Modeling of an different configuration of hybrid energy system for Indian rural areas

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***Abstract*—*The aim of this paper is to model a hybrid energy system applicable to rural areas of India and their optimal and sensitivity analysis in off grid mode. Based on the population growth and their energy demand, modeling of hybrid energy renewable system is proposed. The proposed hybrid renewable system consists of solar-wind-hydrokinetic-bioenergy. Overall techno-economic analysis including Optimization and sensitive analysis are evaluated by HOMER software. During simulation of proposed model, HOMER displays 12 optimal outcomes for final assessment considering two sensitive parameters viz. biodiesel fuel price and wind speed. Optimized results are evaluated considering total net present cost, cost of energy, annual electric generation and CO_2 emission. In additional, using different combination of architecture obtained from numbers of simulation performed by HOMER, five different cases are considered for further analysis viz. (a) solar-wind-hydrokinetic-bioenergy (b) solar- hydrokinetic-bioenergy (c) solar-bioenergy (d) bioenergy and (e) solar-wind- bioenergy. Finally study shows that performance of the Case (a) is best and able to meet the electric load requirement of the study area. Whereas, case (c) produces comparatively ineffective result which signifies that stand alone electric generation plant using bio diesel fuel is not economically cost effective. On accounting environmental aspects, case (a) and (d) emits very low amount of carbon emission, may also be suitable in this context*

***Keywords*—Hybrid renewable energy; cost of energy; HOMER; sensitivity analysis; rural electrification**

I. INTRODUCTION

Globalization, due to advancements in technologies and excessive human dependency on gadgets increased the consumption of electric energy. Yet globally 1.2 billion people are living without access to electricity and more than 2.7 billion people are living without clean cooking facilities who are mainly the resident of rural areas [1, 2]. At present conventional energy like fossil fuel and nuclear energy are mainly used for the electricity generation across the world. But these sources of energy are limited, emits harmful gases and radiation which results pollution in our environment. In this circumstance, renewable energy may be considered as the future of electricity generation as it is environment friendly and replenishable. In countries like Germany, Denmark, Australia and some US states, renewable energy produced electricity like coal and natural gas where high efficiency of HRE is achieved (see Fig. 1) [3]. Study also showed that, in order to reduce environmental temperature, utilization of the renewable energy needs to be increased upto 37% of the power generation by 2040 as compared to present scenario of 23% (Table 1) [4]. This may lead to drastic changes in production and consumption of any form of energy, transportation, electricity generation. This may result in large decrement in carbon and harmful gas emissions from an average of 650 million tonnes per year since 2000 to around 150 million tonnes per year in 2040 in order to maintain WEO-2016 pledges to reduce environmental temperature of 2°C [2].

In 2015, world produced renewable energy resources over more than 10442.6 TW·h/year (terawatt-hours per year). Out of this India produced 160 TW·h/year and on the other hand neighboring country China was leading by producing 1300TW·h/year [5].Study shows that India's energy sector has grown tremendously in the recent years. India has been responsible for almost 10% of the increase in global energy demand since 2000. On the reports of CEL grid operation and distribution wing all India renewable energy sources (RES) the generation of total power is 45916.95MW upto the date of 16 November 2016 [6]. It is observed that Northern, Western and Southern region have better energy generation capacity compared to Eastern and North Eastern region within India (Fig. 1a). Among these energies, RES has very little contribution approx 2% in eastern region. Share of capacity in RES shows that Hydro, wind, solar PV and conventional RES energy contributes the most approximately 10%, 13%, 17% and 57% respectively (Fig. 1b), whereas share of generation further decreases the value (Fig. 1c). This

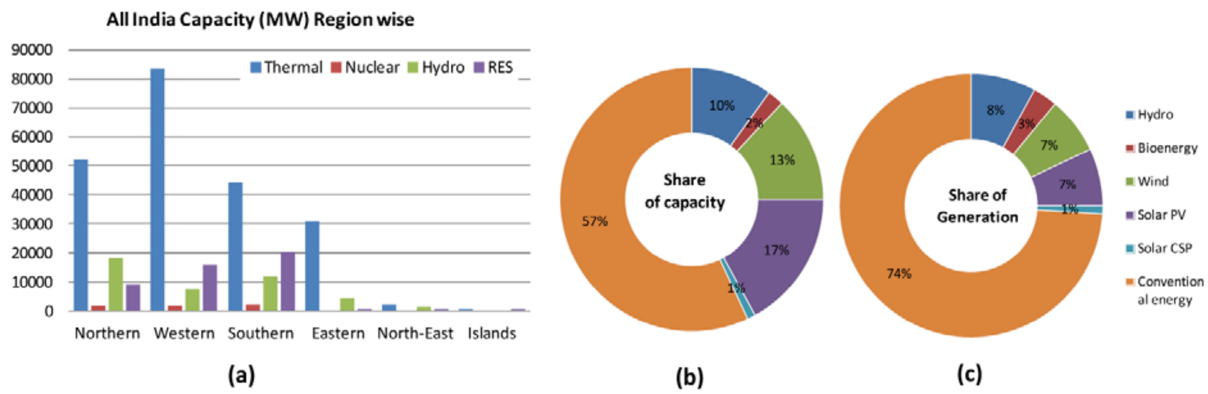

Fig.1 (a) Regional total Installed energy generation capacity in India (b) Capacity of different renewable energy generation plant installed in India (c) Share of actual renewable energy production in India [6]

fact indicates that there is a huge scope for implementing RES plant in Eastern region for producing environment friendly alternate electric generation plant in order to fulfill increasing electric demand of the area.

Several literatures show that among different RES, solar-wind energy system is a good resource of hybrid renewable energy. Solar energy is basically utilized in two ways (i) either to use it directly without using an intermediate electric circuit. Generally solar flat plate collectors are used to generate thermal energy by heating fluid (either air or water). Further this thermal energy may be converted into electrical energy [7]. (ii) To convert it into electrical energy by using photovoltaic (PV) modules. Direct conversion of solar radiation into electrical energy is the most convenient way of utilizing solar energy [8]. In addition, wind turbine also generates electricity without creating pollution and it is well suited for isolated places with no connections to the outside grid [9].Yang et al. tried to optimize the capacity sizes of different components of hybrid solar-wind power generation systems employing a battery bank [10]. Similar exercise has been performed by Xing et al. by calculating the system optimum configurations by considering some decision variables included in the optimization process [11].

Daud and Ismail proposed a hybrid renewable system to solve power-supply problem for remote and isolated areas far from the grids [13]. This system consists of wind-solar system along with diesel engine to accomplish or to recover the load requirements for peak time. Similar exercise is done by Ismail et al., where sensitivity analysis was undertaken to evaluate the effect of change of some parameters on the cost of energy [12]. The results indicated that the optimal scenario is the one that consists of a combination of the PV panels, battery bank and a diesel generator and powering a rural house using this hybrid system. Mainly, wind energy was used at the peak demand time. Some of non renewable energy like bio fuel or bio mass also has been used to form hybrid renewable energy [14, 15]. Fodder (residual of crop) may be used to produce bio fuel. Sometimes bi-product of sugar cane is also used to extract ethanol from it. Blottnitz and Curran conducted a literature survey on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective [16].

On concluding all the literature, it is clearly depicted that the technical and economic feasibility as well as optimality of hybrid energy resources system (HRES). Though the use of renewable energies are in trend, but the combinations of renewable energies i.e. hybrid energy system are limited. Our main concern is to implement HRES is rural areas to fulfill the load requirement at lowest cost. In our research various aspects have motivated viz. utilizing all the available renewable energy resources, optimization of cost variables, minimizing emission of CO_2, fulfilling electric load demand and capacity to store energy. These issues are concerned in this study fill the knowledge gap. Thus following objectives have been set for this study: (i) modeling RES for the rural area in Eastern India with different combinations (ii) optimality and sensitivity analysis of the same in order to find the cost of electricity and generation capacity.

II. METHODOLOGY

The RES including solar, hydro, wind, biomass and biogas energy are depicted in Fig. 2. Here Hydrokinetic turbines (HKT) are considered for harnessing hydro energy whose working principle is analogues to wind turbine. This HKT is capable of producing energy from very low head channel, tidal energy and ocean energy [17]. Therefore it is very effective to use in remote areas in hilly region, near coastal region or water scared region. For solar energy a PV module array system is considered [18]. Literature showed that the PV panel alone converts solar energy into the electrical energy, which could be stored in battery storage cells with an efficiency of 25-38% [19]. Proposed HES consist of wind turbine also, that converts wind energy into the mechanical energy into electrical energy. This electrical energy will be further transmitted through the step up transformer to the storage cells (Fig. 2). This storage cell fulfills the peak load or fluctuating load demand having approximate efficiency of 27-48% [20]. Generally, in the bio-mass plant cattle dung like cow dung, poultry or piggery dropping and crop residue are used for the generation of the gas. Further, crop residues are mixed and blend with water to form the slurry by the help of mechanical energy, which is extracted from the wind energy. This slurry is kept for fermentation. In the proposed hybrid system, biomass and bio fuel will also be included for performance investigation in combination with other The governing equations of all components used in RES are stated as follows.

Solar Energy

For finding the maximum power output the equation is shown in Eq (1).

$$P_{max} = FF.\ V_{oc}.\ I_{sc} = \frac{V_{oc}-\ln(V_{oc}+0.72)}{1+v_{oc}}.\left(1-\frac{R_S}{V_{OC}/I_{SC}}\right).\frac{V_{OC0}}{1+\beta\ln\frac{G_0}{G}}.\left(\frac{T_0}{T}\right)^{\lambda}.I_{SC0}\left(\frac{G}{G_0}\right)^{\alpha} \quad (1)$$

Where P_{max} is the maximum Power generated, FF is the fill factor of the PV module, V_{oc} is open circuit voltage, I_{sc} is the short circuit current, R_S is the series resistance of the PV module, T is the PV module temperature (K), G is the solar irradiance (W/m^2), G_0 is the standard solar irradiance (W/m^2) α, β, λ is the exponent responsible for all the non-linear effects that the photocurrent depends on [21].

Wind energy

The maximum power output is shown by Eq. (2).

$$P_{MAX} = 0.5\rho AC_p\left[\frac{R}{TSR_{TARGET}}\right]^3 \times \omega_m^3 \quad (2)$$

Where P_{max} is the maximum Power generated by wind turbine (kW), ρ is density of the air (kg/m^3), A is the swept area, C_P is the coefficient of wind turbine, ω_m is the rotor speed (mechanical rad/s), TSR_{TARGET} is tip speed ratio, R is the radius of the blade (m), V is the linear speed of the wind (m/s) [22].

Hydro kinetic energy

Power developed (P) by hydro kinetic turbine is as follows.

$$P = \frac{1}{2}\rho AU^3 4a(1-a)^2,\quad a=(U-V_1)/U \quad (3)$$

Where P is the power developed A, ρ, U, V_1 are turbine swept area, water density, free stream velocity and water velocity at plane of rotor respectively.

Biomass energy/ Biogas

Conversion of methane from slurry through fermentation is as follows. Same as like of methane from excreted manure in the presence of yeast through fermentation is as follows.

$$Slurry(in\,kg/(20\text{-}40)days) \xrightarrow{mesophilic\ temp(22-38^\circ C)} CH_4(kg/(20\text{-}40)days) + CO_2 \quad (4)$$

$$Excreted\ manure + Water \xrightarrow[at\,22^\circ-38^\circ C]{Hydrolysis} Decomposition(actetic\ acid, H_2, CO_2) \xrightarrow{Presence\ of\ yeast} CH_4 + CO_2 \quad (5)$$

III. Implementation of the Model in HOMER Software

The above said concept has been implemented through Hybrid Optimization of Multiple Electric Renewable (HOMER) software. HOMER evaluates designs of both off-grid and grid-connected power systems for a variety of applications. It simulates the operation of a system by making energy balance calculations in each time step of the year. For each time step, HOMER can compare the electric demand in that time step to the energy that the system can supply in that time step. Further it calculates the flows of energy to and from each component of the system.

In this study different renewable resources is combined to form following five HRES: (a) solar-wind-hydrokinetic-bioenergy (b) solar- hydrokinetic-bioenergy (c) solar-bioenergy (d) bioenergy and (e) solar-wind- bioenergy (Fig. 3). These combinations are selected according to the cost of energy, net present cost highest renewable fraction along with lowest emission of CO_2. The availability of renewable energy resources, its economy and effect on environment are considered while simulating the power production in HOMER software. For this purpose, an area of Eastern India is considered as study area, which is described as follows.

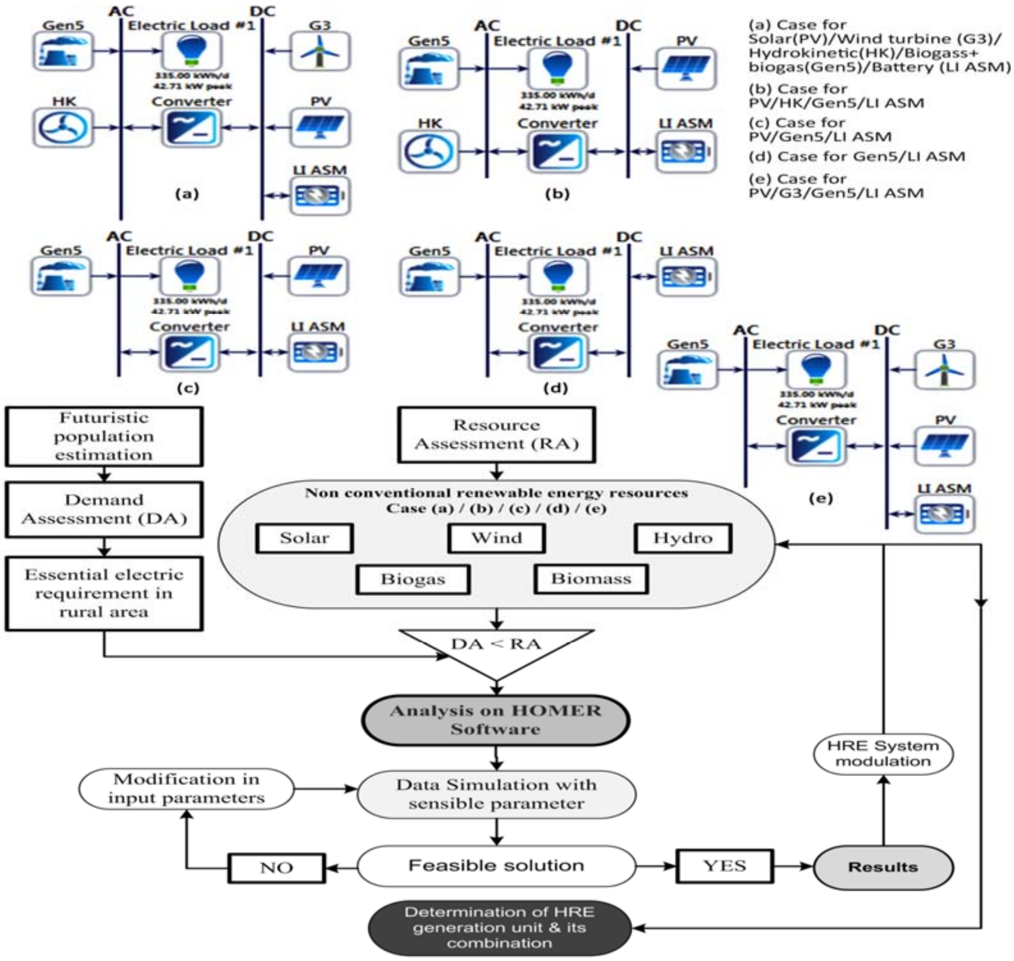

Fig. 2 Implementation of proposed hybrid energy model through different combination of non conventional energy in HOMER

IV. *MODEL INPUTS TO HOMER CORRESPONDING TO STUDY AREA RESOURCES*

The load profile of the study area is estimated corresponding to power consumed by kWh/day/capita in Jharkhand state. As per 2011 census, presently 31.9 million people of Jharkhand consume power is 835kWh/day [23]. Accordingly total estimated population energy to be consumed by the community is considered as 335 kWh/day as shown in Fig. 3.

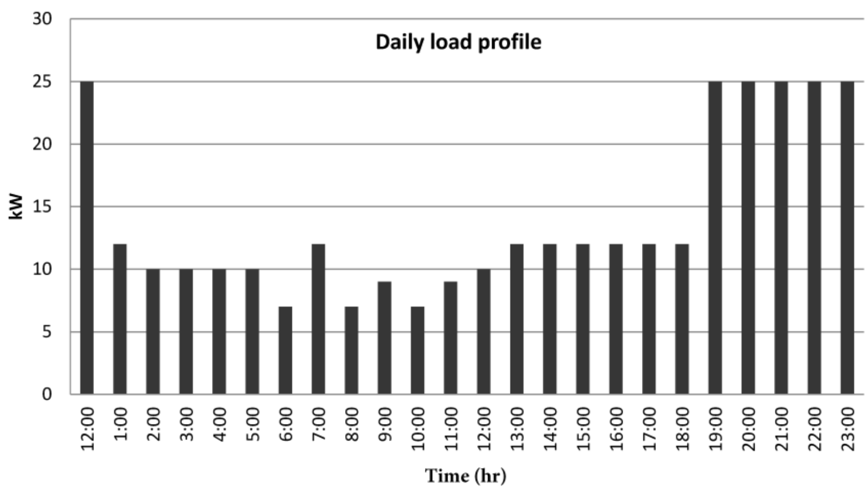

Fig. 3 Average daily load profile of India in hourly basis

A. *Solar energy*

It is observed that average solar radiation is 4-7.8 kWh/m^2/day throughout the year. Due to the clear weather, direct and diffuse radiation on this region is appropriate for solar Photovoltaic cells. The capital, replacement and operating and maintenance (O&M) cost is considered as $1667, $1667 and $19.38/year for the search space of 0 to 50kW in HOMER analysis.

B. Wind energy

The wind speed profile of study area is considered as 3.8-6.5 m/s for the study area. Wind turbine capital cost and replacement costs include shipping, tariffs, installation, and dealer mark-ups are considered as $1200, $1200 and $18/ year.

C. Hydro kinetic energy

The hydrokinetic plant requires heavy components and suitable water supply. The initial capital cost for microhydro (i.e. hydrokinetic) system, is considered as $1283.33/kW and O&M cost as $44.05/kW.

D. *Biomass*

The biomass generator of 1kwh is considered for the system for the size 9kW having capital cost, replacement cost, O&M cost as $917,$917 and $0.020 respectively and for the size 6kW having capital cost, replacement cost, O&M cost is $742, $742 and $0.015 respectively.

E. Converter

A device needed to convert AC & DC components for energy flow to grid is converter. The capital cost, replacement cost & O&M cost is $465, $465 and $9.00. Operational hours is 15year, input search space is 0 to 50kW.

F. Battery

Li-ion 1kwh battery is used of 7.4V, capital cost, replacement cost & O&M cost is $80, $80 and $8,search space is 0, 50, 100 and 150.

G. Sensitive Parameter

The key variables for the input of sensitive parameter is bio-diesel (methane and biomass) price $0.95, $1, $1.5 and $2, wind speed 4, 5, 6 and 7m/s. These parameters are considered for the sensitive analysis, which are the input to search space.

V. RESULT AND DISCUSSION

In this analysis, economic aspect and electricity generation with cost parameter is also considered including environmental aspects. Generally, during analysis HOMER performs numbers of simulation. In this study, out of these, HOMER displays 12 optimal outcomes for final assessment in Table 1 considering sensitive parameters. Outcome shows that the architecture of PV array is 10kW, wind turbine is 3kW, biomass/biogas generator is 16kW, Li-ion battery is 300kW and converter with cyclic charging is 30kW. Above configurations are obtained corresponding to the wind speed range of 4 to 4.5m/sec, biodiesel price range of $0.95/liter to $2/liter, levelised cost of energy (COE) range of $0.36/kWh to $0.68/kWh, total net present cost (NPC) range of $1067361 to $561148 (Table 1), it is clear that with increase in wind speed (in a range of 4-6 m/s), NPC decreases and annual electric generation increases.

If wind speed is kept constant by varying biodiesel price, it is observed that with the increase in biodiesel, NPC and COE also increase (Fig. 4a & 4b). Optimal solution is found out within search space and by considering sensitive variable (i.e. biodiesel fuel price and wind speed) along with other parameters like COE, fuel cost, and renewable fraction (RF). It is observed that minimum value of COE is obtained as $0.33 at biodiesel/biogas price of $0.95 and 7 m/sec wind speed at a RF value of 14.Whereas, maximum value of COE is obtained as $0.68 at biodiesel /biogas price of $2.0and 4m/sec wind speed at a RF value of 10 (Fig. 4b & 4d). Therefore, it is observed that system having wind turbine-biodiesel-battery combination produce optimal result in higher wind speed (4.5 – 7.0 m/s), whereas solar-biodiesel-battery combination able to produces optimal result in lower wind speed. Moreover, in solar-biodiesel-battery combination if total footprint value increases with decrease in NPC, whereas RF and COE shows moderate values.

VI. CONCLUSION

In this study, a hybrid energy renewable system configuration is proposed for simulation and optimization in HOMER. In this analysis, economic aspect and electricity generation with cost parameter are also considered including environmental aspects. Detailed findings of the same are discussed as follows.

(1) A hybrid energy renewable system model is proposed by combination of non conventional energies viz. solar, wind, hydro kinetic, biomass and bio gas which is analyzed in HOMER software.

(2) During simulation of this model, HOMER produces 12 optimal outcomes for final assessment by considering sensitive parameters viz. biodiesel fuel price ($0.95/liter, $1/liter, $1.5/liter, $2/liter) and wind speed (4m/sec, 5m/sec, 6m/sec, 7m/sec).

(3) Optimized results are also evaluated considering total net present cost, cost of energy, annual electric generation, renewable fraction and CO_2 emission.

Table 1 Optimal result obtained in HOMER considering sensitive parameter of proposed HRES model

Sensitivity		Architecture						Cost				Electricity Production (kWh)			
Bio Fuel Price ($/L)	Wind velocity Average (m/s)	PV (kW)	G3 (Nos)	Gen5 (kW)	LI ASM	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Gen5	PV	G3	LI ASM
0.95	4	10	3	16	300	30	CC	0.355	561147.6	38846.3	58962	108620	18186.2	6238.5	33393.3
0.95	5	--	5	16	300	40	CC	0.358	564980.4	39886.9	49342	111604	--	21573.2	31605.3
0.95	6	--	3	16	300	30	CC	0.352	556741.4	39794.9	42292	112172	--	20664.9	30238.7
0.95	7	--	3	16	300	30	CC	0.335	528910.6	37642.1	42292	105472.8	--	28034.1	32415.4
1	4	10	--	16	300	30	CC	0.383	604444.7	42473.9	55362	114260	18186.2	--	31123.1
1	5	--	5	16	300	40	CC	0.373	589074.9	41750.7	49342	111604	--	21573.2	31685.1
1	6	--	3	16	300	30	CC	0.368	580889.3	41662.9	42292	112156	--	20664.9	30203.0
1	7	--	3	16	300	30	CC	0.349	551752.4	39409.0	42292	105488.8	--	28034.1	32434.5
1.5	4	10	3	16	300	30	CC	0.518	818267.8	58735.6	58962	108492	18186.2	6238.5	33079.9
1.5	5	--	5	16	300	30	CC	0.521	822467.1	60164.3	44692	111576.3	--	21573.2	31514.2
1.5	6	--	3	16	300	30	CC	0.521	822929.1	60385.7	42292	112140	--	20664.9	30081.6
1.5	7	--	3	16	300	30	CC	0.493	779193.1	57002.5	42292	105440.8	--	28034.1	32225.8
CC- cyclic charging, G3- 3kW wind turbine, Gen5 indicates biodiesel generator, Li ASM is Li-ion battery															

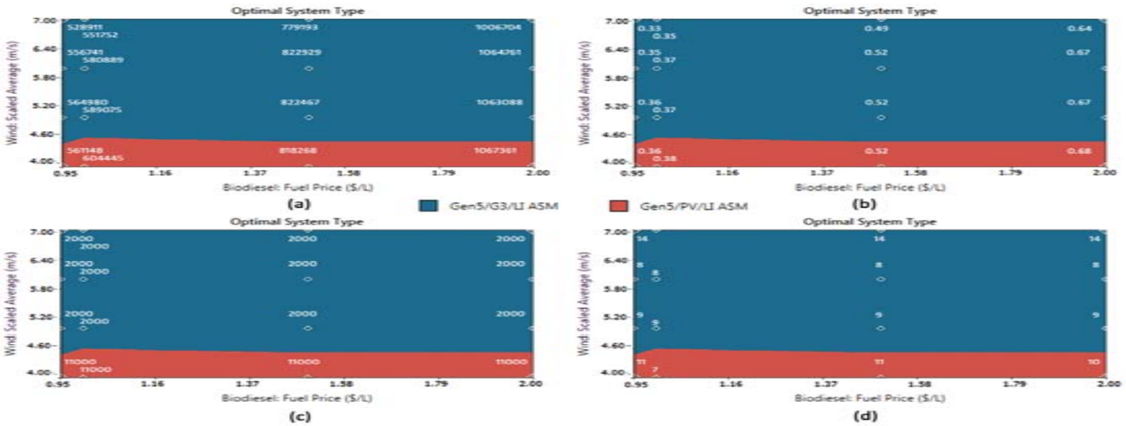

Fig. 4 Optimal system (a) based on NPC ($) (b) based on COE ($) (c) based on total footprint (d) based on RF.

(4) It is observed that proposed system including wind turbine-biodiesel-battery combination produces optimal result at higher wind speed (4.5 – 7.0 m/s), whereas solar-biodiesel-battery combination is able to produce optimal result at lower wind speed (< 4.5 m/s). Moreover, in solar-biodiesel-battery combination, total footprint value increases with decrease in net present cost. However, renewable fraction and cost of energy shows moderate values.

(5) Therefore, analysis shows that in order to produce more power, higher cost of biodiesel should be a good option, but it may increase CO_2 emission. In addition, in this situation battery storage also shows moderate value. However, battery storage capacity is found more corresponding to the moderate price of biodiesel. On the other hand, with the increase in wind speed, electricity generation and its consumption during peak time is more. At the same time there is less CO_2 emission which is suitable for environment.

(6) Case (a) produces best result having configuration of 10 kW of PV array, three numbers of 3kW wind turbine, biodiesel generator of 16kW, one number of hydrokinetic turbine, 150 numbers of battery string size and 30kW of convertor, having cyclic charging. Therefore, it can be concluded that Case (a) is able to meet the electric load requirement of the study area.

(7) On the other hand Case (c) produces comparatively ineffective result. This signifies that stand alone electric generation plant using bio diesel fuel is not economically cost effective, as well as it is not able to fulfill electric load demand completely.

(8) On accounting environmental factor case (a) and (d) emits very low amount of carbon emission. These results might be helpful to reach 2°C temperature phenomenon targeted to protect environmental degradation.

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