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ECONOMIC ANALYSIS AND ENVIRONMENTAL ASSESSMENT OF MICROGRID OPERATIONS IN SMART GRID ENVIRONMENT

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ABSTRACT

The introduction of Microgrids in modern distribution networks enable the use of non-conventional energy sources, distributed generation (DG) and storage systems, while allowing economic operation, improving the quality of electric power, reducing losses and emission of pollutants thus making electrical system more ecofriendly and cost effective.As with large amount of CO_2 *emissions one can loss significant amount of money in the form of carbon tax. The main objective of this paper is simulating Microgrids in different modes using HOMER software to perform detail economic analysis and their impact on environments. For the analysis purpose a typical load profile is assumed which combines a deferrable load of 3.8kWh/day having peak demand of 500W, with a primary load of 43kWh/day having peak demand of 8.6kW. The daily noise is taken as 15% and hourly noise as 20%. Microgrids are modeled for both grid connected and isolated modes. Breakeven analysis for grid extension distance is also done to decide the economic feasibility to extend the grid to reach an area over the distributed generation alternative for the area.*

Keywords: Breakeven Analysis, Carbon tax, Distributed Generation, HOMER, Microgrids.

I. INTRODUCTION

Demand of energy is increasing all around the world. Electricity is the most versatile form of energy which can be used to meet this demand as it can be easily controlled, distributed and transmitted. But electric transmission and distributed system is still operating through conventional ways in many places, resulting in inefficiency and instability [1]. It is anticipated that incorporation of distributed generation (DG) powered by non-conventional sources will improve the system reliability, flexibility and environmental friendliness [2, 3]. When few of these distributed sources and loads are merged together, entities known as Microgrids are formed. However, actual implementation of distributed generation and renewable resources to provide electrical energy is not feasible without applying the concept of Microgrid operations in SmartGrid environments. As in final implementation of any technological concept, besides technical issues, generally twoother major issues are required to be scrutinized. One is the economical operation other is the environmental impact. The integration of wind power into diesel based system, their economic analysis and environmental impact is presented by Anwari et al. [4] and Yadav et al [5] using HOMER software. The cost analysis by calculating total system net present cost is done by kansara et al., in [6].Considerable amount of research work is available in literature on technical feasibility and economic operation of hybrid Microgrid system [7-14]. However most of these studies are performed for standalone systems. All modes of Microgrid are not compared properly for a particular load profile, when it is required to see economy and check emissions of pollutants. This paper focuses on both, grid connected and isolated systems. A Microgrid load profile of a place is assumed. When grid connection is available then saving obtained by availing net metering is shown. When grid connection is not available Breakeven Grid Extension Distance (BGED) is calculated. If the load is located at a distance greater than BGED than, one need to go for isolated Microgrid instead of grid extension. Therefore, economic analysis and environmental impact of isolated grid is also presented in this paper. Three modes of isolated operation of Microgrid are simulated and discussed in this paper. In first case results are presented for only diesel based Microgrid, in second case hybrid diesel PV based system with storage is simulated. Finally fully renewable energy based system, suited for eco cities or zero carbon cities are presented using only solar PV panels and battery bank as power sources. A detailed economic and environmental analysis is carried out for all these cases in this paper.

II. HOMER BASED ANALYSIS

HOMER (Hybrid Optimization of Multiple Energy Resources) is used for simulating Microgrid in various modes. This software is developed by the National Renewable Energy Laboratory situated in the United States [15]. This software is used to design and assess technically and monetarily the options for off-grid and on-grid power systems for stand-alone, remote, and distributed generation applications. It permits considering an ample number of technology choices to account for energy resource accessibility and other variables. DOE (Department of Energy) developed HOMER software in year 1993 for evaluating the tradeoffs between various configurations of power system design. A few years later, HOMER was made available to designers and engineers to design renewable energy based systems. Since then HOMER has grown in to a very robust tool for modeling and analysis of both conventional non-conventional energy based systems [16].The aim of this paper is to see the economics and environmental impact of providing a load demand in different configuration of Microgrid operations. For the analysis purpose, a typical load profile is assumed which combines a deferrable load of 3.8kwh/day having peak demand of 500W, with a primary load of 43kWh/day having peak demand of 8.6kW. The daily noise is taken as 15% and hourly noise as 20%. Microgrid is modeled in different modes. The different modes are as follows:

A. Grid Connected Mode

- ✓ Grid Connected without Net-Metering.
- ✓ Grid Connected with Net-Metering.

B. Grid Isolated (off grid) Mode

- ✓ Only Diesel Generator based.
- ✓ Hybrid Diesel- solar PV based with storage.
- ✓ Only solar PV based.

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III. MODELLING AND ANALYSIS OF MICROGRID

The Microgrid is modeled by assuming a project lifetime of 25 years and with annual real interest rate of 8%. The seasonal load profile is shown in fig.1. The peak load is occurring in the month of July. Now, assuming this particular seasonal load profile demand is to be met. Let us now consider various modes of operation of Microgrid, and see their economy and environmental impact.

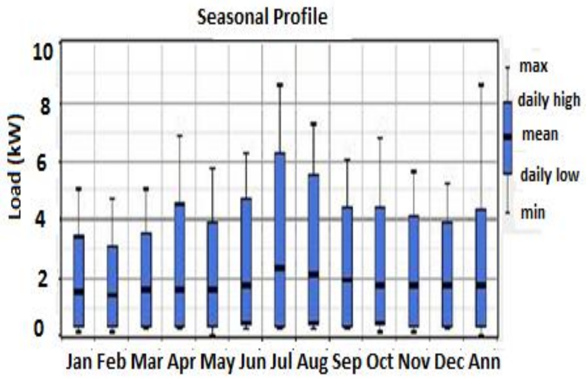


Figure 1: Seasonal load profile

3.1 Grid Connected Mode:

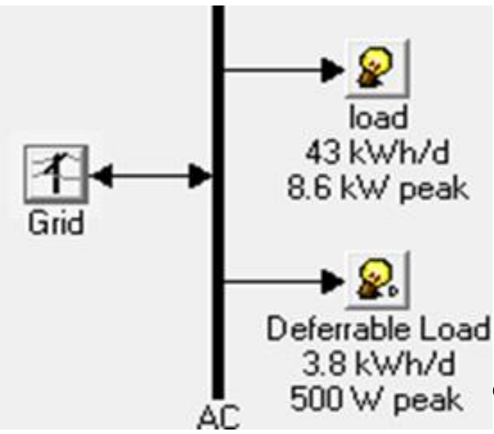
When grid connection is available, two possibilities are there:

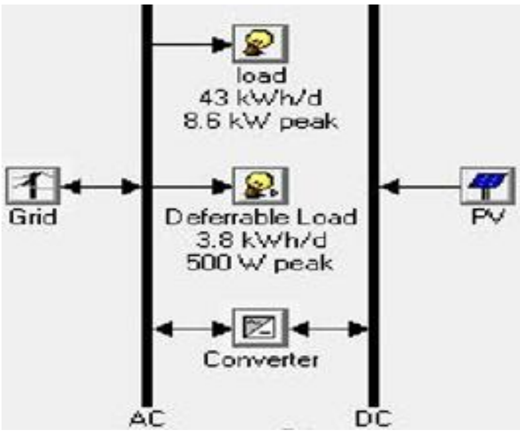
3.1.1 Grid Connected without Net-Metering:

In this mode load is directly connected to grid as shown in fig.2.For the grid, energy purchase rate of \$0.094/kWh and fixed demand charge of \$1.130/kWh/month is taken. After simulations, it gives levelized COE (cost of energy) as \$0.099/kWh and CO_2 emission of 10,728 kg/year.

3.1.2 Grid Connected with Net-Metering:

Net metering is a kind of billing mechanism that credits solar energy system holders for the solar power they add to the grid. For availing Net-Metering, solar PV panels are installed at consumer premises. The model of the grid for this case is shown in fig.3.Solar Global Horizontal radiation (GHR) in kWh/sq.m/day is shown in fig.4. Solar GHR of any place can be assumed for comparison purpose. However, in this case solar GHR data of Aligarh district of Uttar Pradesh India is assumed. Solar PV panel of 8 kW is used because generally the maximum permissible kW capacity of solar PV panels to avail net metering is equal to maximum demand.





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The cost of solar PV panel is assumed to be $580/kWh with replacement cost of $490/kWh. A converter of 8kW is also needed. Its capital cost is assumed as $150/kWh, with same replacement cost. After simulating the model, the levelized COE comes out as $0.040/kWh.

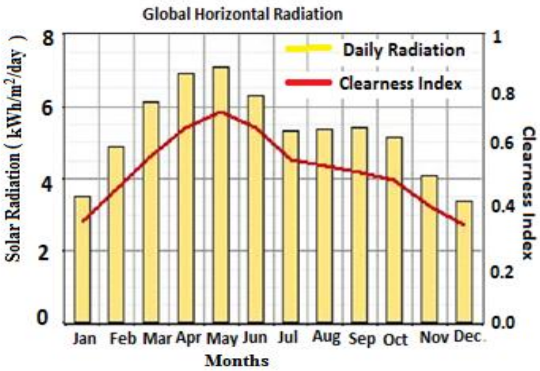

Figure 4: Solar GHR data of Aligarh

The overall bill using net-metering is shown in Table 1. It shows a net purchase of 2,516 kWh of energy. Simulation result shows the carbon dioxide emitted per year from this configuration as 1590kg. There are other pollutants also, like sulphur dioxide 6.89kg/year and nitrogen oxide as 3.37kg/year. But from economic point of view CO_2 emissions is most important because carbon tax, in most of the countries is generally applied on CO_2 emissions. Carbon tax typically ranges from $20 to bit over $100 per ton emission of carbon dioxide.

TABLE 1: Annual billing with net-metering

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)
Jan	804	307	497
Feb	553	445	108
Mar	599	700	-101
Apr	551	855	-304
May	507	1,028	-521
June	590	739	-149
July	1,051	392	660
Aug	918	418	501
Sept	770	437	332
Oct	715	338	327
Nov	826	339	487
Dec	875	195	680
Annual	8,757	6,241	2,516

3.1.3 Breakeven grid extension distance (BGED) calculation:

When grid connection is not available, breakeven grid extension distance (BGED) is required. To calculate BGED, for this case, grid extension cost is taken as $8000/km and operation and maintenance cost of grid is taken as $160 per km per year with same unit levelized COE of $0.099 that we have in grid connected mode, break even grid extension distance comes out to be 6.32 km as shown in fig.5. This is in contrast with a

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standalone system having a combination of diesel generator, PV panel and batteries. Therefore from economic point of view, when load is located at a distance below than BGE distance i.e. 6.32 km, it is economical to extend the grid. If the place is farther than 6.32km we need to go for Isolated Microgrid. It should be noted here that besides economic constraint there are certain other constraints which defies grid extension. Those constraints may be due to political issues, social issues or due to geographical restrictions. Hence off grid Microgrid operation cannot be ruled out.

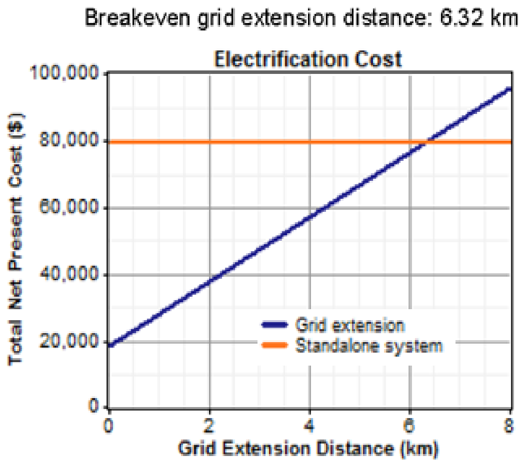

Figure 5: BGED calculation

3.2. Grid Isolated (off grid) Mode

In off grid mode, there are three possibilities. The load can be supplied solely through conventional energy like through diesel Generators only or through hybrid combination of conventional and non-conventional energy like through PV panels and Diesel generators (with or without storage) or we can also use 100% renewable energy resources like solar PV panels with storage. Analysis of all three cases is done here.

3.2.1. Only Diesel Generators based Microgrid:

The schematic diagram of Microgrid in this mode is shown in fig. 6. It has three diesel generators supplying the load. Most optimal size is as follows: Generator 1 is of 9 kW, generator 2 is of 3 kW and generator 3 is of 1 kW. Capital cost for each generator is assumed to be $260 per kWh and replacement cost is $240 per kWh. O&M cost is 0.007$/hour. Lifetime of generator is 15000 operating hours. Cost of diesel is taken as $0.7/ liter. From this configuration levelized COE comes out as $0.301/kWh. The output of three generators is shown in fig.7.Simulation result shows the CO_2 emitted from this configuration of Microgrid is 16,705 kg/year.

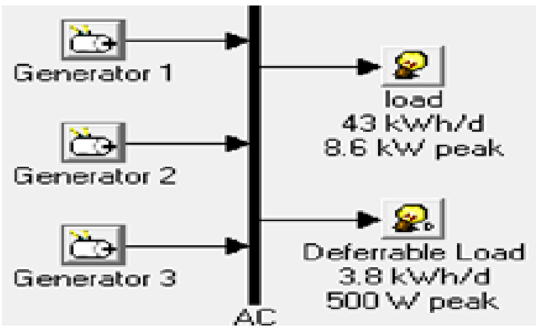

Figure 6: Diesel generators based Micro-Grid

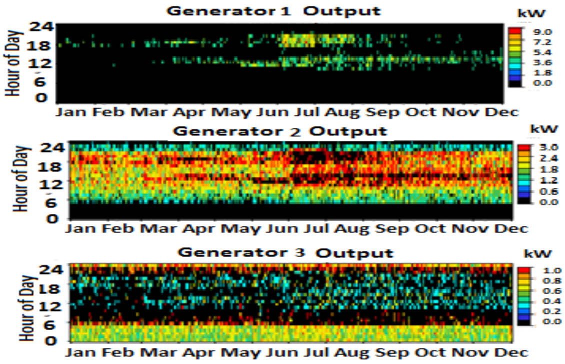

Figure 7: Operation of three diesel generators

3.2.2. Hybrid Diesel Generators and PV based Microgrid with storage:

The schematic diagram of Microgrid for this configuration is shown in fig.8.

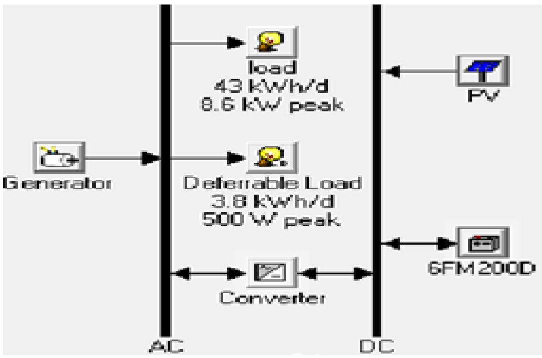

Figure 8: Hybrid Diesel- PV based Microgrid System

It contains a Diesel generator of 9kW, solar PV panel of 7kW, converter of 6kW and 20 batteries each of 12V, 200A-h. The capital cost of each battery is taken as $320 and replacement cost is $270 with O&M cost of $1.30/year. After simulating this model, the levelized cost of energy for this case comes out as $0.281/kWh. The battery bank's marginal cost of generation is equal to the sum of the battery wear cost and the battery energy cost. In this case it comes out to be $0.466/kWh. The battery wear cost is the cost of cycling energy through the battery bank. In any time step, the battery energy cost is the average cost of the energy that the system has put into the battery bank up until that time step. The levelized COE from solar PV panel for this case is $0.0184/kWh. The combination of two costs cause an overall levelized cost of $0.281/kWh. The CO_2 emitted from this configuration of Microgrid are 7,794 kg.

3.2.3. Only solar PV based Microgrid with storage:

The schematic diagram of Microgrid for this configuration is shown in fig.9. This is 100% renewable energy based design. It contains only solar PV panels, converter and 50 batteries each of 12V, 200A-h. 45kW solar PV array comes out to be most optimal for this case. It is used with 8kW converter. The size of the converter is 8kW only because rest of the solar PV panels will be used to charge the batteries. But this optimal size of the converter will cause very small unmet load of 10.5kWh/yr. The levelized cost of energy for this case comes out as $0.284/kWh.

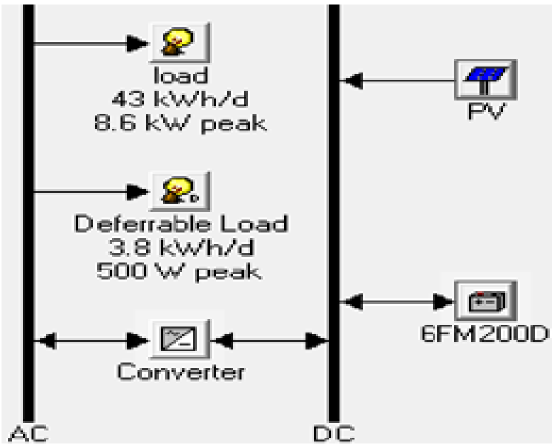

Figure 9: solar PV and battery based Microgrid System

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The levelized COE for solar PV panels is \$0.0160/kWh and the levelized COE for battery bank is \$0.329. The battery energy cost will always be zero under the load following dispatch strategy, because under load following the system never pays to charge the battery bank, it only uses excess electricity to charge the battery bank. Hence, overall levelized COE is \$0.284/kWh**.** The pollutants emitted from this configuration of Microgrid are absolutely zero, as no conventional power source is used. Such configurations are widely used in eco-cities (zero carbon cities) like masdar in United Arab Emirate (UAE) [17].

IV. COMPARISON OF RESULTS FOR ALL MODES

Comparisons of different modes are shown in tables below.

4.1. Grid connected mode:

Comparisons of cost and emissions of pollutants for two cases are shown in table 2. It shows the comparison of levelized cost of energy (COE) for the grid connected mode when no net metering is used with the case when net metering is used. The comparisons for net present cost and emissions of pollutants for the two cases are also shown.

TABLE 2: COST AND EMISSIONS OF POLLUTANTS FOR GRID CONNECTED MODE

Specifications	Without Net-Metering	With Net-Metering
Levelized COE	\$0.099/Kwh	\$0.040/Kwh
Net Present Cost	\$17912	\$9950
CO_2 Emissions	10,728 Kg/Yr.	1590 Kg/Yr.

4.2. Off-grid (Isolated) mode:

Comparisons of costs and emissions of pollutants for different cases of grid isolated mode are shown in table 3.

TABLE 3: COST AND EMISSIONS OF POLLUTANTS FOR GRID ISOLATED MODE

Specifications	Diesel Generator Based	Hybrid Diesel-PV With Storage	PV And Storage Based
Levelized COE	\$0.301/kWh	\$0.281/kWh	\$0.284kWh
Net present Cost	\$54543	\$50980	\$51443
CO_2 Emission	16705 kg/yr.	7794 kg/yr.	0 kg/yr.

It is to be noted that the levelized COE and Net present cost for solar PV & battery based system is higher than the Diesel & PV-battery system. However the CO_2 emission is absolutely nullified in PV and battery based system. So, if carbon tax/price is taken into the consideration PV and battery based system will become cheaper than Diesel & PV-battery system.

Carbon pricing is the method favored by many economists for reducing global-warming emissions — charges those who emit carbon dioxide (CO_2) for their emissions. That charge, called a carbon price, is the amount that must be paid for the right to emit one ton of CO_2 into the atmosphere. This price varies from country to country and lies in the range of \$20-\$100 per ton emission of CO_2. It will further rise in coming years as carbon trading will also coming in the picture. If a carbon tax of \$60/ton emission of CO_2 is assumed than levelized COE and Net present cost of Diesel &solar PV-battery system will rise, which is presently appearing bit cheaper than PV-

Battery based system. The new levelized COE for Diesel& PV-storage system will rise to \$0.311/kWh from \$0.281/Kwh and Net present cost will rise to \$56308 from \$50980.

V. CONCLUSION

It can be concluded that fully renewable energy based system will form the future Microgrid systems. A Microgrid system acts as an ideal citizen to the grid and helps the grid in improving the reliability of electric supply. A grid connected system with net metering seems an economical and smart solution over a system without any net-metering. Moreover, the breakeven analysis showed a way to decide whether grid extension will be economically feasible to supply power to a distribution network or one should opt stand alone Microgrid as the solution. For such a standalone Microgrid system, a PV and storage based Microgrid system will be the best option for future Microgrids in terms of the economy considering the carbon tax credits despite more net present cost of such a system against all diesel or hybrid PV-diesel Microgrids. Considering these expected benefits in near future countries around the world are following this trend and more Zero carbon cities are being developed. A zero-carbon city runs entirely on renewable energy; it has no carbon footprint and will, in this respect, do not cause any harm to the planet. One example of Zero carbon cities is, Masdar City, it is one of the world's first zero-carbon cities is being constructed in the Gulf emirate of Abu Dhabi. It is set to house 50,000 people. Construction of this large-scale project will occur in two phases. In phase one, a solar photovoltaic power plant will be built as a central energy source. In phase two, urban growth will occur [17]. However, power quality issues need to be tackled when electricity is generated solely through renewable energy. Regulation of voltage and frequency in a grid connected system is controlled by the main grid itself whereas keeping voltage and frequency within safe operating limits in a standalone Microgrid is a challenging task and is an important aspect which can be explored further.

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