOA, the population of butterflies is divided into groups, called sub-swarms, which move independently and explore different regions of the search space. Each sub-swarm consists of several butterflies that communicate with each other and exchange information about their current position and fitness value.

The algorithm also employs a dynamic update mechanism that adjusts the exploration and exploitation behavior of the sub-swarms based on the search progress. This allows the algorithm to balance between the exploration of the search space and the exploitation of promising regions.

The algorithm works in the following steps:

- *Initialization*: The algorithm starts by initializing a population of virtual butterflies. Each butterfly represents a potential solution to the optimization problem. In this algorithm the fragrance (f) can be given as [22]

$$f = MS^a \quad (13)$$

where M is the sensor modulus, S is the intensity of the stimulus, and a is the exponent of power that depends on M.

- *Sub-swarm formation*: The population of butterflies is divided into several sub-swarms. Each sub-swarm consists of several butterflies that communicate with each other and exchange information about their current position and fitness value.
- *Movement*: The butterflies in each sub-swarm move according to a set of rules based on the foraging behavior of real butterflies. The movement of each butterfly is determined by its current position, the position of the best butterfly in its sub-swarm, and the position of the global best butterfly in the population.
- *Update*: After each iteration, the fitness value of each butterfly is evaluated, and the positions of the best butterfly in each sub-swarm and the global best butterfly are updated.
- *Dynamic update*: The algorithm employs a dynamic update mechanism that adjusts the exploration and exploitation behavior of the sub-swarms based on the search progress. This allows the algorithm to balance between the exploration of the search space and the exploitation of promising regions.
- *Termination:* The algorithm terminates when a stopping criterion is met, such as reaching a maximum number of iterations or a desired level of solution quality.

The following are the global and local search expressions [22]

$$x_i^{t+1} = x_i^t + (r^2 \times g^* - x_i^t)f_i \quad (14)$$

$$x_i^{t+1} = x_i^t + (r^2 \times x_j^t - x_i^t)f_i \quad (15)$$

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05

Where g^* is the finest solution, f_i is the fragrance for the i^{th} butterfly, r is the arbitrary value, x_j^t is the j^{th} butterfly, and x^t_k is the kth butterfly in the solution plot.

Overall, the DBOA balances between exploration and exploitation to efficiently search the solution space and find the optimal solution for the given optimization problem.

V. SIMULATION AND CASE STUDY RESULTS

Utilizing MATLAB software, the proposed interconnected system is simulated. Areas 1 and 2 are linked, as shown in the Fig. 1. Area-1 comprises with solar photovoltaic modules, bio-diesel engine generator as source while area-2 comprises with combined solar gas turbine as sources. BESS and SMESU are the storage units and RG is the thermostatic load. Among all the algorithms, the implementation of the DBOA optimized PID controller is found to be most effective. To establish the same the convergence curve is shown in Fig 4. The frequency response is investigated using the mentioned ub and lb as well as tuning PID controller. The maximum number of iterations is taken as 200.

Table 5: Optimized parameters of different algorithm

	PSO	BOA	DBOA
J_{min}	0. 00321	0.00459	0.00051
K_{P1}	5.82970	8.32762	1.985
K_{I1}	0.4564	0.55625	0.7865
K_{D1}	9.6573	9.23509	1.9854
K_{P2}	2.9867	6.27910	6.8765
K_{I2}	4.6744	7.58315	3.7684
K_{D2}	0.9654	0.07536	0.3785
K_{P3}	9.99999	8.26881	3.9865
K_{I3}	9.99993	9.85611	8.2345
K_{D3}	0.61651	9.91870	0.1768

Table 6 - Computed statistical values and time.

	J_{max}	J_{min}	Compute time (sec)	Average
PSO	0.00622	0.00321	4291.7522	0.00496
BOA	0.00762	0.00459	6230.1685	0.00520
DBOA	0.00432	0.00051	3433.1144	0.00050

A. Case-1: With the Assistance of all the Generating Units

In this case, the interconnected hybrid model is supplied by all the considered sources and also equipped with the storing units. The contribution of all the modules along with frequency and tie-power is shown in figure 9. A sudden increase in load occurs at t = 40s because of which overshoot and undershoot is observed in the range of ±0.025 at t = 40s and gradually settling at 75s and 80s for area-1 and area-2 respectively.

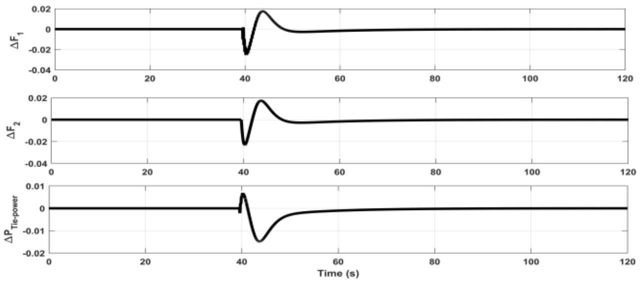


Fig 9: Frequency and tie power response of area 1 and area 2 when all the components are in working state

B. Case-2: In The Absence Of Storage Unit

In this case, the intermittency problem of the renewable power can be seen due to the absence of storage units. During the load change t = 40s the frequency of the system changes as seen in figure 10. It is observed that the system starts to settle from 80s in both area-1 and area-2. In tie-line power curve the frequency starts to settle at 70s.

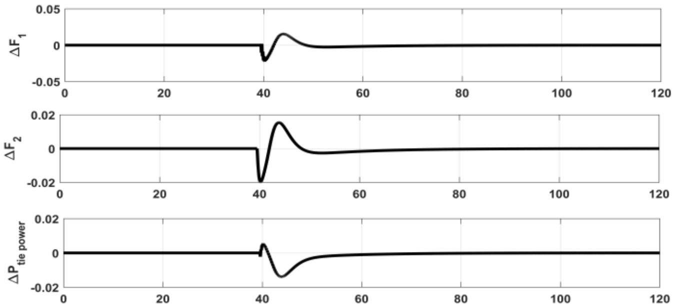
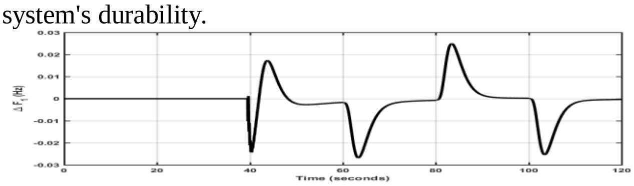


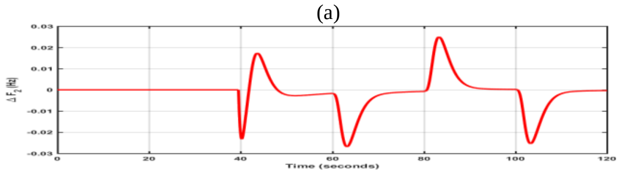
Fig 10: Frequency and tie power response of area 1 and area 2 in absence of storage units

C. Case-3: Sensitivity analysis

In this case the system is exposed to numerous assumed natural changes and the frequency and tie power the reaction is studied and found to be satisfactory. Figure 11, portrays the change in frequency and tie power response of the system. The frequency fluctuations compared to the original step loading condition and it is found that the system is stable even under such unfavorable conditions, exhibiting the system's durability.

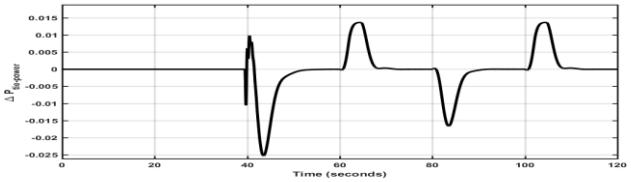


(a)



(b)

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 6- Issue 2, August 2023
Paper : 05



(c)

Fig 11: (a) Frequency response of area 1 (b) Frequency response of area 2 (c) Tie power response of the system

VI. CONCLUSION

The study examines a interconnected hybrid system that includes a solar PV, a biodiesel engine generator, a combined solar gas turbine, and energy storage systems. Case studies and analysis have been used to assess the effectiveness of DBOA optimized PID controllers. The system responsiveness minimized objective function, overshoot, undershoot, frequency variation, and settling time are all compared. Finally, sensitivity analysis is performed that proves the robustness of the DBOA tuned PID controller. The work can be further extended by performing case studies on some real time datas. New controllers and optimization algorithms can also be considered.

REFERENCES

[1] https://www.ren21.net/what-are-the-current-trends-in-renewable-energy/accessed on 11th February 2023.

[2] B. Khokhar, S. Dahiya, and K. P. S. Parmar, “A novel hybrid fuzzy PD-TID controller for load frequency control of a standalone microgrid,” Arab. J. Sci. Eng., Vol. 46, pp. 1053–65, 2021.

[3] D. C. Das, N. Sinha, and A. K. Roy, “Small signal stability analysis of dish-Stirling solar thermal based autonomous hybrid energy system,” Int. J. Electr Power Energy Syst, Vol. 63, pp. 485–98, 2014.

[4] S. Ranjan, D. C. Das, S. Behera, and N. Sinha, “Parabolic trough solar–thermal–wind–diesel isolated hybrid power system: active power/frequency control analysis,” IET Renew. Power Gener, Vol. 12, no. 16, pp. 1893–903, 2018.

[5] A. K. Barik, and D. C. Das, “Proficient load-frequency regulation of demand response supported bio-renewable cogeneration-based hybrid microgrids with quasi oppositional selfish-herd optimization,” IETGener. Transm. Distr, Vol. 13, no. 13, pp. 2889–98, 2019.

[6] A. Latif, D. C. Das, A. K. Barik, and S. Ranjan, “Maiden coordinated load frequency control strategy for ST-AWECGEC-BDDG based independent three area interconnected microgrid system with combined effect of diverse energy storage and DC link using BOA optimized PFOID controller,” IET Renew. Power Gener, Vol. 13, no. 14, pp.2634–46, 2019.

[7] R.K.Khadanga, S. Padhy, S. Panda, and A.Kumar, “Design and analysis of tilt integral derivative controller for frequency control in an islanded microgrid: A novel hybrid dragonfly and pattern search algorithm approach,” Arab. J. Sci. Eng., Vol. 43, pp. 3103–14, 2018.

[8] I. Hussain, S. Ranjan, D. C. Das, and N. Sinha, “Performance analysis of flower pollination algorithm optimized PID controller for wind - PV- SMES - BESS – diesel autonomous hybrid power system,” Int. J. Renew. Energy Res, Vol. 7, no. 2, pp. 643–51, 2017.

[9] F.S Al-Ismail “DC Microgrid Planning, Operation, and Control: A Comprehensive Review”, IEEE Access, 2021.

[10] 10.1109/ACCESS.2021.3062840D. Razmi, Tianguang Lu, “A literature review of the control challenges of distributed energy based on microgrids(MG’s): Past, Present and Future”, Energies 2022, 15, 4676., 10.3390/en15134676.

[11] Z.Ahmad et.al, “Control of distributed generation systems for microgrid applications: A technological review”, International Transactions on Electrical Energy Systems, 2019, DOI: 10.1002/2050-7038.12072, Wiley Online Library.

[12] A.K.Barik, D.C.Das, “Expeditious frequency control of solar photovoltaic/ biogas/biodiesel generator based isolated renewable microgrid using Grasshopper Optimization Algorithm”, IET Renewable Power Generation, 2018, DOI: 10.1049/iet-rpg.2018.5196

[13] H. H. Al-Kayiem, and O. C. Aja, “Historic and recent progress in solar chimney power plant enhancing technologies,” Renew. Sustain. Energy Rev,Vol. 58, pp. 1269–92, 2016.

[14] J. Buzás, and R. Kicsiny, “Transfer functions of solar collectors for dynamical analysis and control design,” Renew. Energy, Vol. 68, pp. 146–55, 2014.

[15] J.D Spelling, “Hybrid solar gas turbine power plant- A thermos-economic analysis”, Ph.D. thesis, KTH Royal Institute of Technology, 2013.

[16] V. K. Singh, A. Verma, and T. S. Bhatti, “Interconnection of rural microgrids and its control,” IETE J. Res, 2021. DOI:10.1080/03772063.2021.1875271.

[17] S. Mishra, R. C. Prusty, and S. Panda, “Design and analysis of 2DOF-PID controller for frequency regulation of multi-microgrid using hybrid dragonfly and pattern search algorithm,” J. Control Autom. Electr. Syst, Vol. 31, pp.813–27, 2020.

[18] https://www.sunrun.com/go-solar-center/solar-terms/definition/solar-array accessed on 8th March 2023.

[19] A. K. Barik and D. Chandra Das, "Optimal Load-frequency Regulation of BioRenewable Cogeneration based Interconnected Hybrid Microgrids with Demand Response Support," 2018 15th IEEE India Council International Conference (INDICON), Coimbatore, India, 2018, pp. 1-6, doi: 10.1109/INDICON45594.2018.8987124..

[20] Ibrahim, Rehab Ali, et al. "Improved salp swarm algorithm based on particle swarm optimization for feature selection." *Journal of Ambient Intelligence and Humanized Computing* 10 (2019): 3155-3169.

[21] https://images.app.goo.gl/aGWr6CQUmCa2wAub9

[22] M. Bhuyan, D Das & Amar Kumar Barik (2022) Combined voltage and frequency response in a solar thermal system with thermostatically controlled loads in an isolated hybrid microgrid scheme, International Journal of Sustainable Energy, 41:11, 2020-2043, DOI: 10.1080/14786451.2022.2126842