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Unit Commitment Using GWO in Multi Micro-grid Networks Based on Battery SOC Model

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Abstract: **A troubling consequence of the fact that unit commitment needs be solved well in advance to the actual operations is that the future state of the system is not known exactly, and therefore needs be estimated. This had made it necessary to resort to appropriate mathematical modeling techniques to properly take uncertainty into account, such as, stochastic optimization approaches. The combination of the traditional forms of Unit Commitment UC problems with the several new forms of uncertainty gives rise to the even larger family of Uncertain Unit Commitment (UUC) problems, which are currently at the frontier of applied and methodological research. This project is also genesis an Uncertain Unit commitment problem based on battery cost modeling. This work also reported with the microgrid power consideration and the battery SOC based unit commitment scheduling is taken here. The battery cost model is optimized with the help of grey wolf optimization technique to face the stochastic behavior of the microgrid such as, Solar and Wind. The proposed work is producing effective results with the real tie forecasted data of renewable energy. This project work is also promoting the energy conservation and effective utilization of microgrid. The simulation works are carried out for different load demands and which are showing the state-of-art of both battery cost modeling as well as GWO based optimization. Thus Grey Wolf Optimization (GWO) approach is used to incorporate the uncertainties of the renewable sources and load demands into the Unit Commitment (UC) and Economic Dispatch Problems (EDP).**

Keywords: Grey Wolf Optimization (GWO) Unit Commitment (UC) and Economic Dispatch Problems (EDP) Uncertain Unit Commitment (UUC).

INTRODUCTION

Everything that happens in the world is the expression of flow of energy in one of its forms. Energy is the primary and most universal measure of all kinds of work by human beings and nature. Due to rapid increase in the population and standard of living; we are faced with energy crisis. Energy is an important input in all sectors of a country's economy. The standard of living is directly related to per capita energy consumption Conventional sources of energy are increasingly depleted. Hence, Non Conventional Energy Sources have emerged as potential source of energy in India and world at large.

During the past decades, the electric power industry has undergone significant changes in response to the rising concerns of global climate change and volatile fossil fuel prices. For more efficient, reliable, and environmentally friendly energy production, it is critical to increase the deployment of distributed generation, especially from Renewable Energy resources (RE), as well as distributed Energy Storage (ES). This trend has evolved into the concept of a "microgrid" which can be described as a cluster of distributed energy resources, energy storage and local loads, managed by an intelligent energy management system. Similar to bulk power grid operation, microgrid operation can be determined by Unit Commitment (UC) and Economic Dispatch(ED). The UC is performed from one day to one week ahead providing the start up and shut down schedule for each generation and storage unit, which can minimize the operating cost of the microgrid. After the UC is determined, then ED is performed from few minutes to one hour in advance to economically allocate the demand to the on line units while considering all unit and system constraints.

Metaheuristic algorithms are powerful methods for solving many real-world engineering problems. The majority of these algorithms have been derived from the survival of fittest theory of evolutionary algorithms, collective intelligence of swarm particles, behavior of biological inspired algorithms, and/or logical behavior of physical algorithms in nature. In the previous phase we propose Simulated Annealing (SA) metaheuristic algorithm which is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space. It is often used when the search space is discrete. For problems where finding an approximate global optimum is more important than finding a precise local optimum in a fixed amount of time, simulated annealing may be preferable to alternatives such as gradient descent.

Here we propose the Grey Wolf Optimizer algorithm is recently developed heuristics inspired from the leadership hierarchy and hunting mechanism of grey wolves in nature and has been successfully applied for solving economic dispatch problems. It has more advantage than the Simulated Annealing algorithm and also it overcomes the drawbacks of it.

Evolutionary algorithms are those who mimic the evolutionary processes in nature. The evolutionary algorithms are based on survival of fittest candidate for a given environment. These algorithms begin with a population which tries to survive in an environment. The parent population shares its properties of adaptation to the environment to the children with various mechanisms of evolution such as genetic crossover and mutation. The process continues over a number of generations till the solutions are found to be most suitable for the environment.

The Unit Commitment problem (UC) in electrical power production is a large family of mathematical optimization problems where the production of a set of electrical generators is coordinated in order to achieve some common target, usually either match the energy demand at minimum cost or maximize revenues from energy production. Unit Commitment typically covers several hours to several days. Unit Commitment involves the starting and synchronizing of thermal generation so that it is available when needed to meet expected electricity demand. The economic dispatch is to include variables that affect operational costs, such as the generator distance from the load, type of fuel, load capacity and transmission line losses. Battery storage was already used in the early days of direct current electric power. Battery systems connected to large solid-state converters have been used to stabilize power distribution networks.

GREY WOLF OPTIMIZATION

A.OPTIMIZATION BASED ON GREY WOLF OPTIMIZATION ALGORITHM

Grey Wolf Optimizer (GWO) is a typical swarm-intelligence algorithm which is inspired from the leadership hierarchy and hunting mechanism of grey wolves in nature. Grey wolves are considered as apex predators; they have average group size of 5–12. In a pack, the grey wolves follow very firm social leadership hierarchy. The leaders of the pack are a male and female, are called alpha (α). The second level of grey wolves, which are subordinate wolves that help the leaders, are called beta (β). Deltas (δ) are the third level of grey wolves which has to submit to alphas and betas, but dominate the omega. The lowest rank of the grey wolf is omega (ω), which have to surrender to all the other governing wolves.

The three phases of grey wolf hunting are:

(i) Tracking, chasing, and approaching the prey.

(ii) Pursuing, encircling, and harassing the prey until it stops moving.

(iii) Attacking the prey.

B. PROCEDURE FOR GWO ALGORITHM

Step 1: The input data for the chosen test system is read to compute the total fuel cost of the system.

Step 2: GWO parameters i.e., population size N and select the stopping criteria are initialized.

Step 3: The number of design variables, D required for the test system is selected and are initialized. According to the population size, the design variable for the test system is generated randomly using Eqn

$$P_{ij}=P_{i,min}+rand(i)*(P_{imax}-P_{imin})$$

where j=1,2….N,

i=1,2….D.

Therefore, the matrix of D * N is initialized.

Step 4: The fitness of each population is calculated using F_T After sorting the fitness value in descending order, alpha (α), beta (β) and delta (δ) grey wolves are determined.

$F_{T\alpha}=F_T(N)$, $F_{T\beta}=F_T(N\text{-}1)$, $F_{T\delta}=F_T(N\text{-}2)$.

Step 5: The design variables corresponding to $F_{T\alpha}$,

$F_{T\beta}$ and $F_{T\delta}$ are saved as

$\vec{P}_{\alpha(t)}$, $\vec{P}_{\beta(t)}$ and $\vec{P}_{\delta(t)}$ respectively.

Step 6: Using Eqn .$\vec{A} = 2\vec{a}.\vec{r}1 - \vec{a}$ and

Eqn $\vec{B} = 2.\vec{r}2$

Where $\overrightarrow{r1}$ and $\overrightarrow{r2}$ are random vectors between (0,1) and a is linearly decreasing from 2 to 0 over each iteration problem.

$\vec{A}_i$ and $\vec{B}$; i=1,2 & 3 are determined

Step 7: The position of each grey wolf in the population gets updated

Step 8: Proper termination criterion is selected Step 4 to step 7 will be repeated till the termination criteria is reached by the algorithm

DESCRIPTION OF SIX BUS MODEL

A six bus multi machine system is taken here for the analysis purpose as shown in the figure. It consists of 6buses, 3 feeders, 1 diesel generator, 2 wind generators, 1 PV generator and 3 battery storage systems 1 transformer and 15 loads are connected on a 13.8kV main grid

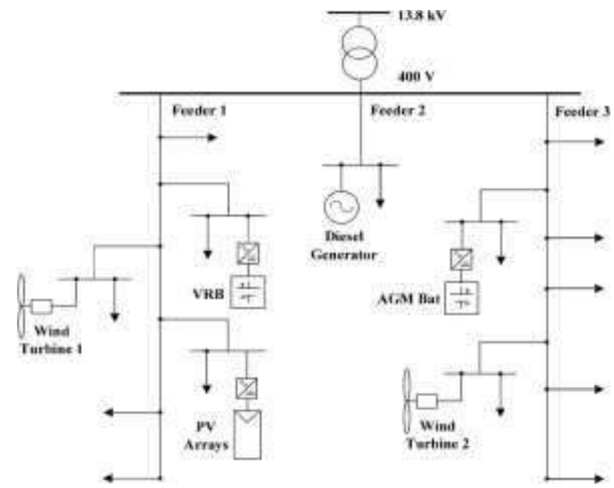

Fig 1: Single line diagram of six bus system

DESCRIPTION OF PROPOSED SYSTEM

This work is proposing an approach to incorporate the uncertainties into the UC and ED for microgrids. In this approach, the hard constraint of exact power balance is relaxed by introducing a probabilistic constraint which contains renewable powers and load demands as random variables. The power balance constraint is enforced with high probability while the penalty for the constraint violation is applied in the cost function. The advantage of this method over the scenario base method is that all possibilities of load demands and renewable generations are covered without the need to consider a large number of scenarios. Furthermore a Simulated Annealing optimization technique is used to solve the UC.

The primary attribute of the proposed method is that it better describes the actual performance of the energy storage system performance and adjusts the allocation of resources in response. Specifically, most energy management and resource allocation approaches do not explicitly consider lifecycle degradation due to deep discharge nor do they consider efficiency as a function of output(or input) power. In this case study, the VRB and AGM lead-acid batteries fared similarly; even though the VRB was considerably more expensive to install, its better lifecycle attributes and efficiency characteristics produced similar long-term economic profiles to the AGM lead acid batteries. Furthermore, both batteries were more cost effective than the diesel generator. Thus, it makes better economic sense to increase the size of the energy storage system with respect to the diesel generator.

FLOWCHART OF GREY WOLF OPTIMIZER ALGORITHM

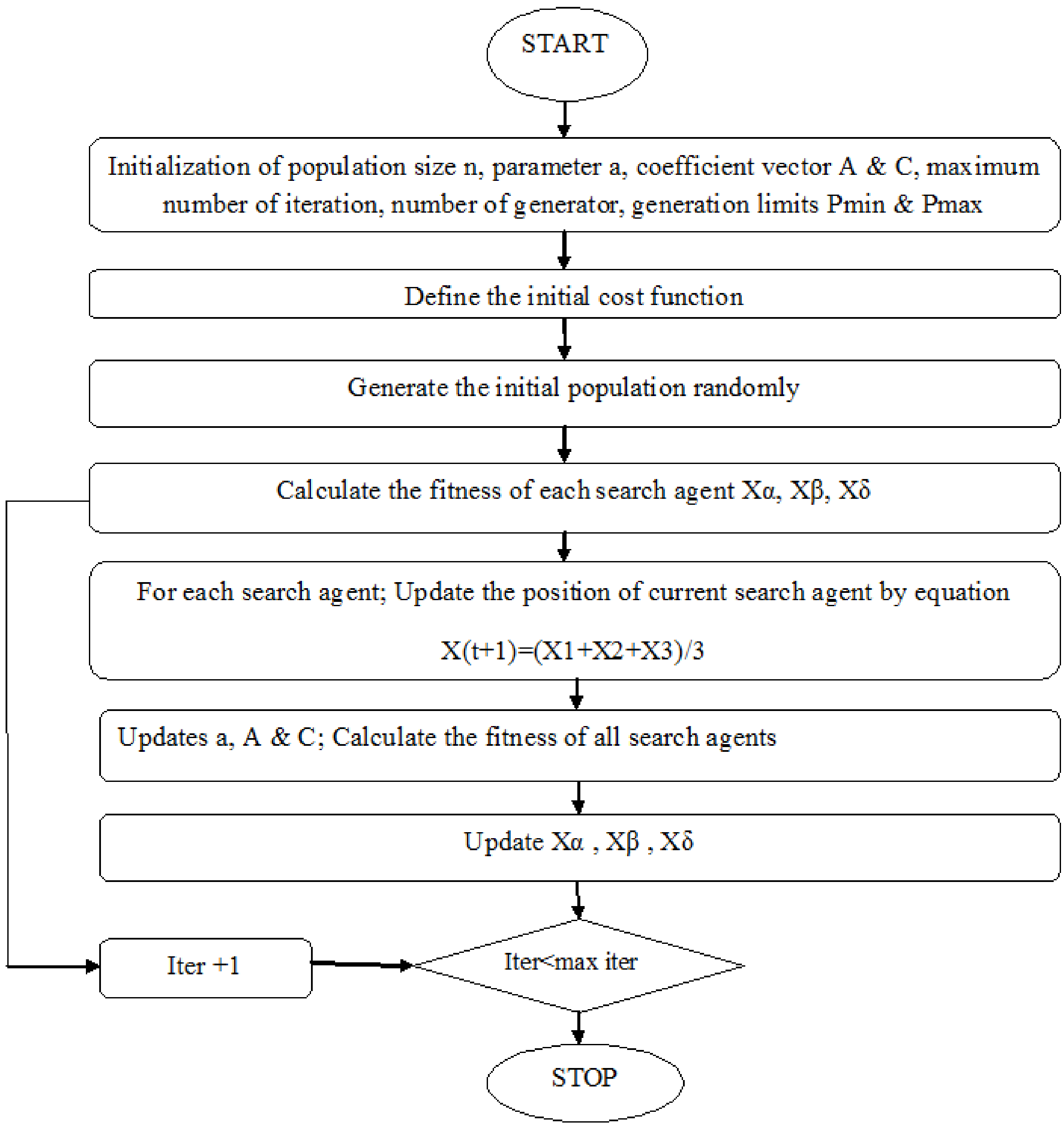

Fig 2: Flowchart Of Grey Wolf Optimizer Algorithm

Fig 2 shows the flowchart of the Grey Wolf Optimizer algorithm which has the main advantage of the low time consumption. The main and the first step of this process were initializing all the necessary values. Then check the limitation of the power flow constraints. If it was satisfied then update all the initialized values. This process repeated again and again until the optimized values were obtained.

BLOCK DIAGRAM

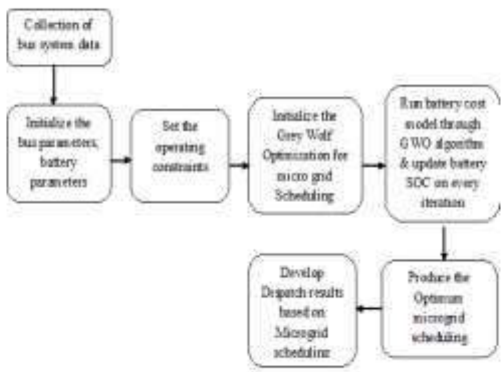

Fig 3:Block diagram of Proposed System

The figure 3 shows the block diagram of proposed model. It explained the various blocks that included in the proposed system.

The rating of diesel generators and battery data are given in the below table 1 & 2.

Table 1: Diesel Generator Data

a_{dg}	b_{dg}	C_{dg}	Start-up	Cgen
3.10^{-4} (gal/h)/kW^2	0.052 (gal/h)/kW	0.8 gal/h	$1	$4/gal
$T_{dg}^{up,min}$	$T_{dg}^{dw,min}$	P_{dg}^{min}	P_{dg}^{max}	Ini.state
2hr	2hr	5kW	50kW	1hr

Table 2: Battery Data

	L_r	DODr	Cr	Vr
VRB	1000 cycles	30%	40kWh	60V
AGM	1000 cycles	50%	30kWh	60V

	SOC_{min}	SOC_{max}	Ini.SOC	kWh_f Price
VRB	0.3	0.8	0.5	0.1$/$kWh_f$
AGM	0.5	1	0.5	0.59$/$kWh_f$

The Wind and Solar Power Generation Data rating are given below in the following table 3.

Table 3: Wind and Solar Power Generation Data

Hour	**Wind Power1 (kW)**	**Wind Power2 (kW)**	**Solar Power (kW)**
1.00	2.31	16.95	0.00
2.00	3.36	15.70	0.00
3.00	3.80	15.10	0.00
4.00	5.00	14.00	0.00
5.00	5.57	9.00	1.81
6.00	7.33	7.35	8.81
7.00	8.91	6.05	20.07
8.00	10.07	5.70	31.09
9.00	10.86	4.50	40.05
10.00	10.93	4.00	46.08
11.00	13.36	3.65	49.03
12.00	16.90	3.45	48.77
13.00	17.47	3.70	46.05
14.00	19.83	3.25	41.06
15.00	21.43	2.70	33.33
16.00	21.76	3.40	23.82
17.00	18.76	3.45	0.00
18.00	18.67	2.30	0.00
19.00	17.21	2.70	0.00
20.00	17.24	2.85	0.00
21.00	18.21	3.05	0.00
22.00	19.40	3.45	0.00
23.00	16.91	4.10	0.00
24.00	17.73	4.25	0.00

COST FUNCTION:

In this Project, the stochastic unit commitment is formulated to minimize the expected operation cost of a microgrid over a time horizon. The objective function is therefore

$$\min C = \sum_{k=1}^{N} (F_k + S_k)$$

$$F_k = \mathbb{E}\{F_{g,k} + F_{b,k}^{d} + F_{b,k}^{c} + F_{m,k}\}$$

$$F_{g,k} = \sum_{i=1}^{n_1} s_{gi,k} F_{gi}(P_{gi,k}) T = \sum_{i=1}^{n_1} s_{gi,k} c_{gi} H_{gi}(P_{gi,k}) T$$

$$F_{b,k}^{d} = \sum_{i=1}^{n_2} s_{bi,k}^{d} F_{bi}^{d}(P_{bi,k}^{d}) T = \sum_{i=1}^{n_2} s_{bi,k}^{d} c_{bi} H_{bi}^{d}(P_{bi,k}^{d}) T$$

$$F_{b,k}^{c} = \sum_{i=1}^{n_2} s_{bi,k}^{c} F_{bi}^{c}(P_{bi,k}^{c}) T = \sum_{i=1}^{n_2} s_{bi,k}^{c} c_{bi} L_{bi}^{c}(P_{bi,k}^{c}) T$$

$$F_{m,k} = F_m(P_{m,k})T$$

N is the time horizon, is the time step; F_k is the total expected operation cost in period; S_k is the total transition cost which accounts for the start-up and shut-down cost of the generators in period.

$n1$ and $n2$ are the number of generators and batteries, respectively; gi and bi denote generator and battery , respectively;

$F_{g,k}, F^d_{b,k}, F^c_{b,k}(\$)$ are respectively the total operation cost during period of the generators, the discharging batteries and the charging batteries; is the cost due to power mismatch;

$s_{g,k}, s^d_{b,k}, s^c_{b,k}$ are respectively the binary status during period of the generator i and battery i; due to the fact that a battery could not charge and discharge at the same time.

$C_{gi}(\$/gal)$ is the fuel price for generator i; $C_{bi}(\$/kWhf)$ is the price for battery i

$H_{gi}(\$/gal)$ is the fuel consumption of generator i; $H_{bi}(kWhf/h)$ and $L_{bi}(kWh_f/h)$ are respectively the consumptions during discharging and charging of battery i;

Table4: Pload And Pnet Value

Hour	Load demand (kW)	Pnet (kW)	Hour	Load demand (kW)	Pnet (kW)
1.00	32.93	13.66	13.00	49.20	-18.02
2.00	30.40	11.34	14.00	48.27	-15.86
3.00	29.13	10.23	15.00	47.93	-9.53
4.00	28.43	9.43	16.00	47.69	-1.30
5.00	28.60	12.22	17.00	48.99	26.78
6.00	28.74	5.25	18.00	49.94	28.97
7.00	33.06	-1.98	19.00	47.76	27.84
8.00	39.71	-7.15	20.00	44.71	24.62
9.00	44.94	-10.46	21.00	42.69	21.42
10.00	47.37	-13.64	22.00	42.19	19.34
11.00	47.91	-18.13	23.00	41.07	20.06
12.00	48.39	-20.74	24.00	36.53	14.55

Where,

$P_{gi,k}, P^d_{bi,k}, P^d_{bi,k}(kW)$ are respectively the dispatched power during period to generator, discharging battery I and charging battery i; is the power mismatch during period k.

SIMULATION RESULTS

The power generated from the renewable generation like wind and solar power outputs (in kW)is plotted in the bellowed figure 4.

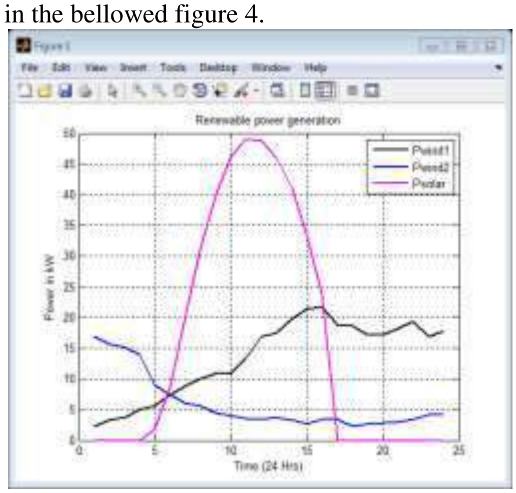

Fig 4: Renewable Power Generation

The load demand and the Pnet values are tabulated in the following table 4 and the curve response is shown in Fig 5.

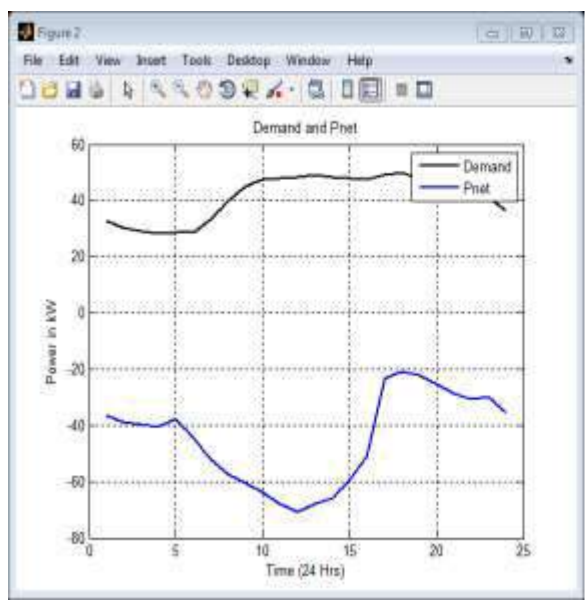

Fig 5: Demand And Pnet Profile

The proposed work addressing a stochastic optimization of micro grid based on battery cost model. This work proposes an idea of optimizing the micro grid power delivery based on battery operating condition.

Because batteries are clean to environment and can introduce minimum fuel cost when compared to the existing Diesel generators. The cost model is I need of the battery specification especially VRB batteries are highly recommended for the microgrid operation because of its lower DoD compared to other battery

The unit commitment obtained due to this stochastic optimization described in the following table 5

Table 5: Unit Commitment from Stochastic Optimization

Hour	DG	VRB charge	VRB Dis charge	AGM Charge	AGM Dis charge
1:00	1	0	1	0	1
2:00	1	0	0	0	0
3:00	1	0	0	0	0
4:00	1	0	0	0	0
5:00	1	0	0	0	0
6:00	1	0	0	0	0
7:00	0	1	0	1	0
8:00	0	0	1	0	1
9:00	0	1	0	1	0
10:00	0	0	1	0	1
11:00	0	1	0	1	0
12:00	0	0	1	0	1
13:00	0	0	1	1	0
14:00	0	1	0	0	1
15:00	0	1	0	1	0
16:00	0	0	1	0	1
17:00	1	0	0	0	0
18:00	1	0	0	0	0
19:00	1	0	0	0	0
20:00	1	0	0	0	0
21:00	1	0	0	0	0
22:00	1	0	0	0	0
23:00	1	0	0	0	0
0:00	1	0	0	0	0

The Grey Wolf Optimization algorithm optimizing the power required for compensating the load demand as well as reducing the cost for the while system. Where the battery storage systems are not allowed to charge form the Diesel generator outputs and also not allowed to discharge beyond its own DOD

The Economic dispatch from the proposed stochastic model is shown in the following table 6 The power delivery is based on the load requirement as well as battery SOCs, renewable energy generations.

Table 6: Power delivery based on load and battery SOCs.

Hour	P_{DG} (kW)	P_{VRB} (kW)	P_{AGM} (kW)
1:00	24.5386332	8.49831691	7.82929037
2:00	37.7515813	0	0
3:00	19.1298446	0	0
4:00	41.7198112	0	0
5:00	34.69597582	0	0
6:00	18.3610523	0	0
7:00	0	-8.5004205	-11.287087
8:00	0	7.90017258	9.65508073
9:00	0	-8.6410110	-8.5775860
10:00	0	4.7871266	7.88088517
11:00	0	-5.4613604	-10.958428
12:00	0	3.3408634	10.4921866
13:00	0	8.8137456	-9.9692017
14:00	0	-4.2716087	6.42882152
15:00	0	-8.3796460	-7.3452788
16:00	0	8.09067149	8.08952564
17:00	7.41401691	0	0
18:00	28.7940791	0	0
19:00	23.1061080	0	0
20:00	32.0440809	0	0
21:00	40.5269757	0	0
22:00	10.2841441	0	0
23:00	29.2307531	0	0
0:00	39.8519228	0	0

The above table consists of optimized power ratings of Diesel generators, VRB battery and AGM battery. The positive power represents the power delivery to the grid, and negative power represents (especially batteries) charging instances. The battery as well as Diesel generators may kept idle whenever the load demands very low. The stochastic optimization of micro gird is shown as a curve in the following figure 6.

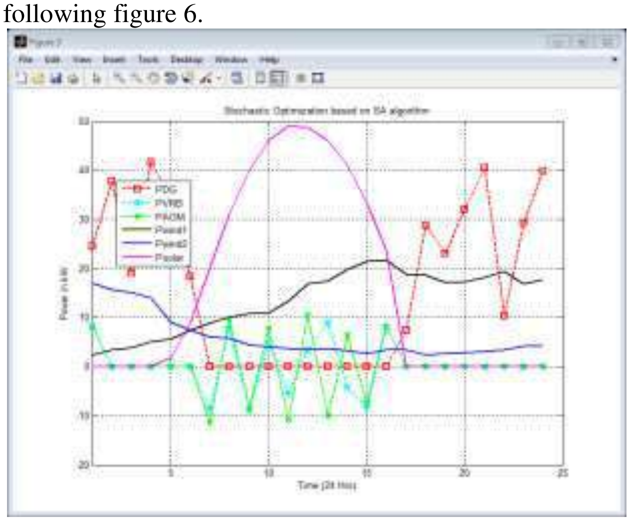

Fig 6: Power Responses after Stochastic Optimization Of Microgrid

The above plot represents the following notes about the superiority in the proposed work.

- By incorporating the operation cost functions of the batteries, the ED tends to dispatch power to the batteries which have a longer cycle life, lower replacement cost, and higher efficiency.
- In this case, the VRB has lower kWhf, however the AGM battery has higher efficiency, therefore their dispatched powers, as shown in the results, are close.
- Compared to the diesel generator, the batteries have lower operating cost due to lower "fuel" price and higher efficiency. However, the batteries are limited by their maximum depth of discharge.
- For that reason, the batteries can only discharge for few hours at night, as observed in the results.
- Furthermore, note that although not explicitly expressed, the two energy storage units were committed in accordance with their individual operating profiles to maximize their life spans.
- Furthermore, both batteries were more cost effective than the diesel generator. Thus, it makes better economic sense to increase the size of the energy storage system with respect to the diesel generator.

CONCLUSION

The main aim of the work is to promote the battery operation in micro grids and to improve the electricity distribution as well as to reduce the fuel cost. This proposed work is most suitable for the stand alone system. Still now, the diesel generators are the only a bulky source to face the peak loads in standalone systems because the renewable energy resources are stochastic in nature. This can be solved by operating the system by adding battery storage system and it is possible to schedule the diesel generators and also can reduce the fuel cost. This project genesis a Grey Wolf Optimization based economic schedule of microgrid based on battery storage system. According to the SOC and renewable energy systems, the economic dispatch is prepared as stochastic not deterministic. This can schedule the diesel generator for a while. The MATLAB simulation results are showing the effectiveness of the proposed work on six bus stand alone systems.

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