Generation Scheduling of Grid Connected Microgrid Using GAMS

Indurekha Shial, Rajat Kanti Samal and Chinmaya Bhuyan

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Indurekha Shial
Dept. of Electrical Engineering
Veer Surendra Sai
University of Technology
Burla, India
indushial86@gmail.com

Rajat Kanti Samal
Dept. of Electrical Engineering
Veer Surendra Sai
University of Technology
Burla, India
rksamal_ee@vssut.ac.in

Chinmaya Bhuyan
Dept. of Electrical Engineering
Veer Surendra Sai
University of Technology
Burla, India
chinmayabhuyan2000@gmail.com

***Abstract*—The integrated form of distributed energy resources make a small-scale power grid called microgrid. Based on the production of electrical energy renewable energy sources are integrated especially wind energy which gives various features to the power system.Here a grid-connected mode of microgrid with wind energy resources is used which offers a positive impact on quality of life, climate change and energy efficiency.In this paper an integrated scheduling model is used to find an optimal solution of distributed energy resource network and depository devices in such a way that both cost and emission are reduced by using General Algebraic Modelling System(GAMS). The results show that this system can efficiently synchronize the power generation of distributed energy system and the fluctuations of wind power production is reduced due to the presence of Energy Storage System (ESS). Such that the system is handling uncertainties correctly in electrical microgrid.**

***Index Terms*—GAMS, Microgrid, Renewable sources, Optimal, Scheduling.**

I. Introduction

In power systems generally distributed energy resources (DERs) are established to increase the efficiency and security of energy supply with the usage of renewable energies. Optimal scheduling of different distributed energy resources (DERs) such as MT, FC, PV, WT, etc. is key to the profitable operation of any microgrid that reduces both cost and emission where as the use of thermal energy gives more cost emission.Microgrid provides a favourable and systematic solution by integrating various distributed renewable energy sources,energy storage system. Microgrids are self-ruling systems that generate, diffuse, reserve, manage energy and bear a flexible and efficient electric grid by enabling the integration of a growing classification of distributed energy resources. Microgrids exchange power with the external grid to maintain the electric supply in the local grid in case of grid-connected mode.The recommendations of grid connected microgrid can provides the economic benefits to owners through many activities such as demand response,high shaving. Nowadays wind energy is very dominant in microgrids but due to the alternation of wind power, the optimal solution gives many troubles.

To optimize the scheduling operation of microgrids, many researchers have taken non-identical objective functions with various DERs.Some researchers have taken specialist Energy Management System for optimal operation [1].Here a multi-objective EEMS is proposed to develop the microgrid behavior as follows the total cost of performance and the network emission are reduced at the same time. The optimum operation of microgrid having a fuel cell MT, PV array, WT, FC, hydrogen tank, boiler, reformer and electrical ,thermal load evaluate power generation with a profit [2].Here the power generation by wind turbine depends on the natural condition, as a result it fluctuates. Due to fluctuation the operation of microgrids is desired to take uncertainties of renewable power generation.In some paper Microgrid with the integration of wind energy system explains both the static and dynamic issues [3]. A real-time dynamic optimal energy management (OEM) is used for the formulation of the Markove decision process which is based on deep reinforcement learning (DRL) algorithm [4].An optimal energy management strategy (EMS) is used for DC microgrids where it is based on salp swarm algorithm and control power sharing [5]. Many researchers study on unreliability in wind generation.Due to unpredictability in wind generation power system operation faces many complications.In paper [6] to limit the unreliability of power,the wind speed correlation is modeled using gaussian copula and Weibull distribution.A novel metric that is a high adaption capability adjusts the system due to the intrinsic unreliability of wind energy which is based on compromise programming [7]. For energy consumers that is industrial, commercial and public sector organizations Energy management system (EMS) is used to improve energy-saving technologies for the energy consumers.Mostly EMS is used for the optimization of microgrid operation.To minimize the operational cost of microgrid smart EMS is applied for power optimization of DG sources and ESS [8]. Grid-connected renewable energy resources have many control issues which is vertically integrated or regulated the power system [9].In paper [11] due to uncertainties in load demand a self-adaptive gravitational search algorithm is applied to find out the accurate distribution of the total energy and cost of microgrid operation. To house the requirement of renewable energy at a big amount,the micro source generator operation and planning has studied [12].Here the total use of renewable energy and emission reduced the total carbon emission. In [10] a distributed model of a microgrid is explained. The working operation of a microgrid in stand-alone mode, a microgrid with a grid-tied and microgrid network is reproduced with a multiagent infrastructure.Due to multiple microgrids in a network,the distribution of power affects on the performance of the microgrid. The uncertain nature of renewable DER in microgrid has introduced and optimal scheduling has done by using the state -of -the -ant information gap decision theory (IGDT) [13]. It improves voltage profile ,minimizes power losses and also boosts the system performance.In [14] Grid connected microgrid having renewable generator i.e. wind generator and PV generator has taken for optimal scheduling using the mixed integer linear programming (MILP) method and problem has solved by general algebraic modeling system (GAMS).Their reactive power capacity is considered for the characterization of problem optimization,wind speed and demand curves has been considered for the optimal placement and wind turbine sizing [15]. Here optimization problem has been solved by using GAMS. The microgrid system with renewable sources of wind and hydro has modeled and simulated to find out the different issues technically [16]. Here for monitoring the microgrid system, a control coordinator is required. The optimization problem in microgrid including renewable sources has been solved by using guaranteed convergence PSO with Gaussian Mutation [17]. It results in high power quality and low costs. Non-dispatchable renewable energy sources has considered in microgrids for optimization and the problem has been solved by using GAMS [19]. With demand side participation in energy and reserve scheduling has been presented by a model for distribution [21]. In [18] microgrid systems with wind energy generators, solar photovoltaics, EVs, Battery energy storage (BES) , and demand response (DR) has optimized. BES minimized the system fluctuation.The optimization solution has been implemented by using GAMS software.

In this study, optimization scheduling of a grid-connected microgrid is considering for generation to achieve demand response for 24 hours using GAMS software.

II. Problem Formulation

The goal of the proposed work is to optimally schedule the DERs, the ESS and the grid in the 24 hours duration. The unit commitment of DERs as well as the scheduling of the ESS is calculated for the charging and discharging. The power exchange between the grid and the microgrid is also determined. As a generalized formulation the following can be used to determine the optimal scheduling

Minimize

$$Cost = \sum_{t=1}^{T}\Big\{\sum_{i=1}^{N_g}\big[u_{gi}(t)P_{gi}(t)B_{gi}(t) + S_{gi}|u_i(t) - u_i(t-1)|\big] + \sum_{i=1}^{N_{Es}}\big[u_{sj}(t)P_{sj}(t)B_{sj}(t)\big] + P_{grid}(t)B_{grid}(t)\Big\} \quad (1)$$

where N_g is the overall number of generators and N_{Es} is the total number of energy storage devices The bids for the ith DG unit and the jth battery, respectively, are $B_{gi}(t)$ and $B_{sj}(t)$. The DG unit's active power generation is denoted by $P_{gi}(t)$. The power to charge or discharge the jth storage at hour t is $P_{sj}(t)$. The state vector $u_{gi}(t)$ shows the ON or OFF states of all units at hour t, S_{gi} is the cost to start or stop the ith DG unit, and The utility's active power at hour t is represented by $P_{grid}(t)$, and its bid is represented by $B_{grid}(t)$.

$$\sum_{i=1}^{N_g} P_{gi}(t) + \sum_{j=1}^{N_{Es}} P_{sj}(t) + P_{grid} = P_d(t) \quad (2)$$

The above equation shows the equality constraint i.e the power balance equation. It ensures that the total amount of power produced across all units, the power drawn from energy storage systems, and the power exchanged with the grid all correspond to the hourly demand that is currently in place.

$$YP_{gi}^{min}(t) \leq P_{gi}(t) \leq P_{gi}^{max}(t) \quad (3)$$

$$|P_{grid}| \leq P_{exch}^{max} \quad (4)$$

The power flow must stay within the minimum and maximum ranges set by inequality constraints. Here P_{exch}^{max} is the maximum exchanging active power between utility and micro-grid.

$$P_{sj}(t) = E_{sj}(t) - E_{sj}(t-1) \quad t = 1, 2, 3...T \quad (5)$$

$$P_{sj}(t)/\eta_D \leq P_{dech}^{max} \quad (6)$$

$$-\eta_C P_{sj}(t) \leq P_{ch}^{max} \quad (7)$$

Here $E_{sj}(t)$ represents the state of the charge of the jth battery at t hour. For discharging $P_{sj}(t) > 0$ and for charging $P_{sj}(t) < 0$.

$$E_s^{min} - E_s(0) \leq \sum_{t=1}^{T} P_s(t) \leq E_s^{max} - E_s(0) \quad (8)$$

The output power of energy storage device (charging and discharging) is within its permissible minimum and maximum limits.

$$\frac{1}{\eta_D} \sum_{P_s(t)>0, t=1}^{T} P_s(t) + \eta_C \sum_{P_s(t)<0, t=1}^{T} P_s(t) = 0 \quad (9)$$

The starting and final states of charge of the storage system must be same (ES(0) = ES(T)) in order to optimise the microgrid's overall energy output throughout a T-hour period.

A. Test system

In grid-connected system ,in which the energy is controllable,this system can be considered by the grid as a small plant,not only as a negative load. For the smart grid development more distributed energy resources (DERS) like wind,solar etc sources of units.

The power generation by wind turbines (WTs) strongly depends on natural conditions,due to which fluctuation increases.

Similarly microturbines are small version of gas-turbines used for distributed generation of electricity.Integrating fuel cells (FCs) into microgrids has been denoted to be a favorable solution to provide cost-aggressive,highly reliable, systematic,clean and flexible energies. Energy Storage System (ESS) have an important and diverse role in microgrid which improve reliability,resilience,integrate generation sources and minimizes the total environmental impact and operating cost as well as consumer money.During disruptions ESS provides back up power to the grid and reduces the fluctuation of power. For the optimization problem, a test system is taken into consideration. The test system consists of a MT, a FC, a PV cell, a wind turbine and an ESS connected to the utility grid. The typical structure of the microgrid is shown in following figure 1. Their specifications are given in table I and table II. For the ESS,η_C=η_D=90%,E_s^{max}=150kW and $E_s(0)$=15kW. The figure 2 and 3 shows the generated power of PV cell and wind turbine per hour respectively. Table III shows the bids of all DERs and grid per hour. For renewable energy sources these bids are relatively low. Table IV shows the demand per hour of the microgrid[1].

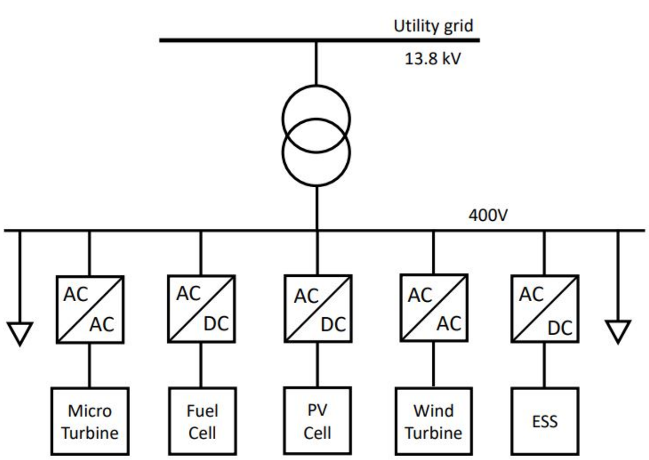

Fig. 1. Microgrid Structure

TABLE I
SYSTEM PARAMETERS OF MICROGRID

Type of Generator	Min Power (kW)	Max Power (kW)	Start up or Shut down cost (Euro/kW)
MT	6	30	0.107
FC	3	30	0.138
PV	0	25	0
WT	0	20	0
ESS	-30	30	0

B. GAMS (General Algebraic Modelling System)Section to Solution Methodology

GAMS is a highly effective mathematical modelling approach for optimization problems that are complex, linear, nonlinear, and involving mixed integers. GAMS is the easiest

TABLE II
EMISSION FACTORS

Emission type	Emission factors (kg/MW)		
	MT	FC	Grid
NO_x	0.2	0.0136	2.295
CO_2	724	489	922
SO_2	0.0036	0.0027	3.583

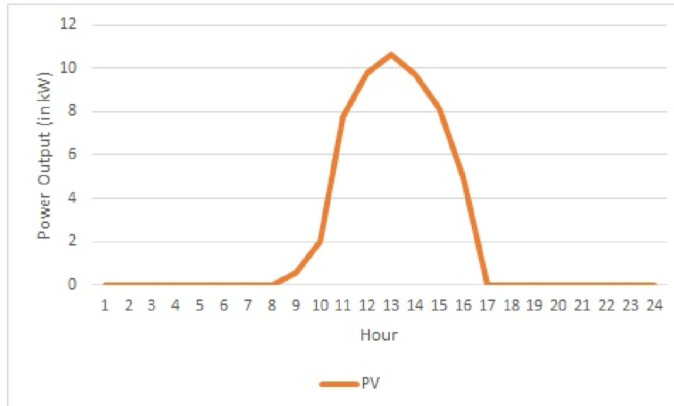

Fig. 2. Power output of PV

TABLE III
BIDS OF DERS AND ELECTRICITY PRICES OF GRID PER HOUR

Hour	MT	FC	PV	WT	ESS	Grid
1	0.0823	0.1277	0	0.021	0.1192	0.033
2	0.0823	0.1277	0	0.017	0.1192	0.027
3	0.0831	0.1285	0	0.0125	0.1269	0.02
4	0.0831	0.129	0	0.011	0.1346	0.017
5	0.0838	0.1285	0	0.051	0.1423	0.017
6	0.0838	0.1292	0	0.085	0.15	0.029
7	0.0846	0.1292	0	0.091	0.1577	0.033
8	0.0854	0.13	0.0646	0.11	0.1608	0.054
9	0.0862	0.1308	0.0654	0.14	0.1662	0.215
10	0.0862	0.1315	0.0662	0.143	0.1677	0.572
11	0.0892	0.1323	0.0669	0.15	0.1731	0.572
12	0.09	0.1315	0.0677	0.155	0.1769	0.572
13	0.0885	0.1308	0.0662	0.137	0.1692	0.215
14	0.0885	0.1308	0.0654	0.135	0.16	0.572
15	0.0885	0.1308	0.0646	0.132	0.1538	0.286
16	0.09	0.1315	0.0638	0.114	0.15	0.279
17	0.0908	0.1331	0.0638	0.11	0.1523	0.086
18	0.0915	0.1331	0.0662	0.093	0.15	0.059
19	0.0908	0.1338	0	0.091	0.1462	0.05
20	0.0885	0.1331	0	0.083	0.1462	0.061
21	0.0862	0.1315	0	0.033	0.1431	0.181
22	0.0846	0.1308	0	0.025	0.1385	0.077
23	0.0838	0.13	0	0.021	0.1346	0.043
24	0.0831	0.1285	0	0.017	0.1269	0.037

way of problem formulation.It is especially helpful when dealing with huge, complex issues where it may take a while

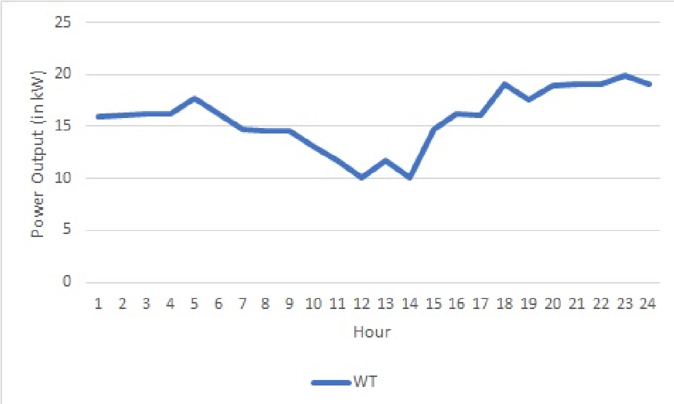

Fig. 3. Power output of WT

TABLE IV
DEMANDS OF MICROGRID IN KW PER HOUR

Hour	Demand
1	52
2	50
3	50
4	51
5	56
6	63
7	70
8	75
9	76
10	80
11	78
12	74
13	72
14	72
15	76
16	80
17	85
18	88
19	90
20	87
21	78
22	71
23	65
24	56

to develop an appropriate error-free model. The same GAMS model file can be used for simultaneous model development, solution, and documentation. It can handle simultaneous linear and non-linear equation systems in addition to a wide range of optimization problems, and future developments would encompass (linear and non-linear) complex issues and general equilibrium problems. Sets, data, variables, equations, models, and outputs make up the basic structure of a mathematical model coded in GAMS. Here are the steps for solving the model.[20].

GAMS formulation follows the basic format as given below:

- Sets: Declaration, Assignment of members;
- Data (parameters, tables, scalars), Declaration, Assignment of values;
- Variables: Declaration, Assignment of type, Assignment of bounds and/or initial values (optional);
- Equations: Declaration, Definition;
- Model and solve statements;
- Display statements (optional)

III. RESULTS AND DISCUSSION

The microgrid test system consisting WT, PV, MT, FC and ESS was scheduled using GAMS and their power generation as well as unit commitment were obtained. As the operation cost largely depends on the bids of grid power, its dependence on grid energy should be observed. Here three scenarios were considered. In the first scenario, the there is a limitation to the power exchange between the microgrid and the utility grid and PV & WT may operate withing their limits. In the second scenario, there is no such limitation on the power exchange with PV & WT operating within their limits. In the third scenario, there is no such limitation on the power exchange with PV & WT must operate at their limits which can also be considered as an environmental scenario as for the renewable energy sources there is no emission.

The whole problem was modelled in GAMS in the form of equations. Then the model was optimised. Primarily CONOPT and DICOPT solvers were used for getting results. The results obtained for scenario 1 were shown in table V. In this case we get 56.543 Euro total operating cost for 24 hrs. Similarly for scenario 2 the results were shown in table VI. But here we get 52.991 Euro total operating cost which is less than the scenario 1. For the last scenario the results are given in table VII where we get the least emission of 2744.448 kg

It can be noticed that some quantities are associated with negative sign. In case of the ESS, this negative sign indicates that the power is used in charging; while in case of grid it indicates that some power is bought by the grid.

It should be mentioned that for the ESS,E_s^{max}=150kW and $E_s(0)$=15kW. So if the initial state of charge of the ESS is increased, then the total operating cost is decreased and vice versa.

IV. CONCLUSION AND FUTURE SCOPE

In this work a grid connected microgrid operation of a system containing MT, FC, PV, WT, ESS of renewable power generation units is presented.The system is optimized for scheduling load demand meeting by using CONOPT and DICOPT solver with implementing GAMS software.A ESS is introduced with the microgrid system to decrease the wind power fluctuation.It determines both charging and discharging schedule.Here the distributed renewable energy sources integration in grid connected microgrid reduces both cost and emission. The use of ESS explains the power exchange between the utility grid and microgrid with limitation .But it shows low cost with zero limitation.The presence of ESS also improves the system performance.

TABLE V
OPTIMAL SCHEDULING OF MICROGRID (SCENARIO 1)

Hour	MT	FC	PV	WT	ESS	Grid
1	0	0	0	16.0133	5	30.9867
2	6	3	0	16.08	0	24.92
3	0	0	0	16.16	0	33.84
4	0	3	0	16.1733	-27	58.8267
5	6	3	0	0	-27	74
6	0	0	0	0	-27	90
7	0	3	0	0	-23	90
8	0	0	0	0	-15	90
9	30	30	0.59	14.6533	0	0.7567
10	30	30	1.98	13.16	27	-22.14
11	30	30	7.75	11.6667	27	-28.4167
12	30	30	9.8	10.1467	27	-32.9467
13	30	30	10.65	11.6667	0	-10.3167
14	30	30	9.7	10.146	27	-34.846
15	30	30	8.12	14.7467	0	-6.8667
16	30	30	4.95	16.2133	27	-28.1633
17	0	0	0	0	-4.44	85
18	0	0	0	0	-2	90
19	0	3	0	0	-3	90
20	0	0	0	0	0	87
21	30	0	0	19.04	0	28.96
22	6	3	0	19.1067	0	42.8933
23	6	3	0	19.9333	-27	63.0667
24	6	0	0	19.1467	21	9.8533
Total operation cost					56.543 Euro	
Total emission					3403.859 kg	

TABLE VI
OPTIMAL SCHEDULING OF MICROGRID (SCENARIO 2)

Hour	MT	FC	PV	WT	ESS	Grid
1	0	0	0	16.0133	5	30.9867
2	0	3	0	16.08	5	25.92
3	0	0	0	16.16	-27	60.84
4	0	0	0	16.1733	-27	61.8267
5	6	3	0	0	-27	74
6	0	3	0	0	-27	87
7	0	0	0	0	-27	97
8	6	0	0	0	0	69
9	30	30	0.59	14.6533	0	0.7567
10	30	30	1.98	13.16	27	-22.14
11	30	30	7.75	11.6667	27	-28.4167
12	30	30	9.8	10.1467	27	-32.9467
13	30	30	10.65	11.6667	0	-10.3167
14	30	30	9.7	10.146	27	-34.846
15	30	30	8.12	14.7467	0	-6.8667
16	30	30	4.95	16.2133	27	-28.1633
17	6	3	0	0	-1.421	76
18	6	0	0	0	-1.387	82
19	0	0	0	0	-27	117
20	6	0	0	0	0	81
21	30	30	0	19.04	0	-1.04
22	6	3	0	19.1067	0	42.8933
23	0	0	0	19.9333	0	45.0667
24	0	0	0	19.1467	27	9.8533
Total operation cost					52.991 Euro	
Total emission					3316.851 kg	

In this microgrid system PV generation uncertainity is also present ,this may be considered in future.The above may be used for energy management in microgrid.

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TABLE VII
OPTIMAL SCHEDULING OF MICROGRID (SCENARIO 3)

Hour	MT	FC	PV	WT	ESS	Grid
1	0	0	0	16.0133	5	30.9867
2	6	3	0	16.08	0	24.92
3	0	0	0	16.16	0	33.84
4	6	0	0	16.1733	-27	55.8267
5	0	3	0	17.68	-27	62.32
6	6	0	0	16.1733	-27	67.8267
7	6	0	0	14.7333	-27	76.2667
8	6	3	0	14.56	-22	73.44
9	30	30	0.59	14.6533	0	0.7567
10	30	30	1.98	13.16	27	-22.14
11	30	30	7.75	11.6667	27	-28.4167
12	30	30	9.8	10.1467	27	-32.9467
13	30	30	10.65	11.6667	0	-10.3167
14	30	30	9.7	10.146	27	-34.846
15	30	30	8.12	14.7467	0	-6.8667
16	30	30	4.95	16.2133	27	-28.1633
17	6	3	0	16.1467	0	59.8533
18	0	0	0	19.1333	0	68.8667
19	6	3	0	17.5333	-27	90.4667
20	6	0	0	18.9467	0	62.0533
21	30	30	0	19.04	27	-28.04
22	6	0	0	19.1067	0	45.8933
23	0	0	0	19.9333	0	45.0667
24	6	0	0	19.1467	0	30.8533
Total operation cost					56.874 Euro	
Total emission					2744.448 kg	

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