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Feasibility Study: Photovoltaic Module and Biomass Based Hybrid Power System Connected to Grid- South Australia Context, Australia

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ABSTRACT: *In recent days there is an increase in usage of Renewable energy (RE), this is because RE is known as clean sources of generating electricity, and it also reduces Green house gas emission spread in the atmosphere. The method of integrating two or more different power systems together to supply electricity is known as hybrid power system (HPS). A grid connected hybrid power systems avails multiple advantages such as selling back excess electricity to grid or supplying it to the necessary/nearest location, and consuming unmet load from grid. In fact it is always not possible to supply electricity to a load with a standalone hybrid system; this is because the consumption of electricity load, climatic condition and environmental factors differ time to time. 100 percent renewable energy is not easy to implement within short period as it involves huge investment. Since huge investments are already invested in Non-RE power plants, in order to overcome these issues, a grid connected distributed HPS was proposed by considering Photovoltaic and Biomass as major renewable resource and the remaining unmet load with Non-RE. The reason of choosing PV set up and Biomass based generator is because currently SA government is mainly planning to invest its funds on Wind fuelled generators and a tiny contribution to solar and biomass. The above concerns led to a desire to investigate the feasibility study of PV-biomass based generator connected to grid. A study was conducted by collecting the solar radiation data from Bureau of Metrology (BOM), an average annual solar radiation was compared and a ranking system was performed. During the ranking system, it was revealed that Roxby Downs has maximum solar radiation exposure. The study also revealed that, with the designed HPS, an optimum cost of electricity (COE) of $ 0.129, Renewable Fraction (RF) of 0.79 can be obtained.*

KEYWORDS: *Hybrid power system (HPS), Renewable energy (RE), Photovoltaic (PV) modules, Battery, Converter, Rectifier, Grid.*

I. INTRODUCTION

Electricity plays a vital role in the modern world [1]. The average electricity consumption of South Australia (SA) in the year 2012-13 is 13,300 giga watt hours (GWH); materially the consumption of electricity is reduced by 0.3 percent or 42 GWh while compared to the year 2011-12. According to the consumption forecast it is most likely considered that a decrease of 0.1 percent each year over 10 years of outlook. In the year 2012-13, a maximum demand (MD) occurred during summer i.e. 3,158 mega watts (MW). Therefore, an increase of 179 MW occurred during the year 2011-12, but lower than the recorded MD of 3424 MW occurred in the year 2012-13. The national renewable energy (RET) scheme, commenced in 2010 January stated that RE 20-2020 i.e. achieving 20 percent of RE by 2020; 41000 GWH of renewable energy by 2020. The news update stated that "So we're now announcing an even tougher target of 33 per cent by 2020 which will keep us at the Forefront internationally of jurisdictions supporting renewable energy"[2].

The renewable energy distribution target by government of SA is majorly of Wind generators, where as solar and biomass is the least. However substantial solar energy does exist in SA i.e. a minimum of 14 Mj/m^2 to a maximum of 24 Mj/m^2 annually which is fairly a descent solar exposure is available. The distribution of solar energy in SA is shown in the Fig. 1 [3].

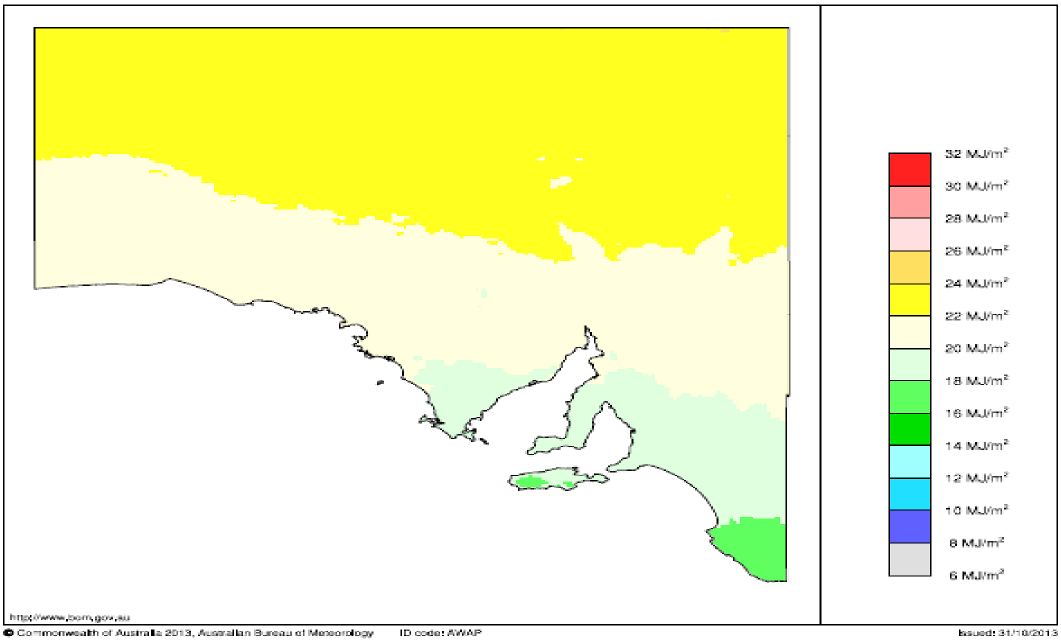

Fig. 1. Average solar radiation received in SA in the year 2012 (BOM)

II. METHODOLOGY

The methodology followed for designing HPS is as shown in Fig. 2. The whole analysis is conducted in HOMER NREL tool analytically i.e. designing grid connected HPS.

1) The grid connected electricity is imported in HOMER NREL tool, and the average electricity load per day and peak load is identified
2) A ranking system was conducted by comparing the average annual data collected from BOM for 2012 year of 25 major cities- South Australia context for site selection, and PV sizing was modeled with the available solar radiation and by considering various de-rating factors.
3) A suitable Biomass generator was opted and an assumption was made that 1 tons/day of biomass is available each day. A sizing of biomass generator was performed as per the target of power supply.
4) Integration of HPS to grid system in order to supply electricity to SA grid connected load.

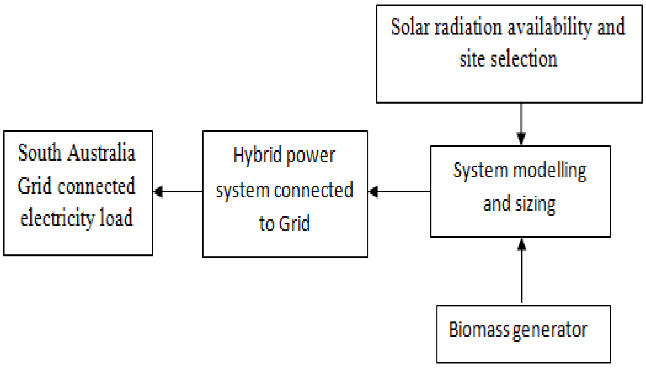

Fig.2. Methodology steps

III. PROPOSED HYBRID POWER SYSTEM

A RE HPS system i.e. a combination of various power systems such as PV, Wind, Hydro, Geothermal, and Biomass can be connected to grid to supply electricity to the targeted location where grid connection is available. The proposed system is as shown in the Fig. 3. The system component consists of PV, a supporting converter, battery for storage. RE fuelled power generation method are intermittent by nature, as it majorly depends on environmental factors, and whether conditions, so an optimum size battery is used to store electricity.

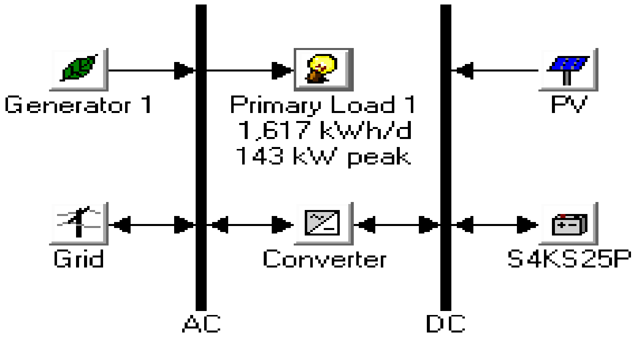

Fig. 3. Proposed HPS

IV. ELECTRICITY LOAD

Grid connected electricity load profile of SA for each month is shown in the Fig. 4 .The consumption of electricity is un-steady, and varies each month. The grid connected electricity seasonal profile detail was provided by "Electra Net, ETSA utilities, Envestra" - special thanks to them. From Fig. 4. it can be noticed that the consumption of electricity is high during the month of October, November, December, January, February when compared to remaining months in a year; an average of 1,617 kWh/d load demand, and with a peak load of 143 kW of load is occured.

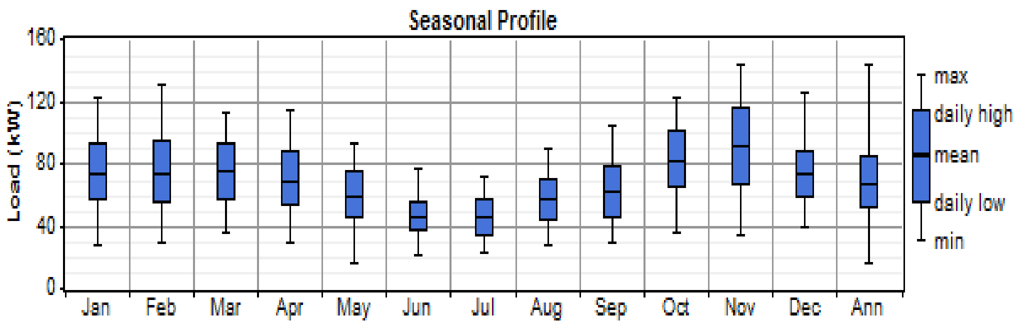

Fig. 4. Grid connected Seasonal Electricity profile of SA

The electricity load profile for each point in time is as shown in the Fig. 5. The color variation with respect to the load in kW is shown in the Fig. 5.

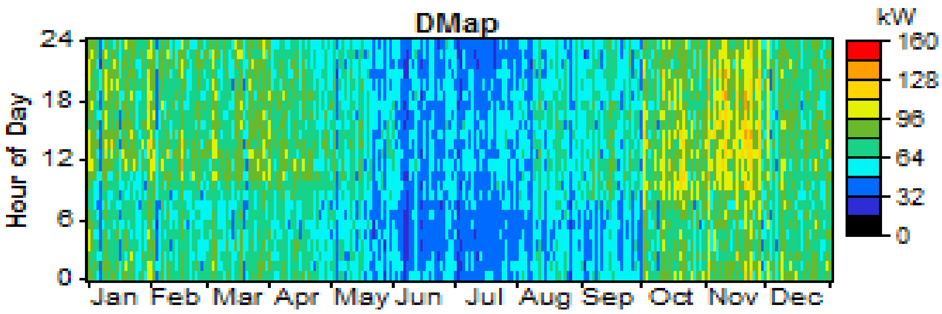

Fig. 5. Electricity load for each hour

V. SOLAR ENERGY RANKING

The major 23 cities, its location details, average annual solar radiation, and its solar ranking are listed in 1. The solar data for year 2012 was collected from Bureau of Metrology (BOM) [4], and with the collected data a ranking was performed to identify the maximum solar energy available at each selected city. The performed investigation helps to gain maximum solar energy i.e. to generate maximum energy through PV modules. During ranking the location receiving same solar radiation is ranked as same position, and the location receiving higher solar radiation is ranked as first and location receiving less solar radiation is ranked as highest. The performed ranking revealed that Roxby Downs receives highest annual solar radiation of 5.6 kWh/m^2/day.

Table 1: location details, annual solar radiation received in 2012 and its solar ranking of major cities in SA

City	Latitude (South)	Longitude (East)	Annual solar radiation (average) kWh/m^2	Solar ranking
Roxby Downs	30.48	136.88	5.6	1
Port Augusta	32.49	137.77	5.3	2
Whyalla	33.03	137.58	5.3	2
Port Pirie	33.19	137.99	5.3	2
Kadina	32.88	148.25	5.1	5
Berri	34.28	140.60	5.1	5
Naime	34.45	140.57	5.1	5
Moonta	34.07	137.59	5.1	5
Victoria	34.24	138.13	5.0	9
Clare	33.83	138.61	5.0	9
Adelaid	34.93	138.60	4.9	11
Gawler	34.60	138.74	4.9	11
Murray Bridge	35.12	139.27	4.9	11
Nuriootpa	34.47	139.00	4.9	11
Tanunda	34.52	138.96	4.9	11
Port Lincoln	34.73	135.86	4.9	11
Mount Barker	35.07	138.86	4.8	17
Strathalbyn	35.26	138.89	4.8	17
Goolwa	35.50	138.78	4.8	17
Crafers	34.99	138.71	4.7	20
Naracoorte	36.96	139.00	4.7	20
Millicent	37.60	140.36	4.6	22
Mount Gambier	37.82	140.78	4.5	23

VI. INPUT PARAMETERS, COST, AND INFORMATION

The monthly average solar radiation data was collected from BOM [3]; is imported in to HOMER NREL tool, and the location latitude, and longitude i.e. 30.48 south, 136.59 east, time zone +9:30 Darwin, Adelaide was selected. An average of 5.65 $kWh/m^2/day$ was available at selected location. The HOMER automatically simulates clearness index, and an average of 0.642 was available, and is shown in Fig. 6.

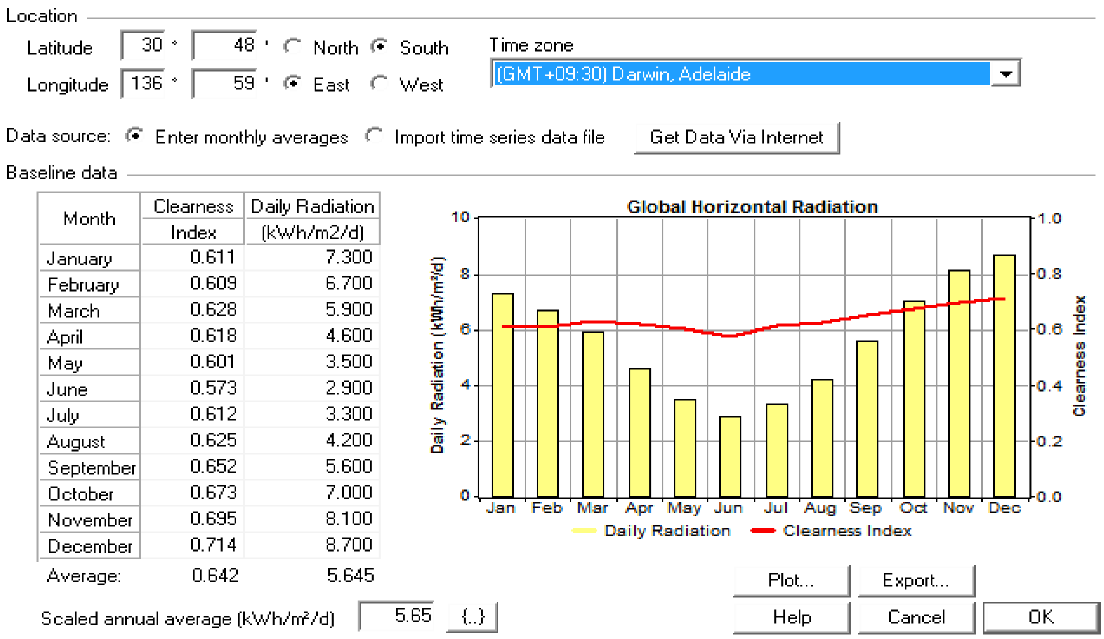

Fig. 6. Global horizontal radiation and clearness Index

The global horizontal solar radiation available for over 24 hrs of time is as shown in the Fig. 7. Majorly the solar radiation is available between 5 am to 19 pm hrs, however during the other period of time there is no solar energy available. Therefore it can be concluded that there is no power generation during the time when there is no solar energy gain. From Fig. 7. It can be noticed that during the month of October, November, December, January, and February highest solar energy is available while compared to remaining months.

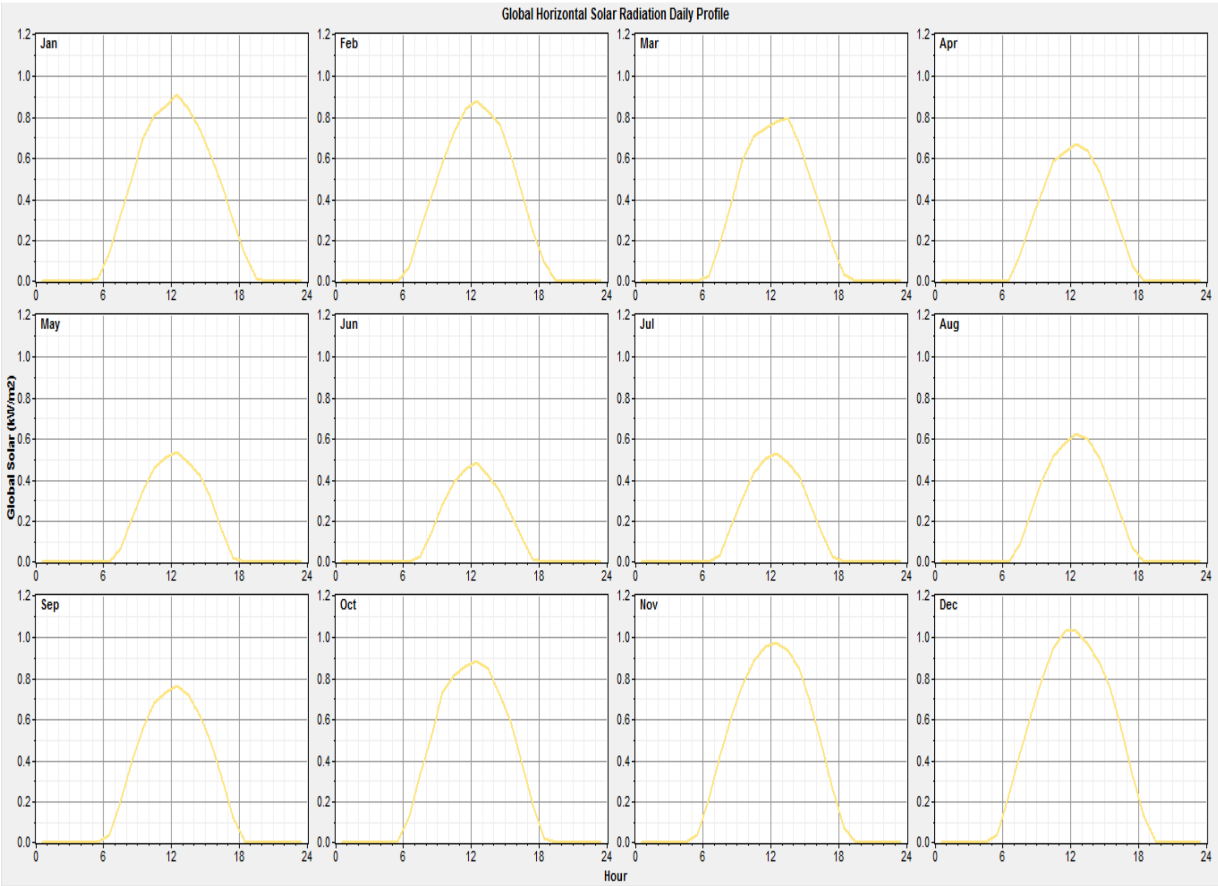

Fig. 7. Horizontal global solar radiation for 12 month

The in-put cost and information of PV, Converter, Battery, and Biomass generator in HOMER tool is listed in 2, 3, 4, and 5.

Table 2: PV module coat and information

Description	Cost/Information
Capital cost	$ 1100.00 per kW
Replacement cost	$ 900.00 per kW
Life time cost	25 years
PV	Fixed (horizontal)
De-rating factor	85%

Table 3: Converter prices

Description	Cost/information
Capital cost	$ 220.00
Replacement cost	$ 180.00
Efficiency	90%

Table 4: Battery cost and information

Description	Cost/information
Capital cost	$ 200.00/ 4 V 1900 Ah
Replacement cost	$ 130.00/ 4 V 1900 Ah
Batteries per string	1 [4 V bus]

Table 5: Biomass generator

Description	Cost/Information
Capital cost	$ 800.00 per kW
Replacement cost	$ 700.00 per kW
Life time operating hours	15000
Maximum load ratio	30 %
Fuel	Biogas

VII. SIMULATION RESULTS AND DISCUSSION

1.1 PV MODULES

Photovoltaic module converts solar energy directly in to electric current [5]. The PV module in HOMER produces direct current (DC), but the electricity load consumption is alternate current (AC), in order to convert from DC to AC a converter is hooked to PV. PV systems can be used in two methods, they are

1.1.1 PV standalone system- A PV stand alone system majorly consists of PV modules, Converters, Battery storage, minor number of controllers, and electricity load [6]. PV stand alone systems are not hooked to the grid, and they are independent. Sized stand alone systems have been proven to be reliable, low maintenance ways for generating electricity in moderate amounts in isolated unmanned sites [7].

1.1.2 Grid connected PV system- Grid connected PV system is similar as standalone system (supporting converter), where as the system is hooked to grid. The uniqueness of the grid system is it allows to sell the excess electricity produced from PV and also the electricity can be drawn from grid when there is an unmet load. However the Grid connected PV system may or may not use a battery storage device for electricity storage purpose.

The rated capacity of PV is 200 kW, and is shown in Fig. 8. It is operated for 4,385 hr/yr and generates an output of 358,686 kWh/yr.

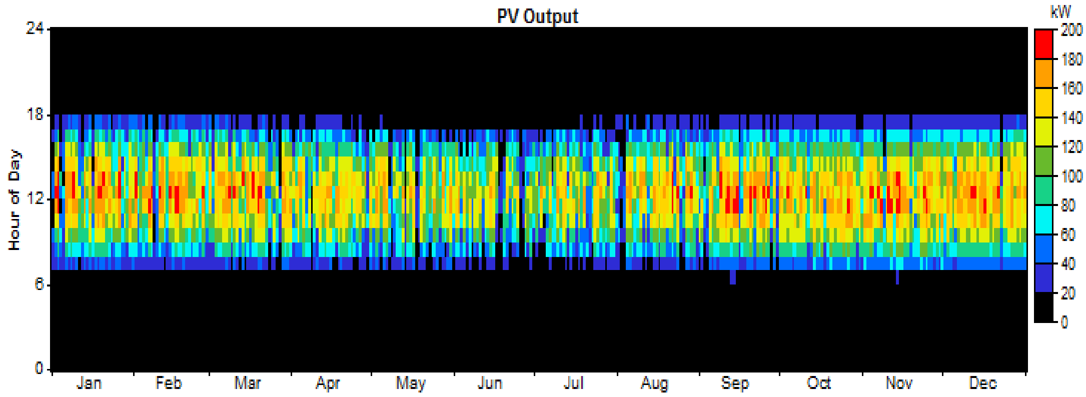

Fig. 8. The electricity generated through PV modules with the available solar radiation

1.2 Battery

Battery plays a vital role for storage purpose. The electricity generated through PV module is not always same, as it majorly depends on the available solar energy, but the fact that solar energy is intermittent as it majorly depends on the environment factors, and more over the electricity load is also not steady and same at each time as the consumption of electricity may vary as per the consumption. The advantage of battery is it stores electricity and helps to gain increased usage of RE i.e. charges when excess electricity is produced from PV module and discharges when demand occurs.

The battery state of charge is as shown in the Fig. 9. A rated capacity of 150 batteries was used for storage purpose, and hooked with 1 string for each battery. The maximum peak charge occurred between 12 pm to 20 pm. A total energy of 133584 kWh/yr energy was introduced in the battery and 107,066 kWh/yr energy was consumed i.e. by discharging the battery. However 26,228 kWh/yr of energy of loss occurred due to system losses. The state of charge can be calculated using (1) [8]

$$SOC(i+1)=SOC(i)\text{-}SOC\ (i).\sigma_{SDR} \pm I_B(i).\Delta t.\eta_{BCE} \quad (1)$$

Where SOC (t)-state of charge,

σ_{SDR}- self discharge rate,
$\pm I_B(t)$-battery charge (+) and discharge (-) current,
Δt- time in hours,
η_{BCE}- battery charging efficiency.
During discharge, η_{BCE} is assumed as one.
During charging, η_{BCE}-0.65 to 0.85, Varies, and depends on charge of current

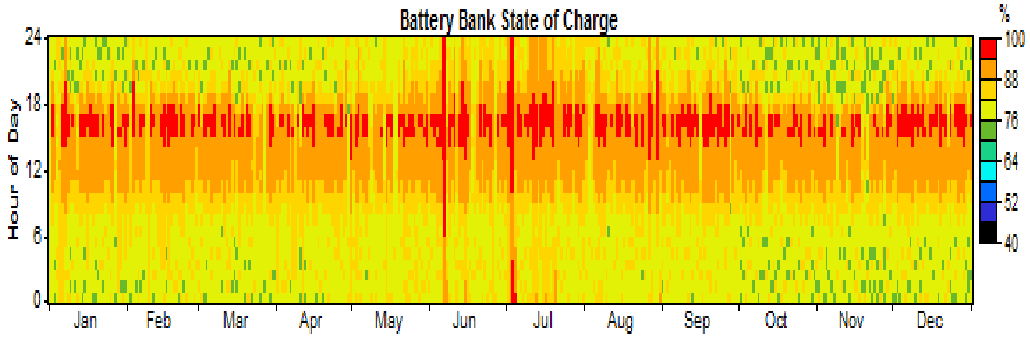

Fig. 9. The battery bank state of charge

1.3 Converter and rectifier

The converter output hooked to PV module converts direct current (DC) to alternate current (AC), is as shown in the Fig. 10. A rated capacity 200 kw converter was opted for 200 kw of PV module. The converter was operated for 6649 hy/yr with a total production of 401,530 kWh/yr energy and with an energy output of 361,378 kWh/yr from the system. Therefore 40,152 kWh/yr energy loss occurred due to system loss.

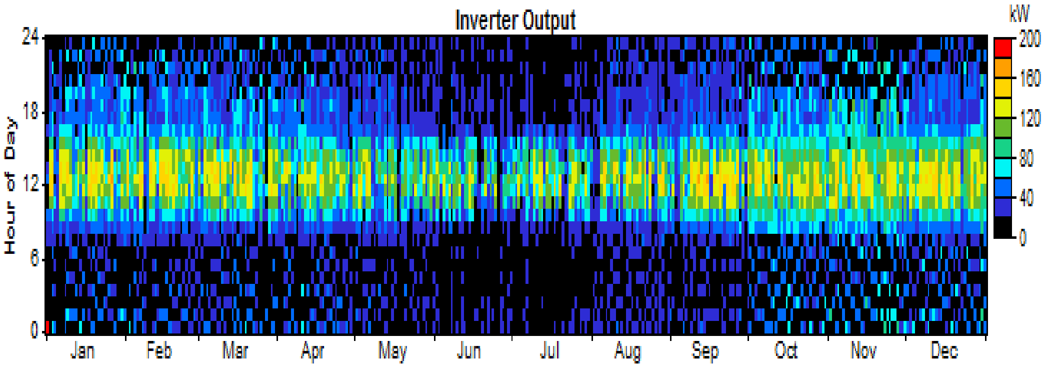

Fig. 10. Inverter output

A rectifier output is as shown in the Fig. 11. A maximum of 45 kW rectifiers was used during the overall process. The rectifier was operated for 1,875 hr/yr with a total production of 401,530 kWh/yr, and 69,327 kWh/yr energy output. Therefore 12,235 kWh/yr energy loss occurred due to system loss.

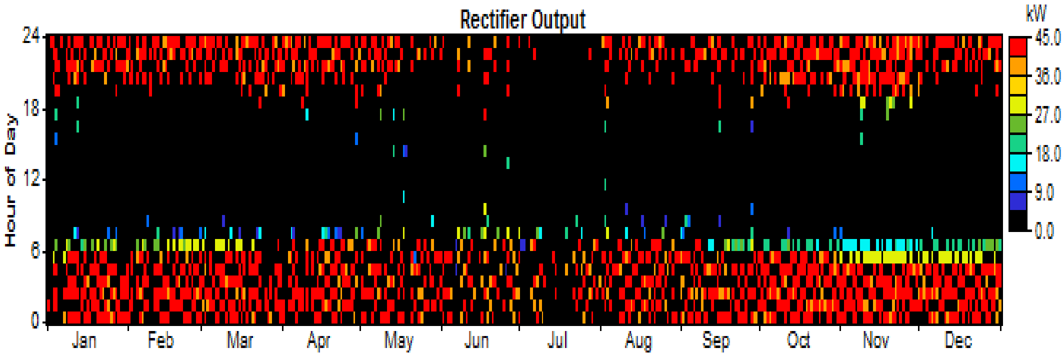

Fig. 11. Rectifier output

1.4 Biomass generator

A rated capacity of 30 kW biomass based generator was used, the system was forced to use all the time. From the Fig. 12 it can be noticed that a maximum usage occurred at all the time from biomass generator. A total of 8,760 hrs/yr was used to generate a total production of 262,800 kWh/yr, and with a bio-feed consumption of 124 tones/yr.

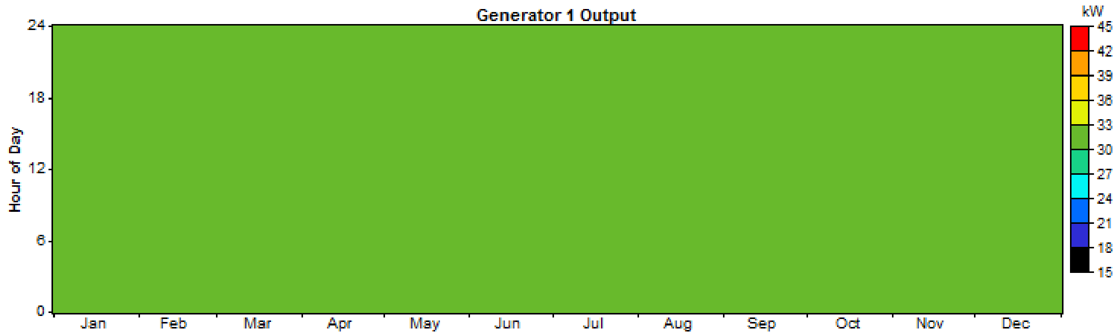

Fig. 12. Biogas generator output

1.5 Electricity production

The monthly average electric production of each power system in a HPS is as shown in the Fig. 13. The annual production by PV, generators is 358,685 kWh/yr, and 262,800 kWh/yr. Annually, a total percentage contribution to electricity load by PV and generator are 45, and 33 percent. However the remaining unmet electricity is purchased from grid i.e. a total of 170,099 kWh/yr of electricity i.e. 21 percent. The remaining electricity is drawn from grid.

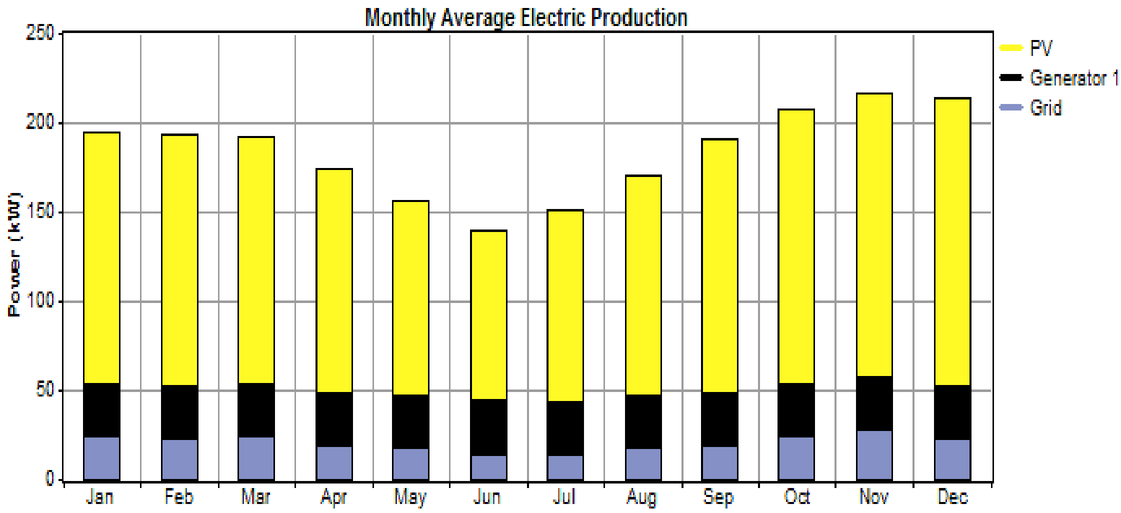

Fig. 13. Monthly average electricity production

1.6 Cash flow

The cash flow summary of each system is as shown in the Fig. 14. The capital cost and replacement cost for PV and biogas generator HPS are $ 318,000, and $ 236,290.

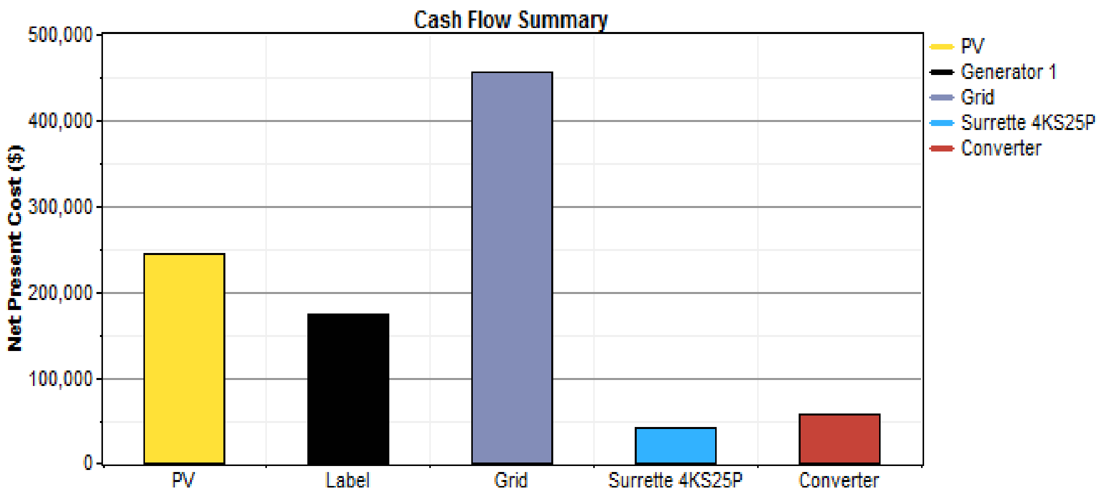

Fig. 14. Cash flow summary

1.7 COE

The cost of electricity (COE) of separate (each) and combined power system are as shown in the Fig. 15. The optimum COE among the system is PV and biomass based generator connected to grid is more economical i.e. with a COE of 0.129 \$/kWh. To configure the system it needs an initial capital cost of \$ 318,000, operating cost \$ 51,112, total net present cost (NPC) is \$ 971,377 \$, and the obtained renewable fraction is 0.79.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

PV (kW)	Label (kW)	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Biomass (t)	Label (hrs)
200	30	150	200	1000	\$ 318,000	51,112	\$ 971,377	0.129	0.79	124	8,760
	30	150	200	1000	\$ 98,000	101,167	\$ 1,391,250	0.184	0.45	124	8,760
200		150	200	1000	\$ 294,000	93,285	\$ 1,486,492	0.197	0.50		
		150	200	1000	\$ 74,000	159,990	\$ 2,119,209	0.281	0.00		

Fig. 15. Optimized COE

VIII. CONCLUSION

With the recently increased concern towards environment and future sustainability has encouraged interests in designing a HPS. An attempt to design HPS has made to explore the possibility of exploiting solar energy, and biomass to meet electricity load requirement for SA grid connected load. The performed feasibility study revealed that for annually varying electricity load a grid connected HPS system could be economical, environmental friendly and viable solution. The feasible study also revealed that Roxby Downs location could be the best suitable location to obtain maximum solar energy gain. Therefore the obtained results from HOMER NREL showed that an economical COE of 0.129, and the usage of battery system for storage purpose has escalated the usage of RE.

REFERENCES

[1] Paul Breeze, *Power Generation Technologies*. Burlington, UK: ELSEVIER, 2005.

[2] Government of South Australia. (2009, June) South Australia government. [Online]. http://www.renewablessa.sa.gov.au/files/news-release---budget-2009---renewables.pdf

[3] Australian Government. (2013, feb) Burea of Metrology. [Online]. http://water.bom.gov.au/waterstorage/awris/

[4] Australian Government. (2013, August) Bureau of Metrology. [Online]. http://www.bom.gov.au/climate/data/index.shtml?bookmark=136&zoom=3&lat=-37.1235&lon=145.2&layers=B00000TFFFFFFFTFFFFFFFFFFFFFFFFFFFFFFTTT&dp=IDC10002-d

[5] Edward N. Stirewait Paul D. Maycock, *Photovoltaics*, Jack Howell, Ed. Andover, United States of America: Brick House Publishing Co., Inc, 1981.

[6] Michael Boxwell, *Solar Electricity Handbook*, 6th ed. UK: Greenstream Publishers, 2012.

[7] Kishore Chatterjee , Santanu Bandyopadhyay E.S. Sreeraj, "Design of isolated renewable hybrid power systems," *Elsevier*, pp. 1124-1136, April 2010.

[8] Akhtar Kalam Ahmad Zahedi, "Balancing Cost and Performance in a PV/Wind/Battery Hybrid Power System," , Melbourne, pp. 1-5.