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Optimal Operation Strategy of an Islanded Microgrid using Genetic Algorithm

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Abstract*: The intermittent nature of renewable energy sources calls for efficient energy management systems in islanded microgrid operation. In order to ensure continuity of power supply to demand all the time, battery energy storage systems(BESS) are employed along with an alternative energy source like a diesel generator. It is essential that the overall operational cost minimization is achieved ensuring the health monitoring of BESS. At every hour, optimal set of actions by the renewable energy resources, BESS and diesel generator need to be found out satisfying the demand and state of charge consideration yielding minimal cost of operation. An attempt has been made to employ genetic algorithm to find the optimal set of actions for overall cost minimization. Results are compared with dynamic programming(DP)andapproximate dynamic programming(ADP).

Index Terms*: dynamic programming(DP), approximate dynamic programming(ADP), genetic algorithm(GA), battery energy storage systems(BESS).

I. INTRODUCTION

Now a days, need for electrical energy is increasing, which can be obtained from conventional and non-conventional energy resources. Because of scarcity of fossil fuels and environmental problems, non-conventional energy resources like solar and wind power can be extensively used [1], [2]. Even though renewable energy resources has advantages, they have disadvantages as well. The power generated by wind turbines and PVs depends majorly on weather conditions which is time varying. Hence, the power supplied by wind turbines and PVs is intermittent and stochastic [3].

It is hard to attain interconnection with large power grid for islands faraway from mainland. Moreover using single diesel generator have some drawbacks like high cost, noise, emitting air pollutants. So, with the integration of renewable energy resources such as wind and solar as main power source with battery energy storage system and diesel generator can be effectively used to supply power for an islanded microgrid [4]-[6]. Battery energy storage system(BESS) plays an important role in islanded microgrids. Power management strategy is used for finding proper set of actions by varying SOC over a certain limit.

Dynamic programming(DP) is one of the optimization techniques widely used to find optimal control policy in islanded microgrids. But this dynamic programming is computationally inflexible when state space becomes large [7]. This inflexibility is termed as "curse of dimensionality"[8]. Another technique called approximate dynamic programming(ADP) is used to analyze the economic operation of BESS [9]. Although it reduces computational complexity compared to dynamic programming but still there are some complex computations.

Also, optimal allocation of BESS and micro-turbine in a microgrid is explained in [10] where it represents a two stage planning framework. Lifetime extension of BES devices is a promising approach [11]. Integrated modelling and solving of stand-alone microgrid planning and optimization scheduling problem are realized using mixed integer linear programming(MILP), where an optimized scheduling model for microgrid consider the initial investment cost, maintenance and replacement cost, fuel cost, environmental management cost and power shortage penalty cost [12]. Simultaneously there are some limitations of MILP formulation such as impossibility of taking into account non-linear effects, the need of considering all time periods at once, the risk of high dimensionality of the problem. Approximate dynamic programming(ADP) is used to find the optimal operation of energy storage systems in islanded microgrids considering the stochastic wind energy and load demand and hence proved that it is better compared to traditional dynamic programming(DP) and also computational time required for ADP is less compared to traditional DP [13].Artificial intelligence techniques like genetic algorithm is used to solve optimization problems. An optimization algorithm like genetic algorithm for microgrid incorporating demand side management(DSM) has been analyzed in [14]. Mixed integer linear programming(MILP) and genetic algorithm(GA) are used simultaneously to solve the optimization problems and both the methods are compared which produce reliable, robust and cost effective solutions [15]. Allocation of wind turbine(WT), photovoltaic(PV) and energy storage systems(ESS) in distribution networks can be optimized by bi-level model where at the upper level, the capacity of PV and WT in each bus can be optimized by using genetic algorithm(GA) by minimizing the cost of investment and maintenance, power purchase and power losses and at the lower level,

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power flow can be smoothened by using an operation strategy of energy storage systems(ESS) [16].

Particle swarm optimization(PSO) is used to find minimum cost in islanded microgrids [17], [18]. However, PSO converges prematurely and also trapped into a local minimum especially with complex problems. Power management strategy between PV system, battery and load is explained in [19].

Motivated by the aforesaid references which is clear that dynamic programming has computational complexity for calculating daily operational cost through finding of actions, genetic algorithm is used to find set of actions in the islanded microgrid. The objective is to minimize the everyday operative cost of islanded microgrid. This paper mainly focuses on following things:

- Genetic algorithm(GA) is proposed to find the optimal power transfer actions in an islanded microgrid.
- Minimization of operational cost of the islanded microgrid is achieved using genetic algorithm along with health monitoring of BESS.
- Computational time has been considerably reduced compared to dynamic and approximate dynamic programming.

The rest of the paper is sectionalized as follows. Typical portrayal of islanded microgrid is shown in section II. Problem description is explained in section III. Genetic algorithm is presented in section IV. Results are presented in section V. Conclusions are presented in section VI.

II. TYPICAL PORTRAYAL OF ISLANDED MICROGRID

The model consists of a wind turbine, a battery bank and a diesel generator as power supply units and load demand as power demand units. The excess charging of the battery can be prevented by charge controller(CC). The excess energy produced by power supply units is absorbed by dumping load. When SOC of battery bank is less than a certain value then wind turbine and diesel generator charges the battery bank. The model of islanded microgrid[13] is shown in figure(1).

At any instant of time, state variable can be written as

$$s_t = (B_t, W_t, D_t) \quad (1)$$

where,

B_t is battery energy storage system's energy(BESS) at time *t*, in kW.

W_t is output power of wind turbine at time *t*, in kW.

D_t is load demand at time *t*, in kW.

Transfer of power from one block to other is termed as action. Totally five different actions which are well-defined by the five-dimensional, non-negative decision vector as,

$$a_t = (a_t^{wd}, a_t^{gd}, a_t^{bd}, a_t^{wb}, a_t^{gb})^T \geq 0, a_t \in X_t, t \in \mathbf{T} \quad (2)$$

Where $\mathbf{T} = \{0, \Delta t, 2\Delta t, \ldots\ldots, T-\Delta t, T\}$; $\Delta t = 1$ hour & T = 24 hours

a_t^{ij} means transfer of power from *i* to *j* at time *t* and *w* represents wind, *d* represents demand, *g* represents generator and *b* represents battery.

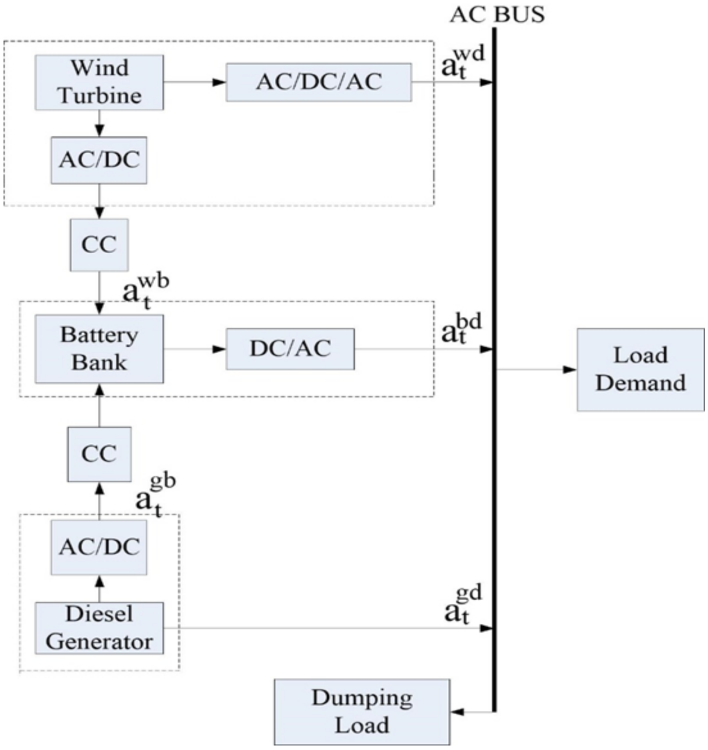

Figure 1: Typical layout of Islanded microgrid

III. PROBLEM DESCRIPTION

A. Wind Turbine Model

The renewable energy resource used in this paper is wind turbine which is the major power supply unit of an islanded microgrid . The wind power output in terms of wind speed can be given as,

$$W_t = \begin{cases} 0 & v < v_i \ or \ v > v_o \\ \dfrac{W_r(v - v_i)}{(v_r - v_i)} & v_i \leq v \leq v_r \\ W_r & v_r \leq v \leq v_o \end{cases}$$

where, v_i is wind turbine cut-in speed, in *m/s*.

v_o is wind turbine cut-off speed, in *m/s*.

v_r is rated wind speed in *m/s*.

W_r is wind turbine's rated output power, in *kW*.

B. Battery Energy Storage System Model

Battery energy storage systems or battery bank is one of the essential parts of the system. Optimizing the BESS have effect on the performance of the overall system. For proper health monitoring of the battery, the state of charge (SOC) of the battery should be within acceptable range defined by

$$SOC_{min} \leq SOC \leq SOC_{max} \quad (3)$$

The next hour SOC can be calculated as follows:

$$SOC_{t+\Delta t} = SOC_t + soc_t \quad (4)$$

where $$soc_t = \frac{\emptyset^c(a_t^{gb}+a_t^{wb})}{B^c} - \frac{a_t^{bd}}{B^c\emptyset^d} \qquad (5)$$

$\emptyset^c$ means charging efficiency of BESS.
$\emptyset^d$ means discharging efficiency of BESS.
B^c means BESS's energy capacity, in *kWh*.

The daily operational cost of BESS can be calculated as,

$$C_t^{BESS} = C_w P_t^B \Delta t \qquad (6)$$

where C_w is wear cost of the battery , in $/*kWh*.
P_t^B is energy discharged from BESS and can be expressed as [13]

$$P_t^B = a_t^{bd} \lambda_{soc} \qquad (7)$$

λ_{soc} = weighting factor which depends on SOC and can be expressed as follows:

$$\lambda_{soc} = p * SOC + q \qquad (8)$$

where p and q values used in this paper are obtained from [21]

The wear cost of the battery can be calculated as [13],

$$C_w = \frac{C_i}{\emptyset^d B^c N_c \delta} \qquad (9)$$

where C_i = initial investment cost of the battery in $.
N_c = corresponding number of life cycles at rated DOD.
δ= Depth of discharge of BESS.

C. Diesel Generator Model

Diesel generators is used as back up power source. The fuel consumption (L) of diesel generator can be expressed as follows[13]:

$$L_t = \left(L_o \times P_{rated} + L_1 \times P_t^{gen}\right) \qquad (10)$$

where L_o and L_1 are 0.08415 and 0.246 respectively [22]

$$P_t^{gen} = a_t^{gd} + a_t^{gb} \qquad (11)$$

Therange of P_t^{gen} can be expressed as

$$k_{gen} P_{rated} \le P_t^{gen} \le P_{rated}. \qquad (12)$$

From [19], the value of k_{gen} is taken as 0.3.

The daily operational cost of diesel generator can be expressed as,

$$C_t^{gen} = C_t^{die-fuel} + C_{die-om} + C_{die-loss} \qquad (13)$$

where $C_t^{die-fuel} = F \times L_t$is the diesel generator fuel cost.
F is fuel cost of diesel generator in $/*L* obtained from [13].

D. Objective Function And Constraints

The objective function to minimize daily operational cost of an islanded microgrid is as follows:

$$C(S_t, a_t) = M_1 \times C_t^{gen} + M_2 \times C_t^{BESS} \qquad (14)$$

where M_1 and M_2 are the weighted parameters obtained from weighted sum method [19].

The total objective function of system is written as,

$$V = \min_{a_t \epsilon X_t} \mathbb{E}[\sum_{t=0}^{T-1} C(S_t, a_t)] \qquad (15)$$

where $\mathbb{E}$ = expectation operator.

The constraints set is as follows:

$$a_t^{wd} + a_t^{gd} + a_t^{bd} = D_t \qquad (16)$$

$$a_t^{wb} + a_t^{wd} \le W_t \qquad (17)$$

$$a_t^{wb} + a_t^{gb} \le \min\left(\frac{B^c - B_t}{\Delta t}, \psi^c\right) \qquad (18)$$

$$a_t^{gb} + a_t^{gd} \le G_t \qquad (19)$$

$$a_t^{bd} \le \min\left(\frac{B_t - B_{min}}{\Delta t}, \psi^d\right) \qquad (20)$$

Ultimately, proper set of actions need to be found in order to minimize overall system cost of an islanded microgrid,

$$a_t = \arg\min_{a_t \epsilon X_t} V \qquad (21)$$

E. Battery Control Strategy

If W ≥ D, then wind power meets the demand and remaining actions will be equal to zero. Excess wind power(Wexcess) if any after meeting the demand is used to charge the battery, if battery SOC is less than a certain value. Otherwise Wexcess will goes to dump load.

If W < D, a_{wb} = 0 and a_{wd} = W and Dexcess = D-W. Now, the battery control strategy for this case is as follows:

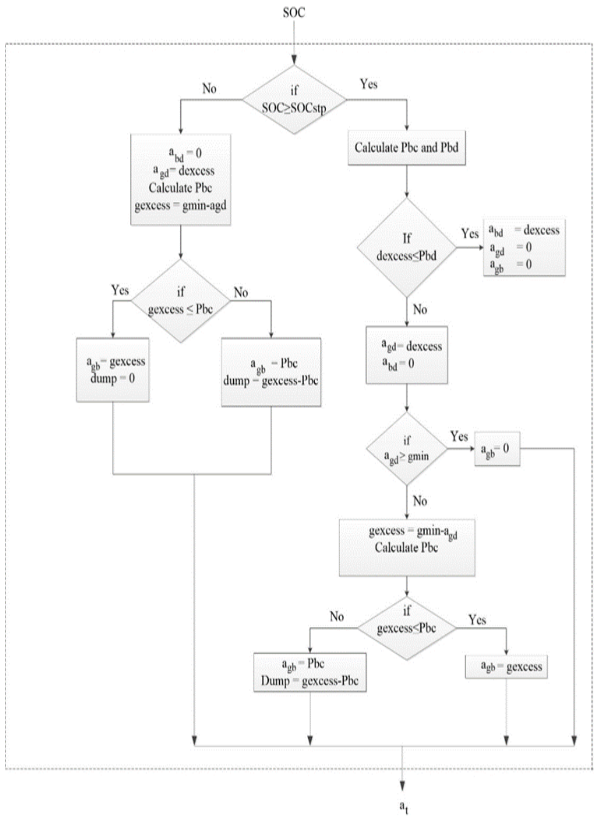

Figure 2: Battery Control strategy

Pbc means permissible battery charging power
Pbd means permissible battery discharging power

$$(Pbc) = \frac{(SOC_{max} - SOC) * B_c}{\varphi_c * 100} \qquad (22)$$

$$(Pbd) = \frac{\varphi_d * (SOC - SOC_{stp}) * B_c}{100} \qquad (23)$$

The battery control strategy is found for 24 hours and at every hour, decision vector consisting of actions is completed.

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IV. OPTIMIZATION APPROACHES

A. Dynamic Programming Approach

Bellman's optimality equation [8] is used to minimize daily operational cost of an islanded microgrid which can be written as follows,

$$V_t^*(S_t) = \min_{a_t \in X_t}\left[C(S_t, a_t) + \sum_{s'} P_t(s'|S_t, a_t) V_{t+\Delta t}^*(s')\right] \quad (24)$$

where $P_t(s'|S_t, a_t)$ is the probability of going from state S_t to state s' for a_t.

B. Approximate Dynamic Programming Approach

In approximate dynamic programming [9], expectation operator is used in place of probability in which can be written as follows,

$$V_t^*(S_t) = \min_{a_t \in X_t}\left[C(S_t, a_t) + \mathbb{E}\{V_{t+1}^*(S_{t+1})|S_t\}\right] \quad (25)$$

The value function in state S_t^n, can be expressed as,

$$\tilde{v}_t^n = \min_{a_t \epsilon x_t}\left[C(S_t^n, a_t) + V_t^{a,n-1}\left(S^{M,a}(S_t^n, a_t)\right)\right] \quad (26)$$

C. Genetic Algorithm

Genetic algorithms(GA) are mostly used to generate high quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection. Genetic algorithm used here is to solve the optimization problem which gives the actions to calculate the daily operational cost of an islanded microgrid. The basic mechanisms common to almost all genetic algorithms are:

- A fitness function for optimization
- A population of chromosomes
- Chromosomes selection
- Crossover to produce next generation of chromosomes
- Random mutation of chromosomes in new generation

The sequence of steps for GA are as follows:

Step 1:Initialization of population.

Step 2: Calculate fitness values of the candidate solutions .

Step 3: Selection is done to prefer best solutions from worstones.

Step 4: Crossover is done to combine two or more parental solutions to create better solutions.

Step 5: However recombination/crossover operates on two or more parental chromosomes butmutation randomly modifies a solution.

Step 6:Repeat steps 2-5 till a terminating state is reached.

V. RESULTS:

The islanded microgrid consisting of a wind generator, battery bank and diesel generator is supplying a varying load. All the data related to the microgrid is drawn from [13]. The BESS parameters are shown in table 1.The system parameters are presented in table 2.

Table 1: Battery Parameters

Battery	Lead-Acid
Type	2V/1000Ah
Quantity	75
Capacity	150 kWh
Minimum Limit	75 kWh
Cycle life	1000 @ 50% DOD
Charging and discharging efficiencies ($\emptyset^c$ and $\emptyset^d$)	80%
Maximum charging and discharging rates (ψ^c and ψ^d)	50 kWh/Δt
Battery cost	$80 per kWh
Installation cost	$20 per kWh
Transportation cost	$20 per kWh

Table 2: The System Parameters

Name	Wind Speed(m/s)	Demand (kW)	Diesel generator (kW)	Wind power (kW)
Maximum	30	50	70	50
Minimum	0	20	21	0

In this paper, average load of 20 kW is considered with a peak load of 50 kW. The cut-in speed of wind turbine is presumed to be 5 m/s, cut-off speed of wind turbine is presumed to be 30 m/s and rated speed of wind turbine is presumed to be 15 m/s. Variable wind speed is assumed as is shown in figure 3. The load demand and the output from wind turbine are shown in figure 3.

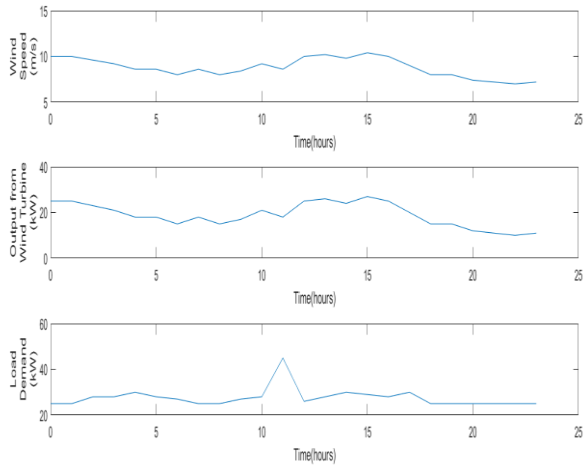

Figure 3: wind speed profile, output from wind turbine and a typical load demand of the island.

Table 3: Daily operational cost of an islanded microgrid for SOC_{stp}=0.55 with genetic algorithm:

S.no	W (kW)	D (kW)	awd (kW)	awb (kW)	awl (kW)	agd (kW)	agb (kW)	agl (kW)	abd (kW)	SOC (%)	Pbc (kW)	Pbd (kW)	Cost ($)
1	25	25	25	0	0	0	0	0	0	100	0	50	4
2	25	25	25	0	0	0	0	0	0	100	0	50	4
3	23	28	23	0	0	0	0	0	5	100	0	50	4.005
4	21	28	21	0	0	0	0	0	7	93.75	11.7188	46.5	4.0084
5	18	30	18	0	0	0	0	0	12	85	28.125	36	4.0178
6	18	28	18	0	0	0	0	0	10	70	50	18	4.0196
7	15	27	14.9999	0.0006	0	9	12.0006	0	2.9993	57.5	50	3	6.2583
8	18	25	18	0	0	0	0	0	7	63.3518	50	10.0221	4.0152
9	15	25	14.9994	0.0003	0	10	10.9991	0	0	54.6018	50	0	6.2511
10	17	27	17	0	0	0	0	0	10	63.4013	50	10.0815	4.0217
11	21	28	20.9994	0.0008	0	7	14.0002	0	0	50.9013	50	0	6.2512
12	18	45	15.4775	2.5223	0	20.9993	0.0055	0	8.5223	62.1021	50	8.5225	6.2709
13	25	26	25	0	0	1	20	0	0	53.4714	50	0	6.2512
14	26	28	26	0	0	0	0	0	2	69.4714	50	17.3657	4.004
15	24	30	24	0	0	0	0	0	6	66.9714	50	14.3657	4.0123
16	27	29	27	0	0	0	0	0	2	59.4714	50	5.3657	4.0046
17	25	28	25	0.0004	0	0.6343	20.3656	0	2.365	56.9714	50	2.3657	6.2568
18	20	30	20	0	0	0	0	0	10	70.308	50	18.3696	4.0195
19	15	25	15	0.0002	0	6.6304	14.3688	0	3.369	57.808	50	3.3696	6.259
20	15	25	15	0	0	0	0	0	10	65.092	50	12.1104	4.0212
21	12	25	4	8	0	20.999	0.0008	0	0	52.592	50	0	6.2512
22	11	25	0.001	11	0	20.2088	0.7919	0	4.7902	58.9927	50	4.7912	6.2623
23	10	25	0.0008	10	0	16.074	4.9239	0.0013	8.9249	62.4384	50	8.926	6.2833
24	11	25	0.0002	11.0001	0	15.1346	5.866	0	9.8646	63.2213	50	9.8656	6.2727
Total													121.0173

The cost of an islanded microgrid with SOC_{stp} of 0.55 using DP and ADP is 136.44$ and 136.57$ respectively whereas with genetic algorithm is 121.0173$. So, the overall cost of an islanded microgrid is reduced slightly by using genetic algorithm compared to that of using DP and ADP. The computational time taken to perform traditional dynamic programming and approximate dynamic programming is 7123.04 seconds and 392.23 seconds respectively, whereas the computational time taken to perform genetic algorithm is 361.32 seconds for a day.

VI. CONCLUSION

In this paper, the overall operational cost minimization of an islanded microgrid is done ensuring health monitoring of BESS. Genetic algorithm is used to find set of actions and overall cost of an islanded microgrid for a day. Application of artificial intelligence technique has been found to yield satisfactory results. This GA method can be easily adopted when more than one renewable energy resource is present in the microgrid. This can be achieved by increasing the number of power transfer actions to be determined. The computational time required for executing genetic algorithm is less compared to traditional dynamic and approximate dynamic programming.

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