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Optimal Design of Standalone Microgrid Using Hybrid Energy Sources

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Abstract:-This paper gives the idea of optimized hybrid energy system for a particular site in western India (Vataria, Ankleshwar). Optimization is done by comparison of various Systems using reliable alternative energy source consisting of solar, diesel and wind to create an autonomous energy source that is both dependable and consistent. The use of renewable sources reduces combustion of fossil fuels and the consequent CO_2 emission which is the principle cause of global warming. The pattern of load consumption of educational institute are studied and suitably modified for optimization of the autonomous micro grid using hybrid sources. This system is more cost effective and environmental friendly over the only conventional diesel generator. For this whole optimal design purpose we have used Hybrid Optimization Model for Electric Renewable (HOMER) software is used for the analysis of sizing and sensitivity, performed in order to obtain the most feasible configuration of a hybrid renewable energy system. The simulation results indicate that the proposed hybrid system would be feasible solution for the site. Main objective of this paper is to develop optimal design of stand-alone hybrid energy system and to maximize use of renewable energy generation system while minimizing the total system cost.

Keywords:- Optimization, Sensitivity Analysis, Hybrid system, Renewable energy, HOMER

I. INTRODUCTION

Nowadays energy becomes the basic need of all human beings and major demands are met by conventional energy resources like coal, natural gas crude oil. Which are fast depleting, finite and are threatening the future energy demands [1]. Further the combustion of fuels causing the emission of greenhouse gases which enhances environmental problems [2]. These problems can be overcome by developing sustainable renewable energy sources that may offer the most efficient and effective solutions [3]. Hybrid energy systems integrating renewable energy sources with fossil fuel system may provide source of electricity that can be fed directly into the grid or the batteries for energy storage for used in off grid mode [4]. Moreover use of hybrid energy sources is a viable alternative solution [5].

This concept is used in order to find the alternative source. But today we are also facing a problem that the grid cannot reach at all places like hilly isolated areas. So autonomous micro grid is used. In other words it is also called as standalone or isolated or independent system. Also the power grid fails many a times we have power cut for long time.

In order to overcome this here we have autonomous micro grid which is useful for isolated remote areas, hospitals, educational institute, malls, and industries. No doubt the installation cost would be a bit higher but it has many advantages in itself such as we have clean power, anytime, anywhere, maintenance cost could be less, and running cost would be less. Whereas the total initial cost would be overcome in the coming few years.

II. MICROGRID

WHAT IS MICROGIRD?

"A micro grid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A micro grid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode." Any small-scale localized station with its own power resources, generation and loads and definable boundaries qualifies as a micro grid. Micro grids can be intended as back-up power or to bolster the main power grid during periods of heavy demand. Often, micro grids involve multiple energy sources as a way of incorporating renewable power. Other purposes include reducing costs and enhancing reliability.

The modular nature of micro grids could make the main grid less susceptible to localized disaster. Modularity also means that micro grids can be used, piece by piece, to gradually modernize the existing grid.
The practice of using micro grids is known as distributed, dispersed, decentralized, district or embedded energy generation. [24]

TYPE OF MICRO-GRID
ON Grid:

On Grid system are solar PV systems that only generate power when the utility power grid is available. They must connect to the grid to function. They send excess power generated back to the grid when you are overproducing so you credit it for later use.

OFF Grid:
These systems allow you to store your solar power in batteries for use when the power grid goes down or if you are not on the grid. Hybrid systems provide power to offset the grid power whenever the sun is shining and will even send excess power to grid for credit for later use.

MERITS AND DEMERITS OF MICROGRID
Merits:
Have much smaller financial commitments.
1. Use renewable resources hence are more environmentally friendly with lower carbon footprints.
2. Require fewer technical skills to operate and rely more on automation.
3. They are isolated from any grid disturbance or outage.
4. Place the consumer out of the grip of large corporations that run the generation networks.
5. In peak load periods it prevents utility grid failure by reducing the load on the grid.

De-Merits:
1. Electrical energy needs to be stored in battery banks thus requiring more space and maintenance.
2. Resynchronization with the utility grid is difficult.
3. Micro grid protection is one of the most important challenges facing the implementation of Micro grids.
4. Issues such as standby charges and net metering may pose obstacles for Micro-grid.
5. Interconnection standards need to be developed to ensure consistency.

III. HYBRID ENERGY SYSTEM COMPONENTS & IT'S MATHEMATICAL MODELLING

The proposed hybrid system consists of the following:

A. Photovoltaic System (PV Module)

A photovoltaic (in short PV) module is a packaged, connected assembly of typically 6×10 solar cells. Solar Photovoltaic panels constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions, and typically ranges from 100 to 365 watts. The efficiency of a module determines the area of a module given the same rated output – an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. A few solar panels are exceeding 19% efficiency. A single solar module can produce only a limited amount of power; most installations contain multiple modules. A photovoltaic system typically includes a panel or an array of solar modules, a solar inverter, and sometimes a battery and/or solar tracker and interconnection wiring. [20]

The Mathematical model of solar photovoltaic module is given below:
Using the solar radiation available on the tilted surface the hourly energy output (EPVG) of the PV generator can be calculated according to the following equation:

$$\mathbf{PVG\ E = G\ (t) \times A \times P \times \square}$$

Here assumes that the temperature effects (on PV cells) are ignored. [6]
Where, A = Surface area of the PV modules in m^2
P = PV penetration level factor
G (t) = Hourly irradiance in kWh/m^2

B. Wind generator

A wind turbine is a device that converts kinetic energy from the wind into electrical power. The term appears to have migrated from parallel hydro electrical technology (rotary propeller). The technical description for this type of machine is an aerofoil-powered generator.
Wind is a natural phenomenon related to the movement of air masses caused primarily by the differential solar heating of the earth's surface. Seasonal variations in the energy received from the sun affect the strength and direction of the wind.

The wind turbine captures the winds kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. The turbine is mounted on a tall tower to enhance the energy capture [19].

The Mathematical modelling of wind generator is given below:

Hourly energy generated (EWEG) by wind generator with rated power output (PWEG) Defined by the following expression:[17],[18]

$$\mathbf{P\ WEG = (1/2)\ \square\ Wind\ Av\ C\ P\ (\square , \square) \times \square t \times \square g}$$

$$\mathbf{EWEG\ (t) = PWEG * t}$$

Where,
P WEG = Electrical power generated by wind generator
EWEG (t) = Hourly energy generated by wind generator
ρ Wind = Density of air in 1.22Kg / m^3
v = Wind speed (m/s)
C P = Performance coefficient of the turbine
λ = Tip speed ratio of the rotor blade tip speed to wind speed
β = Blade pitch angle (deg) as 00
ηt = Wind turbine efficiency
ηg = Generator efficiency

C. Diesel generator (DG set)

A diesel generator is the combination of a diesel engine with an electric generator (often an alternator) to generate electrical energy. This is a specific case of engine-generator a diesel compression-ignition engine often is designed to run on fuel oil, but some types are adapted for other liquid fuels or natural gas.

Diesel generating sets are used in places without connection to a power grid, or as emergency power-supply if the grid fails, as well as for more complex applications such as peak-lopping, grid support and export to the power grid.

Sizing of diesel generators is critical to avoid low-load or a shortage of power and is complicated by modern electronic, specifically non-linear loads. In size ranges around 50 MW and above, an open cycle gas turbine is more efficient at full load than an array of diesel engines, and far more compact, with comparable capital costs; but for regular part-loading, even at these power levels, diesel arrays are sometimes preferred to open cycle gas turbines, due to their superior efficiencies. [21]

The Mathematical model of diesel generator is given below:
Hourly energy generated (EDEG) by diesel generator with rated power output (PDEG) is Defined by the following expression:

$$\mathbf{DEG\ E\ (t) = P\ (t) \times \square}$$

Where, E (t) = Energy generated by diesel generator
P (t) = Power Generated DG set
For better performance and higher efficiency the diesel generator will always operate between 80 %and 100% of their kW rating. [7]

D. Battery

An electric battery is a device consisting of two or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell has a positive terminal, or cathode, and a negative terminal, or anode. The terminal marked positive is at a higher electrical potential energy than is the terminal marked negative. The terminal marked negative is the source of electrons that when connected to an external circuit will flow and deliver energy to an external device. When a battery is connected to an external circuit, electrolytes are able to move as ions within, allowing the chemical reactions to be completed at the separate terminals and so deliver energy to the external circuit. It is the movement of those ions within the battery which allows current to flow out of the battery to perform work. Although the term battery technically means a device with multiple cells, single cells are also popularly called batteries.

The Mathematical model of battery bank is given below:
The battery state of charge (SOC) is the cumulative sum of the daily charge/discharge transfers. At any hour the state of battery is related to the previous state of charge and to the Energy production and consumption situation of the system during the time from t -1 to t.

During the charging process, when the total output of all generators exceeds the load Demand, the available battery bank capacity at hour t can be described by, [13]

$$\mathbf{EBAT\ (t) = EBAT\ (t-1) + ECC-OUT\ (t) \times \eta CHG}$$

Where,
EBAT (t) = Energy stored in battery at hour t, kWh
EBAT (t −1) = Energy stored in battery at hour t-1, kWh
ECC−OUT (t) = Hourly energy output from charge controller, kWh
ηCHG = Battery charging efficiency

On the other hand, when the load demand is greater than the available energy generated, Battery bank is in discharging state. Therefore, the available battery bank capacity at hour can be expressed as: [14]

$$\mathbf{EBAT\ (t) = EBAT\ (t-1) - ENeeded(t)}$$

Let d be the ratio of minimum allowable SOC voltage limit to the maximum SOC voltage across the battery terminals when it is fully charged. So, the Depth of Discharge (DOD) [15]

$$\mathbf{DOD = (1 - d) \times 100}$$

DOD is a measure of how much energy has been withdrawn from a storage device, expressed as a percentage of full capacity. The maximum value of SOC is 1, and the minimum SOC is determined by maximum depth of discharge (DOD), [16]

$$\mathbf{SOC\ Min = 1-(DOD/100)}$$

E. Power convertor

A converter is included in order to maintain the flow of energy between the AC and the DC bus. The conventional load is DC type, but generated power from diesel generator is AC type. In the proposed scheme converter consists up of both rectifier and inverter.

Inverter:

An inverter is an electric apparatus that changes direct current (DC) to alternating current (AC). It is not the same thing as an alternator, which converts mechanical energy (e.g. movement) into alternating current.
An inverter usually also increases the voltage. In order to increase the voltage, the current must be decreased, so an inverter will use a lot of current on the DC side when only a small amount is being used on the AC side.
Inverters are made in many different sizes. They can be as small as 150 watts, or as large as 1 megawatt (1 million watts). [22]

The Mathematical model of converter is given below:

In the proposed scheme converter contains both rectifier and inverter. PV generator and Battery sub-systems are connected with DC bus. Hydro, wind energy generator and diesel Generating unit sub-systems are connected with AC bus. The electric loads connected in this Schemes are AC loads.
The inverter model for photovoltaic generator and battery bank are given below: [8], [9]

$$\mathbf{EPVG-IN\ (t) = EPVG\ (t) \times \eta\ INV}$$

$$\mathbf{EBAT-INV(t) = [(EBAT\ (t-1) - ELoad\ (t)) / (\eta\ INV \times \eta\ DCHG)]}$$

Where,
EPVG−IN (t) = Hourly energy output from inverter (in case of PV), kWh
η INV = Efficiency of inverter

ELoad (t) = Hourly energy consumed by the load side, kWh
ηDCHG = Battery discharging efficiency

Rectifier:

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of a flame. [23]

The rectifier is used to transform the surplus AC power from the micro hydro unit, wind Energy generator and diesel electric generator to DC power of constant voltage, when the Energy generated by the hybrid energy system exceeds the load demand. The rectifier model is given below: [10], [11], [12]

$$E_{REC-OUT}(t) = E_{REC-IN}(t) \times \eta_{REC}$$
$$E_{REC-IN}(t) = E_{SUR-AC}(t)$$

At any time t,

$$E_{SUR-AC}(t) = ESHP(t) + EWEG(t) + EDEG(t) - ELoad(t)$$

Where,
E REC−OUT (t) = Hourly energy output from rectifier, kWh
E REC−IN (t) = Hourly energy input to rectifier, kWh
ηREC = Efficiency of rectifier
E SUR−AC (t) = Amount of surplus energy from AC sources, kWh
EWEG(t) = Hourly energy generated by wind generator
EDEG(t) = Hourly energy generated by diesel generator
ELoad (t) = Hourly energy consumed by the load side, kWh

IV. HOMER AND ASSESSMENT CRITERIA

HOMER is computer software that has been developed by United States (US) National Renewable Energy Laboratory (NREL) since 1993. It simplifies the task of evaluating design option of varied off-grid and grid connected systems for autonomous, remote, and distributed generation (DG) applications. It also facilitates the comparison of power generation technologies across a wide range of applications. HOMER allows the modeller to compare a number of different design options, taking into account the technical and economic features of system components and providing a method to find the lowest cost system design the basis of energy source data, system components, and a given load size. It also helps researchers understand and quantify the effect of uncertainty or changes in the inputs.

Assessment criteria

HOMER first assesses the technical feasibility of the system and whether it can meet load demand. Second, it estimates the total net present cost (NPC) of the system, which is the life-cycle cost of the system, including the initial set up costs (IC), component cost (OM), fuel costs (FC), and the purchasing power costs (PC) from the grid. HOMER calculates NPC by the following formula:

$$NPC = \frac{Ctotal}{CRF(i,Tp)}$$

Where, Ctotal = The total annualized cost of the system ($/year),
I = The annual real interest rate (%)
Tp = The project lifetime
CRF = The capital recovery factor
Which is calculated in the following formula:

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Where, n = the number of years.

In the HOMER, the salvages costs (SC), which are the residual values of the system components at the end of the project lifetime, are taken into account in the estimation of the NPC. HOMER uses the following formula:

$$SC = C_{RC}\,\frac{Trem}{Tcom}$$

Where, CRC = the replacement cost of the components ($),
Trem = the remaining life of the component (year),
Tcom = the lifetime of the component (year),
In HOMER, we use the following formula to calculate the levelized cost of energy (COE)

$$COE = \frac{Ctotal}{Etotal}$$

Where, Etotal = the electricity consumption per year (kWh/year).
Components of the proposed hybrid system
Considering our project site we have designed our hybrid system with power source of Wind Energy, Solar Energy and diesel.

V. DATA OF SITE

This study is done in Shroff S R Rotary Institute of Chemical Technology at Vataria, Ankleshwar, Gujarat (latitude-21.560, longitude -73.10 0). The Load Profile of the site is shown in Fig.1.

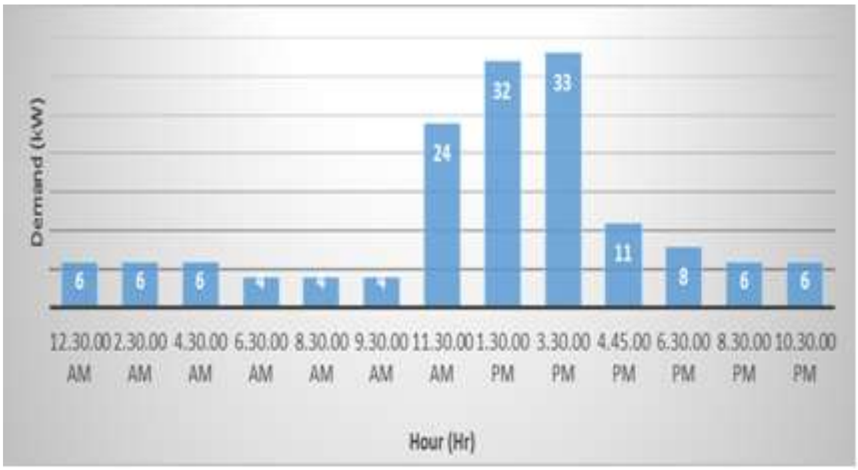

Fig.1 Daily Load profile of site

The hourly electrical load representing a nominal consumption profile for the site in vataria, Gujarat, is required the methodology. The hourly load acquired for a day in a typical year is the minimum requirement. Then, HOMER is capable of synthesizing the 8760 hourly site electrical load values for whole year, using this hourly, load profile and adding random variability factors, known as day-to-day variability and time step-to-step variability, with each approximated to be around 2% respectively.

In general, the energy consumed by this site is 130 kWh/day, and the peak load of the day is 32 kW. The energy consumption of a typical location site. Fig. 2 shows Monthly Power demand of site.

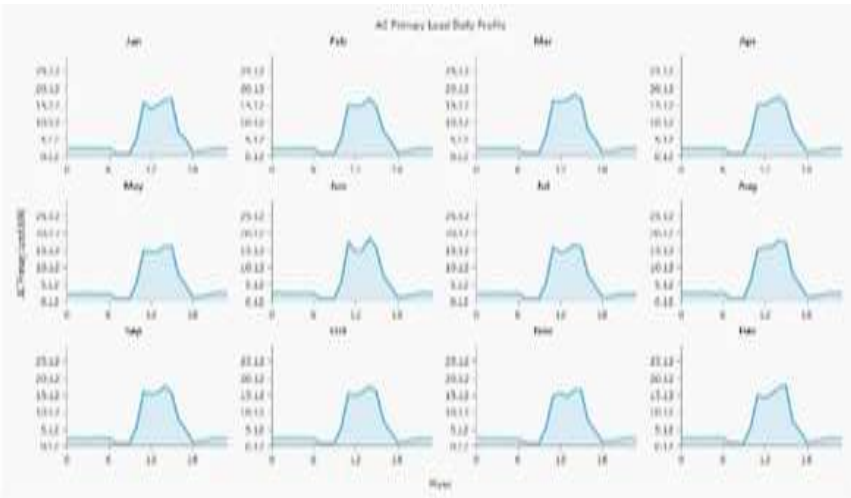

Fig. 2 shows Monthly Power demand of site.

Solar resource:

Main electrical generator of the proposed system is photovoltaic panel which converts solar irradiation directly into Electricity. Since the solar radiation varies daily, hourly and seasonally the electricity produced by the PV array vary accordingly. It can be seen that the solar radiation ranges from 4.220 kWh/m2/day to 6.790 kWh/m2/day, and the annual average of the solar radiation is estimate to be 5.30 kWh/m2/day.

At the same time, the fig.3 shows that more solar radiation can be expected from March to June while less solar radiation is expected from July to Sept. The array slop angle is set to 21.9 degrees and the array azimuth is 0 degrees which are referring to the South direction & two axis tacking system. The lifetime of this PV array system is 20 years with de-rating factor 90% and ground reflectance is 20%.

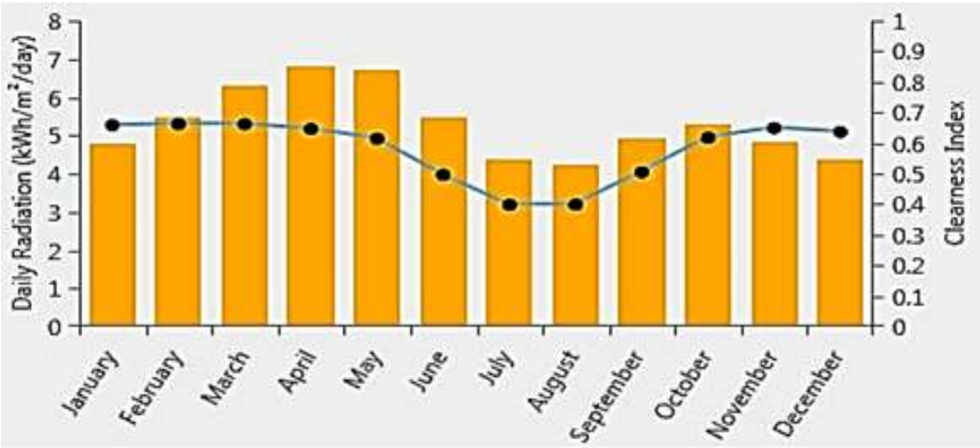

Fig.3 The month wise solar radiation (KWH/m^2/day) in site.

Wind resource:

Second electrical generator of the proposed system is Wind generator which converts wind directly into Electricity. Since the wind speed varies daily, hourly and seasonally the electricity produced by the wind generator vary accordingly. It can be seen that the wind speed ranges from 1.850 m/s to 4.140 m/s, and the annual average of the solar radiation is estimate to be 2.87 m/s.

At the same time, the fig.3 shows that more wind speed can be expected from May to August while less solar radiation is expected from October to January. Most of time the wind speed get at North-South corner side. The lifetime of this Wind generator system is 10 years.

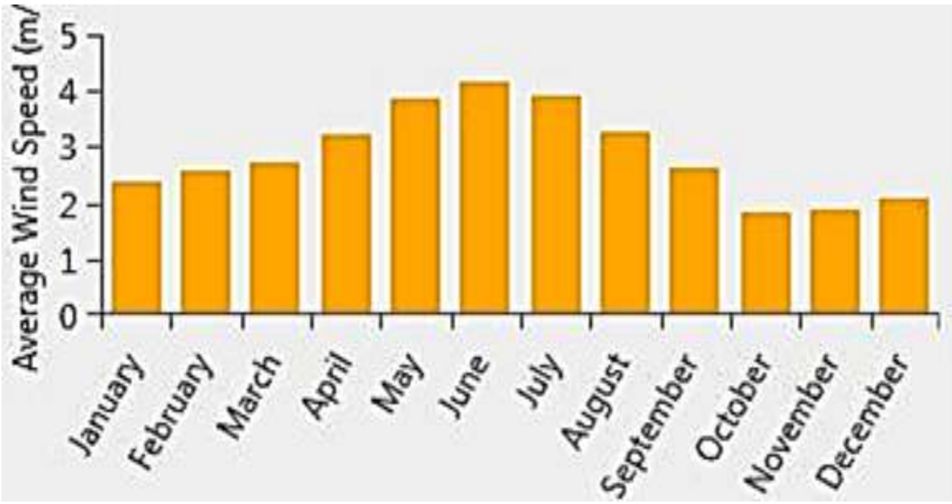

Fig. 4 The monthwise wind speed (M/S) at site

VI. PROPOSED HYBRID ENERGY SYSTEM

HOMER simulates all the possible system configuration that meet the suggested load for the selected sites under given condition of renewable resources. It performs the energy balance calculations for each feasible system configuration according to NPC in an increasing order. The configuration of the hybrid PV/Diesel/Wind/Battery system used in HOMER software is depicted in Fig.5 Based on the collected data and load from Vataria, a total of 840 runs are made. The simulation was done with a project lifetime of 20 years.

The PV capacity is varied for 0 – 40 kW, the battery storage varies form 0 unit to 24 units, while Wind capacity is varied for 0 – 10 kW for comparison purpose.

Fig. 5 Model of PV/Diesel/Wind/Battery Hybrid system in HOMER

VII. SIMULATIONS AND RESULTS

HOMER performs the simulation for a number of prospective designed configurations. After examine every design, it selects the one that meets the load with the system constrains at the least life cycle cost. HOMER performs its optimization and sensitivity analysis across all mentioned components and their resources, technical, cost parameters, system constrains and sensitivity data over a range of exogenous variables.

It is clear that two or more different power system options, which are the hybrid PV/Diesel/Battery, and PV/Diesel/Wind/Battery. The hybrid PV/Diesel/Battery system with 40 kW of PV modules, 50 kW generator, 24 units of batteries each of 1 kWh, and 70 kW sized power converters is an optimal system for the location site. It reduces the NPC about 42.11 % of PV/diesel/Battery system compared with other systems, which has similar consequence for the COE. The suggested optimal hybrid system was found to have an initial cost of $ 72524, annual operating cost of $ 8611, and a levellized cost of energy (COE) of $ 0.300/kWh.

Configuration	PV(kW)	Diesel Generator (kW)	Battery Storage	Wind (kW)	Converter (kW)	Initial Capital($)	Total Net Present	COE($/kWh)	COE (Rs./Kwh)
I.	40	50	24	10	70	122,524	244,740	0.399	26.44
II.	40	50	24	0	70	72,524	183,841	0.300	19.96

Table 1: Optimization result of Hybrid Energy System

	Battery/DG/ PV/Wind	DG/PV/ Battery
COE ($) kWh	0.498	0.300
NPC ($)	305467	183841
O & M cost ($) yr	10284	8611

Table 2 The NPC, O & M and COE of both cases.

Table 2 shows the NPC, O&M and COE values of both the case. We can see that the NPC and COE value of the system increase in Battery/DG/PV/Wind power system compare to hybrid system.

	Battery/DG/ PV	DG/PV/ Battery/Wind
Carbon dioxide	12879	14653
Carbon monoxide	31.79	36.17
Unburned hydrocarbons	3.52	4.01
Particulate matter	2.40	2.73
Sulphur dioxide	25.86	29.43
Nitrogen oxides	283.66	322.73

Table 3 Comparison of pollutants generated by both systems.

Table 3 shows comparison of pollutants generated by both systems. From Table 2 it has been seen that PV/Gen/battery system produces less pollutants as compare to Battery/DG/PV/Wind.

VIII. CONCLUSION

In this paper, it is clear that in so far as the needs of a location site in SRICT, Vataria, Gujarat are concerned, the standalone hybrid diesel/PV/Battery power system is more cost effective when compared to Battery/DG/PV/Wind power system. The optimized hybrid PV/Diesel/Battery system with 40 kW of PV modules, 50 kW generator, 24 units of batteries each of 1 kWh, and 70 kW sized power converters is an optimal system for the location site. It reduces the NPC about 42.11 % of PV/diesel/Battery system compared with Battery/DG/PV/Wind power system. The suggested optimal hybrid system was found with a total net cost of energy (NPC) of $ 183841 and a levelized cost of energy (COE) of $ 0.300. Given the economic analysis, it is clear that the hybrid Diesel/PV/Battery power system more efficient in terms of technical, economical & environmental as compare to other power system.

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