The 6th International Conference on Renewable Power Generation (RPG)

19–20 October 2017

Energy management system controller for a rural microgrid

Abhishek Kumar[1], Yan Deng[1], Xiangning He[1], Praveen Kumar[2], Ramesh C. Bansal[3]

[1]*College of Electrical Engineering, Zhejiang University, Zhejiang, People's Republic of China*
[2]*Department of Electronics and Electrical Engineering, IIT Guwahati, Guwahati, India*
[3]*Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa*
E-mail: abhi@zju.edu.cn

Published in *The Journal of Engineering*; Received on 6th October 2017; Accepted on 2nd November 2017

Abstract: An energy management system (EMS) for an isolated microgrid in a typical rural location is presented. The rural microgrid consists of locally available renewable energy resources, such as solar, wind, along with diesel generator for backup and battery as storage to meet the electrical load demand. The grid electricity supply in the village is characterised by frequent outages with the poor quality of supply. Firstly, the proposed system controller's (PSC) dispatch rules are formulated using MATLAB. Then, PSC rules designed in MATLAB are integrated with hybrid optimisation of multiple electric renewables (HOMER PRO) software to design an isolated microgrid. A detailed techno-economic analysis is presented to obtain the cost-effective sizing of the microgrid considering a yearly load growth over the project lifetime. Finally, to show the effectiveness, a comparative analysis of the PSC with the inbuilt load following controller of the HOMER PRO is also illustrated. Also, a simple procedure showing the integration of MATLAB with HOMER PRO is outlined briefly.

1 Introduction

As per International Energy Agency, the energy demand is going to rise by 30% globally till 2040 with significant contributions from India and China due to their fast urbanisation and development goals [1]. Despite many intensified efforts by many countries, still, 38% of the global population suffers from energy poverty and majority (80%) of which are concentrated in rural areas of developing countries such as India and South Africa [1–3]. A combined population equivalent of the European Union and USA still do not have access to electricity in India (240 million) specifically in remote locations along with 840 million population relying mostly on solid biomass to meet their daily household energy demand [2, 4, 5]. India's continued economic expansions and population growth will continue to rise its energy demand. Fossil fuels meet most of the energy demand in India with significant contributions from coal (44%) followed by oil (23%) and biomass (24%), respectively [5]. In November 2016, the Paris Agreement (COP 21) on climate and temperature change occurring globally due to the emission of greenhouse gas (GHG) have been forced with 147 member countries with India as one of the signatories to this accord [1, 6]. Now, tough challenges lie ahead for India to maintain its GHG emission as per COP 21 agreement and also to meet its growing energy demand. Renewable energy technologies (RETs) can play a great role in supporting its development goals as well as meeting its demand [7]. However, just by expanding the installation capacity of generation based on RETs will not be able to solve this problem as India faces an operational shortage of power along with non-existence of a unified organisational framework and power fluctuations from one province to others are some of the potential reasons [5]. Still, 30% of rural areas have no access to electricity till date, most of them (~2100 villages) are located in North-eastern states of India [8]. These areas are characterised by challenging demography such as rivers, harsh weather conditions, heavy rainfall, poor road infrastructure, forest [9–11]. Grid extension in these areas is expensive as well as unreliable due to frequent outages mostly occurring by transmission line faults [10–13]. Off-grid solutions based on locally available renewable energy resources can be a key to electrifying these regions without affecting the environment [11, 12, 14–17].

As the RETs are of intermittent nature, and their generation capacity is affected by weather conditions specific to a particular location their proper sizing depending upon the load demand is mandatory [12, 13, 18, 19]. Moreover, an energy management system (EMS) has to be designed in such a way that, it can not only meet the load demand but at the same time is cost effective [20]. Several studies have been reported in the literature for determining the optimal sizing of microgrid based on RETs [9, 12–14, 16, 19–22]. Upadhya and Sharma [12] have designed hybrid energy system based on solar, biogas and micro-hydro system using soft computing techniques for a remote village in India using different type of EMS. An iterative optimisation approach following total energy deficit, total net present cost and energy cost have been developed for sizing the components of a stand-alone PV/wind/diesel/battery hybrid system [23]. In [19], a detailed review providing insights to the various configurations, sizing methods with control and energy management of hybrid energy system is presented. Authors in [24] have used particle swarm optimisation method for investigating cost-effective optimal sizes of the hybrid energy system in grid connected and isolated mode of an academic institution in Egypt. Using single objective optimisation technique to minimise the life cycle cost with lower power loss a sizing approach for an isolated microgrid is reported in [25]. Many studies based on HOMER software for determining the optimal sizes of various elements of energy systems for rural electrification with a real-time EMS have been reported in [9, 13, 26–31]. A case study to determine the feasibility of satisfying electrical energy needs considering technical and economic criteria with hybrid energy systems for a medium-size hotel on Kish Island, Iran is evaluated using HOMER in [32]. A detailed review based on utilisation of HOMER software and its application in the optimal planning of energy system has been reported in [33]. A hybrid energy system combining RETs (PV and wind) with a fuel cell is proposed in [34]. A load following strategy is utilised to manage the power flow from source to load, and the fuel cell acts as a backup to the renewable energy system. The energy storage device will operate in charge-sustaining mode during a load cycle considering the peaks of RETs power and an imposed SOC window. Most of the work outlined so far in the literature have taken no account of yearly load growth while determining the sizing and energy management strategy. The energy management strategy illustrated in various works [12, 13, 20, 21, 35] has been verified mostly for a year that too without considering the load growth which may give results far from reality. Moreover, in most of studies authors have just selected the energy alternatives based on their choice for designing the hybrid energy systems without following any proper methodology or framework which may indeed lead to errors and in many cases to complete project failures in the real world [3, 7, 10].

In this work, sizing of microgrid for a rural location considering a yearly load growth using HOMER PRO is presented. Two EMS load following controller (LFC) based on HOMER and PSC developed with MATLAB and integrated with HOMER is utilised for cost-effective power management between generation and demand. The selected energy alternative for designing of the microgrids for the specified location (Leporiang Village) is obtained after sustainable evaluation based on decision analysis tool [10]. A simple procedure outlining the integration of dispatch algorithm developed in MATLAB with HOMER is also illustrated. The paper is organised as follows: Section 2 explains the various details about the study area, Section 3 discusses the architecture with specific details about the key simulation parameters, Section 4 discusses the EMSs used to determine the sizing of the elements of microgrid followed with results and conclusion in Sections 5 and 6, respectively.

2 Village profile

The selected village, Leporiang is located in Papumpare District of North-eastern state of India [10, 11, 17]. The daily community load profile was estimated based on the door-to-door survey conducted with a set of questions [10, 11]. The total connected load of the village as per the data collected in February 2014 was 104.6 kW (83 kW domestic, 12 kW office and 9.6 kW school) [11]. Due to better road connectivity and rise in the economic condition of the community people, an increase in total load demand to 136.54 kW (110 kW domestic, 14.54 kW office and 12 kW school) was observed as per the data collected in August 2015 [10]. The annual average daily solar radiation in the village area is 3.94 kWh/m^2/day with an annual average wind speed of 4.2 m/s [36].

3 Microgrid architecture and key simulation parameters

Based on the results obtained in our previous analysis as reported in [10] a combination of PV, WT as primary power generation technologies with diesel generator (DG) as a backup and lead-acid battery as storage is considered. Specific details about the architecture and parameters used for simulating the microgrid is outlined in section to follow.

3.1 Architecture

The architecture of the microgrid is shown in Fig. 1.

As seen in Fig. 1, the total energy consumption of the village as per August 2015 data is 876.41 kWh/day with a peak load of 101 kW. The load factor as calculated by HOMER was 0.36. The microgrid consists of a small DG system, PV, and WT as RETs and tubular flooded lead-acid battery (TLAB) as storage along with a bi-directional converter (CON) to maintain the flow of power from AC to DC bus. The community load is connected to the AC bus of the microgrid as shown in Fig. 1.

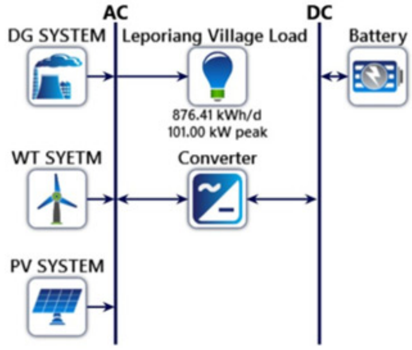

Fig. 1 *Microgrid architecture*

3.2 Key simulation parameters and component details

To determine the cost-effective sizing of the individual elements, the component cost of RETs (capital, operation and maintenance cost) are as per the certified rate of central electricity regulatory commission, Government of India [37] and other elements from relevant literature or authorised dealers/manufacturers. The prices are converted from Indian National Rupee (INR) to United States Dollars (USD) using a monthly average rate of 1 USD = 64.38 INR, obtained from State Bank of India [38]. A flat plate fixed type PV system with a capital cost (CC) of USD 823238/MW and operation and maintenance (O&M) cost of USD 10872/MW per year is considered [37]. A small 10 kW horizontal axis wind turbine system with a CC of USD 9672 and O&M of USD 200 per year is taken [37]. A TLAB of 3 kWh individual capacity as a battery storage with a CC of USD 320 and O&M of USD 12 per year is chosen [39]. A small size DG system with a CC of USD 250 per kW and O&M cost of USD 0.20 per hour is considered [12]. As the current generation converters are maintenance free a CC of USD 300 per kW for the bidirectional converter (CON) is taken [12]. A project lifetime of 10 years with a load growth of 6.9% per year is considered in this analysis. The growth rates are assumed on the basis of projections illustrated in India Energy Outlook [5].

4 Energy management system

EMS plays a very crucial role in managing and dispatching power from energy sources to the load in the microgrid. An efficient EMS cannot only save substantial amount of energy but can help in minimising the cost of electricity. In this work, two EMS namely LFC and PEMS are utilised to manage the flow of power from the source to load and then to storage.

4.1 Load following controller

The LFC is an inbuilt EMS of HOMER PRO software which uses a unique control strategy to operate and simulate the microgrid system. In LFC dispatch procedure, the primary objective is to meet the load demand. All the controllable power sources (the generators, storage) are first to serve the primary load and thermal load if any with a least cost at each time step. The charging of the battery bank is accounted as low-priority objective which is the job of RETs only [39]. This controller can directly account for the yearly load growth by a percentage change (6.9% in this case) over the assumed project lifetime.

4.2 PSC and its integration with HOMER PRO

Fig. 2 shows the proposed dispatch algorithm. At first, RETs (PV and WT) are operated to meet the current load demand as a primary objective. If the RETs output power ($P_{\mathrm{RET}} = P_{\mathrm{PV}} + P_{\mathrm{WT}}$) is not able to meet the load demand (P_{L}), then the battery will

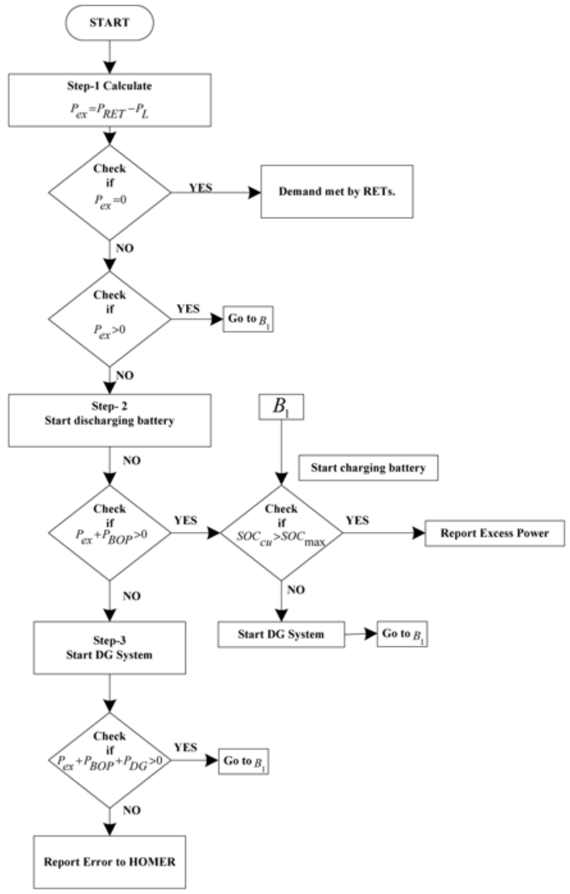

Fig. 2 *Proposed dispatch algorithm*

also be discharged till 20% of its state of charge (SOC_{cu}). In another case, if the RETs and battery output (P_{BOP}) cannot serve the load, then DG should give output (P_{DG}) to meet the demand and then it should be operated till the battery SOC is up to 80% (SOC_{max}). The DG should also run whenever the battery SOC reaches 20% till it restores its SOC to 80%. B_1 is the initialisation command to check for battery SOC to execute the charging process when needed. The dispatch algorithm for the PSC is written using if-else rules in MATLAB, and then it is integrated with HOMER. However, the direct inclusion to model the yearly load growth has not been accommodated in the integration system. So, in this case using the sensitivity variable setup (already present in HOMER) and including the percentage change (6.9%) manually in the algorithm, the load growth projections were carried out and then the optimal system design which can suffice the yearly load growth is modelled. A simple procedure how HOMER integrates and run the user define dispatch is explained in Fig. 3.

5 Results and discussion

All the values of parameters as specified in Section 3.2 are kept same for both the controllers and simulation is run to find the cost-effective optimal size. Table 1 shows the optimal microgrid element size using both the controllers.

Table 2 illustrates the costing incurred for the optimal microgrid obtained using both the EMS.

Figs. 4*a* and *b* show the average monthly electrical output from the PV, WT and DG for the base year (2015) and final year (2024) when the system is using LFC. It can be observed from Fig. 4*a* that DG is only operated for a short period during August and September only. However, when the load demand increases with time in the projected year 2024, the DG is needed in every

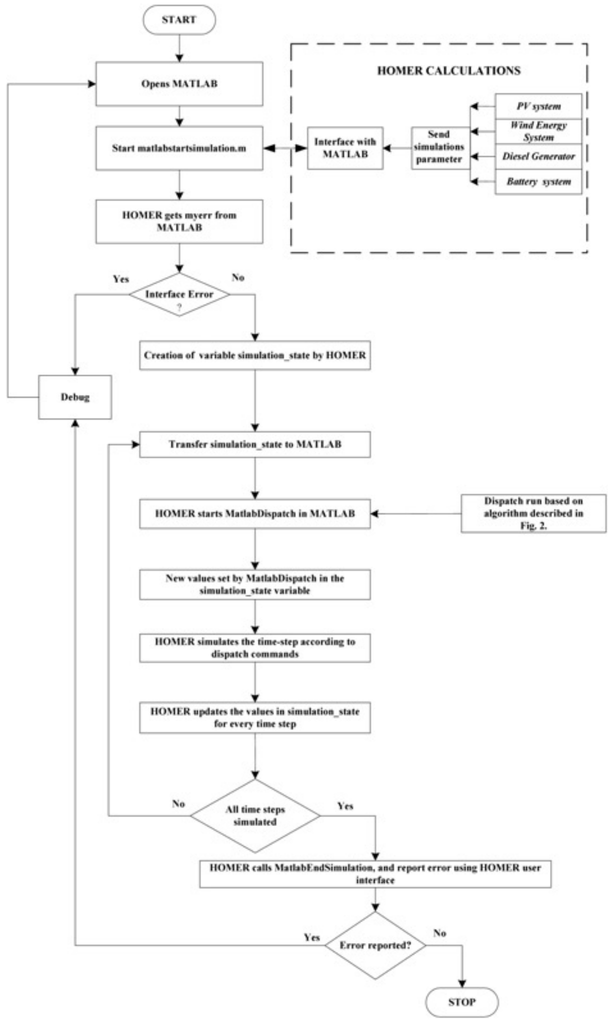

Fig. 3 *Process of MATLAB integration with HOMER*

Table 1 Optimal size of microgrid elements

EMS	Components				
	PV, kW	WT, kW	DG, kW	CON, kW	TLB, (numbers)
LFC	500	100	300	700	800
PSC	600	100	200	400	1000

Table 2 Total cost of the optimal system

EMS	Capital cost, USD	Net present cost, USD	O&M cost, USD	Fuel cost, USD	LCOE, USD/kWh
LFC	1,048,898	1,130,330	208,114	52,771	0.39
PSC	1,080,222	1,108,578	173,127	44,085	0.38

month. The working of the LF controller for a typical day in January on an hourly basis using the load of the base year (2015) is shown Figs. 5*a* and *b*. Fig. 5*a* illustrates the power management by LFC based on the hourly load variation. In early morning hours (1st–3rd), LFC takes power from RETs to the load demand.

However, from 3rd to 6th when power output from RETs is unavailable, it discharges the battery to meet the load demand. During

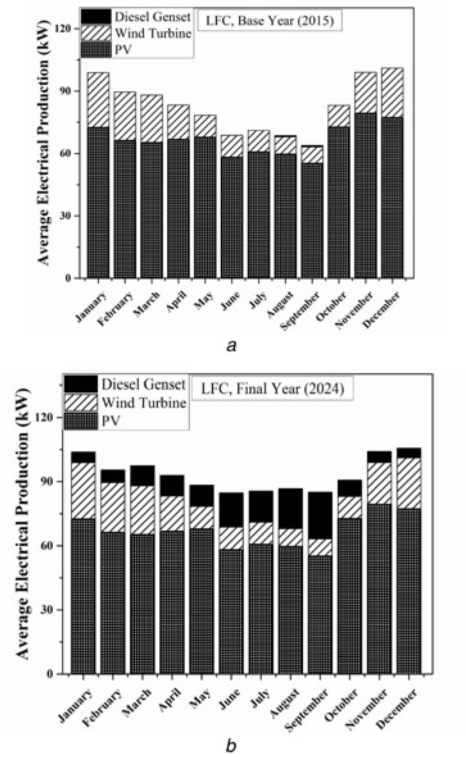

Fig. 4 *Monthly average generation profiles using LFC*
a Monthly average production using LFC (2015)
b Monthly average production using LFC (2024)

6th to 16th hour when load demand is lower to RETs power output, the controller first meets the demand and sends the excess power to charge the battery. The charging and discharging of battery with variation in its SOC are shown in Fig. 5*b*. Figs. 6*a* and *b* show the monthly averages of electrical production using PSC for the base year (2015) and final year (2024), respectively. DG operates for a short while in 2015 during August month only as shown in Fig. 6*a*. However, in 2024 DG as compared to 2015 profile is used more, and it operates in all the months as illustrated in Fig. 6*b*. To show the effectiveness of the PSC algorithm and to incorporate the operation of DG, a daily profile on an hourly basis from the month of August is selected and illustrated in Figs. 7*a* and *b*. During the early morning hours 1st to 6th when the contribution from the RETs is not enough, the battery discharges almost to 20% of its SOC to meet the load demand as shown in Figs. 7*a* and *b*.

DG starts to operate after 5th hour to support the RETs to meet the load demand as well as charge the battery.

Even when, the load demand is lower than RETs output, DG keeps operating from 5th to 14th hour to charge the battery to an SOC of 80% as seen in Figs. 7*a* and *b* as per the dispatch algorithm of PSC. RETs maintain the battery SOC to 80% and meet the demand till 17th hour. During evening hours when load increases and RETs are not able to meet the demand, battery again starts discharging to serve the load.

As seen from above, both the controllers (LFC and PSC) can meet the load demand effectively. However, in the case of PSC the majority of contribution is from PV as seen in Fig. 8. The optimised results show that the element size obtained from using PSC is more for PV and TLB as compared to LFC as mentioned in Table 1. However, the levelised cost of energy (LCOE) is slightly lower for PSC as shown in Table 2. Also, net present, O&M and fuel cost are also low in case of PSC as given in Table 2.

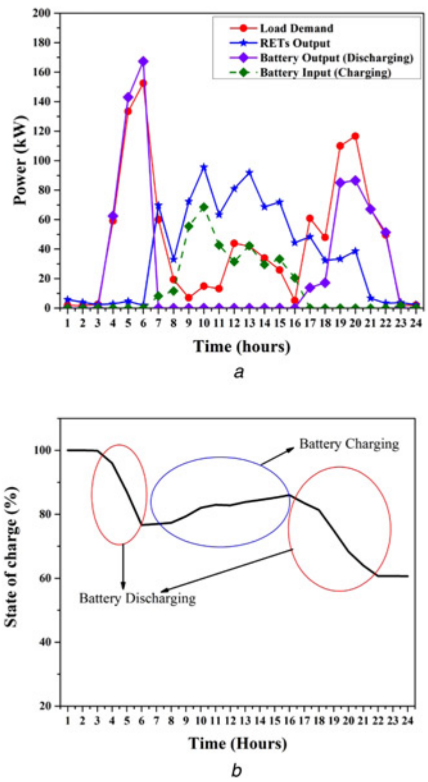

Fig. 5 *Various hourly profiles using LFC for the year 2015*
a Power management hourly profile using LFC (2015)
b Hourly battery characteristics (LFC)

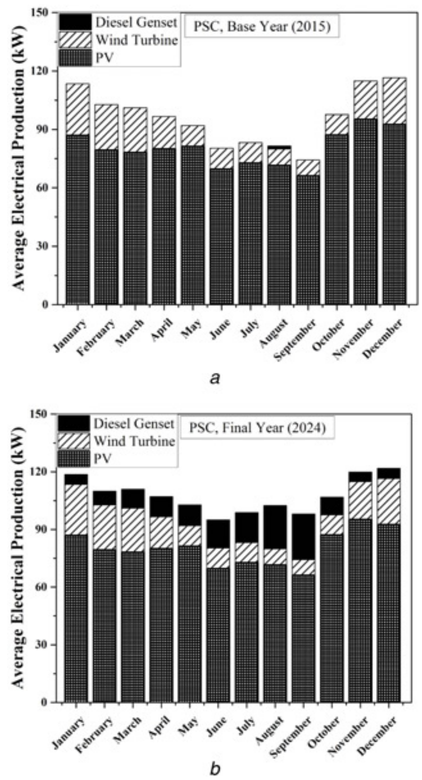

Fig. 6 *Monthly average generation profiles using PSC*
a Monthly average production using PSC (2015)
b Monthly average production using PSC (2024)

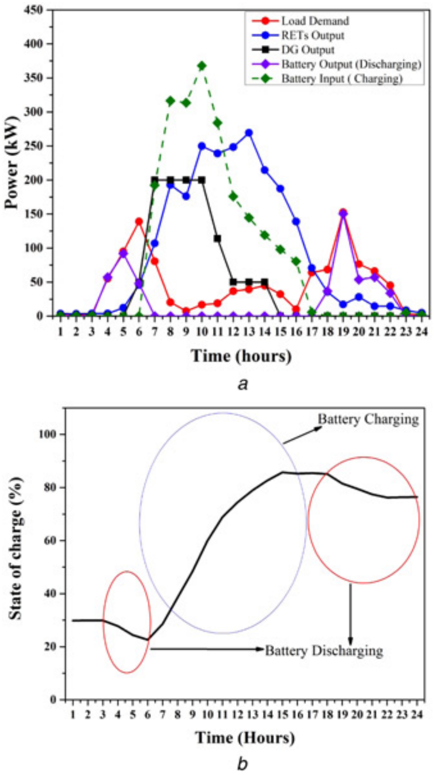

Fig. 7 *Various hourly profiles using PSC for the year 2015*
a Power management hourly profile using PSC (2015)
b Hourly battery characteristics (PSC)

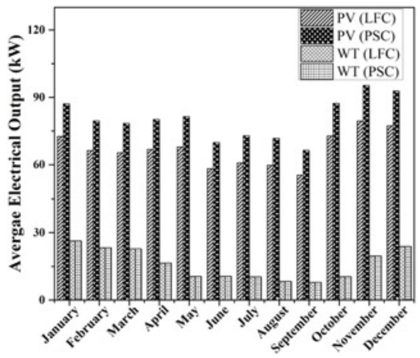

Fig. 8 *Comparative illustration of monthly production (2015)*

6 Conclusion

In this study, EMSs (LFC and PSC) for a rural microgrid based on locally available resources are presented. The EMSs are used to obtain technically robust and economic feasible solution to electrify a remote village considering a yearly load growth scenario. The proposed controllers (PSC) dispatch is developed in MATLAB, and then its integration with HOMER PRO is done to study its working. Results obtained shows that the PSC is effectively working to manage the power flow from source to load in a cost-effective manner. The LCOE obtained by PSC is slightly lower. The simulation execution time to get the optimal sizes in case of PSC is more as compared to LFC.

7 Acknowledgements

Authors express their gratitude towards Mr. Chera Taring, for his endless support through the years in helping to understand the community characteristics and data collection.

8 References

[1] I. E. Agency: 'World energy outlook 2016 – factsheet', 2016
[2] I. E. Agency: 'WEO 2016Biomass database', 2016
[3] Sovacool B.K.: 'Design principles for renewable energy programs in developing countries', *Energy Environ. Sci.*, 2012, **5**, pp. 9157–9162
[4] I. E. Agency: 'World energy outlook 2016, electricity access in 2014 – regional aggregates' (International Energy Agency, 2016)
[5] I. E. Agency: 'India energy outlook', 2015
[6] United Nations Framework Convention on Climate Change (UNFCCC): 'COP 21, Paris agreement', 2015. Available at http://www.cop21.gouv.fr/en
[7] Kumar A., Sah B., Singh A.R., ET AL.: 'A review of multi-criteria decision making (MCDM) towards sustainable renewable energy development', *Renew. Sustain. Energy Rev.*, 2017, **69**, pp. 596–609
[8] Rural Electrification Corporation (REC), Ministry of Power, Government of India: 'Garv Grameen Vidyutikaran'. Available at http://garv.gov.in/dashboard/ue
[9] Amutha W.M., Rajini V.: 'Cost benefit and technical analysis of rural electrification alternatives in southern India using HOMER', *Renew. Sustain. Energy Rev.*, 2016, **62**, pp. 236–246
[10] Kumar A., Deng Y., He X., ET AL.: 'A multi criteria decision based rural electrification system'. IECON-42nd Annual Conf. IEEE Industrial Electronics Society, 2016, pp. 4025–4030
[11] Kumar A., Bam G., Sah B., ET AL.: 'A hybrid micro grid for remote village in Himalayas'. 3Rd IET Renewable Power Generation Conf. (RPG), Naples, Italy, 2014, pp. 1–6
[12] Upadhyay S., Sharma M.P.: 'Selection of a suitable energy management strategy for a hybrid energy system in a remote rural area of India', *Energy*, 2016, **94**, pp. 352–366
[13] Ramchandran N., Pai R., Parihar A.K.S.: 'Feasibility assessment of anchor-business-community model for off-grid rural electrification in India', *Renew. Energy*, 2016, **97**, pp. 197–209
[14] Rajanna S., Saini R.P.: 'Modeling of integrated renewable energy system for electrification of a remote area in India', *Renew. Energy*, 2016, **90**, pp. 175–187
[15] Shahidehpour M., Pullins S.: 'Microgrids, modernization, and rural electrification', *IEEE Electrif. Mag.*, 2015, **3**, pp. 2–6
[16] Singal S.K. Varun, Singh R.P.: 'Rural electrification of a remote island by renewable energy sources', *Renew. Energy*, 2007, **32**, pp. 2491–2501
[17] Kumar A., Sah B., Deng Y., ET AL.: 'Autonomous hybrid renewable energy system optimization for minimum cost'. 4th IET Renewable Power Generation Conf. (RPG), Beijing, China, 2015, pp. 1–6
[18] Mandelli S., Barbieri J., Mereu R., ET AL.: 'Off-grid systems for rural electrification in developing countries: definitions, classification and a comprehensive literature review', *Renew. Sustain. Energy Rev.*, 2016, **58**, pp. 1621–1646
[19] Upadhyay S., Sharma M.P.: 'A review on configurations, control, and sizing methodologies of hybrid energy systems', *Renew. Sustain. Energy Rev.*, 2014, **38**, pp. 47–63
[20] Lin W.-M., Tu C.-S., Tsai M.-T.: 'Energy management strategy for microgrids by using enhanced bee colony optimization', *Energies*, 2015, **9**, p. 5
[21] Ismail M.S., Moghavvemi M., Mahlia T.M.I., ET AL.: 'Effective utilization of excess energy in standalone hybrid renewable energy systems for improving comfort ability and reducing cost of energy: a review and analysis', *Renew. Sustain. Energy Rev.*, 2015, **42**, pp. 726–734
[22] Shaahid S., El-Amin I.: 'Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia – a way forward for sustainable development', *Renew. Sustain. Energy Rev.*, 2009, **13**, pp. 625–633
[23] Kaabeche A., Ibtiouen R.: 'Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system', *Sol. Energy*, 2014, **103**, pp. 171–182
[24] Hassan A., Saadawi M., Kandil M., ET AL.: 'Modified particle swarm optimisation technique for optimal design of small renewable energy system supplying a specific load at Mansoura University', *IET Renew. Power Gener.*, 2015, **9**, pp. 474–483
[25] Bhuiyan F.A., Yazdani A., Primak S.L.: 'Optimal sizing approach for islanded microgrids', *IET Renew. Power Gener.*, 2015, **9**, pp. 166–175
[26] Makhija S.P., Dubey S.P.: 'Techno-economic analysis of standalone hybrid energy systems to run auxiliaries of a cement plant located in Jamul, Chhattisgarh, India', *Environ. Progress Sustain. Energy*, 2016, **35**, pp. 221–229

[27] Khan A.N., Akhter P., Mufti G.M.: 'Techno-economic evaluation of the centralized hybrid renewable energy systems for off-grid rural electrification', *Int. J. Smart Home*, 2016, **10**, pp. 61–68
[28] Chauhan A., Saini R.P.: 'Techno-economic feasibility study on integrated renewable energy system for an isolated community of India', *Renew. Sustain. Energy Rev.*, 2016, **59**, pp. 388–405
[29] Bhatt A., Sharma M.P., Saini R.P.: 'Feasibility and sensitivity analysis of an off-grid micro hydro-photovoltaic-biomass and biogas-diesel-battery hybrid energy system for a remote area in Uttarakhand state, India', *Renew. Sustain. Energy Rev.*, 2016, **61**, pp. 53–69
[30] Stuchly J., Misak S., Prokop L.: 'Techno-Economic analyses of an off-grid system using HOMER simulation tool'. Proc. 8th Int. Scientific Symp. Electrical Power Engineering, (Elektroenergetika), 2015, pp. 109–112
[31] Pradhan A.K., Kar S.K., Mohanty M.K.: 'Modeling, simulation and economic analysis of offgrid hybrid renewable power system for an un-electrified village in Odisha'. Int. Conf. Electrical, Electronics, Signals, Communication and Optimization (EESCO), 2015, pp. 1–6
[32] Fazelpour F., Soltani N., Rosen M.A.: 'Feasibility of satisfying electrical energy needs with hybrid systems for a medium-size hotel on Kish Island, Iran', *Energy*, 2014, **73**, pp. 856–865
[33] Bahramara S., Moghaddam M.P., Haghifam M.R.: 'Optimal planning of hybrid renewable energy systems using HOMER: a review', *Renew. Sustain. Energy Rev.*, 2016, **62**, pp. 609–620
[34] Bizon N.: 'Load-following mode control of a standalone renewable/fuel cell hybrid power source', *Energy Convers. Manage.*, 2014, **77**, pp. 763–772
[35] Bizon N., Oproescu M., Raceanu M.: 'Efficient energy control strategies for a standalone renewable/fuel cell hybrid power source', *Energy Convers. Manage.*, 2015, **90**, pp. 93–110
[36] NASA Surface meteorology and Solar Energy. Available at https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi?email=skip@larc.nasa.gov
[37] Determination of levellised generic tariff for FY 2016-17 under Regulation 8 of the Central Electricity Regulatory Commission (Terms and Conditions for Tariff determination from Renewable Energy Sources), G. o. I. Central Electricity Regulatory Commission, 2016
[38] State Bank of India. Available at https://www.sbi.co.in
[39] HOMER Energy Support. Available at http://usersupport.homerenergy.com/