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RESEARCH ARTICLE OPEN ACCESS

An Improved MultiobjectiveControl Technique for Wind-PV Hybrid DC Microgrid System Considering Storage

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ABSTRACT:
Microgrids have paved way to integrate renewable energy system to the existing power system. Over the years due to the intermittent nature of the renewables the need for storage system has alleviated to supply uninterrupted power to the load. Batter is quiet popular as energy stirage system (ESS) and is ewmployed in this study. This paper proposes a novel control topology of hybrid wind and solar energy systems operating in standalone mode. The results depicts that power is delivered at minimum cost mainataining the state of charge of the ESS along with the dc link voltage. A multiobjective function is developed for cost minimization and energy management strategy. A hybrid Moth Optimization Water Cycle Algorithm (MOWCA) is proposed which gives better performance over convention Genetic Algorithm (GA) and Particle Swarm Optimization (PSO).

Keywords- Microgrid,PV, Wind, BESS, MOWCA.

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I. INTRODUCTION

With the advancement of the universe, the ned of electricity has increased enormously. Traditionally coal based thermal power plants are the major source of electricity generation. With the depletion of coal and other conventional energy sources, the need for a renewable based generation has arisen tremendously.[1-2] The intermittent nature of renewable sources like solar wind has caused a hindrance in their usage.[3] Moreover to generate a large amount of electricity for huge load requirements is extremely difficult using renewable sources. This has led to the decreased structure of the grid and hence microgrid [4] is proposed to alleviate the impact of this problem [5]. Previous research has shown that in remote areas, that this method can make the reliability of power system better. [6, 7]. Many studies have been conducted in recent years to determine the best design and sizing of microgrid systems to minimisethe cost of the life cycle of the system and providing better power quality[8–11].HOMER [12] and HYBRID [13] are two powerful optimal design software tools that have been developed. The sporadic nature of renewables has given a major challenge to the researchers to deliver optimal power to the utility[14]. Many studies were conducted to minimise the cost of generation as well as to maximise the environmental impact [15]. In [16] multiobjective function is proposed to minimise cost and improve system reliability. A microgrid can operate both in islanded and stand alone mode [17]. The major objective is to deliver optimal power with minimization of the cost of generation along with improving network security [18]. In [19] made a trade-off between three competing goals: system reliability, electricity production cost, and environmental impact. In [20] optimised the design of a hybrid renewable energy scheme (WT/PV/BAT) using forecast load information rather than past data to reduce the scheme's TLCC.

The microgrid optimal scheduling model, on the other hand, is a multi-constrained, multi-objective problem. This problem is being addressed using a variety of approaches. One of the most popular approach is to formulate a single objective function combining all the objectives [21] by weighted sum method.There are other methods which are also employed seamelessly like mixed integer method [22], min max approach [23] space optimization [24]. Most of the multiobjective problems have mutually exclusive decision variables and hence meta-heuristic methods are applied to solve the non-linear functions. Moreover to search a global optimum amidst a huge search area and to achieve fast convergence with the highest accuracy proposed a real challenge to the research world using conventional techniques. This has led to the rise of bio-inspired evolutionary programming [26] methods like Genetic Algorithm (GA). Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) etc. To solve multiobjective multi constrained problem a set of Pareto solutions is obtained using the weightage factor and further hybrid optimization techniques are used to converge the problem with fast accuracy. In few research fuzzy [27] sets are used to find the non dominated state but most of the problems lack proper decision making accounting for all the non-linear objectives. Microgrid normally comprises of distributed generator (DG) [28] as source and, maybe connected with main grid or can work in stand-alone mode. Several works are reported with multiple generating sources such as solar wind hydro and in few works, a backup storage device is reported to store energy during excess generation. This increases the reliability of the power supply especially during peak hours however the cost of the storage device invites additional costs to the system.

In this paper, the cost optimization of a standalone microgrid is presented using the hybrid Moth Optimization Water Cycle Algorithm (MOWCA. The system comprises Solar Photo Voltaic (PV), Wind Energy as renewable energy sources and Battery Energy Storage System (BESS). The proposed algorithm is compared with existing standard algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for justification of its superiority.

II. SYSTEM MODELLING

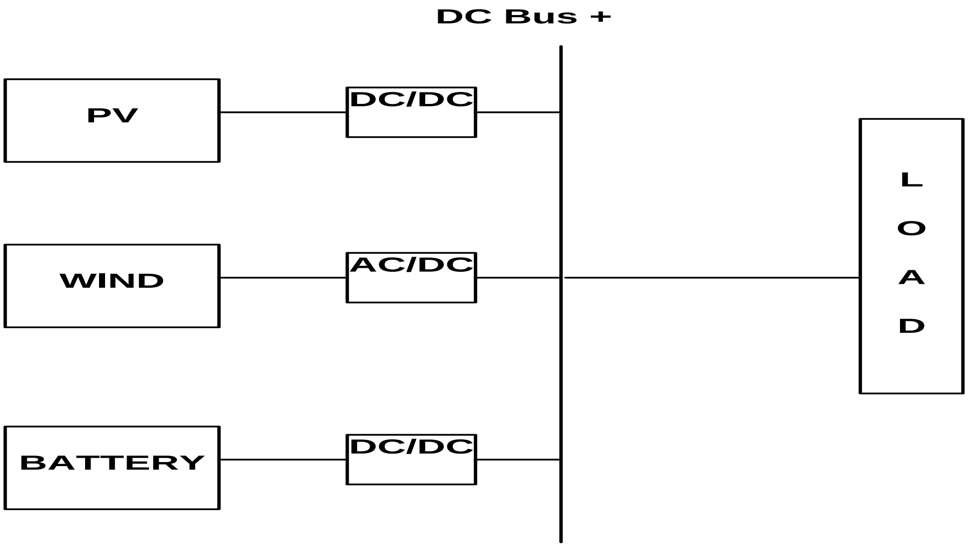


Fig 1: Proposed Microgrid System

2.1. Solar energy system

The output power of PV generating unit is expressed as a function of incident irradiance G and cell temperature T using the following formula [29]

$$P_{PV} = F_{PV} \times P_{PV,R} \times \frac{G}{G_{STC}} [1 + \alpha_T (T - T_{STC})] (1)$$

where:

FPV is the factor reflecting shading, and wiring losses,

α_T represents the temperature coefficient, and

G_{STC} and T_{STC} represent the incident irradiance and the PV cell temperature under Standard Test Conditions, respectively.

2.2. Wind System

MPPT algorithm is implemented to extract maximum power from available variable wind speed. The basic nature of Wind Turbine is non-linear and is represented by the Weibull distribution function

The power developed by a wind turbine is given by: [30]

$$P_m = \frac{1}{2} \rho A C_P (\lambda) V^3 (2)$$

Where,

$$\lambda = \frac{r_m \omega_r}{V_w} (3)$$

Pm =Mechanical Power(W);

Cp = power coefficient; Vw =Wind velocity (m/s);

The general variation of wind speed can be characterized by Weibull Distribution Function which is given as [28].

$$F(v) = 1 - \exp\left(-\left(\frac{V}{C}\right)^{\sigma}\right) (4)$$

$$v = c[-\ln(1-r))]^{\frac{1}{\sigma}} (5)$$

$$v = c[-\ln(r)]^{\frac{1}{\sigma}} \quad (6)$$

where σ is shape factor, c is scale factor, v is wind speed in m/sec and, r is uniform random number. The values of c and r obtained from the localised data. The power output of the turbine can be calculated as

$$P_{WT}(v) = \begin{cases} 0, & v < v_{ci} \\ P_{rated} \times \frac{v - v_{ci}}{v_r - v_{ci}} & v_{ci} \le v \le v_r \\ P_{rated} & v_r \le v < v_{co} \\ 0 & v \ge v_{co} \end{cases} \quad (7)$$

wherevci, vr , and vco are cut-in, rated, and cut-out speeds respectively, PWT is the output power of WT, and Prated is the rated power of WT.

2.3. Battery Module

The storage system for the microgrid is managed by BESS which has Battery Monitoring System to ensure the safe operation of each battery units and supervisory control to monitor the overall function of the module. Normally a BESS module of several battery units which have individual charging and discharging pattern. The main control objective of the BESS module is to maintain the overall charging and discharging as determined by the power management algorithm for the supply of power in case of peak demand or to store energy in case of excess generation [31].

2.4. State of Charge (SOC) Computation Module

The amount of charge stored in a battery is given by SOC which is given by the percentage of total charge stored in a battery and indicates the amount of energy left in the storage unit. Based on the SOC of the BESS unit operation modes are decided and signals are generated following the knowledge of SOC. Based on Coloumb technique a computing module of SoC is developed. The charge stored in a battery is the integration of the current injected into the battery, we have[32].

$$Q(t) = Q(t-1) + \Delta Q(t) \quad (8)$$

Where

$$\Delta Q(t) = I_B(t)\Delta(t) = \frac{P_B(t)}{V_{DC}(t)}\Delta(t) \quad (9)$$

Where, QB(t), IB(t), PB(t) and VDC are the charge stored in, current and power injected to, and dc-link voltage of the battery module, respectively. SOC can be derived by (15) where SizeB identifies battery size in kWh.

$$SOC(t) = SOC(t-1) + \frac{1}{3.6}\frac{1}{SIZE_B}\frac{P_B(t)}{V_{DC}(t)}\Delta(t) \quad (10)$$

III. MULTIOBJECTIVE OPTIMIZATION MODEL

To establish the proposed method a multiobjective function is developed taking into account the battery depreciation cost, generation cost and the cost related to environmental aspects.

$$\min(Cx) = C_g(x) + C_b(x) + C_e(x) \quad (11)$$

Where Cg is the generation cost, Cb battery cost and Ce is the environmental cost.

$$Cg(x) = \sum_{t=1}^{T} C_F(x) + C_m(x) \quad (12)$$

Where CF is the fuel cost of all the generating units and CM is the maintenance cost of the generating units and T is the number of time intervals in the optimization period, which is 24 hours.

The output from the battery is chosen as a decision variable since the power output from the solar and the wind system are intermittent in nature. The decision variable is represented in 24 vector based on the time interval.

3.1. Environmental Cost.

Another major parameter that is considered is environmental pollution

$$minC_e = \sum_{t=1}^{T}\sum_{t=1}^{n}\sum_{j=1}^{4}[(\gamma_{1j} + \gamma_{2j})B_{ij}P_{i,t}] \quad (13)$$

where t is the time interval; T is the total number periods, here T = 24; n is the total number of renewable generators; j is the type of pollutant,; γ_{1j} and γ_{2j} are penalty costs and environmental values of pollutant j, respectively; Bij represents emission of the pollutant j from renewable generatorI per unit of power generation; and Pi,t represents the power generated by renewable generatorI in period t.

3.2.*Constraint Conditions*.

The system is considered for power balance and the limits of generation hence following constraints are employed,

Total generation should be greater than equals to the load:

Pload (t)=PPv(t)+Pw(t)+Pbat(t) (14)

wherePload(t) is the load demand, Pbat(t) is the power output from battery module and Ppv(t) and Pwt(t) are the power output from PV and wind turbine respectively.

0 ≤Ppv(t) ≤Ppv,max,

0≤Pwt(t) ≤Pwt,max,

wherePpv,max and Pwt,max are the maximum output power of PV and wind system, respectively.

The constraints of battery system are

SOCmin ≤SOC(t) ≤SOCmax,

-Pbat,max ≤Pbat(t) ≤Pbat,max

wherePbat,max is the maximum power of charging and discharging the battery; SOCmin and SOCmax are the minimum and maximum limits of SoC respectively.

IV. HYBRID WATER CYCLE MOTH-FLAME OPTIMIZATION (WCMFO) ALGORITHM [33]

The movement of streams and waves are employed in Water Cycle Algorithm (WCA). It is a search solution based algorithm where the waves of the seas and rivers updates their positions concerning the best locations. But it has a limitation of identifying an operator which can perform exploitation. Moth Flame Optimization (MFO) [35] mimics the operation of moths in search of flames. This inherently gives a capacity for exploitation but it cannot traverse and utilise the search space effectively. Hence it has a good exploitation technique but poor space utilization. This has been attributed to creating a hybrid algorithm of Water Cycle Moth-Flame Optimization (WCMFO) combining the dominant complementary nature of both the algorithms. WCA is taken as the standard algorithm and modifications is done to it. The first modification is incorporating the spiral movements of the moths in the streams and waves so that they can update their position. In conventional WCA the space between the rivers and streams is used as the search criteria hence lacks exploitation. But with the introduction of the spiral searching of moths towards the flame exploitation of total space is introduced hence it can search the entire region.

Randomization is another aspect that plays a vital role in metaheuristic algorithms. Raining process in conventional WCA plays the role of randomization. In the hybrid topology raining process is updated when the space or distance between sea and stream is less than a predefined maximum distancedmax, the WCMFO undergoes raining to create new solutions. Another method is to allow to fill the sea using random behaviourlike (Levy flight). During an iteration in WCA if the solution is updated but the best solution is not reached it wont update its position ultil the next iteration. This increases the search time. In the proposed hybrid algorithm to introduce randomization streams are updated as per Lavy Flight equation as

xi+1 = xi + Levy(dim) ⊗ xi (15)

where xi+1 is the next position of the stream, xi is the current position of the stream and dim is the dimension of the problem or number of the decision variables. The Levy flight is calculated using below formula

$$Levy(x) = \frac{0.01 \times \sigma \times r_1}{\left| r_2^{\frac{1}{\beta}} \right|} \quad (16)$$

where r1 and r2 are randomly generated numbers between 0 and 1. In the above formulation, the parameter σ is calculated.

$$\sigma = \left(\frac{r(1+\beta) \times sin\frac{\pi\beta}{2}}{r\frac{(1+\beta)}{2} \times \beta \times 2^{\frac{\beta-1}{2}}} \right) (17)$$

V. RESULTS AND DISCUSSION

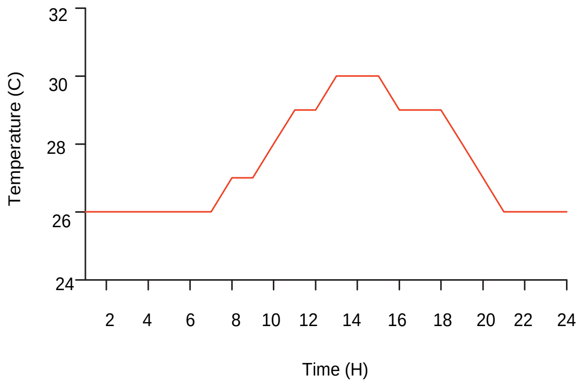
The proposed multiobjective function is tested in an islanded microgrid of PV, Wind and BESS connected in islanded mode. Optimal solution is obtained using Hybrid WCMFO and the results are placed in Table 2 The system parameters atre given in Tale 1(a) and 1 (b) respectively.

Table 1(a): Operating parameters of the microgrid systemTable 1(b). System Parameters

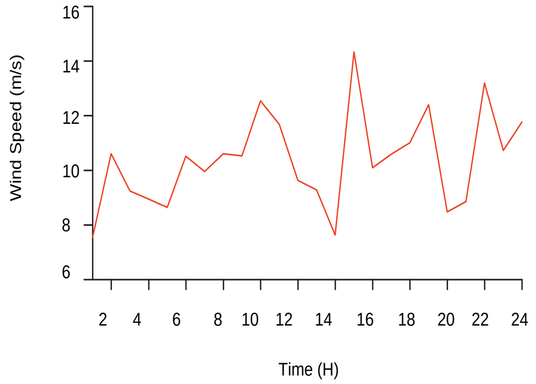
Type	Pmin (KW)	Pmax (KW)	Maintenance Cost (Rs/Hr)
PV	0	200	0.0086
WT	0	100	0.0196
BESS	-400	400	0.0548

PV	
Parameter	Rating
Nominal Capacity	200 KW
Nominal temperature	23°C
Wind	
Nominal capacity	100 KW
Cut in speed	8 m/s
Cut out speed	15 m/s
BESS	
Nominal capacity	1000 KWh
Min SoC	0.3
Max SoC	0.9
Replacement Cost	454 INR

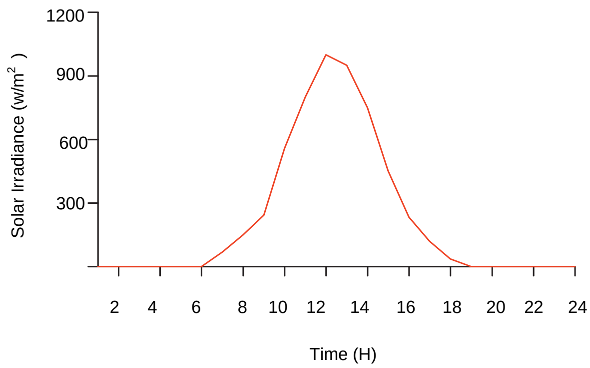
The system is evaluated for daily scheduling with time interval of 24 hoursThe profile of solar irradiance, wind speed and temperature are shown in Figure 2 (a) and 2 (b) respectivelyBased on the problem formulation a typical load curve of a city is considered and is given in Figure 2 (d).



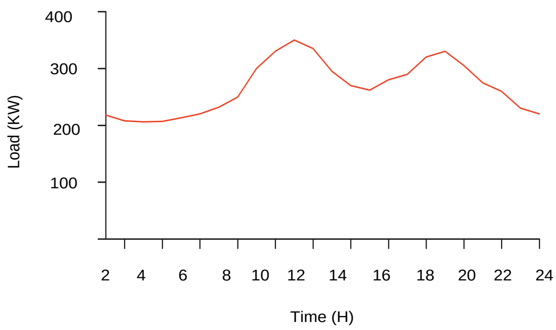
(a)



(b)



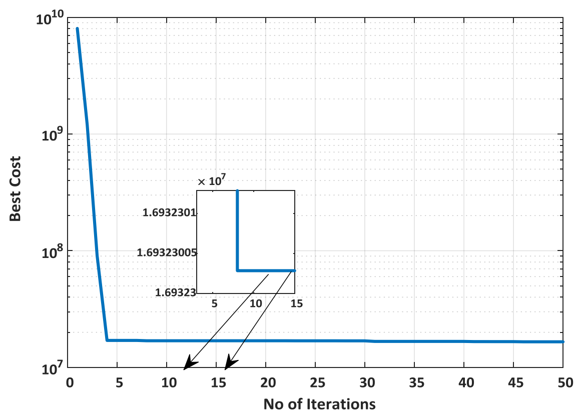
(c)



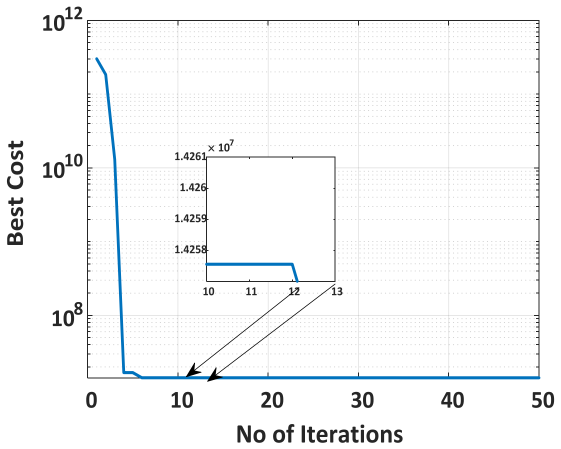
(d)

Figure: 2 Hourly forecasted data of (a) Temperature (b) Wind Speed and (c) Solar irradiation (d) load profile

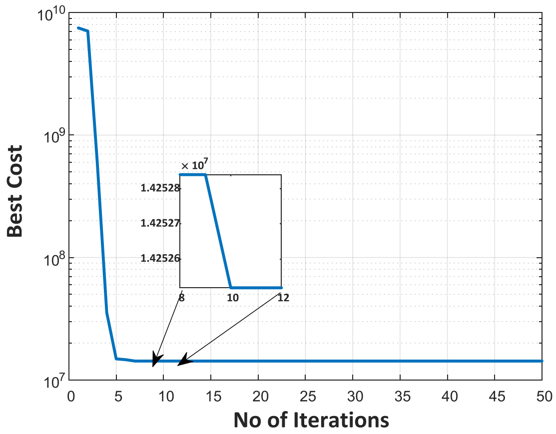
As evident from fig 2 solar and wind are vastly intermittent with the wind profile changing drastically on an hourly basis. The wind speed varies between 8m/s to 15 m/s and the solar temperature is 27 degrees Celcius on average. The system is implemented in MATLAB and the convergence curves for the different algorithms is presented in fig 3.



(a)GA



(b) PSO



(c) WCMFO

Figure 3: Convergence parameters for (a) Genetic Algorithm (GA) (b) Particle Swarm Optimization (PSO) (c) Water Cycle Algorithm (WCMFO)

The system is compared with existing algorithms GA and PSO to test the performance in terms of cost and run time. From Table 2. it is observed that the proposed WCMFO performs better in terms of convergence rate. Fig (3) depicts the performance of the various algorithms and 500 iterations are considered for the test system. MOWCA converges around 120 iterations whereas GA took 180 iterations to converge and 150 for PSO.This establishes the fact that the convergence rate of proposed MOWCA is much quicker as compared to other benchmark algorithms. Further from Table 2 it is observed that the run time of the prposed algorithm is less than the other existing algorithms. Hemce it can be concluded that the proposed alogorithm gives faster convergence rate as well as reduce the run time. This greatly improves to overcome the search space complexity and to deliver power economically.

Table 3. Calculated Costs for different schemes

Algorithm	Cg (INR)	Cb (INR)	Ce (INR)	Total Time (sec)
GA	2408.56	294.24	1314.23	306.2
PSO	2272.56	283.48	1245.87	312.3
MOWCA	2041.87	267.03	1180.05	304.1

VI. CONCLUSION

In this work, a novel optimization approach is proposed for a stand-alone microgrid system that comprises PV, wind and BESS. The battery output is chosen as the decision variable since the output from renewable sources is fluctuating in nature. A multiobjective function is designed to solve the multi-objective multi constraint problem considering generation cost, battery depreciation cost and the environmental impact. A hybrid MOWCA algorithm is used to solve the multiobjective problem and results are compared with existing benchmark optimization algorithms like GA and PSO. The results obtained depicts that the proposed algorithm gives minimum cost and quick convergence as compared to other algorithms.

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