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Economic dispatch of an islanded microgrid

Gowthami Thimmapathruni Venkata Satya, Chennapragada Venkata Krishna Bhanu
Department of EEE, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam, India

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ABSTRACT

Microgrids are increasingly becoming popular to improve energy access and increase the resiliency of weakly connected rural networks. The economic operation of these microgrids with renewable energy resources is key for maximizing the benefits. The objective of this paper is to implement the economic dispatch of a microgrid using quadratic programming, considering the active and reactive power capability of the renewable energy resources. The open distribution system simulator (OpenDSS) is used for obtaining the load flow of the distribution network, and the converged solution is given as input to MATLAB for optimization. The simulation is carried out for one day with a variation of hourly load, solar PV radiation, and wind in both grid-connected and islanded modes under six different cases. The methodology is implemented on a modified IEEE-13 node test feeder distribution system. The simulation result shows that the microgrid with distributed generation (DG) capable of supplying both active and reactive power under islanded conditions is economical when compared to the grid-connected mode. The novelty of the work is that it considers the capability of distributed generation to supply both active and reactive power. That can make it fully autonomous as it can meet the hourly load requirement of the network under islanding mode as per IEEE Standard 1547.4.

Corresponding Author:

Chennapragada Venkata Krishna Bhanu
Department of EEE, Gayatri Vidya Parishad College of Engineering (A)
Visakhapatnam, India
Email: bhanucvk@gvpce.ac.in

1. INTRODUCTION

Microgrid is considered as a solution for the challenges faced by the conventional central grid to improve energy access [1]. The microgrid is simply an integration of distributed energy sources generation which includes renewable energy like PV System, Wind, energy storage, etc., into distribution planning and operation. The microgrid is electrically connected to the utility system at the low-voltage bus of the substation transformer, which constitutes the point of common coupling (PCC) of the microgrid [2]. Due to maintenance at transmission-level or faults at the transmission feeder, the microgrid alters to islanded mode from the grid-connected mode [3]. In the grid-connected mode, the main grid will supply the shortfall and absorb the excessive power of the microgrid. The grid–connected mode of the microgrid is expected to provide sufficient generation capacity, operational strategies, and controls to supply at least a certain amount of the load after being altered to islanded mode [4]. The operation and benefits of microgrid vary depending on the location, components and optimization goals. However, there are barriers also for the successful implementation of microgrids [5].

Microgrid being an emerging technology, the economic operation improvement of the microgrid is being focused on research in order to make use of the benefits of renewable energy sources and other distributed energy resources (DER). The economic dispatch aims at obtaining the least cost of the microgrid.

Either classical or intelligent search techniques are used to solve the problem of economic dispatch. Zhang *et al.* proposed that the multi-objective optimization model can be solved by the mixed integer programming method [6]. A modified mixed integer linear programming with genetic algorithm was proposed by Nemati *et al.* [7] to consider the network restrictions like voltages, equipment loadings and unit constraints. Many dynamic program based economic dispatch methods have been proposed to overcome the increase in number of configurations in case of mixed-integer linear programming [8]–[10]. A dynamic economic dispatch using particle swarm optimization (PSO) algorithm combined with Monte Carlo simulation is proposed in [8]. The approach considers four different operating strategies under grid-connected and islanded mode of the micro-grid and its impact on optimization goals and reliability indices. Dynamic program approach considering variations of load and generation capacity is used to reduce the minimum fuel cost of conventional generators in [9]. A modified dynamic programming which utilizes the quadratic programming is proposed by McLarty *et al.* [10]. The method has successfully captured the non-linear performance and cost of generation with less computational demand compared to mixed-integer programming approaches. The [11] is used to implement the economic dispatch problem for DC microgrids. Kong *et al*. [12] suggested an optimal dispatch strategy including storage devices to obtain the total least operating costs targeting grid-connected microgrids, and this model is solved by an improved dynamic programming technique. An optimal economic dispatch problem considering combined heat and power in microgrids is presented by Bornapour *et al.* [13], and then a modified particle swarm optimization algorithm is used to solve the mixed-integer nonlinear problem. A modified harmony search (MHS) algorithm is proposed to solve the combined economic emission dispatch (CEED) problem of the microgrid taking into account the solar and wind power cost functions [14]. A novel hybrid algorithm consisting of grey wolf optimizer, sine-cosine algorithm and crow search algorithm has been implemented for economic dispatch of a three-unit stand-alone microgrid supported by wind energy [15]. Weirong Liu *et al.* [16] proposed a cooperative reinforcement algorithm for distributed economic dispatch in microgrids. This method has the advantage of reducing the complexity of stochastic modelling of renewable resource uncertainty. Energy Storage is a key technology for deriving certain benefits in micro-grid systems like improvement in power quality, smoothing power fluctuations from renewables. A backcasting algorithm is used to estimate the net storage value to participate in arbitrage [17]. An economic dispatch model for energy storage system in micro-grid environment which meets non-anticipative constraints is proposed in [18]. The model considers the constraints of micro-grid operation and energy storage system, including the non-anticipative constraints of economic dispatch. The objective function is constructed based on the criterion of minimizing the power consumption cost of micro-grid.

However, as the number of DERs integrating into microgrids is getting bigger, the drawbacks of centralized optimization are gradually known by researchers, such as difficulty in processing and a large amount of data acquisition, vulnerability to the central point of failures, and communication failures [19]. But in many of these works, the network used does not consider different types of loads and discuss generator and modeling issues. It is proposed that in primary control, the marginal costs-frequency droop control and equal marginal costs can be achieved accurately. While considering the power constraints of DERs, upper or lower power limits have arrived for some DERs, then equal marginal costs can still be obtained among the rest of DERs by applying a consensus-based "virtual" controller. The distributed secondary frequency control (DSFC) is suggested to achieve the transition between non-economic and economically stable operation in autonomous microgrids in a distributed fashion in order to restore the system frequency effectively [19].

The economic dispatch problem can be formulated as a quadratic programming problem as shown in [20]. The results of applying this approach to real systems have been included from which it is observed that this method has many desirable characteristics. The economic dispatch and load flow problems can be solved by quadratic programming. When compared to other methods of solving economic dispatch problems, the mathematical operations involved in quadratic programming are relatively simple. In the phase of optimization, all intermediate results are feasible and the algorithm indicates if a feasible solution is possible or not. Convergence is independent of the penalty factors or gradient step size and is very fast. Hence, this method has several advantages over existing methods of solving the economic dispatch problem.

The major focus in the literature so far is on finding a feasible solution or a control algorithm for achieving the economic dispatch. The result that is obtained was tested on systems that mostly do not consider different types of load, the capability of active and reactive power of DER under-islanding conditions as per IEEE Standard 1547.4 [21]. The capability of supplying both active and reactive power by DER will enable the microgrid to operate and supply the entire load in the islanded mode. This has not been explored so far. Also, there is no discussion on the software tool used and their modeling aspects of the network or components, particularly distributed generation like solar PV and wind. This paper addresses these issues and implements a cost minimization algorithm on the distribution test system meeting some of the requirements as per IEEE Standard 1547.4. This work uses OpenDSS, an electric power distribution system software developed by EPRI, USA for solving power flow and utilizes its MATLAB COM interface feature for solving optimization algorithm. The methodology is detailed in section 2. The description of the micro-grid, used to demonstrate the methodology, is discussed in section 3. In section 4 simulation results are analyzed and discussed. Section 5 presents conclusions.

2. METHOD

This section presents the methodology used in the work. The flow chart of the work carried out is shown in Figure 1. OpenDSS is used for obtaining the load flow of the distribution network and the converged solution is given as input to MATLAB for optimization. The simulation is carried out for one day with a step size of one hour.

2.1. The open distribution system simulator (OpenDSS) software

The OpenDSS is an open-source and general-purpose frequency-domain simulation engine. It has the capability to obtain the time- and location-dependent value of DG. By modeling the DG in its actual location on the circuit, the location–dependent values can be obtained. In order to obtain the time-dependent values, the extraordinary load-shape modeling capability is required which is in-built. This feature is used in this work for optimization of cost while allocating DG resources like PV and Wind for meeting the load requirements [22].

– PV system model: The PV system model in OpenDSS consists of a solar PV array and an inverter. The power output of the model is a function of the irradiation, temperature, and inverter efficiency. The model can be programmed to deliver both active and reactive power.
– Wind system model: Double fed induction generator (DFIG) model is used in this work. It consists of a wounded rotor induction generator (WRIG) along with back-to-back converter. The grid is connected to the stator winding of a WRIG and the rotor is connected through a converter. The purpose of using this model is to make use of its capability to decouple active and reactive power [23].
– Modeling of solar PV and wind generators: Both solar PV and wind generators are modeled as current sources ($I_{source)}$ to avoid convergence issues. The daily profile is added to the I_{source} to make it match with the generation from PV system or wind generator for a day on an hourly basis. The corresponding current value is calculated considering the impedance of the element, which is used as a reference for the I_{source}.

2.2. Quadratic programming

Among many methods, quadratic programming is a method to solve the optimization problem. Quadratic programming is an effective optimization method to find global solutions especially when the objective function is quadratic. The classical formulation of economic dispatch is:

$$Minimize \sum_{i=1}^{NG} F_i\left(P_{g_i}\right) \tag{1}$$

Constraints subjected to:

a) Equality constraint

Real power balance:

$$\sum_{i=1}^{NS} P_{gi} = P_D \tag{2}$$

b) Inequality constraint

Unit generation capacity limits:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \tag{3}$$

The cost function of the thermal generator uses a second-order lagrangian function as

$$F_i\left(P_{g_i}\right) = a_i + b_i P_{g_i} + c_i P_{g_i}^2 \tag{4}$$

where i is ith generating source, P_i is the electrical power output of source i, F_i is operating cost of source i in \$/hr; a_i, b_i, c_i are the cost coefficients, P_i^{min} is the minimum output power of source i, P_i^{max} is the maximum output power of source i, NS is a number of sources and P_D is the total system demand.

The cost function of solar generator and wind generator is [24]:

$$F(P_{s/w}) = aI^{p}P_{s/w} + G^{E}P_{s/w} \quad (5)$$

where, a is the annuitization coefficient, r is the rate of interest, N is a lifetime investment, I^P is the cost of investment per unit installed power G^E is the operation and maintenance cost and $P_{S/W}$ is the capacity of solar/wind generation in MW.

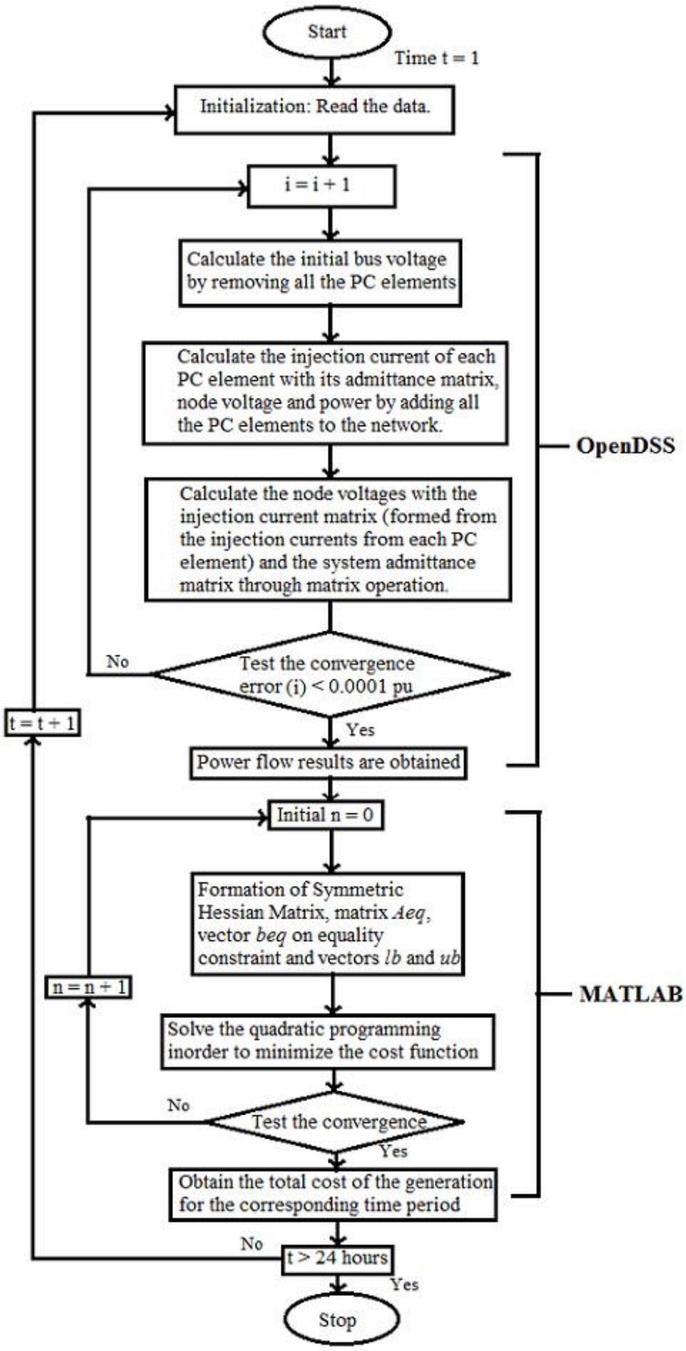


Figure 1. Flow chart of the methodology

The proposed methodology is implemented on a modified IEEE-13 node test feeder distribution system [25] shown in Figure 2. The following modifications have been carried out in the standard IEEE-13 node test feeder: i) Inclusion of PV system at the node 675; ii) Inclusion of wind generator at node 680; and iii) An isolator is added between nodes 632 and 671. When isolated, the network operates as two different sub-networks, one connected to the grid and other isolated from the grid. The two sub-networks are shown in dotted lines in Figure 2.

The purpose of modifications is to design and operate an isolated DR system also called a micro-grid as per the standard IEEE 1547.4. An isolator and distributed generation (PV and wind generation) are added to the standard test system for including the functionalities of the micro-grid and to enable the system to operate in both parallel mode and isolated mode. The system has only one point of common coupling (PCC) at node no. 632 through an isolating switch. The purpose of the isolator is to create islanding either intentionally or under fault conditions. There are various configurations of islanding in micro-grid [12]. In this paper, circuit islanding is considered. Besides, there are four modes of operation-normal parallel mode, transition-to-island mode, island mode, and reconnection mode. In this paper, only two modes-normal parallel mode and island mode are considered. The ratings of the PV system and Wind generations are 2640 kW and 2820 kW at nodes 675 and 680 respectively. The ratings of the distributed generation is so selected such that the system can independently supply all the load required based on daily load shape, reserve margin under islanded conditions.

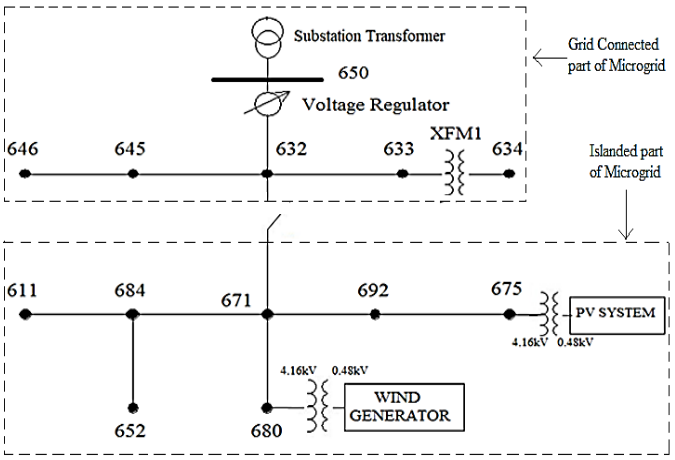


Figure 2. Modified IEEE-13 node test feeder

3. RESULTS AND DISCUSSION

The proposed methodology described earlier is implemented on the modified network for a day with an hourly variation of load, wind, and solar radiation. The hourly load profile of the micro-grid is shown in Figure 3 with a maximum demand of 2169.68 kW in the 18th hour. Similarly, the solar irradiance and wind profile are shown in Figures 4 and 5 respectively. The data required for economic dispatch i.e. cost coefficients of the main grid, PV system, and wind generator are taken from [24] and [26]. The following six cases have been considered for implementing economic dispatch and evaluating the benefits of the microgrid. The first four cases represent grid-connected microgrid and the latter two cases present microgrid under islanded conditions.

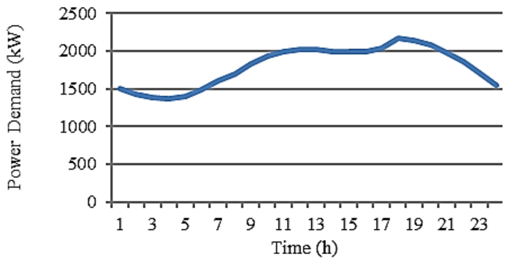


Figure 3. Load profile of the microgrid

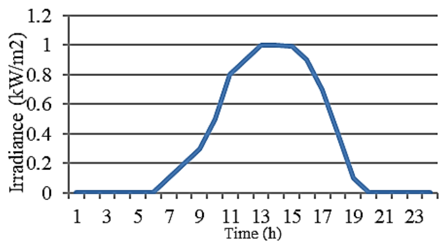


Figure 4. Irradiance profile of the solar photovoltaic system

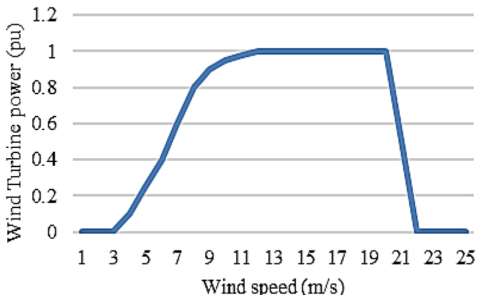


Figure 5. Output power curve of the wind system

– Case 1: Original network (IEEE -13 bus distribution test system–without DG)

The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 6 that shows hourly load met by grid including system losses. In this case, the grid supplies a total energy of 43863.46 kWh and the losses are 705.04 kWh, that is, 1.6% of the total energy supplied to the load in a day. The cost of generation is the US $131.7/MWh.

– Case 2: Microgrid in grid-connected mode (Modified IEEE–3 bus distribution test system with both solar PV and wind)

The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 7 which gives the hourly contribution of various sources-grid, PV, and Wind to meet the load requirement and the losses. In this case, out of total demand in the day, the grid supplies 25213.02 kWh, which is 57.85% of the total energy supplied, 5391.67 kWh by the PV System that is 12.37%, and 12977.31 kWh by the wind generator, which is 29.77%.

The losses sum up to be only 0.995%, that is, 433.73 kWh of the energy being supplied whereas the losses in the case of simulation of Case 1 are 1.6%. Hence, the losses are less when DG is present in the grid–connected microgrid than a simple IEEE-13 node test feeder (without DG). The cost of generation is the US $79.62/MWh.

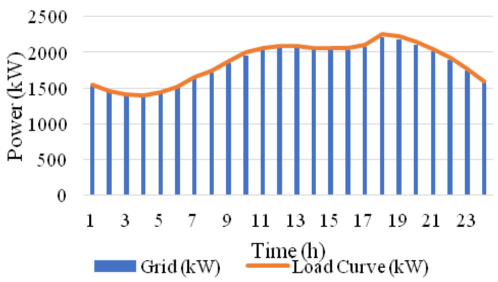


Figure 6. Result of simulation of Case 1

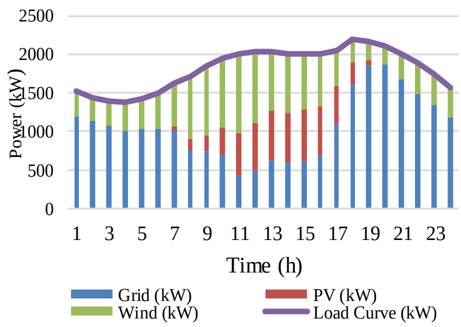


Figure 7. Results of simulation of Case 2

– Case 3: Microgrid in grid-connected mode (Modified IEEE–13 bus distribution test system with only solar PV present)

In this case, the load requirement is met through the grid and solar PV as shown in Figure 8. Wind generation is not present. During the daytime, when there is solar radiation present, the load is supplied by both grid and solar. The total contribution of solar energy is 38% of the total energy consumed by the load. The cost of generation is the US $ 120.07 /MWh.

– Case 4: Microgrid in grid-connected mode (Modified IEEE–13 bus distribution test system with only wind resource)

In this case, the load requirement is met through the grid and wind generation as shown in Figure 9. Solar PV generation is not present. The total contribution of wind is 30% of the total energy consumed by the load. The cost of generation is the US $92.6 /MWh.

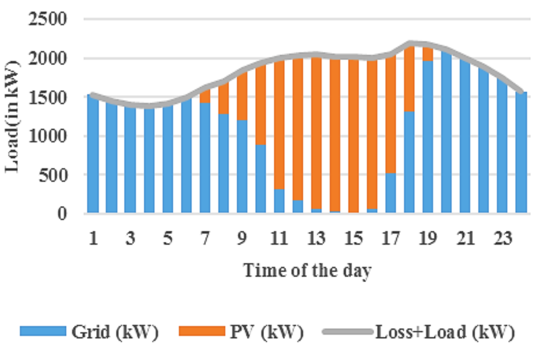


Figure 8. Result of simulation of Case 3

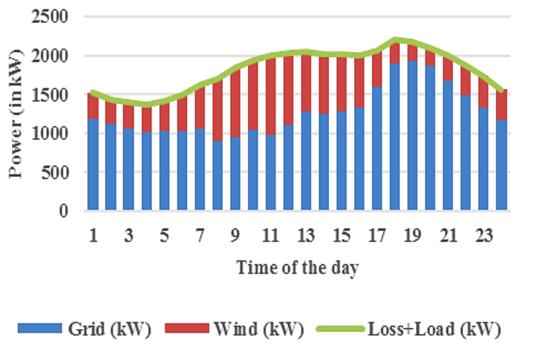
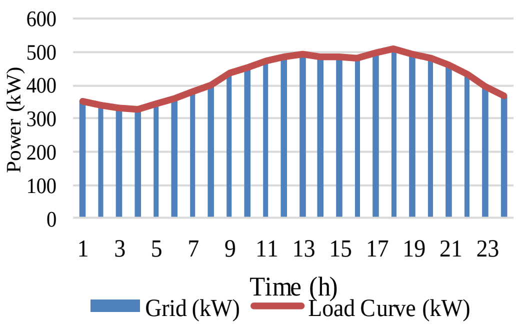


Figure 9. Result of simulation of Case 4

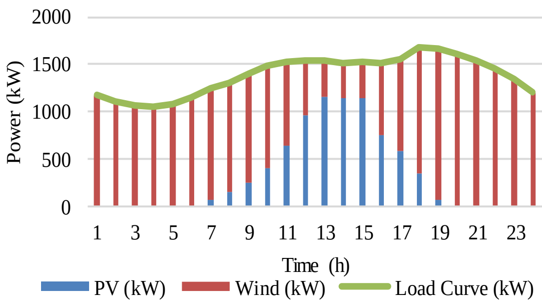
– Case 5: Microgrid in Islanded mode (Modified IEEE–13 bus distribution test system with both solar PV and Wind present)

The economic dispatch was performed for the IEEE-13 node test feeder with PV system and wind generator in islanded mode. Figure 2 depicts the IEEE-13 node test feeder with PV system and wind generator islanded from the grid. In this case, there are two parts in the system-grid-connected part and islanded part of the microgrid.

a) Case 5(a): Grid-connected part of the microgrid: The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 10(a) as shown in. In this case, the grid supplies a total energy of 10287.53 kWh and the losses are 14.03 kWh which is 1.75% of the energy being supplied.
b) Case 5(b): Islanded part of the microgrid: The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 10(b) below. In this case, out of total demand, 22.99%, that is 7655.99 kWh is supplied by the PV system, and 25636.85 kWh, that is, 77.01% by the wind generator. The losses sum up to be 244.61 kWh which is 0.73% of the energy being supplied which is quite less than that in the case of the grid–connected part of the proposed microgrid.



(a)



(b)

Figure 10. Results of simulation of (a) Case 5(a) and (b) Case 5(b)

Figure 11 gives hourly load for microgrid under islanded conditions, considering both grid-connected part and islanded part for 24 hours can be seen. The grid supplies 23.59%, PV system supplies 17.57%, and wind supplies 58.83% of the total energy in a day. The losses in this are 0.975% of the total energy being supplied.

– Case 6: Microgrid in Islanded mode (Modified IEEE–13 bus distribution test system with only wind present)

a) Grid-Connected part of the microgrid: The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 12(a). In this case, the grid supplies a total energy of 10287.53 kW h.
b) Islanded part of the microgrid: The generation schedule obtained through the algorithm from each source for 24 hours can be seen in Figure 12(b). The entire energy requirement is met by the wind source.

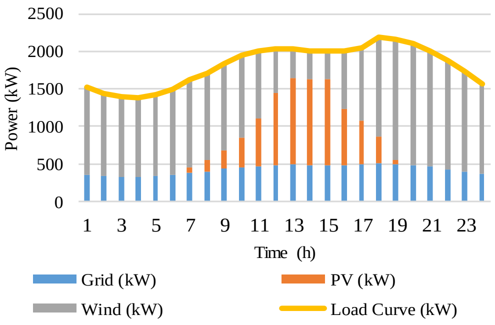


Figure 11. Results of simulation of Case 5

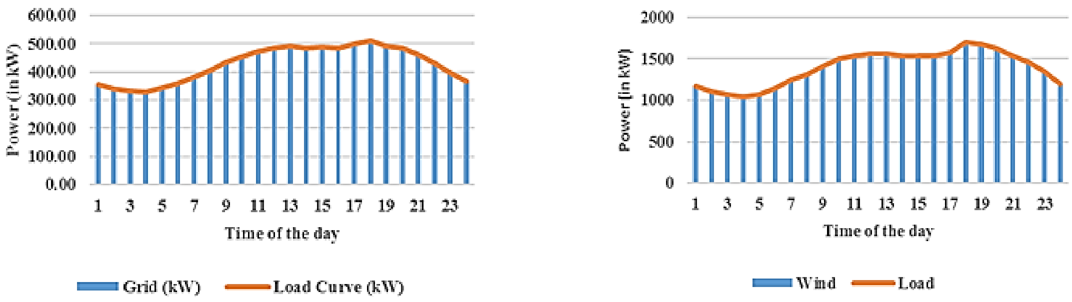


Figure 12. Results of simulation of Case 6: (a) Grid connected part of the microgrid and (b) Islanded part of the microgrid

The cost of generation in this case (including both grid-connected part and isolated part of the microgrid) is the US $ 32.81/MWh. This is the least cost of generation among all the cases considered in this work. Table 1 presents the results of the economic dispatch of a microgrid both in grid-connected mode and isolated mode. Cost of generation and system losses in the table represent total values for one day of operation. The total energy supplied to the load is 43148.27 kWh which is the same in all cases. The following observations can be made from the above table:

- The minimum cost of generation is the US $ 32.18/MWh with the load supplied by only wind generation under islanded conditions.
- The cost of a generation when both solar PV and Wind are present is more in grid-connected mode when compared to the islanded mode of operation.
- Using wind as a resource is less expensive (US $ 92.66/MWh) when compared with solar in the grid-connected mode. This is because of the availability of wind throughout the day.
- When no DG is present, the cost of generation is maximum with US $ 131.71/MWh in grid-connected mode.
- In islanded mode, the load could not be met with solar PV alone as it is available only during the daytime. However, it is possible to meet the load requirement with wind generation.

Table 1. Summary of economic dispatch of all cases

Case	Description of the Case	Cost of Generation (in US $/MWh)	System Losses (in kWh)
1	Grid-Connected Mode (Original Test System)	131.71	705.04 (1.6%)
2	Grid-Connected Mode with both Solar PV and Wind present	79.62	433.73 (0.95%)
3	Grid-Connected Mode with only Solar PV	120.07	481.4 (1.1%)
4	Grid-Connected Mode with Wind only	92.66	430.2 (0.99%)
5	Islanded Mode with both Solar PV and Wind	63.87	424.9 (0.975%)
6	Islanded Mode with only Wind	32.18	583.1 (1.33%)

4. CONCLUSION

In this paper, the economic dispatch of a microgrid using quadratic programming has been carried out using open DSS and MATLAB. The proposed methodology has been implemented on a modified IEEE-13 bus distribution test feeder. Previous research in this area did not take into account different types of loads and the capability of DER to supply both active and reactive power under islanding conditions in order to meet the load design requirements specified in IEEE Standard 1547.4. This paper addresses all these issues and includes appropriate changes in the original test system and modifies the network accordingly. The paper also discusses the modeling issues of DER in open DSS. From the work carried out, the following conclusions can be drawn: i) microgrid with DG capable of supplying both active and reactive power under islanded conditions is economical when compared to grid-connected mode; and ii) when DG (Solar PV and Wind) is included, the cost of dispatch in both grid-connected mode and islanded mode is low when compared to without DG.

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REFERENCES

[1] J. P. Carvallo, D. S. Lounsbury, R. Deshmukh, and D. Schnitzer, “Microgrids for Rural Electrification: A critical review of best practices based on seven case studies,” Washington, D.C., Amerika, 2014. doi: 10.13140/RG.2.1.1399.9600.

[2] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, “Microgrids management,” *IEEE Power and Energy Magazine*, vol. 6, no. 3, pp. 54–65, May 2008, doi: 10.1109/MPE.2008.918702.

[3] S. Ramabhotla, S. Bayne, and M. Giesselmann, “Economic dispatch optimization of microgrid in islanded mode,” in *International Energy and Sustainability Conference 2014*, Oct. 2014, pp. 1–5. doi: 10.1109/IESC.2014.7061838.

[4] F. Chen *et al.*, “Cost-Based Droop Schemes for Economic Dispatch in Islanded Microgrids,” *IEEE Transactions on Smart Grid*, vol. 8, no. 1, pp. 63–74, Jan. 2017, doi: 10.1109/TSG.2016.2581488.

[5] M. Soshinskaya, W. H. J. Crijns-Graus, J. M. Guerrero, and J. C. Vasquez, “Microgrids: Experiences, barriers and success factors,” *Renewable and Sustainable Energy Reviews*, vol. 40, pp. 659–672, Dec. 2014, doi: 10.1016/j.rser.2014.07.198.

[6] X. Zhang, R. Sharma, and Yanyi He, “Optimal energy management of a rural microgrid system using multi-objective optimization,” in *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, Jan. 2012, pp. 1–8. doi: 10.1109/ISGT.2012.6175655.

[7] M. Nemati, M. Braun, and S. Tenbohlen, “Optimization of unit commitment and economic dispatch in microgrids based on genetic algorithm and mixed integer linear programming,” *Applied Energy*, vol. 210, pp. 944–963, Jan. 2018, doi: 10.1016/j.apenergy.2017.07.007.

[8] H. Wu, X. Liu, and M. Ding, “Dynamic economic dispatch of a microgrid: Mathematical models and solution algorithm,” *International Journal of Electrical Power & Energy Systems*, vol. 63, pp. 336–346, Dec. 2014, doi: 10.1016/j.ijepes.2014.06.002.

[9] F. D. Santillán-Lemus, H. Minor-Popocatl, O. Aguilar-Mejía, and R. Tapia-Olvera, “Optimal Economic Dispatch in Microgrids with Renewable Energy Sources,” *Energies*, vol. 12, no. 1, p. 181, Jan. 2019, doi: 10.3390/en12010181.

[10] D. McLarty, N. Panossian, F. Jabbari, and A. Traverso, “Dynamic economic dispatch using complementary quadratic programming,” *Energy*, vol. 166, pp. 755–764, Jan. 2019, doi: 10.1016/j.energy.2018.10.087.

[11] C. Li, F. de Bosio, F. Chen, S. K. Chaudhary, J. C. Vasquez, and J. M. Guerrero, “Economic Dispatch for Operating Cost Minimization Under Real-Time Pricing in Droop-Controlled DC Microgrid,” *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 5, no. 1, pp. 587–595, Mar. 2017, doi: 10.1109/JESTPE.2016.2634026.

[12] X. KONG, L. BAI, Q. HU, F. LI, and C. WANG, “Day-ahead optimal scheduling method for grid-connected microgrid based on energy storage control strategy,” *Journal of Modern Power Systems and Clean Energy*, vol. 4, no. 4, pp. 648–658, Oct. 2016, doi: 10.1007/s40565-016-0245-0.

[13] M. Bornapour, R.-A. Hooshmand, A. Khodabakhshian, and M. Parastegari, “Optimal coordinated scheduling of combined heat and power fuel cell, wind, and photovoltaic units in micro grids considering uncertainties,” *Energy*, vol. 117, pp. 176–189, Dec. 2016, doi: 10.1016/j.energy.2016.10.072.

[14] E. E. Elattar, “Modified harmony search algorithm for combined economic emission dispatch of microgrid incorporating renewable sources,” *Energy*, vol. 159, pp. 496–507, Sep. 2018, doi: 10.1016/j.energy.2018.06.137.

[15] B. Dey, B. Bhattacharyya, S. Raj, and R. Babu, “Economic emission dispatch on unit commitment-based microgrid system considering wind and load uncertainty using hybrid MGWOSCACSA,” *Journal of Electrical Systems and Information Technology*, vol. 7, no. 1, p. 15, Dec. 2020, doi: 10.1186/s43067-020-00023-6.

[16] W. Liu, P. Zhuang, H. Liang, J. Peng, and Z. Huang, “Distributed Economic Dispatch in Microgrids Based on Cooperative Reinforcement Learning,” *IEEE Transactions on Neural Networks and Learning Systems*, vol. 29, no. 6, pp. 2192–2203, Jun. 2018, doi: 10.1109/TNNLS.2018.2801880.

[17] M. Ross, C. Abbey, F. Bouffard, and G. Joos, “Microgrid Economic Dispatch With Energy Storage Systems,” *IEEE Transactions on Smart Grid*, vol. 9, no. 4, pp. 3039–3047, Jul. 2018, doi: 10.1109/TSG.2016.2624756.

[18] M. Zhou, Q. Zhai, and Y. Zhou, “Economic Dispatch of Energy Storage System in Micro-grid,” *IOP Conference Series: Materials Science and Engineering*, vol. 563, no. 5, pp. 1–13, 2019, [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/563/5/052108/pdf

[19] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, “Microgrid supervisory controllers and energy management systems: A literature review,” *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1263–1273, Jul. 2016, doi: 10.1016/j.rser.2016.03.003.

[20] G. Reid and L. Hasdorff, “Economic Dispatch Using Quadratic Programming,” *IEEE Transactions on Power Apparatus and*

Systems, vol. PAS-92, no. 6, pp. 2015–2023, Nov. 1973, doi: 10.1109/TPAS.1973.293582.

[21] "IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems," 2011 doi: 10.1109/IEEESTD.2011.5960751.
[22] R. C. Dugan, "Reference Guide - The Open Distribution System Simulator (OpenDSS)," 2016.
[23] P. Radatz, N. Kagan, C. Rocha, J. Smith, and R. C. Dugan, "Assessing maximum DG penetration levels in a real distribution feeder by using OpenDSS," in *2016 17th International Conference on Harmonics and Quality of Power (ICHQP)*, Oct. 2016, pp. 71–76. doi: 10.1109/ICHQP.2016.7783416.
[24] N. Augustine, S. Suresh, P. Moghe, and K. Sheikh, "Economic dispatch for a microgrid considering renewable energy cost functions," in *2012 IEEE PES Innovative Smart Grid Technologies (ISGT)*, Jan. 2012, pp. 1–7. doi: 10.1109/ISGT.2012.6175747.
[25] W. H. Kersting, "Radial distribution test feeders," in *2001 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.01CH37194)*, vol. 2, pp. 908–912. doi: 10.1109/PESW.2001.916993.
[26] R. S. Wibowo, K. R. Firmansyah, N. K. Aryani, and A. Soeprijanto, "Dynamic economic dispatch of hybrid microgrid with energy storage using quadratic programming," in *2016 IEEE Region 10 Conference (TENCON)*, Nov. 2016, pp. 667–670. doi: 10.1109/TENCON.2016.7848086.

BIOGRAPHIES OF AUTHORS

Gowthami Thimmapathruni Venkata Satya received her B.Tech and M.Tech from Jawaharlal Nehru Technological University, Kakinada in 2015 and 2018 respectively. During the summer of 2015, she was the visiting scholar with Visakhapatnam Steel Plant where she worked on the basics of SCADA. In the year 2015, she worked as Assistant System Engineer at IBM on various coding languages like C, C++, Java, and Python. During the summer of 2017, as the part of Cirucullum of her Masters, she had done her internship with Visakhapatnam Steel Plant on the topic of Health Monitoring of Transformers: A Case Study. Her research interests include Distribution automation, utilization of renewable energy, and optimization of power system operation. She can be contacted at email: gowthami.tvs@gmail.com.

Chennapragada Venkata Krishna Bhanu received his B.E., M.E., and Ph.D. in 1990, 1999, and 2009 respectively. He joined Visakhapatnam Steel Plant in 1990 and worked for five years till 1995. He was involved in the Testing and Commissioning of Electrical equipment including 12MW Gas Turbines in the Visakhapatnam Steel Plant. He joined Gayatri Vidya Parishad College of Engineering as a teaching assistant in 1997 and is working as Professor to date. With his initiation, a 100 kWp grid-connected solar PV plant and an 80 m3 biogas plant on the campus. He is a senior member of IEEE and a Fellow, the Institution of Engineers (India). He is also a Certified Energy Auditor, BEE, Ministry of Power, Government of India. His areas of research include Restructured Power Systems, Renewable Energy Systems, Microgrids, and Energy Storage. He can be contacted at email: bhanucvk@gvpce.ac.in.