Performance Analysis of Battery Banks with PV-Wind Connected Hybrid Distributed Power System

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***Abstract* — *This paper proposes a standalone hybrid power generation system, fed by wind, solar power, and storage battery. Hybrid renewable energy sources (HRES) is an excellent solution for electrification of remote rural areas where the grid extension is difficult and not economical. Most of the isolated grid is powered by the diesel generation system. Such system has several problems like high cost of fuel with extra transportation cost& negative environmental effect etc. The reduction of pollutant emission is achieved by choosing to supply the load by hybrid system with battery of different capacity rather than diesel generator. The sources can operate in parallel to the grid or can operate in island, providing UPS services and smart grid controls individual small micro grid to monitor and control. This paper analyses the feasibility of hybrid power generation over wind & solar standalone system with various combination of battery capacity for reducing the system overall cost. For this hybrid system, the meteorological data of solar isolation is taken for Mumbai and the pattern of load consumption are studied and modeled for optimization of the hybrid energy system using HOMER software. HOMER (Hybrid Optimization Model for Electric Renewable) is a designed model that determines the optimal architecture and control strategy of the hybrid system.*

Keywords — *Storage battery, Hybrid renewable energy sources (HRES), HOMER, Isolated grid, Micro grid, Smart grid.*

I. INTRODUCTION

Electric power system is one of the most critical & strategic infrastructures of industrial society, nowadays it is necessary to modernization of electric power grid to increase energy efficiency, reduce emission & cost of generation etc. [2]. Economic, technology and environmental incentives are changing the face of electricity generation and transmission. The key issue in remote areas are availability, reliability and cost of electricity supplies [16]. Most emerging technologies are micro turbines, photovoltaic, fuel cells and wind generation. These emerging technologies have lower emissions, have the potential to have lower cost negating traditional economies of scale. Energy storage devices are mandatory in standalone hybrid power system due to renewable sources intermittence difficult climate condition forecast and load demand fluctuation[4,14].The battery combined with the renewable results in hybrid system that can drastically reduce the cost of energy COE ($/kwh) along with emission [7]**.** It is found that for higher reliability the independent use of either PV or wind turbine results in considerable over-sizing which in turn makes the design costlier. A hybrid energy system usually consist of two or more energy generating sources together to provide increased system efficiency as well as greater balance in energy supply[11][18].

The comparative economic analysis of a distributed generation power systems, will perform an hourly simulation of every possible combination of components entered and rank the systems according to user specified criteria, such as cost of energy (COE, $/kWh) or capital costs [1,12].

II. MICRO GRID

A micro grid is an electrical system is a collection of consumers, generators and potential energy storage entities connected together and operated as a small grid which is connected to the main grid, but capable of operating a self-sufficient island. The micro grid is typically linked to the grid with the help of a switch, which allows it to work both in grid-connected as well as island mode. In short micro grid means distributed generation on small scale rather than centralized generation.

In future the micro-grid can also improve the stability of utility and inject proper active and /or reactive power into the utility in the condition of utility failure. Furthermore, because of the flexible operation mode of micro-grid such as grid tied mode and islanded mode, the micro-grid can effectively enhance the operation, control, dispatch and start of the utility[5]**.**

The main features of micro grid system are [15]:

- It can be operated independently from conventional utility grid.
- It can make use of power & heat sources collectively.
- It can be interconnected to the utility grid at one point.

III. HYBRID POWER SYSTEM

Hybrid power systems usually integrate renewable energy sources to provide electrical power using batteries as backup in case of lack of primary source without interruptions. They are generally independent of large centralized electric grids and are used in remote areas mostly. For instance on a cloudy day, when the solar panels are producing low levels of electricity, the wind generator can compensate by producing more electric power. The main RES problem is intermittence, since the available power usually depends on environmental condition [10].The considerations can be taken as follows:

A. Systems based mainly on solar and wind as renewable energy sources without grid uses battery for back up.

B. Systems based mainly on solar and wind as renewable energy source considering grid when there is shortage of power. If excess power is produced by the renewable energy it is given to the grid [8].

A. Types of HPS System

The hybrid power system architecture can be divided into two grouped island mode and grid connected mode. These HPS system classification are follows:

- Stand-alone/off-grid/ Islanding – HPS, which are independent of the utility grid, used to meet the load demand in remote areas.
- Grid connected HPS, which are connected in parallel with the central utility power grid and can be used at any location (rural or urban).

Each system has its own advantage & disadvantage. The choice of the layout for particular location depends upon geographical, economical and technical factor.This HPS sytem minimize fuel consumption by minimising fuel consumption by maximizing power from renewable sources [6]. In centralized ac bus layout shown in Fig. 1. facilitate the growth to manage the increasing energy needs but it require synchronisation of the inverter and ac source to maintain the voltage & frequency.

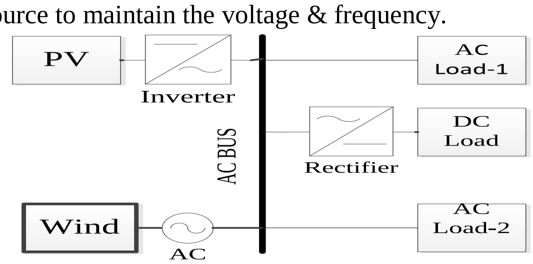

Fig. 1. Centralized ac bus layout

In centralised dc bus layout shown in fig. 2. The DC loads directly connected to the dc bus, which reduces harmonics pollution from power electronic equipment. It eliminates the requirement of frequency & voltage control of the generation source connected to the bus. This design has a limitationn in efficiency because of passsing through two stage conversion between source & load.

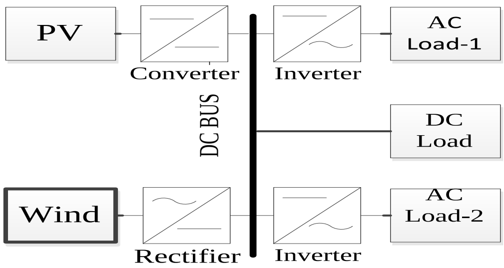

Fig. 2.Centralised dc bus layout

In ac/dc- bus layout shown in fig. 3. has both ac and dc bus . The ac and dc source connected directly to the ac and dc load respectively and both the buses connected through a bidirectional converter that permits power flow between the two buses. This system increase reliability, continuety & efficiency. It is associated with the merits of both centralized ac & dc architecture.

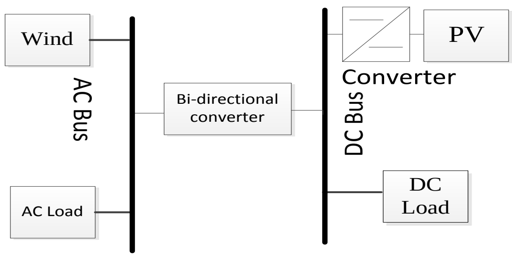

Fig. 3.AC/DC- bus layout

IV. STANDALONE HPS

Simulation of standalone ac/dc-bus layout type HPS system is shown in fig. 4.The location chosen for this case study is Mumbai with latitude of 19˚17□ N longitude72˚8□ E. Load is varied with seasonal and monthly consumption depending on climate. The AC load taken as 400 kwh/day and DC load is 100 kwh/day. this model to compare many different design option based on their technical & economical merits [3,9,17].

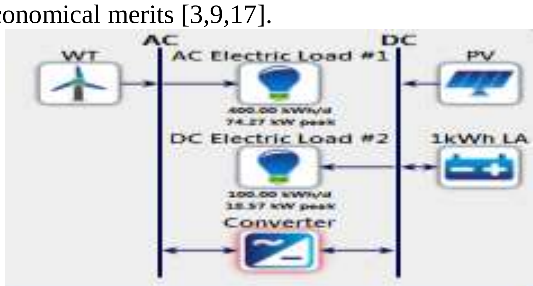

Fig. 4. Standalone ac/dc-bus type HPS

The hybrid wind/solar energy system consist of four main components which include wind turbine, PV panel, battery and converter as shown in figure. 2. Both Wind speed data & solar radiation is collected by NASA surface meteorology and solar energy database and National renewable energy lab.

V. AVAILAIBLE RESOURCES FOR SELECTED REGION

A. Wind Energy Sources

From the data the annual wind speed m/s is around 3.4 to 6.5 m/s, this is illustrated in fig. 5. It can be noticed that highest wind occur during the month of July and lowest in November. With this chosen latitude & longitude, the scaled annual average 4.77 m/s . The capacity of wind turbine output is taken as 360KW and 420 KW. The wind turbine output is define as:

$$P_m(t) = \frac{1}{2} \times \rho \times A \times (v(t))^3 \times Cp(\lambda, \beta) \quad (1)$$

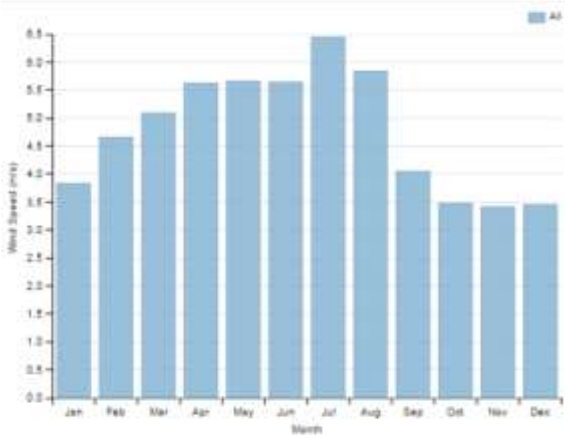

Fig. 5.Monthly wind speed in m/s.

Where v(t) average hourly wind speed, ρ is air density, A is the swept area of rotor, Cp is the efficiency of wind turbine, λ is the tip speed ratio of rotor blade tip speed to wind speed and β is the blade pitch angle.

B. Solar Energy Sources

From the data the annual solar radiation in $Kwh/m^2/d$ is around 5 to 7.4 $Kwh/m^2/d$. this is illustrated in fig. 6. It can be noticed that highest occur during the month of April and lowest in December. With this chosen latitude & longitude HOMER software has automatically collected the global solar rate. The scaled annual average solar radiation is 5.9 $Kwh/m^2/d$. The capacity of PV panel is taken as 120KW, 130KW, 140KW. The output power of PV panel is:

$$P_{PV}(t) = \eta_{PV} \times N_{PVP} \times N_{PVS} \times V_{PV} \times I_{PV} \quad (2)$$

Where η_{PV} is conversion efficiency, N_{PVP} & N_{PVS} is number of PV panel in parallel & series respectively, V_{PV} and I_{PV} is operating voltage & current.

C. Battery

The battery used for this system Lead Acid (LA) battery having 25numbers in each string of 12V is used, so bus voltage is 300V. The power input to the battery bank is calculated as:

$$\Delta P(t) = P_{total}(t) + P_{load}(t) \quad (3)$$

Where $P_{total}(t)$ is the total power produce by the renewable sources, $P_{load}(t) = P_d(t)/\eta_{bl}$, where $P_d(t)$ is power demanded by load, $\eta_{bl}$is inverter efficiency. For battery charging process ($\Delta P(t) > 0$) and discharging ($\Delta P(t) < 0$) of the battery bank.

VI. TABLE I

BATTERY CAPACITY

S.N	String in parallel(S)	Battery capacity = 25*S in Kwh
1	35	875
2	40	1000
3	45	1125
4	50	1250

VII. ANALYSIS OF HPS

The optimization process in order to determine the best configuration. System based on different combinations due to different PV array, wind system and number of batteries. The total expected power generation of our proposed off-grid system is

$$P_{total} = P_{solar} + P_{wind} \quad (4)$$

The designed specification and capacity for each component is provided in the following section. These are the different cases of Wind, solar and battery for supplying the power to load shown in table II.

VIII. TABLE II

COMBINATION OF VARIOUS RENEWABLE SOURCES CONTRIBUTION

Case	PV (KW)	WT (*3KW)	LA (1Kwh)	Converter (KW)
1	140	120	875	100
2	140	120	1000	100
3	130	120	1125	100
4	140	120	1125	100
5	130	120	1250	100
6	140	120	1250	100
7	140	140	875	100
8	130	140	1000	100
9	140	140	1000	100
10	130	140	1125	100
11	140	140	1125	100
12	120	140	1250	100
13	130	140	1250	100
14	140	140	1250	100

A. Cost Analysis

In this part of simulation identifying the detail about analysis of battery hybrid system with cost parameters, Cost of electricity (COE), Net present cost(NPC), Operating Cost (OP) and Operating & maintenance cost (O&M) for each case is shown in table III.

IX. TABLE III

YEARLY COST EVALUATION OF RENEWABLE SOURCES FOR EACH CASE

	Ene-rgy cost ($)	Net Present Cost($)	Operating Cost ($)	Initial Cost($)	O & M Cost($)
1	1.73	4089606	77904.06	3082500	34150
2	1.76	4140665	78952.92	3120000	35400
3	1.78	4191669	82318.14	3127500	36550
4	1.79	4222962	82418.13	3157500	36650
5	1.81	4273966	85783.34	3165000	37800
6	1.82	4305259	85883.34	3195000	37900
7	1.94	4581375	85002.78	3482500	38150
8	1.96	4616738	87158.13	3490000	39300
9	1.97	4648031	87258.13	3520000	39400
10	1.99	4699035	90623.38	3527500	40550
11	2.00	4730328	90723.34	3557500	40650
12	2.01	4750039	93988.53	3535000	41700
13	2.03	4781332	94088.56	3565000	41800
14	2.04	4812625	94188.56	3595000	41900

A. Analysis Of Energy Production & Consumption

The energy production, consumption, excess electricity, unmet load and shortage capacity of complete system shown in table IV. There are various combinations for different cases are used. In cases4,5,6,11,13 and 14,have no capacity shortage & unmet load only one case number 12 having highest shortage capacity that is 158.23 Kwh/yr using the combination of PV is120KW, WT is (140*3KW) and battery capacity is 125Kwh. So PV is below 130KW capacity is not feasible according to available resources. If capacity of PV is 130KW, WT is (140*3KW),and battery capacity is 1125 kwh then shortage capacity is 129.19 kwh/yr so this combination is also not feasible but if capacity of battery is increases to 1125 kwh to 1250 kwh the system has zero shortage capacity and unmet load as in case number 13. In case 5 is having the combination of PV is 130 KW,WT is (120*3KW),and battery capacity is 1250 Kwh having zero unmet load & shortage capacity. So by applying various combination it is found capacity of battery also improve reliability and reduce the cost of overall system.

X. TABLE IV

KWH/YR ACCORDING TO LOAD DEMAND

Case	Electr-icity Prod. kwh/yr	Electr-icity Consu-mption kwh/yr	Excess Electri city kwh/yr	Unmet Load kwh/yr	Shortage capacity Kwh/yr
1	469241	182403	258064	96.46	109.89
2	469241	182468	257976	31.95	37.00
3	451280	182444	239880	55.88	63.52
4	469241	182500	257932	0.00	0.00
5	451280	182500	239804	0.00	0.00
6	469241	182500	257932	0.00	0.00
7	505539	182421	295328	79.34	91.31
8	487578	182385	277241	114.7	129.19
9	505539	182482	295243	17.73	20.67
10	487578	182459	277139	40.91	45.95
11	505539	182500	295219	0.00	0.00
12	469617	182399	259052	100.7	158.23
13	487578	182500	277083	0.00	0.00
14	505539	182500	295219	0.00	0.00

XI. SIMULATION & RESULTS

From the above analysis renewable energy sources will play a significant role in a sustainable development of energy supply in future. The combination of renewable sources considered a PV of 120KW, 130KW &140 KW, WT of 3*120= 360 KW, 3*140=420KW and battery of 875Kwh,1000 Kwh,1125 Kwh, 125Kwh capacity is used for supplying the load is shown in table V.

XII. TABLE V

COMBINATION OF VARIOUS RENEWABLE SOURCES

PV	Generic flat plate PV	120,130, 140	kW
WT	WT Generic 3 kW each	120,140	
LA Battery	1kWh Lead Acid Battery(25 in each string & 12V each)	35,40, 45 &50	strings
Conv-erter	System Converter	100	KW

When a designer designed a hybrid system should consider many items, type of load, load demand, wind and solar environment condition, type of location and economic constraint, Because this system has to work in real condition. The load demand is fulfilled by the WT & PV. Here base demand is fulfilled by PV & peak demand is fulfilled by WT is shown in fig. 7.

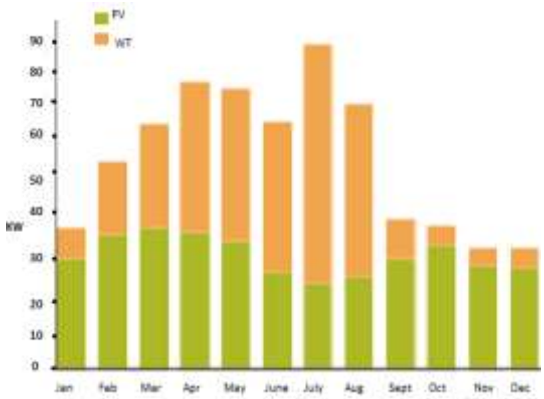

Fig. 7.Annual load demand fulfilled by PV & WT combination.

As it can be seen, in wind & PV system requires money only for wind turbine and its installation so there is nothing more except a O&M, the battery require capital and O&M cost higher but for long term it makes the system more reliable, thus as times go on, using renewable energy become more economic. As the capacity of battery is increase shortage capacity of the system is decreases, so storage system is very important part of the hybrid system. It increases reliability and feasibility of the system. The overall graphical cost analysis is given in figure. 6 and cost analysis is given in table VI.

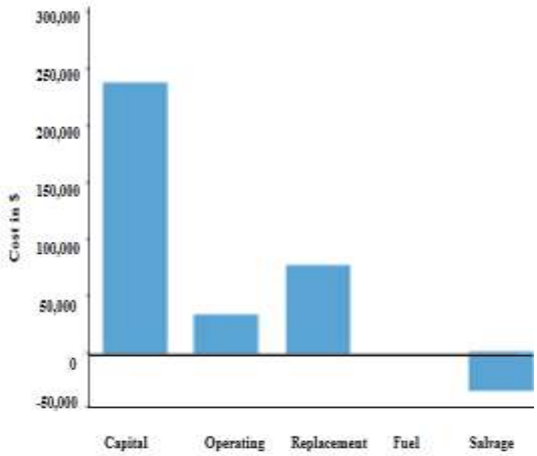

Fig.8. Overall system annual cost

XIII. TABLE. VI.

COST ANALYSIS FOR ALL RENEWABLE SOURCES

	Capital Cost($)	Repla-cement Cost($)	O&M Cost($)	Sal-vage Cost ($)	Tot. Cost ($)
PV (120KW)	27,848	0.00	1200	0.00	29,048
PV (130KW)	30,168	0.00	1300	0.00	31,468
PV (140 KW)	32,489	0.00	1400	0.00	33889
WT (120*3KW)	185,651	59,187	24,000	33,355	235,482
WT (140*3 KW)	216,592	69,051	28,000	38,915	274,729

Percentage of total cost of system used by the batteries shown in table VII. Renewable hybrid power system using four configuration of batteries have been modelled, optimized and compared.

XIV. TABLE VII.

COST ANALYSIS OF BATTERIES

Battery	Capital Cost($)	Repla-cement Cost($)	O&M Cost($)	Salvage Cost($)	Tot. Cost ($)
LA-I (875 kwh)	20,306	19,198	8750	1275	46,978
LA-II (1000 kwh)	23,206	20,501	10,000	2779.6	50,928
LA-III (1125 kwh)	26,107	23,064	11,250	3,127	57,294
LA-IV (1250 kwh)	29,008	25,627	12,500	3,474	63,660

Comparison of the percentage of cost for HRES with various battery cases is shown in table VIII. The case B of battery LA-IV having 20% cost from total cost and renewable sources combination of PV is 130 KW, WT is (120*3KW) has economic solution having lowest cost percentage that is 80% of total cost compare with the other system combinations.

XV. TABLE. VIII.

COMPARISON OF PERCENTAGE COST FOR HRES WITH BATTERY

Case	Total Cost of System(PV+WT+LA) in $		% of PV & WT cost	% of battery cost
Case A PV-140KW WT-140*3KW	LA-I	355,596	87	13
	LA-II	359,546	86	14
	LA-III	365,912	84	16
	LA-IV	372,278	83	17
Case B PV-130KW & WT-120*3KW	LA-I	313,928	86	14
	LA-II	317,878	84	16
	LA-III	324,244	82	18
	LA-IV	330,610	80	20
Case C PV-120KW & WT-140*3KW	LA-I	350,755	87	13
	LA-II	354,705	86	14
	LA-III	361,071	84	16
	LA-IV	367,437	83	17
Case D PV-120KW & WT-140*3KW	LA-I	353,175	87	13
	LA-II	357,125	86	14
	LA-III	363,491	84	16
	LA-IV	369,857	83	17

XVI. CONCLUSION

Due to backup and energy buffer, the energy storage system should be the most adaptable and reliable part of renewable energy based power supply. From observation of this paper it seems that using battery, the cost increases but totally it is useful for whole system in long run. The results obtained by using HOMER software can be realistic and gives very promising results for off-grid system and determine the optimal renewable energy hybrid system design. The environmental friendly nature of the hybrid system with the integration of isolated loads or homes will lead to near off-grid homes without depending on grid power. The success depends on a sincere understanding of not only integrated energy system benefits, but also, the long term planning towards off-grid. It can be an excellent, cost effective & also a reliable solution to mitigate the existing power crisis. It has a great impact on improving the socioeconomic. It was absorbed that with adding some renewable element such as WT, PV and battery to the remote areas it can finds some technical and economic advantages. Hence, the hybrid system is more economical and user friendly.

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