Power Quality Enhancement and Coordination Control of a Microgrid System connected to a Grid using Hybrid Optimization Approach

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2023 International Conference on Power, Instrumentation, Energy and Control (PIECON) | 979-8-3503-9976-9/23/$31.00 ©2023 IEEE | DOI: 10.1109/PIECON56912.2023.10085750

***Abstract*- The intermittent characteristic of the distribution network challenges its stability and the control effectiveness of the Micro Grids (MG) in both grid-connected and autonomous modes. Optimal strategy for power control based on Hybrid Approach for stability enhancement of Hybrid Renewable Energy Sources (HRES) connected smart grid system which consists of Photo-Voltaic (PV), Controllable Loads, Battery Energy Storage System (BESS) and Wind Turbine (WT), through real-time self-tuning method is furnished in this paper. The Elephant Herd Optimization (EHO), which imitates social behavior of elephants, is a newly tendered swarm intelligence and population-based optimization algorithm. Although EHO is good at local search, it is not effective on the global search. In this study, in order to overcome these problems and to provide a balance between exploration and exploitation, Elephant Herd Optimization (EHO) using Cuckoo Search (CS) Algorithm has been proposed. The principal objective of the suggested approach is to attain maximal power as well as stability within the system by optimally tuning parameters of a propound controller. The proposed model has been executed in MATLAB/Simulink platform. The final outcomes reveal that the recommended controller tenders a magnificent retaliation to assure the power quality prerequisites and has more robust performance. To appraise the efficacy of the recommended method, it has been juxtaposed with Artificial Bee Colony (ABC) & Particle Swarm Optimization (PSO) techniques.**

Keywords- Stability Enhancement, Micro Grid (MG), Wind Turbine (WT), Elephant Herd Optimization (EHO), Cuckoo Search Algorithm (CS), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC) Optimization.

I. INTRODUCTION

Active clusters based on Distributed Generators (DG), energy storage systems and loads, and additional on-site electrical elements [1] are the major components of MG. MGs may be designed as a smart grid network using two different operating methods: isolated mode for the local power generation and grid connected mode with a capability necessary to re-sell energy to the grid or to acquire energy from the grid, whenever required [2].The primary grid can take care the power shortfall of the neighborhood loads, and the surplus power produced within a Micro Grid can impart supplemental services to a network partner in Grid-connected mode. Energy produced within a Micro Grid, both effective as well as passive, is in harmony with the local charges offered to ensure device sustainability in the islanded mode [4]. In such undertakings, the two technologies - Grid-Fed as well as Off-Grid are appealing to the Renewable Energy Sources (RES), viz wind, solar, hydro along with biomass. Deregulation and large amount of Distributed Energy Resources (DER) within the partner network are changing significantly during the production process of power systems [7]. DERs in some instances are based on different techniques that enable tiny scale production (micro inputs) retrieving advantages of RES. Figure 1 reveal a microgrid embracing the storage units, loads & energy units.

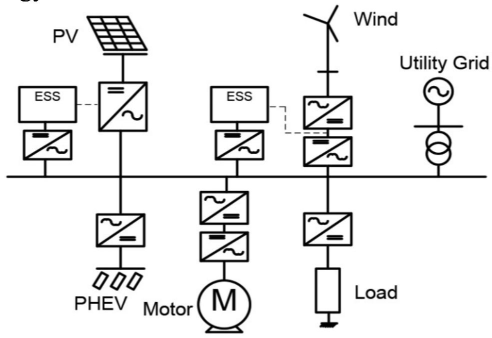

Fig. 1. A sample Microgrid structure [5]

In recent years, the major focus is on the cooperation of PV systems and energy storage [9]. A coordinated control approach was set for the Frequency-Bus-Signaling (FBS) method that modified the Energy Storage System (ESS) to an adequate degree on bus frequency, when the charge level was close to limit and the injected power is reduced by the DG controller [10]. Multiple MGs may include an intelligent delivery scheme [12]. For smoothness in switchover operations and synchronization of grids, the reverse droop based PLL approach is implemented [13]. Renewable energy with the MG framework is handled intermittently and randomly. BESS, the distribution controllable batteries, the integrated natural engines and electric supplies are all included in the MG. The Micro Grid Control (MGC) can also be used to address the problems of continuous cooperation and ensures a secure scheme method.

Nature inclined "metaheuristic algorithms" are nowadays the gracing resolutions for minimizing / maximizing non-differentiable and non-linear function like GA, PSO, but suffering from untimely convergence. More efficacious "swarm intelligence algorithms" have been propounded, such as "Artificial Bee Colony (ABC)", "Cuckoo Search (CS)", "Bat Algorithm (BA)", "Firefly Algorithm", "Ant Lion optimizer (ALO)", "Big Bang – Big Crunch Algorithm (BB-BC)", "Charged System Search (CSS)", "Chaotic Swarming of Particles (CSP)", "Monarch Butterfly Optimization (MBO)", "Krill Herd (KH)", "Earthworm Optimization Algorithm (EWA)", "Multi-Verse Optimizer (MVO)", "Dragonfly Algorithm (DA)", "Grey Wolf Optimizer (GWO)", "Wolf Search Algorithm (WSA)", among many others. These are influenced by the swarm behavior of honeybees, cuckoos, bats, fireflies, animals, butterflies, krill and wolves, respectively [19]. Thus, Swarm-based heuristic search method influenced by the herding characteristic of elephant cluster, known as "Elephant Herding Optimization (EHO)", is suggested for resolving global optimization tasks.

"Cuckoo Search", a nature inclined algorithm is one of various algorithms used enormously to enhance different fields of engineering. It is efficacious in resolving global issues as it can sustain the balance within local & global unplanned walks using switching parameters. The "CS Algorithm" is more computationally efficient than PSO and it has great junction speed to come to the superlative solution. Although, EHO is good at local search, it is not so effective on the global search due to the rapid loss of population diversity. Thereby, to overcome the said problem, EHO with CS Algorithm is proposed.

In this work, a hybrid technique based coordinated control is used for regulating the system's stability in MG. The primary contribution of the paper is that desired maximum output is attained by the suggested method. Also, stability is enhanced and the system exhibited a robust performance as the authors are able to accomplish satisfying results where smoothening of grid current is attained [20]. The paper is systemized as per the following sections: System description and the suggested approach is formulated in Section II and III whereas, section IV iterates its simulated outcomes. Further, section V culminates the proposed hybrid technique.

II. SYSTEM STRUCTURE AND DESCRIPTION

The Micro Grid has micro sources comprehending a Photo-Voltaic, a Wind Turbine, and a Battery. To overcome load requirement of the patrons, Wind Turbine and the Photo-Voltaic are employed to generate power. Photo-Voltaic panels are continuously enhancing & expanding the respective efficiency, whereas, the spasmodic energy generation form is still Photo-Voltaic. Excess power is saved in the storage devices whilst the load requirement is low as compared to the generated power since the energy is already stored in the battery. Hence, to meet the load & functional requirements of the actual application, a storage system is required.

In this presented work, the microgrid model has 66 single-phased parallel, 305 W output Photo-Voltaic arrays, a 6.6Ah battery power bank and 3 single-phase domestic loads. To supply power during the shortage of generated output, Micro Grid and battery power banks are positioned as an assistance with Photo-Voltaic arrays & Wind Turbines to work as the paramount DG units. To set the voltage as well as frequency in a Micro-Grid, PR controller & VMDPC controller is utilized for the BESS and RES respectively that shall inoculate its maximal power to the MG. A utility grid is connected with the MG through a 400 KVA, 260/25 kV distribution transformer. V_d stands for the DC-link voltage. To eradicate high frequency harmonics produced by an inverter, LC filter represented by L_f and C_f is applied.

MG is normally a combination of renewable micro sources situated near the load center. Within a MG, it is necessary to improve stabilization to control the active & reactive power of an individual distributed generator and to perform a smooth task. The proposed methodology enables sharing of power and also keeps up the equilibrium between the power generated and its demand. Thus, the principal objective of this paper is accomplishing the stability improvement and achieving maximum power in the MG system with upgraded EHO with CS algorithm. CS Algorithm is required as an assistant for the improved EHO technique which is being used for assessing the voltage, current and power in a coordinated control structure.

III. PROPOSED CONTROL METHODOLOGY

An efficient Hybrid Technique (Elephant Herd Optimization with Cuckoo Search Algorithm) based coordinated control is presented in the paper to show power flow stability enhancement of the HRESs connected smart grid system which consists of PV, WT, BESS and Controllable Loads [22].

A. Objective Function of proposed methodology

The objective is to maximize the generated power which is required to fulfil the demand at the load side in the suggested system. This task may be appropriately arranged as an optimization concern and its solution can be attained via suggested EHO and CS algorithm. Mathematically, the objective function can then be written as in below equation (7),
Maximize

$$F(obj) = Max(P_G = P^*) \tag{1}$$

Here, objective function is denoted by $F(obj)$, P_G is the power generated whereas P^* is the power required.

Proposed hybrid technique makes use of the inputs of PV and WT i.e., Irradiance, Temperature and Wind Speed to optimally tune the parameters of the PI controller through numerous iterations performed with the ease of a function called "fitness function" (calculated with the combined execution of EHO and CS techniques) which aids in achieving the desired results i.e., a balanced maximum output.

B. Elephant Herd Optimization (EHO) with Cuckoo Search (CS) Algorithm

Description of the basic EHO is given as per the following rules [27]:

1. Matriarch is led by different clans of elephants living together. Number of elephants are fixed in every clan. Therefore, for modelling purpose, we are assuming that there is equal no. of elephants in every clan.
2. Depending upon the elephant's relationship with the matriarch, their positions in a clan are updated. EHO thus represents this behavior of elephants using an updating operator.
3. Family groups are left by the matured male elephants to live alone. Assuming that fixed no. of male elephants leaves the clan every generation, EHO represents the process of updating and accordingly utilizing the separating operator.
4. Usually, eldest female elephant is a matriarch in every clan, hence, for representing & solving the optimization concerns, the most suitable elephant in the clan i.e., the matriarch is considered.

The primary objective of this paper being improvement in the updating process of EHO, the subsection beneath, will explain in depth details of the updating operator used in EHO as originally presented.

To update elephant's position in EHO algorithm, CS algorithm is being used. Initially, PV power, irradiance, temperature, wind speed, wind power and battery power is given as the input of the EHO algorithm post which, the DC link voltage, generated power, grid current and voltage is determined.

Algorithm steps of Elephant Herd Optimization are mathematically described as following:

Below equation is being used to update the elephant's position in every clan,

$$E^i_{new,cj} = E^i_{cj} + A * \left(E_{best,cj} - E^i_{cj}\right) * r \qquad (2)$$

Where, the updated position is $E^i_{new,cj}$, the prior position of elephant 'I' in the clan 'c_j' is E^i_{cj} and matriarch of the clan c_j is denoted by $E_{best,cj}$; which is the fittest of all elephant in the clan. A∈, the scale factor [0, 1]; determines the influence of the matriarch of c_j on E^i_{cj}. r∈ [0, 1], a stochastic distribution, is capable to provide a remarkable improvement for the heterogeneity of the population in the later search phase. For the current work, a constant distribution is used.

Post that, Equation (9) and (10) describes the updating of fittest elephant's position in every clan.

$$E^i_{new,cj} = B * E_{center,cj} \qquad (3)$$

$$E_{center,cj} = \sum_{i=1}^{n} E^{i,d}_{cj} / \eta e \qquad (4)$$

The center of clan c_j, $E_{center,cj}$ can be deliberated for the d^{th} dimension through D calculations, where D is the total dimension. Here, $1 \leq d \leq D$ represents the d^{th} dimension, η_{cj} is the no. of elephants in clan c_j, and $E^{i,d}_{cj}$ is the dth dimension of the individual E^i_{cj} and β∈ [0, 1].

Separation of the worse elephants within the clan is performed using equation (11),

$$E^i_{worst,cj} = E_{min} + (E_{\max} - E_{\min} + 1) * rand() \qquad (5)$$

Where, $E_{\min}$ and $E_{\max}$ are the lower and upper bound, respectively, of the orientation of respective elephants, $E^i_{worst,cj}$ being the worst elephant in clan c_j. Rand∈ [0, 1] being a stochastic distribution, and the uniform distribution in the range [0, 1] is used in our present work.

Arrangement of the respective elephant within the clan is updated based on the equations shown above [37]. Whilst, the convergence nature is impacted in complex problems, using this algorithm. Updating and prediction of the best result is failed by the worse elephants updating function. Hence, in order to update the arrangement of elephants and corresponding worse elephants, more structured technique i.e., CS algorithm is required and thus used in the paper. On contrasting it with the traditional EHO method, it is observed that more accurate results are obtained. The flowchart of EHO with CS algorithm is illustrated in the below Figure 2.

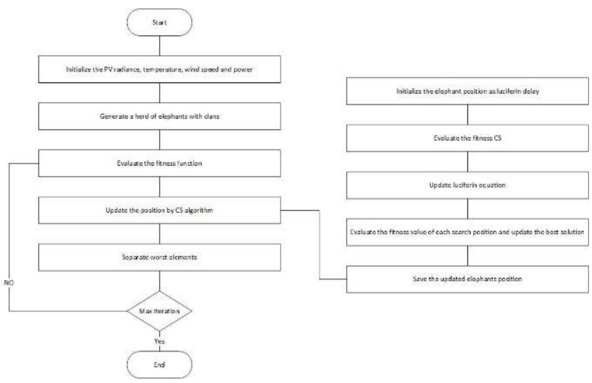

Fig. 2. Proposed flowchart of EHO with CS Algorithm

IV. DISCUSSIONS AND SIMULATION RESULTS

The suggested hybrid method is a combination of EHO and CS algorithm, which optimizes the gain values K_p and K_i of the PI controller for stability enhancement in the proposed MG system. Intel(R) i7 core (TM), 4 GB

RAM machine and MATLAB / Simulink 7.10.0 (R2018a) platform is used for simulation of MG system. Figure 3 illustrates configuration of the suggested MG Simulink model, whereas Figure VI depicts the Simulink model employed with the control system.

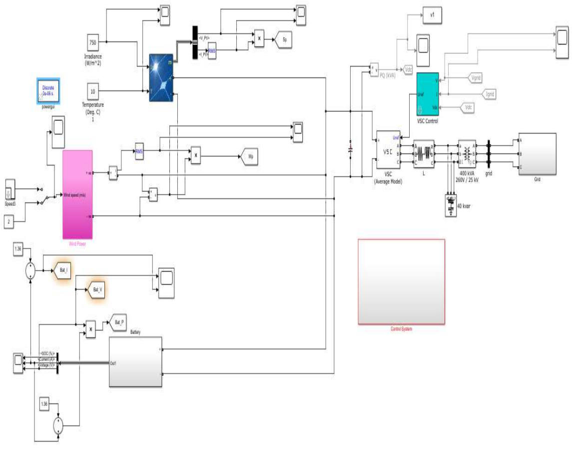

Fig. 3. Configuration of the suggested MG Simulink model

Simulation results are found and scrutinized in two different cases as described in the following sections:

Case 1: When EHO based technique is applied to the MG model

Initially, only EHO based code is executed with the Simulink model to investigate the performance capabilities of the suggested MG design. As a result, the accomplishment of power balance is achieved with the help of EHO based technique. This method could control the DC link voltage in microgrid, thereby enhancing the power management.

The initial implementation parameters considered while performing simulation are taken from standard reference papers [32] and are compiled under Table 1. The values of the model parameters such as series resistance, shunt resistance, etc. are calculated from the Simulink model considered and are listed in Table 1.

Table 1. Implementation parameters considered for the Microgrid System

Microgrid Parameters	Values
Generator's speed	1.2 *(rpm)*
Battery Rated capacity	6.6 *Ah*
Shunt Resistance	269.5934 *(Ohms)*
Series Resistance	0.37152 *(Ohms)*
Output Power	10 *KW*
System Frequency	50 Hz
Transformer Rating	400 kVA, 260/25 kV
Irradiance	750 W/m^2
Temperature	10 °C
Wind Speed	2 m/s
PV Voltage	138 V
PV Current	900 A
Battery Voltage	30.85 V
Wind Current	0.57 A

The simulation has been performed with an assumption that the input in PV array is higher than the wind speed.

Irradiance, temperature and speed of the wind are considered as the input parameters to the PV array and wind turbine. The values considered/taken for simulation purpose are from standard research papers studied as referred in [32] and is shown in Table 1.

Controlling parameters which are voltage, current and power, are thus evaluated from MG model.

Table 2 presents the values of different parameters considered for execution of EHO algorithm. Iterations performed based on EHO technique optimizes the values of PI controller's gains employed and the results for DC-link voltage and Grid current are obtained as shown in Figures 4 and 5.

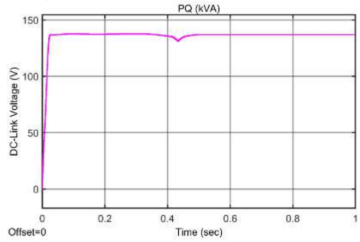

Fig. 4 EHO-DC Link Voltage

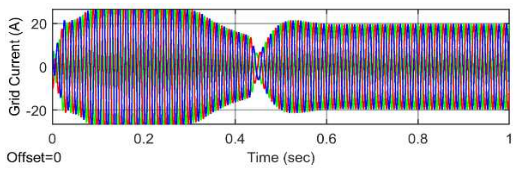

Fig. 5. EHO- Grid Current

Further, as evident from Figure 4, at time t = 1 sec, the DC link voltage is 138V which is at steady state and a minor dip is observed between 0.4 to 0.5 seconds. Also, Figure 5 (which varies from -20A to 20A) depicts a dip in value of current between 0.4 to 0.5 seconds which is because of fast unjustified convergence of EHO algorithm towards the origin and the inappropriate balance between exploration and exploitation; thus, this subject is therefore regarded as a major defect of EHO that needs to be improvised.

Table 2. Parameters taken in EHO algorithm [31]

EHO Parameters	Values
Alpha(α)	0.5
Dimension	3
Beta(β)	0.1
Number of iterations	100
Maximum Generation	10

Table 3. Parameters taken in CS algorithm [31]

CS Parameters	Values
Population size	50
No of variables	6
No of iterations	10
Lower limits	1
Upper limits	100

Case 2: When the proposed hybrid technique is applied to MG model

The proposed hybrid technique is applied to Simulink model, which blends the advantages of both, EHO and CS algorithm. This is done in order to overcome the disadvantage witnessed in Case 1.

Table 3 presents the values of different parameters considered for execution of CS algorithm.

The parameters (voltage, current and power) and values of inputs in the model are taken the same as in Case 1, referring Table 1.

The model is made to run and the graphs of DC link voltage and grid current are obtained as shown in Figures 6 and 7.

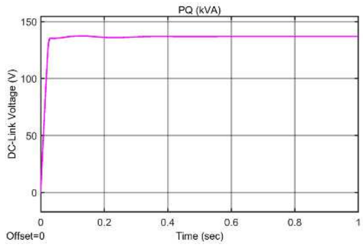

Fig. 6. DC Link Voltage – Hybrid Technique

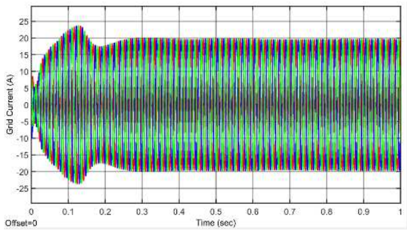

Fig. 7. Grid Current – Hybrid Technique

The results of hybrid technique-based simulation illustrates that a steady straight line in DC link voltage is achieved without any ripples between 0.4 to 0.5 seconds. Also, it is observed that there is no dip in grid current between the same intervals. This helps in attaining the smoothing of current which enables more stable and robust performance of the considered system.

To cope up with the load demand of the grid, Photo-Voltaic and Wind generated power is used. Based upon the mode of operation, maximum power is attained utilizing the battery with an objective to remunerate the load demand by attaining the maximum power from MG as well as stabilizing it. Residual power during the generation after compensating the load demand depends upon the storage process. Thus, the required and generated power are stabilized at the appropriated reference values to maintain the load power value at its required value of 10 kW which is equally compensated by the generated power as shown in Figures 8 and 9.

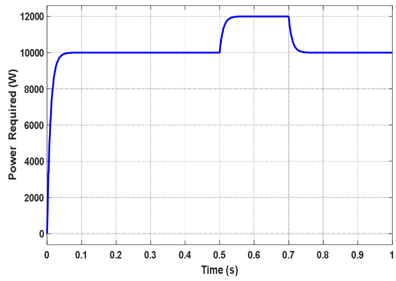

Fig. 8. Required Power at 10 kW

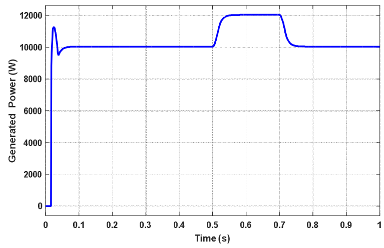

Fig. 9. Power Generated at 10 kW

A. COMPARISON ANALYSIS

The comparison analysis is done to conclude the effectiveness of the presented hybrid technique. The performance analysis of Particle Swarm Optimization (PSO) and Artificial Bee Colony optimization (ABC) and the suggested hybrid technique is compared and is shown in Figure 10.

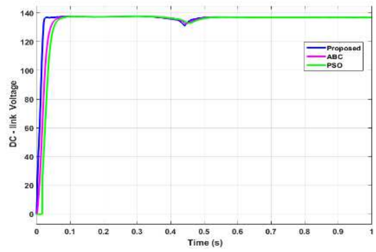

Fig. 10. Comparison analysis – Suggested Hybrid Approach with PSO and ABC Techniques

The potency of the suggested hybrid technique is calculated as per the value of settling time. As per the pictorial representation, the suggested algorithm has a higher efficacy as compared with the other two techniques. Figure 10 depicts that the proposed technique's, ABC method's and the PSO method's settling time at 138V is t=0.04 sec, t=0.055 sec and t=0.065 sec, respectively. The suggested techniques meet the required voltage level and maintains a constant when DC link voltage is 138 V, whereas the two existing methods do not meet the constant value of the DC link voltage.

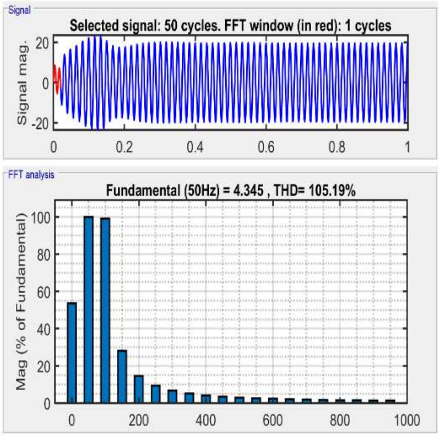

Fig. 11. Performance analysis of THD in current in proposed techniques

Table 4. Comparison analysis of THD % (current) in proposed and existing techniques

Parameter	**Existing Techniques**				**Suggested method**
	CCIs- and VCIs-based hybrid power systems [35]	Active damping method [36]	PSO	ABC	
THD (%)	5.81%	5.45%	5.50%	5.10%	4.345%

The assessment study of THD in current in the proposed technique is shown in Figure 11. Table 4 shows the comparison analysis of the THD in proposed & existing techniques. The existing methods – "Current-Controlled Inverter (CCI) and a Voltage-Controlled Inverter (VCI) method", "active damping method", "PSO and ABC methods" are having the THD percent as 5.81, 5.45, 5.50 and 5.10 respectively. The proposed method has 4.345%, hence it is better in harmonic elimination when differentiated with the existing methods.

V. CONCLUSION

In this presented paper, a MG consisting of PV, WT, BESS and controllable loads is furnished and studied in detail. To attain maximum stability and power in the system, a hybrid approach i.e., Elephant Herd Optimization with Cuckoo Search Algorithm has been proposed, which is used to optimally tune the controller parameters. The presented MG & its control strategy have been verified under two test cases. The results have shown that the furnished approach is able to operate accurately and maintains the stability at grid-connected mode of operation. It also offers an outstanding response to reassure the power quality requirements and has more robust performance. The proposed optimization control technique is employed to control voltage, current, power, and to support the grid demand with maximum possible generated power. A constant and smooth DC link voltage is obtained that aided in smoothening of output in the grid, which is one of the foremost requirements of any power system, and is thus an added advantage of the proposed method used over the other existing approaches. Eventually, results demonstrate that the propound method has accomplished the required objectives and adequate results are found when contrasted with other existing techniques i.e., ABC and PSO algorithms.

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