Chapter 41
Multi-objective Optimization for Hybrid Microgrid Utility with Energy Storage

Kapil Gandhi and S. K. Gupta

Abbreviations

PV	Photovoltaic modules
wt	Wind turbine modules
bat	Battery bank
bio	Biogas power plant
mop	Modules of solar PV
mow	Modules of wind turbines
rat	Rated
ci	Cut-in
co	Cut-out
wp	Wind power available
ES	Maximum energy stored
CP	Charging power of the energy storage units
DCP	Discharging power of the energy storage units
η_{inv}	Efficiency of the inverter
η_{bat}	Efficiency of the battery bank
η_{pv}	Efficiency of the solar PV modules
η_{wt}	Efficiency of the wind turbine modules
η_{bio}	Efficiency of the biogas power plant
δ	Self discharging rate of the battery bank
G_i	Global Irradiance (W/m^2)

K. Gandhi (✉)
Department of EN, KIET Group of Institutions, Delhi NCR, India
e-mail: kapilkiet@gmail.com

S. K. Gupta
Department of EE, DCRUST Murthal, Murthal, India

TRS   Total running cost of the system ($/day)
TES   Total Greenhouse gas emissions of the system (tonne/day)
TGD   Total generation and demand matching (MW/day)
IC_i Initial cost per power plant ($/day)
OM_i Operation and maintenance cost ($/day)
w_1 Weight of cost minimization objective function (%)
w_2 Weight of minimum generation demand mismatch objective function (%)
GE_i Total gas emissions through the plant
GE_{bat} Total gas emissions through the battery bank

Introduction

According to the action plan of the Indian government, the electrical energy demand of the country will rapidly grow up to 2025, which will rapidly accelerate the CO_2 emission in the environment because the most power generation depends on fossil fuels till now. Due to adverse and dangerous effects on the environment, increasing cost, dependency on gulf countries, and limited fossil fuel reserves, renewable energy generation is the only possible solution to fulfil the electrical energy demand of the country [1, 2]. However, renewable energy sources are not reliable due to their dependency on atmospheric conditions. The stand-alone wind turbine or solar PV cannot provide a reliable solution due to the intermittent nature of wind speed or solar radiance. Due to this scenario, the authors provide an acceptable hybrid renewable energy system to deliver reliable power to consider green energy constraints.

The new possibilities for effective management of a smart grid are exposed to the new field of research. The minimum price of electricity to consumers with the maximum reliability of electricity is one of them. The price of electricity is high due to the fixed tariff for the whole time. Due to fixed tariffs, the demand is uncertain at any time of the day, and generation is also uncertain due to renewable penetration. It will affect grid reliability and stability. The price of per unit electricity can decrease when the time-based tariff introduced. It helps to control the load demand during peak hours. It leads to overconsumption during off-peak hours. The United States has only 80–90 h of the peak load during the whole year [3, 4].

The residential buildings generate 42% of carbon prints, and the commercial buildings generate 36% of carbon footprint according to the report of World Bank, 2018 [5]. The energy consumption is exponentially increased from the last decades. It is expected to increase further to 50% by 2035 [6].

When the energy demand increases more than the generation, the power shortage and blackouts are more frequent during peak hours of the day. It will also increase the price of electricity. Demand-side management (DSM) can help to reduce the negative environmental effect, i.e., greenhouse gas emission, and also decrease the price of electricity by managing the consumer load in the manner that optional or unnecessary load will operate during off-peak hours. It also reduces the requirement

of new systems, i.e., generation, transmission, and distribution. DSM improves the system energy efficiency by modifying the load profile through load shifting, energy conservation, load growth, valley filling, flexible load shift, and peak clipping. It also includes changing the low efficient equipment or appliances with highly efficient equipment or appliances, i.e. LED bulb can replace the CFL [7, 8].

The demand response is the technique to shape the demand to manage the problem of dynamic pricing. Demand-side management is the tool to reduce the peak electric load and flexible demand to manage the random generation. In this research paper, the author considers the various types of load, i.e. controllable load, uncontrollable loads, and dump load to balance the excess generation, if any. The generation of electric power is done through Wind turbines, solar PV, and biogas plants. The battery and the grid are also connected to the system. DSM is also introduced to maximize the available utilities. Each load will assign the load profile depending on the load rating and working hours. Every domestic and commercial consumer wishes to maximize its utilities to optimal schedule the electrical power consumption. The overall system will be beneficial if the utility company uses dynamic pricing of the electricity to manage the demand response [9]. However, Real-time dynamic prices (time-based) of electricity are not extensively used in the retail electricity sector [10].

The organization of the remaining paper is as follows: Sect. 41.2 discusses the detailed pricing of retail electricity in the open market. Section 41.3 mathematical modelling of the system and renewable energy systems. The load profile of the district is also discussed in this section. Section 41.4 discusses the methodology and control system of a microgrid. The optimized results of the microgrid system are discussed in Sect. 41.5. Finally, the conclusions of this research paper are drawn in Sect. 41.6.

Pricing in Retail Electricity

In the open market of electricity, there is a lack of policies and guidelines until now. However, the reliable electricity at minimum price is the main challenge and objective for energy market regulators. The aware consumers are responsible for the investment in the energy sector for the investors [11].

The private power producer and seller are providing more reliable electricity to the consumers than a regulated utility by a government agency. Due to this, the number of consumers is attracting private suppliers. Many states in the US and India have opened retail markets for private participants to sell the electricity to different customers. The consumers are not interested in sellers; they are interested in reliable power at a low price. The two-part tariff is more popular among the sellers and consumers. The adoption of dynamic pricing is suitable for social welfare. The power requirement of residential consumers is low as compared to commercial and industrial consumers. The retail price competition will decrease the tariff price of electricity among competitive energy sellers [12] (Table 41.1).

Table 41.1 Comparison of various tariff schemes [10]

Tariff	Economic benefit	Equity	Bill generation	Revenue scope
Flat rate	1	1	5	2
PTR	4	2	5	1
CPP	4	3	3	4
TOU	4	4	3	3
Only variable cost	5	5	1	4
Fixed and variable cost	5	5	2	5

[a]5 represent the 'very good' and 1 represent the 'very bad.'

Mathematical Modelling of System

Gajraula, the district in UP, faces the shortage of electricity to the various industries in the district. In Gajraula, approximately 6700 homes and 72 industries are established. The average load of the residential consumers is 27.3 MW, commercial consumers are 18.1 MW, and industrial consumers are 68 MW. The author proposed the grid-connected microgrid for the district for a reliable power supply. The hybrid microgrid structure is shown in Fig. 41.1. The load profile of the district for a year is available and plotted in Fig. 41.2. The author supposed the load is constant for all days of any month. The load data is available for a day of each month on an hourly basis.
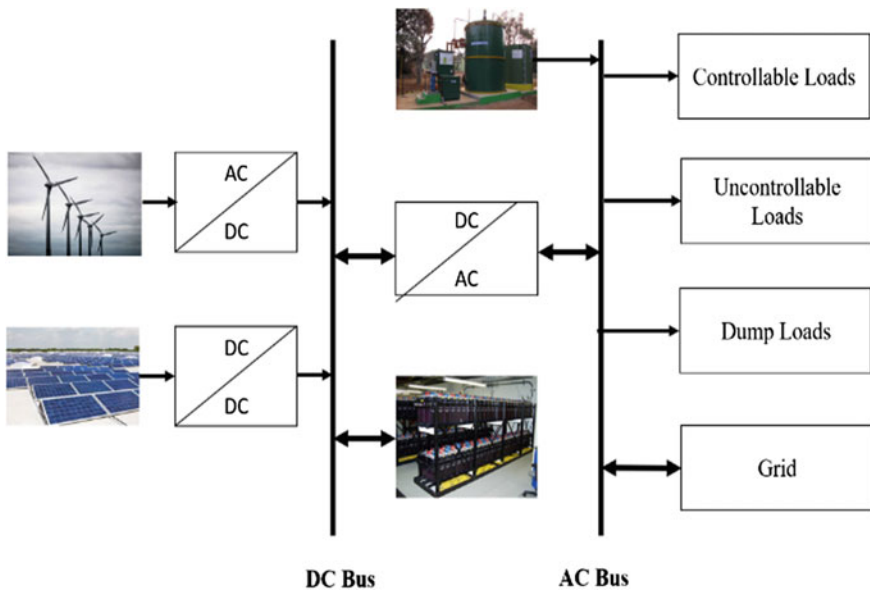

Fig. 41.1 Microgrid system with Solar PV, wind turbine and biogas plant [13]
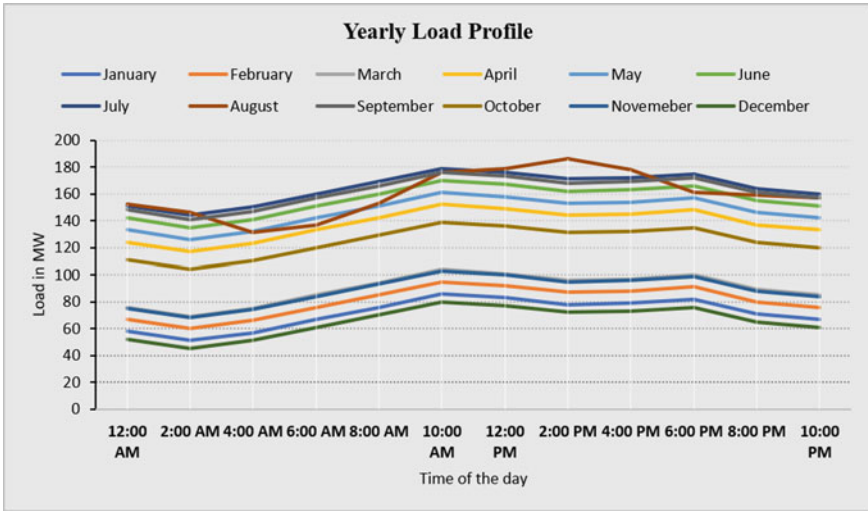
Fig. 41.2 The load profile of the district for a day for every month

The authors formulate the multi-objective optimization problem to optimize the proposed microgrid with three objectives and corresponding weights [14]

$$\text{Objective} = w_1 \cdot \text{TRS} + w_2 \cdot \text{TGD} + (1 - w_1 - w_2) \cdot \text{TES} \qquad (41.1)$$

here

$$\text{TRS} = \sum_{i=\{pv,wt,bg\}} \left[N_i \left(\frac{IC_i}{T_i} + OM_i \right) \right] + \frac{IC_{\text{bat}}}{T_{\text{bat}}} \cdot \frac{\sum_{i=1}^{24} \sum_{m=1}^{12} CP_{\text{bat}}(t,m)}{12 \cdot ES_{\text{bat}}}$$

$$\text{TES} = \sum_{i=\{pv,wt,bg\}} \left[\frac{N_i \cdot GE_i}{T_i} \right] + \frac{GE_{\text{bat}}}{T_{\text{bat}}} \cdot \frac{\sum_{i=1}^{24} \sum_{m=1}^{12} CP_{\text{bat}}(t,m)}{12 \cdot ES_{\text{bat}}}$$

$$\text{TGD} = \sum_{i=\{pv,wt,bg\}} [P_i(t,m)] + DCh_{\text{bat}} - \sum_{\text{All type}} DL(t,m) - Ch_{\text{bat}(t,m)}$$

Modelling of Solar PV System

The output power of the solar PV module can be calculated through Eq. (41.2)

$$P_{pv} = \eta_{pv} \cdot N_{pv} \cdot A_{\text{mop}} \cdot G_i \qquad (41.2)$$

Table 41.2 Ideality factor of the solar modules [15]

Material	Ideality factor
Si-mono	1.2
Si-poly	1.3
a-Si–H	1.8
a-Si–H Tandem	3.3
a-Si–H triple	5.0
cdTe	1.5
CTs	1.5
AsGa	1.3

The parameters of Eq. (41.1) are constant except for Global irradiance and the efficiency of the solar PV modules [13]. The efficiency of solar PV depends on the ambient temperature of the particular hour to generate electricity. Global irradiance depends upon the geographical location of the solar PV plant and the projection of the panels. The Ideality factor of the material of solar module also affects the efficiency of the system (Table 41.2).

Modelling of the Wind Power System

The wind is also the form of solar energy. The output power of the wind turbine modules depends upon the swept area and rotor angle of the rotor, velocity, and direction of the wind and air density. It is given by the following equation

$$P_{wt} = \begin{cases} \alpha \cdot V^3 - \beta \cdot P_{rat}, & V_{ci} < V < V_{rat} \\ P_{rat}, & V_{ci} < V < V_{rat} \\ 0, & \text{else} \end{cases} \tag{41.3}$$

Here

$$\alpha = \frac{P_{rat}}{V_{rat}^3 - V_{ci}^3}$$

$$\beta = \frac{V_{ci}^3}{V_{rat}^3 - V_{ci}^3}$$

The net power available for transmission and distribution from wind turbine generators is given by,

$$P_{wp}(t) = \eta_{wg} \cdot N_{wg} \cdot A_{mow} \cdot P_{wt} \tag{41.4}$$

Here η_{wg} is the combined efficiency of wind turbine generators and required converters [16].

Modelling of Biogas Power Plant

Biogas is another type of renewable energy source with many advantages as compared to solar PV and wind generators. The biogas power plant can start or generate power as per requirement. The output power does not depend on the weather conditions. The energy from the gas converts in mechanical energy through the gas turbine. The output power of the biogas power plant mainly depends on the Total solid waste available from the waste, and it is given by [17],

$$P_{\text{bio}} = \eta_{\text{bio}} \cdot TS_{\text{bio}} \cdot A_{\text{bio}} \tag{41.5}$$

Modelling of Battery

The current development of the renewable energy system requires the integration of energy storage units because the output of the solar PV and wind turbine generators depend on the atmospheric conditions. In micro-grid, multiple functions can perform by energy storage units, e.g. control of power quality, as well as voltage regulation and frequency, smoothing renewable energy output, providing system emergency power, and cost Optimization. The storage unit may be batteries, flywheels, and Ultra-capacitors. Generally, the electrochemical batteries are used in the power system. The battery is charged when the excess power is available or off-peak time and used during power shortage or peak hours. It is quite challenging to identify the exact state of the charge condition of the battery bank. The capacity of a battery bank at any instant is given by [18].

During charging

$$C_{\text{bat}}(t) = C_{\text{bat}}(t-1) \cdot (1-\delta) - PE_{\text{DC}} \cdot \eta_{\text{bat}} \tag{41.6}$$

During Discharging

$$C_{\text{bat}}(t) = C_{\text{bat}}(t-1) \cdot (1-\delta) + PD_{\text{DC}} \cdot \eta_{\text{bat}} \tag{41.7}$$

Availability of AC Power

The price of the electricity will decrease when the electric power does not waste on dump loads. It means the power generation by any means is equal to the power consumed by all loads except the reservoir. The power output through solar and wind cannot control. However, the power available through a biogas power plant and the battery will be optimized in the way that the loss of power will be minimum.

$$P_T = \big(P_{pv}(t) + P_{wt}(t) + C_{\text{bat}}(t)\big) \cdot \eta_{\text{inv}} + P_{\text{bio}} \qquad (41.8)$$

Power Management Methodology

The power management methodology of the microgrid is shown in Fig. 41.3. The main aim of the microgrid central controller is to maintain the balance between power availability and demand. All controllers are automatic, but automation works on predefined algorithms or decisions. Many different situations are discussed and explained through the algorithm in this paper [19]. The algorithm decides the operation biogas power plant or storage units. It also decides whether the excess power is required from the grid to purchase or not.

Results

After applied the multi-objective problem approach for the proposed microgrid, the author configures the system and optimizes the proposed objectives. The cost of the system will be minimum, with the least greenhouse gas emissions in the environment. Figure 41.4 shows that each node on the Pareto front is the unique and optimal solution for the proposed problem. The Pareto front technique is robust as compared to other techniques. The calculations performed by authors are based on various assumptions that are influenced by the literature survey (Table 41.3).

Conclusion

The Pareto front optimization technique is used to optimize the problem of an AC–DC hybrid microgrid. The mathematical modelling of solar PV, wind turbine, biogas power plant, and battery storage as done by the author and the power management algorithm was also developed to minimize the human interface in the decision making. These situations can be the standard mode of operation, overloaded
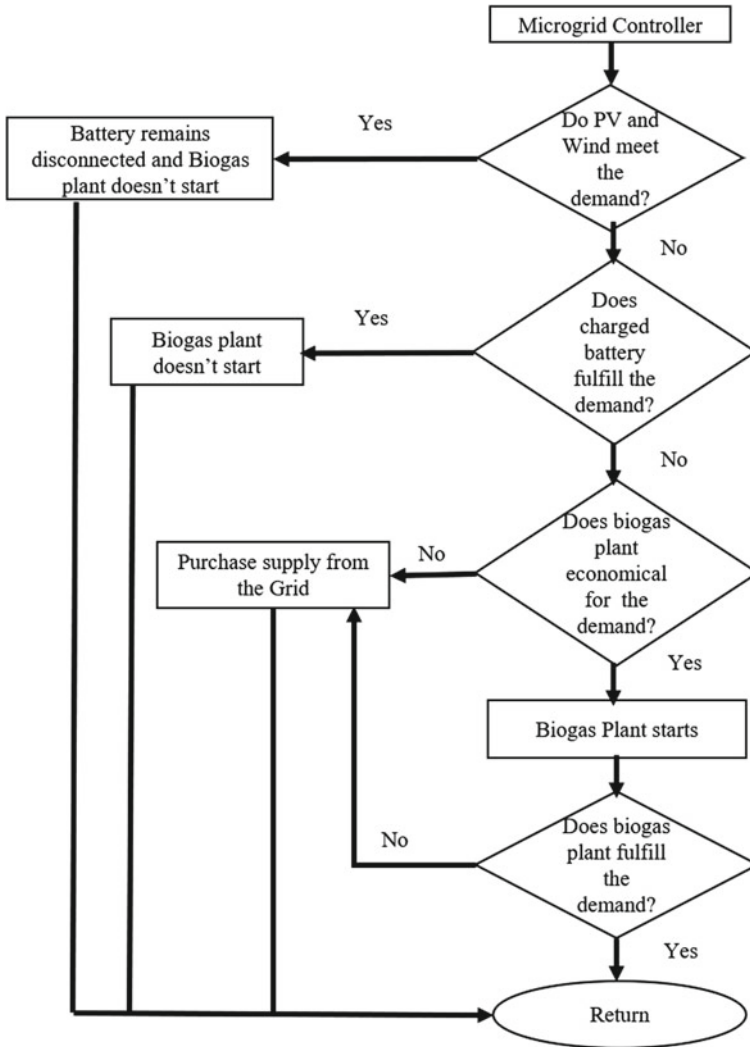
Fig. 41.3 Algorithm for decision making for power management of microgrid

microgrid, or contingency management. The other techniques, Archive-based Micro Genetic Algorithm (AMGA) and Neighborhood Cultivation Genetic Algorithm (NCGA) can also be used instead of the Pareto front optimization technique.
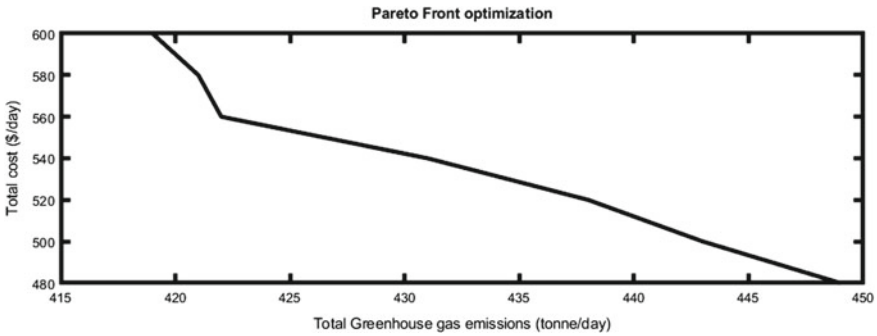
Fig. 41.4 Optimization result for Pareto front optimization techniques

Table 41.3 Weight management of optimization function

S. No.	Weight w_1	Weight w_2
1	0.25	0.50
2	0.30	0.45
3	0.35	0.40
4	0.40	0.35
5	0.45	0.30
6	0.50	0.25

References

1. European Commission (2007) Communication from the commission to the European Council and the European Parliament—an energy policy for Europe. Comm Eur Commun
2. Lau LC, Lee KT (2012) Global warming mitigation and renewable energy policy development from the Kyoto protocol to the Copenhagen accordant comment. Renew Sustain Energy Rev 16(7):5280–5284
3. Faruqui A, Hledik R, Tsoukalis J (2009) The power of dynamic pricing. Electri J 22:42–56
4. Wang Q, Liu M, Jain R (2012) Dynamic pricing of power in smart-grid networks. In: IEEE 51st IEEE conference on decision and control (CDC), pp 1099–1104. https://doi.org/10.1109/CDC.2012.6426839
5. UNEP SBCI (2009) Buildings & climate change—a summary for decision-makers.UNEP DTIE, Paris
6. Birol F (2012) World Energy Outlook 2012. International Energy Agency (IEA), Paris
7. AboGaleela M, El-Marsafawy M, El-Sobki M (2013) Optimal scheme with load forecasting for demand-side management (DSM) in residential areas. Energy PowerEng 5:889
8. Abushnaf J, Rassau A, Górnisiewicz W (2015) Impact of dynamic energy pricing schemes on a novel multi-user home energy management system. Electric Power Syst Res 125:124–132
9. Li N, Chen L, Low SH (2011) Optimal demand response based on utility maximization in power networks. In: IEEE power and energy society general meeting
10. Dutta G, Mitra K (2017) A literature review on dynamic pricing of electricity. J Oper Res Soc 68(10):1131–1145.https://doi.org/10.1057/s41274-016-0149-4
11. Bublitz A, Keles D et al A survey on electricity market design: Insights from theory and real-world implementations of capacity remuneration mechanisms. Chair of Energy Economics,

Institute for Industrial Production (IIP), Karlsruhe Institute of Technology (KIT), Hertzstraße 16, 76187 Karlsruhe, Germany.

12. Puller SL, West J (2013) Efficient retail pricing in electricity and natural gas markets: a familiar problem with new challenges
13. Tafreshi S, Zamani H, Baghdadi M, Vahedi H (2010) Optimal unit sizing of distributed energy resources in microgrid using genetic algorithm. In: IEEE Confenece, 2010, pp836–841
14. Saif A, Gad Elrab K, Zeineldin HH, Kennedy S (2010) Multi-objective capacity planning of a PV-wind-diesel-battery hybrid power system. In: IEEE international energy conference, pp 217–222
15. Tsai H-L, Tu C-S, Su Y-J (2008) Development of generalized photovoltaic model using MATLAB/SIMULINK. In: Proceedings of the world congress on engineering and computer science WCECS. San Francisco, USA
16. Manish K, Harish K, Narveer (2019) Impact of wind units in congestion management for hybrid electricity market. In: International conference on advancements in computing & management (ICACM-2019), pp 605–612
17. Methuku SR, Srivastava AK, Schulz NN (2009) Comprehensive modeling and stability analysis of biomass generation. In: 41st North American power symposium. Starkville, MS, pp 1–6. https://doi.org/10.1109/NAPS.2009.5484005
18. Sidorov DN, Muftahov IR, Tomin N, Karamov DN, Panasetsky DA, Dreglea A, Liu F, Foley A (2019) A Dynamic analysis of energy storage with renewable and diesel generation using volterra equations. IEEE Trans Ind Inf 16(5):3451–3459
19. Milczarek A, Główczyk M, Styński S ()2019 Advanced power management algorithm in DC microgrid subsystem controlled by smart transformer. In: 2019 IEEE 28th international symposium on industrial electronics (ISIE). Vancouver, BC, Canada, pp 2335–2342