Reducing the Grid Dependency of Large Buildings Through Renewable Integrated Microgrids

[1]Manuel S M, [2]Rinu Susan Roy, [3]Jom Joseph, [4]Ebin Jose, [5]Anuraj M Nair

[1]PG Student, [2]Assistant Professor
[1]Faculty of Integrated Technologies,
[1]University of Brunei Darussalam, Gadong, Brunei Darussalam.

Abstract: In this paper, we investigate the possibilities of reducing the grid based conventional energy consumption in large buildings through the integration of a microgrid supplemented by renewable energy sources. An educational building, with an average annual consumption of 317.55 MWh was chosen for the study. Based on the daily energy consumption pattern of the building and renewable energy resource potential at the site, a microgrid has been optimally designed for minimizing the Cost of Energy. It could be seen that, 38.8 % of the total energy demand of the building can be met by wind energy, by installing a turbine of 40kW rated capacity, which would contribute 129.3 MWh per annum to the proposed microgrid. This can also reduce the cost of electricity from the current rate of 0.12 $/kWh to 0.107 $/kWh. Sensitivities of the Cost of Energy, renewable energy system capacity and excess renewable energy, on the renewable penetration levels are presented. The sensitivity of the Cost of Energy on different levels of emission reduction through increased renewable penetration is also discussed. The technical feasibility and economic viability of renewable integrated microgrids, in reducing the grid dependency of large buildings, has been established under this study.

***IndexTerms* - Microgrids, Cost of Energy, Life Cycle Emission, Net Present Cost, HOMER, Renewable Energy Fraction.**

1. INTRODUCTION

Building energy usage accounts for roughly one-third of the global final energy consumption. This makes it responsible for one-third of the total energy related CO2 emissions: both direct and indirect. The energy demand by this sector is projected to further increase significantly, unless serious steps are initiated to reduce the consumption level [1]. This pattern is evident all around the world regardless of developing or developed economies. For example, in a developing country like India, 41% of total energy consumption is accounted to the buildings sector and the consumption is expected to increase by 39.72% by 2040 [2].

One of the effective ways to meet this increasing demand is to supplement the existing grid based supply with energy generated from clean resources. This can be achieved either through centralized generation where large scale renewable systems, installed at regions where the resource is most available, are integrated with the central grid or through decentralized generation where large numbers of smaller renewable systems are installed very close to the demand point. Though there are pros and cons for each approach, considering the intermittency of renewables, integration costs and transmission losses, the best choice would be decentralized generation through renewable integrated microgrids which are integral parts of the building. [3].

For the successful planning, implementation and operation of microgrids, potential energy resources available at the site are to be critically identified, and the system components are to be suitably chosen. In general, renewable energy resources are considered as potential choice for microgrids. Several investigations conducted around the world have highlighted the merits of renewable integrated micro-grids for meeting the energy demand in buildings. Some of the recent studies are discussed in [4]-[12]

One of the major factors deciding the success of such systems is the optimal design of the microgrid. Selecting the objectives for the optimization as well as identifying the possible constraints are very important in the design process. For example, Zheng Zeng et al. [13] developed a mathematical model for optimizing a microgrid by meeting the multiple objectives of maximizing the comfort level and at the same time minimizing the energy demand. Similarly, Balamurugan et al. [14] proposed a method for the optimum microgrid design under several constraints like load demand, non-linear seasonal variations, and equipment sensitivities. Another popular approach is the Berkeley Lab's Distributed Energy Resources Customer Adoption Model (DER-CAM) [15] in which, the microgrid and its operating schedule are optimized in a technology- neutral way. This model minimizes annual energy bill and the negative environmental impacts considering the relevant economic and environmental constraints. In another attempt [16], Prasad et al. proposed a new method for the optimization of a wind-PV hybrid system in which the Deficiency of Power Supply Probability (DPSP), Relative Excess Power Generated (REPG), Unutilized Energy Probability (UEP), Life Cycle Cost (LEC) and Life Cycle Unit Cost (LUC) were considered.

Though, as discussed above, there are several approaches in designing the microgrids, HOMER [17], developed by the National Renewable Energy Laboratories, is the most popular model used to design, size and optimize such systems, especially, those integrated with renewables. The advantage of HOMER is that it adopts a comprehensive approach under which the economic, environmental and technological aspects of the microgrid design are considered. It simplifies the tasks of design, sizing and optimization of both off-grid and grid-connected power systems for a wide range of applications. Simulations are made through energy balance calculations for each of the 8,760 hours in a year and for each hour, the electric and thermal demand is compared with the possible supply in that hour to compute the energy flow, to and from, each component of the system. For systems that include batteries or fuel-powered generators, HOMER also suggests the operating levels of the generators and the charging schedule of the batteries. The principal tasks performed by HOMER are as follows:

- In the ***simulation process***, HOMER models the performance of a particular microgrid configuration in each hour of the year to determine its technical feasibility and life-cycle cost.
- In the ***optimization process***, HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost.
- In the ***sensitivity analysis process***, HOMER assesses the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price.

In this paper, we show how the energy demand in a large public building can be supplemented by renewable energy resources with an optimally designed micro-grid and thereby reducing the grid dependency of the building sector. An educational building was chosen for the analysis considering the higher level of energy consumption of the building and the demonstration value of the project. The first section of the paper describes the study location and the current energy use pattern of the building, which is followed by an analysis of available renewable energy resources. Based on the energy demand and resource potentials, possible components of the micro-grid are identified and the system components are optimized using the HOMER model, which are presented at the last sections of the paper.

2. Study Location

The study has been carried out on Mar Baselios Christian College of Engineering and Technology, Peermade, Kerala, India. The campus is located at 9°35'09.8"N and 76°58'59.4"E, at a height of 1042 meters above sea level. The campus consists of three laboratory blocks, four hostel blocks, twenty six lecture rooms, nearly twelve offices, two seminar halls, a library and few restrooms. The typical feature of the power system in this area is the frequent power failures and blackouts, mainly due to the topographical complexity of the region.

3. Resource Profile

Under a preliminary analysis of the weather data of the campus, it was found that the region is blessed by strong wind and solar resources, which can be potentially used for power generation at the campus. Detailed solar and wind data for the campus location was collected and critically analyzed to bring out the resource potential at different time scales.

Under this analysis, the annual average of solar irradiance at the location is estimated to be 4.82 kWh/m2/day with an averaged clearness index of 0.49. Monthly variations in the solar insolation, along with the clearness indices are shown in Fig. 1. We can see that, the intensity of solar radiation is in its peak level of 6.28 kWh/m2/day in the month of March whereas the lowest intensity is recorded in the month of July (3.78 kWh/m2/day). The clearness indices varied from 0.368 to 0.638 during these months.

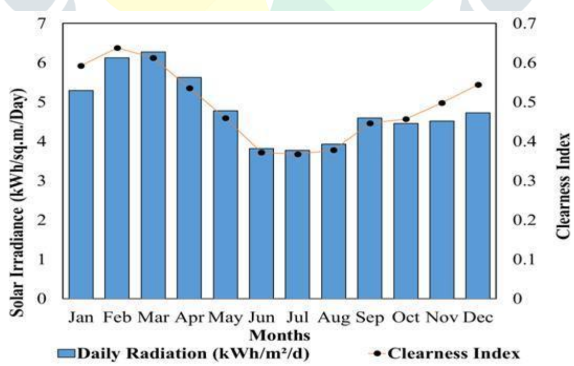

Fig. 1 Monthly average solar radiation and clearness index

Average hourly variations in the solar radiation are shown in Fig. 2. As expected, the intensity of solar radiation is highest at the noon hours. The radiation is well above 500 W/m2during the period from 10 AM to 3.30 PM. Another significant renewable energy resource available at this site is wind. Wind data at 10 m height were collected and analyzed for the study, which is then transformed to hub height of the turbine. The annual average wind speed at the site is 8.87 m/s, which indicates that wind energy projects can be economically viable in the region [18][19]. Monthly variations in wind velocity are shown in Fig. 3. June, July and August are the windy months, whereas, wind velocity is relatively lower in April and May. Probability Density Function (PDF) and Cumulative Distribution Function (CDF) of wind velocities prevailing at the site, assuming Weibull distribution, are shown in Fig. 4 and Fig. 5.

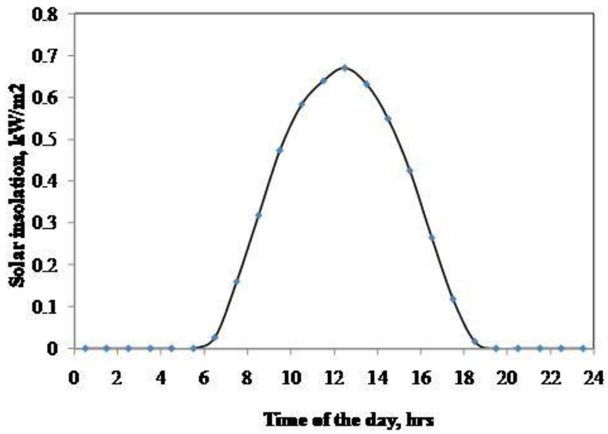

Fig. 2 Average hourly variation in solar insolation.

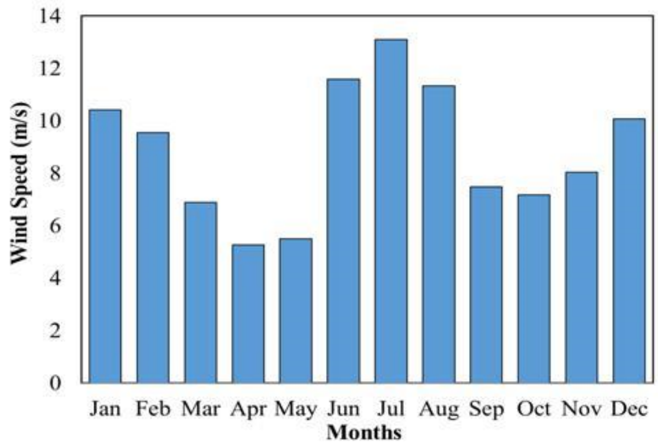

Fig. 3 Monthly average wind speed

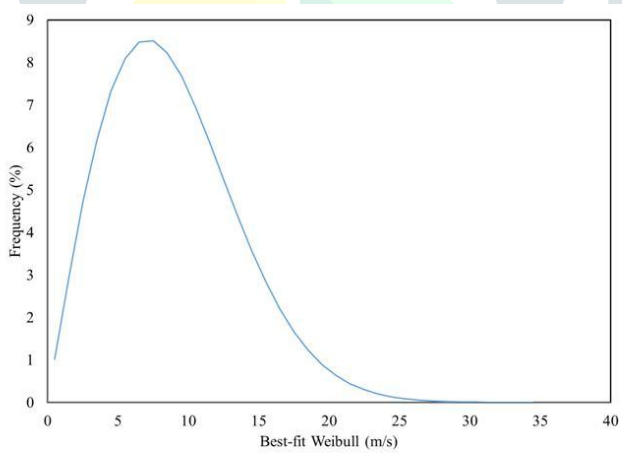

Fig. 4 Probability distribution of wind velocity at the site.

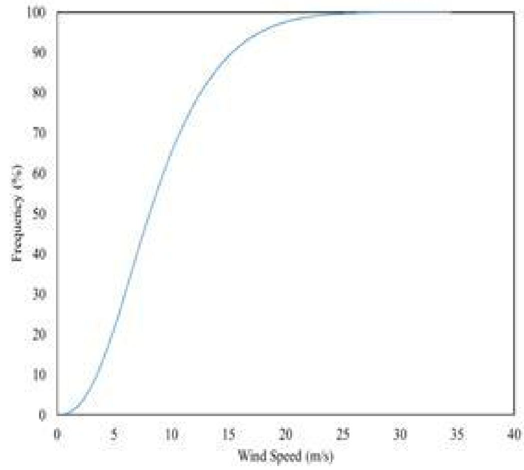

Fig. 5 Cumulative distribution of wind velocity at the site.

The PDF indicates the probability of having a given wind speed at the site where as the CDF shows the time for which the wind is below a given value. From these distributions, it can be seen that the most frequent wind velocity at the site is 7.5 m/s which is expected for 8.50 per cent of the time.

From the cumulative distribution curve we can see that 86.17% of the time the wind velocity is between 4 m/s and 25 m/s, which are the normal operating velocity range of a commercial wind turbine. The above analysis clearly indicates that solar and wind are strong candidate for any renewable based energy projects at the study location.

4. Resource Profile

A major part of the energy consumed in the campus is used for lighting, ventilation and powering the computers and laboratory equipments. The hourly energy consumption of various buildings in the campus was recorded and the average hourly load demand pattern was estimated. The peak load recorded for the Campus was 134 kW. Variation in the electricity demand over a day is shown in Fig. 6. It can be seen that the load is maximum during the evening time from 5 pm to 11 pm which is basically used for the lighting of the campus including the hostel rooms. Monthly variations in the consumption levels at the campus are shown in Fig. 7. The consumption vary significantly from month to month January and November are the months with peak demand while, owing to the semester breaks, June and December showed the least demand.

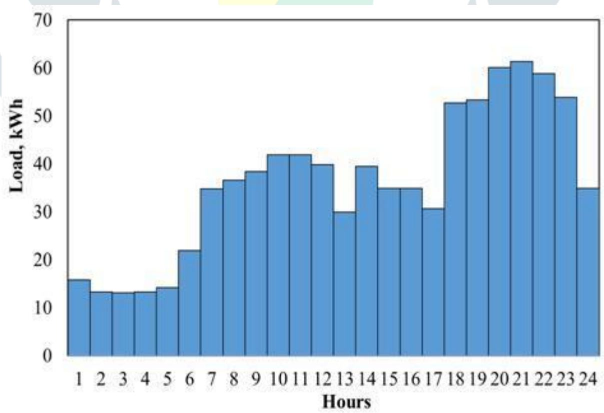

Fig. 6 Typical daily load profile of the campus.

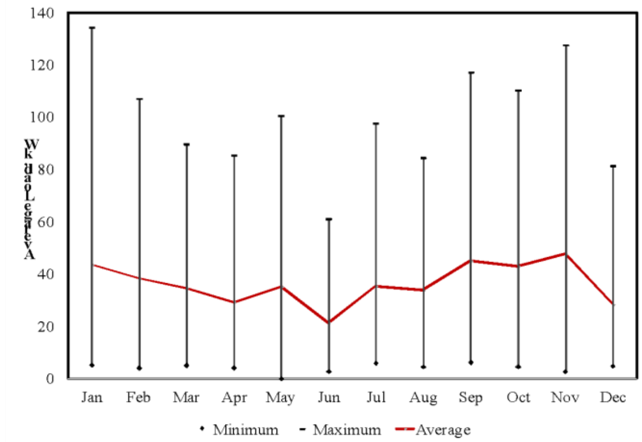

Fig. 7 Seasonal load profile of the campus.

5. SPECIFICATIONS OF THE HYBRID SYSTEM

As evident from the resource analysis, wind and solar area the viable renewable energy options for the micro-grid proposed for the Campus. Hence, a grid tied micro-grid, integrated with solar photovoltaic system and wind turbine is considered for the present study. Storage options were not considered at this point as (i) adding batteries will increase the project's initial investment as well as the maintenance cost and (ii) as the system is designed to be grid tied, the excess demand during the lean period of solar and wind generation can be met from the main grid.

The schematic view of the micro-grid is shown in Fig. 8, and the system components are described in detail in the following sections.

5.1 Wind Turbine

For the flexibility in scaling up the system to different capacities based on the optimized system size, a generic Horizontal Axis Wind Turbine (HAWT) of 10kW rated capacity is initially considered for the study. The cut-in and cut-off velocities of the turbine are 4 m/s and 24 m/s respectively. The turbine reaches its rated power at 14 m/s wind speed. Fig. 9 shows the power curve of the wind turbine. The hub height of the wind turbine is taken as 50m and hence, the wind velocities measured at 10 m height were extrapolated for the hub height of the turbine.

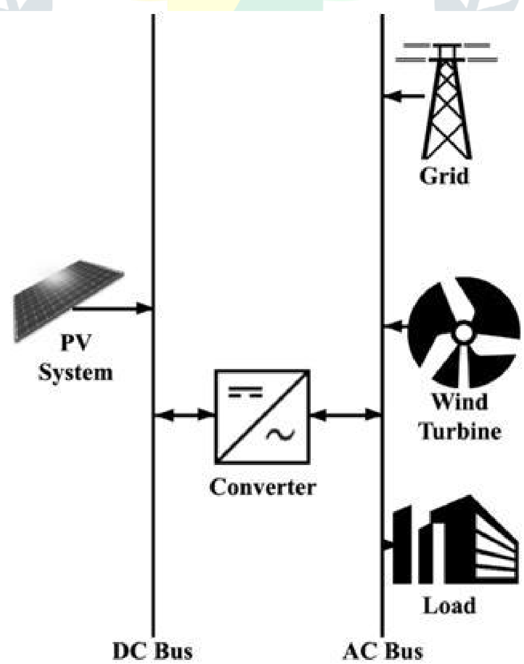

Fig. 8 Configuration of the proposed micro-grid.

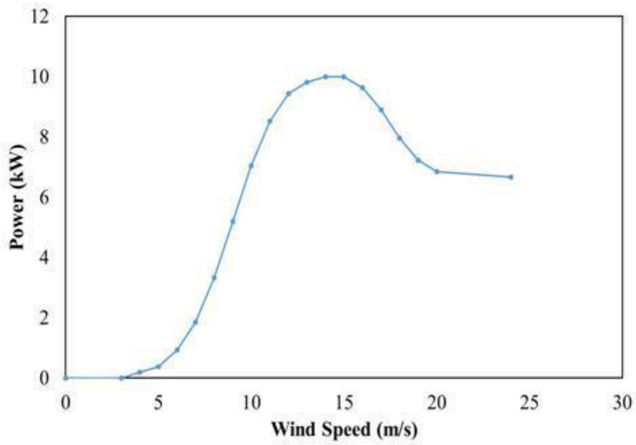

Fig. 9 Power curve of the wind turbine under consideration.

5.2 PV System

The solar energy system considered consists of generic flat plate polycrystalline modules. Size of the PV system is kept flexible between the ranges of 1 kW to 150 kW, so that the optimal size can be identified by the model. The ground reflectance was assumed to be 20% and panel slope has been adjusted to 9.59°. Since the PV output is in DC, a converter of appropriate size has to be added to the system. Similar to the PV system, the converter size has been left open. The

lifetime of inverter was considered as 15 years and the efficiency is taken as 90%.

5.3 Economic Constraints

The proposed micro-grid lifetime was assumed to be 25 years. The nominal discount rate was calculated as 13.85%, considering existing interest, inflation and escalation rates [20]. With these constraints, the system is optimized for the lowest cost of generation at different levels of renewable energy integration, which is discussed in the next section.

6. Results and Discussions

For the given load pattern and available resources at the campus, microgrids with different combinations of potential energy options were designed and optimized. The system which can meet the energy demand in the campus at the lowest possible cost was identified under the optimization. It is seen that, 38.8% of the total energy, consumed annually by the campus buildings, can be met by renewable energy sources. The Cost of Energy (COE), at this level of renewable penetration would be 0.107 $/kWh, against the current grid purchase rate of 0.12 $/kWh. Wind energy system of 40 kW capacity is required for realizing this optimal renewable energy level. The proposed wind energy system will contribute 129.3 MWh of electricity annually to the proposed microgrid. Solar option, in spite of its strong resource, was not recommended under the optimization mainly due to the high initial investment required.

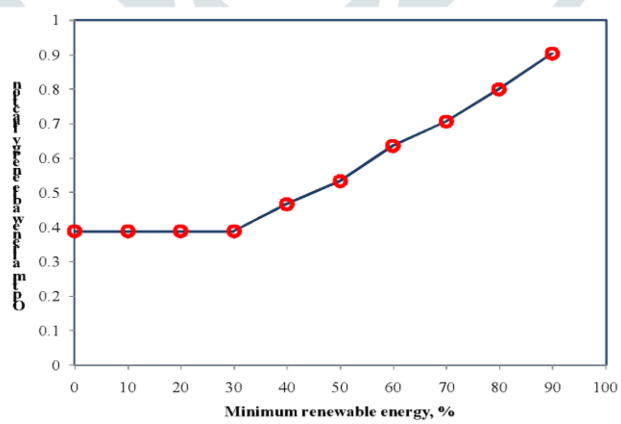

Fig. 10 Optimal renewable energy fraction for different minimum renewable energy targets.

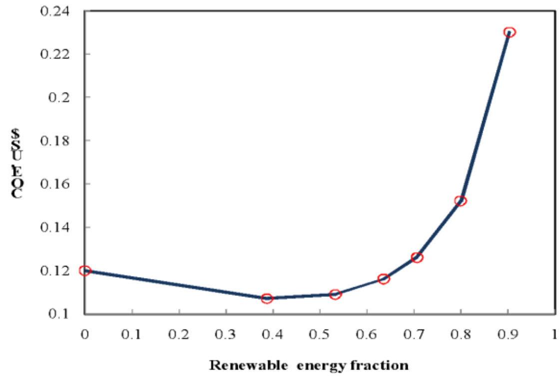

Fig. 11 Cost of Energy for different Renewable Energy Fractions.

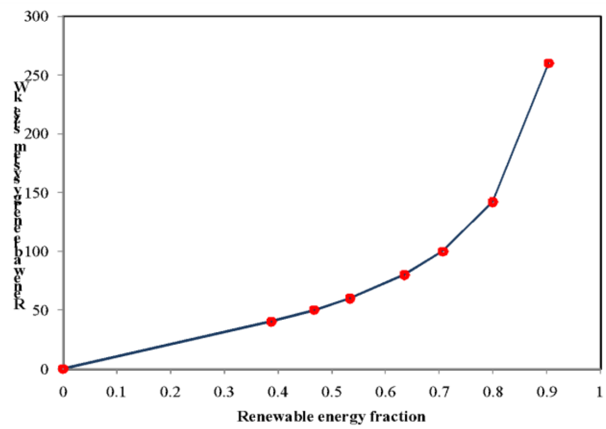

Fig. 12 Size of the renewable energy systems required for different Renewable Energy Fractions.

The optimum levels of renewable energy penetration, at varying levels of minimum penetration targets of renewable energy (Renewable Energy Fractions, REF) are shown in Fig. 10. The maximum REF possible for the microgrid is found to be 90%. Unless and until storage options are considered, a microgrid, which is totally independent of the main grid is not feasible for the Campus. As batteries are expensive components, requiring frequent maintenance and periodic replacements, it is advisable to avoid storage options in the system design.

Fig. 11 shows the variations in the electricity cost with the level of renewable energy penetration. Though the system with up to 90 percent renewable fraction is feasible, the cost of electricity drastically increases beyond the optimum REF. This is more evident for REF levels above 50 %: for example, at the highest feasible REF of 90%, the COE reaches 0.23 $/kWh, which is almost double that of the prevailing grid based electricity rate.

Sizes of the renewable energy systems, required for different REF are shown in Fig. 12. In all scenarios except for 80 percent of REF, wind turbines, as a single source, could meet the energy demand of the microgrid. At 80 % REF, along with 139 kW of wind capacity, 3 kW of solar PV is also recommended. As expected, the system size increases with the increase in REF. At higher REF, due to the fluctuations in the wind speed, bigger renewable systems are required to cover the lean wind resource periods. Interestingly, during the periods of stronger wind, these oversized systems would generate energy in excess to the demand.

This is well evident from Fig. 13, where the hourly load patterns are superimposed with the expected wind energy generation at 90% REF. For demonstrating this further, excess renewable energy generated at different levels of REF are shown in Fig. 14. Even at the optimal REF of 38.8 %, the excess generation accounts to 15.3 MW, whereas at the highest viable level of REF, this could reach to 611 MW per annum. Unfortunately, at present, no policy frameworks or incentive mechanisms are not in place to sell this excess energy back to the grid. Hence, the system would be underutilized and could not exploit its full potential in generating electricity from this clean renewable resource. Currently, a significant portion of the power fed to the central grid is generated from conventional sources. Hence, any attempt to reduce the grid dependency of the building through the proposed microgrid would in turn help in mitigating the emissions due to the energy consumption in the educational buildings. At higher the REF, the share of the conventional energy consumed will be lower which in turn would reduce energy related emission levels. However, as we can see from Fig. 15, with increase in REF beyond the optimal level of 38.8 %, the COE would also increase. Left side of the Fig. 15 represents significant levels of REF whereas the right side represents higher levels of grid dependency. Obviously, the lowest COE per life cycle emission corresponds to the optimal level of REF.

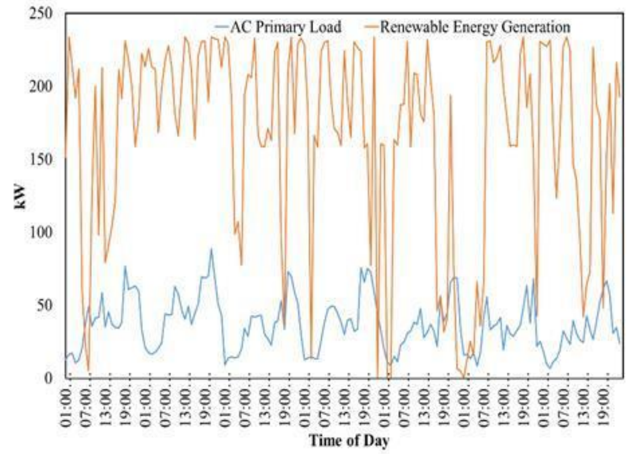

Fig. 13 Hourly variations in the load and expected output from the wind turbines, indicating the excess renewable energy generation.

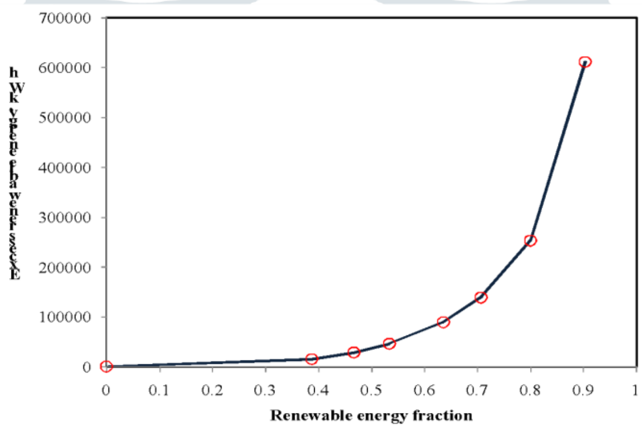

Fig. 14 Excess renewable energy generated at different levels of REF.

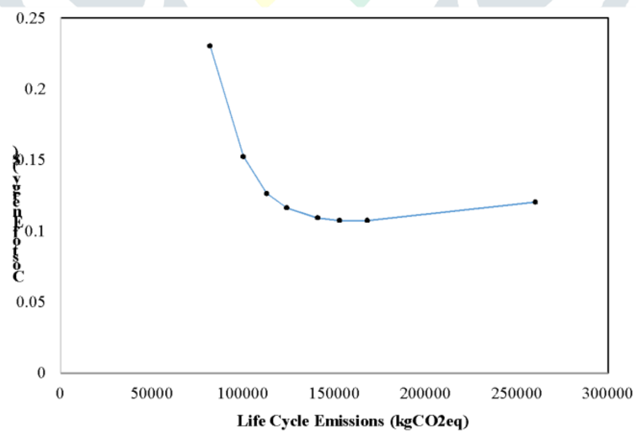

Fig. 15 Variation of Cost of Energy with the Life Cycle Emission.

7. CONCLUSIONS

In this paper, we demonstrate how the grid dependency of a large building can be minimized by incorporating an optimally designed, renewable based microgrid in the power delivery system. Several configurations and design strategies for the microgrid were simulated to identify the optimum solution. Based on the existing load profile and available energy resources, under the economically optimum scenario, 38.8 percent of the total load at the campus could be met by renewable energy resources. The cost of energy could be reduced from the current 0.12 $/kWh to 0.107$/kWh, if the proposed renewable based microgrid is installed at the campus. Due to the high wind potential in the region, wind energy is identified as the best renewable energy option and forty kW of wind capacity is required to meet the optimum level of renewable integration. Even without storage system, it is feasible to meet up to

90 percent of the load at the campus by renewable energy systems. However, the cost of energy would be substantially high for higher levels of REF. Due to the fluctuations in the wind resource, to take care of the load during the lean wind period, renewable energy systems of relative bigger size has to be installed at all levels of REF. This in turn would result in generation excessive to the load during the windy period. As there is no mechanism to sell excess electricity to the main grid, this excessive generation potential would be wasted. This underlines the immediate need for regulatory frameworks, with suitable buy back policies, for making the building integrated renewable energy generation more attractive in the region.

REFERENCES

[1] International Energy Agency, Buildings Overview, Transition to Sustainable Buildings – Strategies and Opportunities to 2050, (2013) p.25

[2] International Energy Agency, Outlook for India's Energy Consumption, India Energy Outlook 2015, (2015), p.63

[3] Lasseter, R.H., Smart Distribution: Coupled Microgrids. Proceedings of the IEEE 99(6) (2011), 1074–1082. doi:10.1109/JPROC.2011.2114630

[4] Gokcol, C., Dursun, B., A comprehensive economical and environmental analysis of the renewable power generating systems for Kırklareli University, Turkey. Energy and Buildings 64 (2013), 249–257. doi:10.1016/j.enbuild.2013.05.005

[5] Dalton, G.J., Lockington, D.A., Baldock, T.E., Case study feasibility analysis of renewable energy supply options for small to medium-sized tourist accommodations. Renewable Energy 34(4) (2009), 1134–1144. doi:10.1016/j.renene.2008.06.018

[6] Khatib, T., Mohamed, A., Sopian, K., Optimization of a PV/wind micro-grid for rural housing electrification using a hybrid iterative/genetic algorithm: Case study of Kuala Terengganu, Malaysia. Energy and Buildings 47 (2012), 321–331. doi:10.1016/j.enbuild.2011.12.006

[7] C. Gokcol, B. Dursun, Determination of the optimum renewable power generating systems for an educational campus in Kirklareli University, Electronic Journal of Vocational Colleges 1(1) (2011), 8–17.

[8] Rezaie, B., Esmailzadeh, E., Dincer, I., Renewable energy options for buildings: Case studies. Energy and Buildings 43(1) (2011), 56–65. doi:10.1016/j.enbuild.2010.08.013

[9] Dalton, G.J., Lockington, D.A., Baldock, T.E., Feasibility analysis of renewable energy supply options for a grid-connected large hotel. Renewable Energy 34(4) (2009), 955–964. doi:10.1016/j.renene.2008.08.012

[10] Al-Karaghouli, A., Kazmerski, L.L., Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Solar Energy 84(4) (2010), 710–714. doi:10.1016/j.solener.2010.01.024

[11] M.A. Ozgur, Technoeconomic evaluation of solar–wind hybrid power systeminKutahya, Turkey, Energy Education Science and Technology – Part A 28 (2)(2012) 785–798.

[12] Cetin, E., Yilanci, A., Ozturk, H.K., Colak, M., Kasikci, I., Iplikci, S., A micro-DC power distribution system for a residential application energized by photovoltaic–wind/fuel cell hybrid energy systems. Energy and Buildings 42 (2010), 1344–1352. doi:10.1016/j.enbuild.2010.03.003

[13] Zeng, Z., Zhao, R., Yang, H., Micro-sources design of an intelligent building integrated with micro-grid. Energy and Buildings 57 (2013), 261–267. doi:10.1016/j.enbuild.2012.11.018

[14] Balamurugan, P., Ashok, S., Jose, T.L., Optimal Operation of Biomass/Wind/PV Hybrid Energy System for Rural Areas. International Journal of Green Energy 6(1) (2009), 104–116. doi:10.1080/15435070802701892

[15] Marnay, C.; Venkataramanan, G.; Stadler, M.; Siddiqui, A.S.; Firestone, R.; Chandran, B., Optimal Technology Selection and Operation of Commercial-Building Microgrids, IEEE Transactions on Power Systems 23(3) (2008) 975-982, doi: 10.1109/TPWRS.2008.922654

[16] Prasad, A., Natarajan, E., Optimization of integrated photovoltaic–wind power generation systems with battery storage. Energy 31(12) (2006), 1943–1954. doi:10.1016/j.energy.2005.10.032

[17] Lambert, T., Gilman, P. and Lilienthal, P. (2005) Micropower System Modeling with Homer, in integration of Alternative Sources of Energy (eds F. A. Farret and M. G. Simões), John Wiley & Sons, Inc., Hoboken, NJ, USA. doi: 10.1002/0471755621.ch15

[18] Mathew, S. Wind energy: fundamentals, resource analysis and economics. Vol. 1. Berlin: Springer, (2006). doi:10.1007/3-540-30906-3

[19] Mathew S, Philip G. S.,Advances in Wind Energy Conversion Technology, Springer Berlin Heidelberg (2011). doi: 10.1007/978-3-540-88258-9

[20] http://data.worldbank.org/indicator/FR.INR.RINR