Embracing Microgrids: Applications for Rural and Urban India

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1. Introduction

Access to a secure, reliable and quality supply of electricity is a major area of concern in India today. According to the 2011 census, an estimate of only around 56% of the rural households have excess to electricity [1]. And with 70% of the population residing in rural areas, this can potentially cause a serious setback to the economic development of the country. The problems are not much lesser for the case of urban areas. Even though majority of urban households have access to electricity, the quality and reliability of the supply remains a worrying issue. With the growing concern of environmental pollution in the recent years, augmentation of conventional generation becomes a difficult decision. This is where renewable generations can play a major role. As of present, India has 31.7 GW of installed renewable generations, which is about 13% of the total installed capacity. Compared to the total available potential of renewable sources in the country, this is a comparatively low number. Much of the work is therefore needed to be done in order to adopt more of renewables and take full advantage of the available potential.

This article details the possibilities on the application of microgrids to solve the ever increasing energy problem in the country. Microgrids opens a gateway for integration of more efficient and cleaner renewable generations into the power distribution network. They have several other advantages which includes reduction in transmission losses, improvement in power quality & reliability, reduction in emissions and even provides provisions for heterogeneous power quality. And most importantly, it also provides a possibility for electrification of remote villages which are far from reach of the conventional grid. The article gives a detailed discussion on the application of DC microgrids for rural and urban scenarios in India. Application in rural areas as community-microgrid is explained in detail with an example of the current work carried out in one of the villages in Bihar state. For urban scenario, application of the DC-microgrid concept to attain the goal of a Zero Energy Building (ZEB) is discussed. An example of a currently operational ZEB is also explained. Finally the article concludes with a note on the importance of microgrids for both rural and urban India.

2. Renewable Energy Scenario in India

Out of the total installed capacity of electricity generation in India, renewable energy contributes to about 13% (31.7GW) [1]. This number excludes the larger hydro power generations. In terms of energy generation, renewable sources contribute up to 6.5% out of the total electricity mix. A breakdown on the contributions of the renewable generations is shown in Figure 1. Wind energy has the maximum contribution accounting for about 67%

(21,132MW), followed by biomass and hydro at 13% (4,013MW) and 12% (3,804MW) respectively. Finally solar energy contributes a mere 8 % (2,647MW) in the total renewable energy capacity.

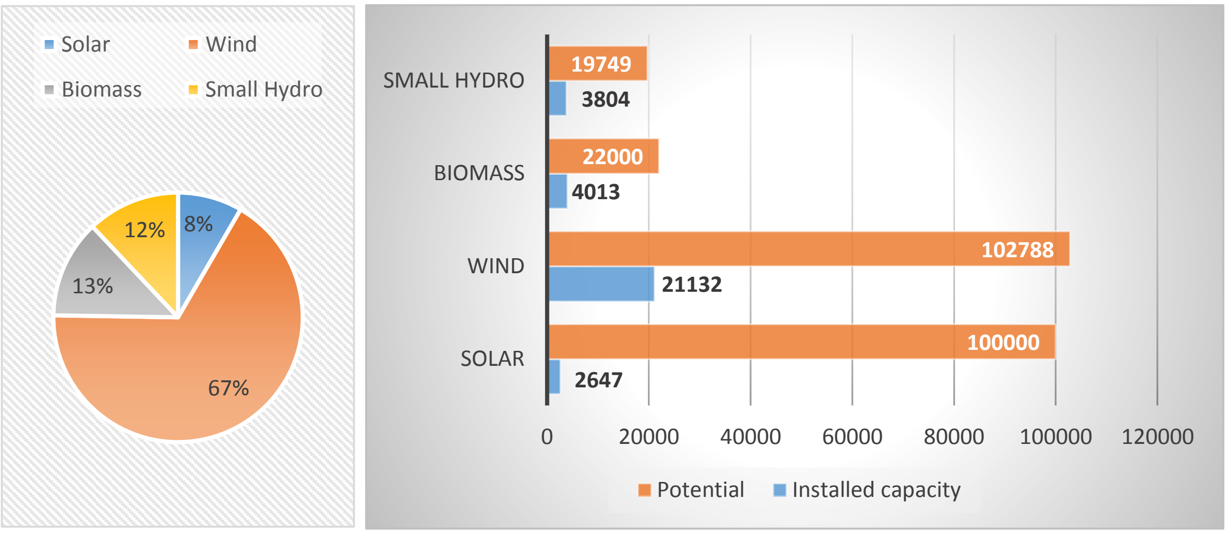

Figure 1: (a) Contribution of various renewable energy generations in its net installed capacity; (b) comparison between installed capacity & potential of renewable energy sources in India.

Figure 1 also shows the comparison between the installed capacity and the reserve potential of these various renewable sources. From this comparison, it can be observed that a lot of renewable energy potential still remains underutilised. And a major gap can be seen in the sources of wind and solar energy. Even though wind energy is more concentrated to specific regions, most part of India receives an abundant amount of solar energy throughout the year. Hence, solar energy could potentially play a major role in meeting the ever increasing energy demand of the country in a much cleaner and cheaper way.

The International Energy Agency (IEA) claims that the prices of renewable energy technologies, primarily wind and solar continues to fall with rapid advancement in the field [1]. This have made renewables increasingly mainstream and competitive with conventional generations. The launching of Jawaharlal Nehru National Solar Mission (JNNSM) has put an ambitious plan in increasing the solar power generation in the country. Much of these schemes are needed in the future to accelerate and increase the contribution from renewable generations.

3. Microgrids

A microgrid can be defined as a collection of distributed sources, loads and energy storage devices which acts a single controllable unit and can operate either in grid connected or islanding mode. A more precise definition given by the Department of Energy - US [2] describes it as "A group of interconnected loads and distributed energy resources with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid (and can) connect and disconnect from the grid to enable it to operate in both grid connected and islanding mode".

The basic structure of a microgrid is given in Figure 2 [3]. It normally consists of radial feeders which are connected to various loads, sources and storage devices. Sources can be in the form of solar PV panels, wind turbines, diesel generators and Combined Heat and Power Plant (CHP). The loads of the system can be either electrical or heat loads. A microgrid system can also have several types of storage options such as battery, flywheel, fuel cell, supercapacitor storage, etc. The radial distribution network is connected to the utility grid through a separation device known as the Point of Common Coupling which is usually implemented as a static switch. The distributed energy sources and loads in the microgrid network are controlled by the action of the Local Controllers (LC) which are generally power electronic converters. The Microgrid as a whole is controlled by the Microgrid Central Controller (MGCC) which gives command signals to each of the LCs.

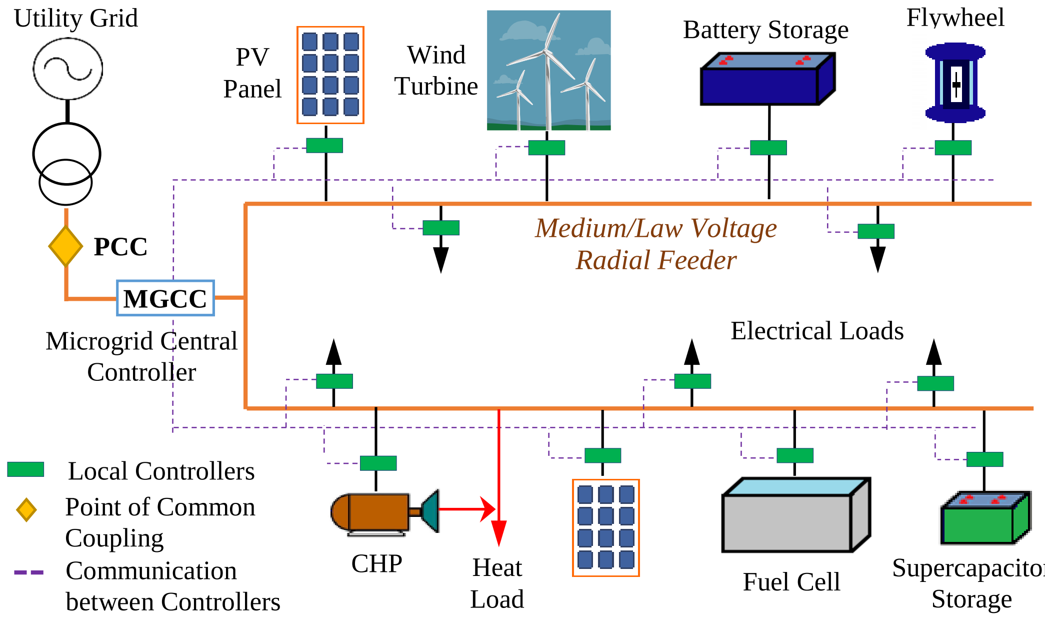

Figure 2: Schematic diagram of a Microgrid.

A microgrid has several advantages as compared to a traditional grid [4]. It opens a gateway for smaller, more efficient distributed generations to be embedded into the distribution network. As the generation is carried nearer to the load centres the losses in bulk power transmission can be reduced to a huge extent. The concept has drawn much attention worldwide because of the growing concerns in the environmental impacts of conventional power generations. A provision for heterogeneous power quality and reliability is presented in a microgrid. The concept of microgrid can also help in load levelling of a certain region of the grid. Electrification of rural areas which are far from reach of the traditional grid is also one of the major benefits.

Microgrids can be classified into three types depending on its operational frequency. They are AC microgrid, DC microgrid and hybrid AC/DC microgrid. The following sections provides brief details on each of these types and the explanations will further help us identify the most practical configuration that is to be used for rural and urban context.

3.1 AC Microgrid

An AC microgrid system may consist of a medium or a low voltage AC distribution network (as shown in Figure 2). Distributed sources, storage devices and loads are connected to this AC network with or without a converter depending on the frequency ratings. Native AC generations such as diesel generators, micro turbines and wind turbines can be directly connected to the AC network without any converters. For native DC sources like PV systems, DC/AC converters are normally used. Similarly, AC loads are connected directly while for the case of DC loads, AC/DC rectifiers are required. Even though a great deal of research work is carried out in AC microgrids, it does have some disadvantages. A few of the major problems in such network include the complexity in control and synchronization issues.

3.2 DC Microgrid

A more recent research trend have shown much interest in the area of development of DC Microgrid systems [5]. Figure 3 shows the schematic of a DC microgrid. As compared to an AC microgrid, it can provide significant energy shavings by reducing the number of converters inside the microgrid system. This includes converters for interfacing the distributed renewable generations, loads and energy storage devices.

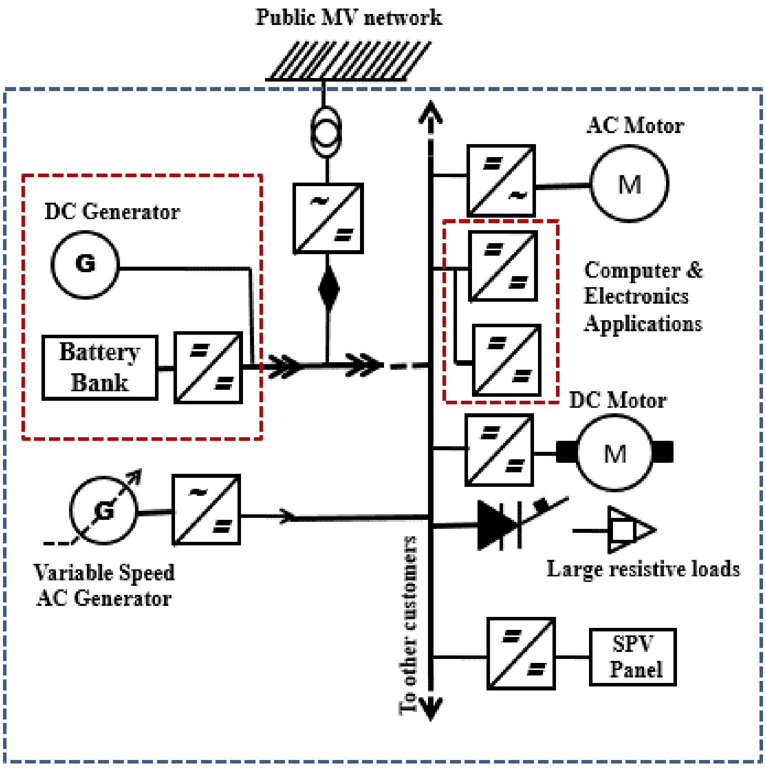

Figure 3: Schematic diagram of a DC Microgrid [6].

A DC system also brings about other significant advantages solving some of the control issues inside a microgrid. For instance, synchronisation of the distributed generations is no longer required and the controls are directly based on DC bus voltage. Moreover the primary control is much simpler due to the absence of reactive power flow control. And finally, most of the modern appliances also runs in DC power, which provides an added benefit.

3.3 Hybrid AC/DC Microgrid

As the name suggest hybrid microgrids consist of AC and DC network connected together by multi-bidirectional converters [7]. A hybrid system can reduce the number of AC-DC-AC and DC-AC-DC conversions in individual AC or DC microgrids. Here, AC sources and loads are connected to the AC network whereas DC sources and loads are tied to the DC network. Energy storage devices can be connected in either of the network. Figure 4 shows the schematic diagram of a hybrid AC/DC microgrid.

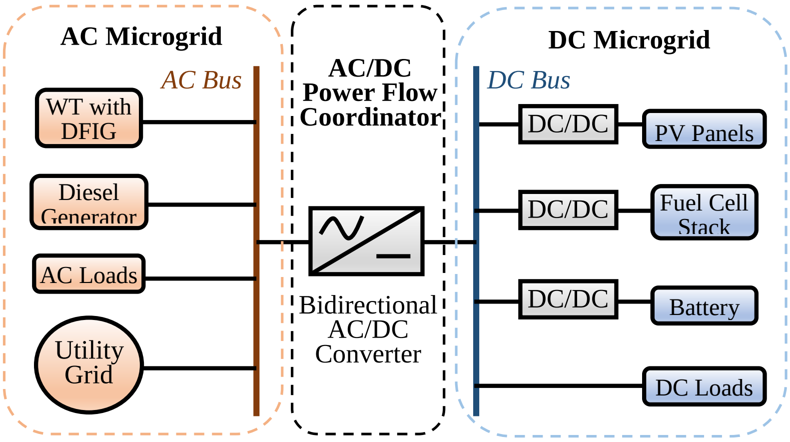

Figure 4: Schematic diagram of hybrid AC/DC microgrid.

Even though a hybrid system reduces the number of converters in individual AC and DC systems, there are some disadvantages for using such type of configuration. The total efficiency of the system greatly depends on the type (AC or DC) and amount of connected sources and loads. Hybrid microgrids are more suitable for smaller isolated installations with PV and wind generations as a major power supply.

From the above discussions, a clear picture on the types and the capabilities of the different microgrid configurations can be seen. And due to the inherent simplicity and advantages of the DC system, the article focuses mainly on the DC microgrid configuration. Further section discusses on its implementation for both rural and urban scenarios of India. For rural applications it can be implemented as a community DC microgrid. While for urban areas, the concept of Zero Energy Building which is supported by DC microgrids is discussed in details.

4. Rural Applications: Community DC Microgrid

As per the census of 2011, 46.5% of the rural households and 32.8 % of the total population in India does not have access to electricity [1]. This amounts to around 800,000 villages in rural India. A majority of the rural households rely on non-conventional inexpensive fuel sources for lighting and cooking. And around half of this population use kerosene for lighting purposes. These fuel sources not only causes environmental pollution, they are also known to have serious health implication on prolong use. With a major chunk of Indian population (around 70%) residing in rural areas where electricity supply is still a big problem, there can be a serious concerns on the future development of the country’s economy.

The cost of installing electrical infrastructure in remote locations is often unrealistic. Microgrids offer a viable solution in providing electricity to some of the most remote areas. A standalone DC microgrid can be used in an economically feasible, environmentally friendly and sustainable fashion to meet the needs of rural communities. The microgrid system can be composed of distributed generations such as PV solar panels and wind turbines depending on the availability of resources. These distributed generations can be connected to the local DC distribution system with appropriate buck or boost converters. The stability of the whole system is to be supported with the help of energy storage devices interfaced by bidirectional buck/boost converters. The amount of generation and storage required are planned depending on the amount of load and availability of the renewable sources throughout the year. The household loads in the villages can include DC loads such as LED bulbs, tube lights and DC fans etc. Most of the modern appliances such as mobile phones, computers and other electronic devices which natively operates on DC power can also be connected to this system.

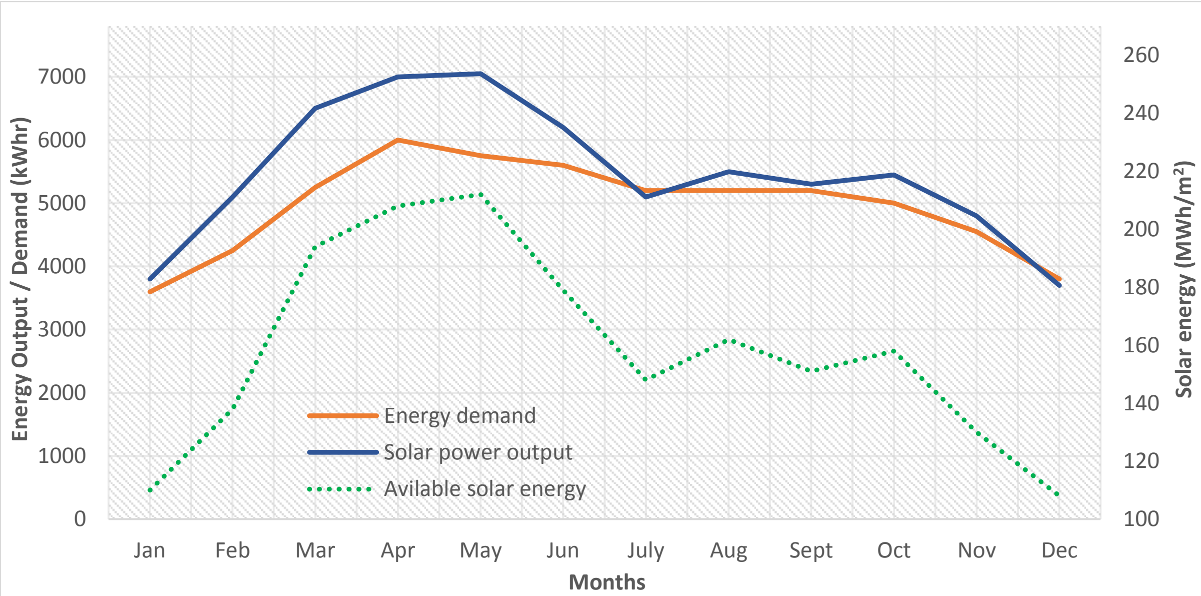

Figure 5: Monthly variation of average energy demand, available solar energy and energy output form 1.35 kWp PV array (5 modules of 270Wp each) for optimal sizing of microgrid in Baal Tanr village.

Much work is being carried out at present to bring about implementation of microgrids in rural areas of India. An example of such work conducted by the Smart Power for Environmentally-sound Economic Development (SPEED) team is presented in [8]. It gives a detailed description on the work carried out for the implementation of a solar microgrid in one of the villages in Bihar state (Baal Tanr). The village has an annual expected load of 59,510 kWh. Firstly, a solar resource model was obtained from recorded data that was measured between 2002 and 2008. This model was used to compute the expected monthly solar energy yield which is shown as green dotted line in Figure 5. Expected monthly energy demand of the village have also been calculated and is shown as the orange curve in the same figure. With this data, an optimal sizing of PV system is computed. Monocrystalline PV panels of 270W each having an efficiency of 15.6% was selected for this purpose. The blue curve on the figure gives the output from an array of 5 solar panels which almost entirely meets the demand. And in order for the microgrid system to provide uninterrupted supply during a worst case scenario of energy production, a backup battery energy storage system is also proposed. Finally for the village of Baal Tanr, the optimal system configuration was proposed as an array of 8 monocrystalline PV panels and a string of 20 Ah lead acid batteries. Many of such community microgrid systems are needed to be implemented in order to bring about large scale electrification of remote villages.

5. Urban Applications: Zero Energy Buildings

Even though most of the urban households in India have access to electricity, it still faces a number of problems. This includes problems of power quality, security of supply and reliability. With an ever increasing demands in peak seasons, power cuts are becoming more and more prominent even in metropolitan cities. And with more concerns of environmental pollution over conventional generations, supplying electricity to an ever increasing urban population becomes a much more challenging task. This is where the concept of Zero Energy Building (ZEB) comes in.

A ZEB is a residential / commercial building with greatly reduced energy needs through efficiency gains such as the balance of energy needs can be supplied with renewable technologies [9]. The goal of a ZEB can vary significantly depending on its definition. Four of the well-known definitions of ZEB are:

i. ***Net zero site energy:*** In a site ZEB the amount of energy produced is equal to the amount consumed over a year, when accounted for the particular site.

ii. ***Net zero source energy:*** A source ZEB produces as much energy as it consumes in a year, when accounted for the source. Source energy here refers to the primary energy which generates and delivers energy to the site.

iii. ***Net zero energy cost:*** A cost ZEB is one in which the cost of the energy utilised in the building is equal to the cost of the energy that the building exports to the main grid.

iv. ***Net zero energy emissions:*** Finally a net- zero emission building is one which produces as much emission free renewable energy as it uses from emission- producing energy sources.

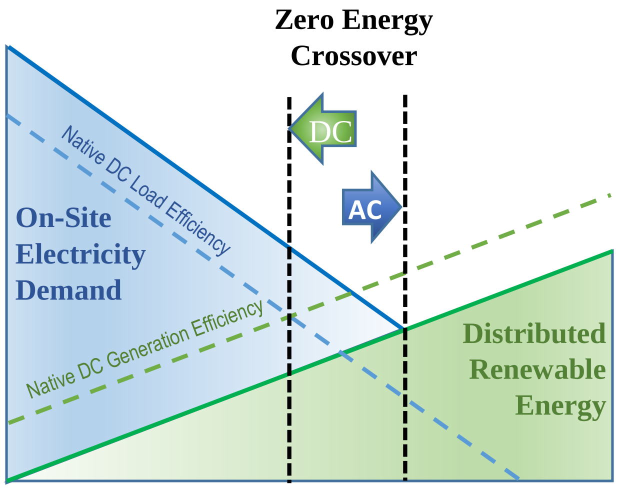

Figure 6: DC microgrid for net Zero Energy Bindings.

The enabling technology that delivers a particular goal of a ZEB can be in the form of a DC microgrid. There can be several advantages for employing a DC system. This can be easily illustrated with the help of Figure 6 [2]. The solid blue curve (moving from left to right) shows the decrease in the load of the building due to increase in overall system efficiency, while the solid green line represents the increase in renewable penetration (area in green) in the building energy system. Here, the point where the two lines meets is the satisfying condition of a ZEB. This point can be obtained at a much lower penetration of renewable sources for a DC system. The two dotted lines, blue and green, shows the native DC load efficiency and generation efficiency when the number of DC/AC conversions are reduced. And hence the goal of ZEB can be obtained much easily in a DC system as compared to an AC system. So, for application in rural India, such a system can be more efficient and practical.

Currently, some of the work in research and development is carried out in order to enable the development of ZEB for urban applications in India. The *Indira Paryavaran Bhawan* is one example of a net ZEB currently in operation which was constructed by the Ministry of Environment and Forest, India [10]. A number of energy saving measures are taken into account in order to reduce energy consumption and increase the overall efficiency of the building (shown in Figure 7). The design of the building was made in such a way to allows 75% of the natural daylight to be utilised. For onsite renewable generation a large 950kW rooftop PV array is employed. Above this, total energy savings of about 40% have also been achieved through adoption of energy efficient chilled beam system.

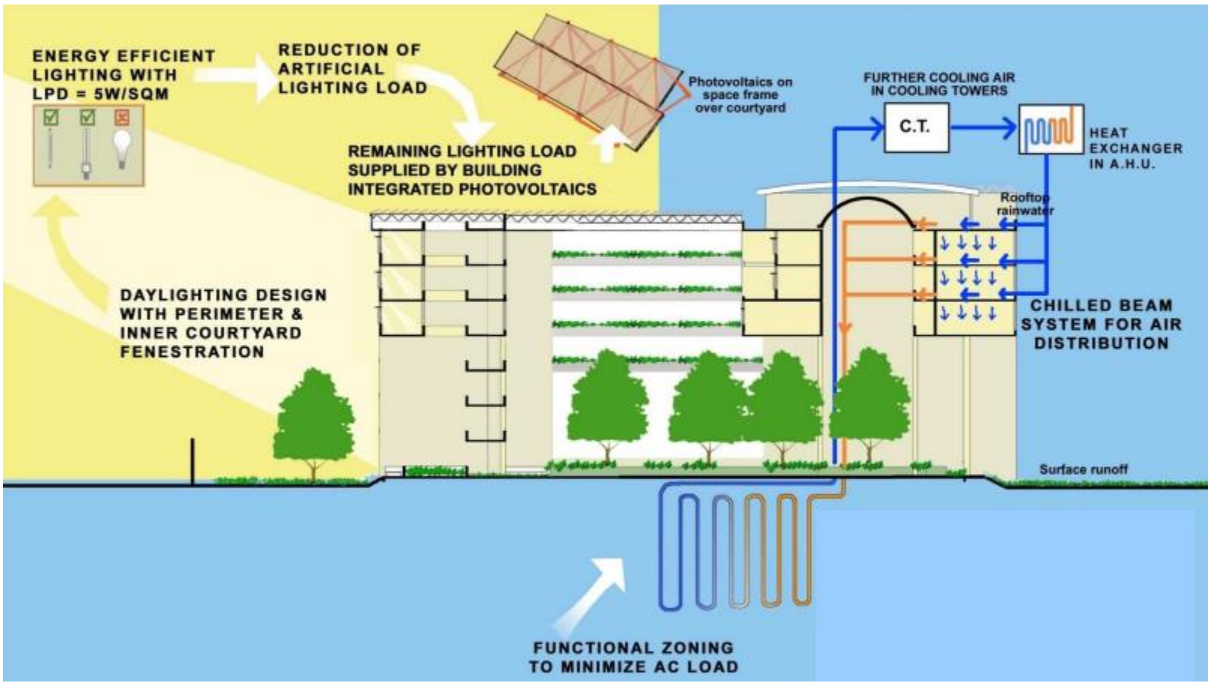

Figure 7: Energy conservation measures in net ZEB of *Indira Paryavaran Bhawan* [10].

Planning and optimal sizing of the components for a ZEB is also one of the bigger aspect in achieving a net ZEB. An example of optimal sizing of a microgrid building using HOMER software is discussed in the paper [11].The paper presents a cost analysis and unit sizing using practical data from an IT business organisation located in Hyderabad. The priority load of the building was measured as 2.8MW per day at a peak demand of 435kW.The newly designed retrofitted microgrid architecture consisted of solar PV, wind turbines and back-up DG system to augment the existing supply system. Various configurations of the microgrid was analysed and the best among them was selected. The optimisation result shows that the most economic system configuration consists of PV system rated at 160kW, 3 wind turbines of 50kW each, a string of 200Ah batteries and a converter of 160kW. The system resulted in an average saving of 6.18% in annualised cost and a reduction in CO_2 emissions by 38.38%.

6. Conclusions

As the standard of living and economic growth of a country is directly related to availability of quality power supply, much of work is needed to be done in order to meet India's growing demands in a much cleaner and environmentally friendly manner. And with an ample amount of renewable potential available in the country, the odds are on the favourable side. The article explores the possibility of incorporating these renewable generations in rural and urban India using the concept of microgrids. And from the discussions it can be concluded that microgrids have in fact proven to be a popular and a practical choice to move forward.

Acknowledgement

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Brief Profile

Chitaranjan Phurailatpam graduated in Electrical Engineering from Malaviya National Institute of Technology – Jaipur, India in 2010. He received his MSc. Degree in Energy and Power Systems form the University of Liverpool – UK, in the year 2013. Presently he is working as a project associate at the School of Computing and Electrical Engg., Indian Institute of Technology – Mandi, India. His research interest include integration and control of distributed generations in microgrid systems.

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