Vol. XIII & Issue No.12 December - 2020
INDUSTRIAL ENGINEERING JOURNAL

DESIGN AND DEVELOPMENT OF SOLAR PV-DG HYBRID SYSTEM FOR RELIABILITY ENHANCEMENT OF AGRICULTURE MICROGRIDS

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Abstract

Agriculture based micro, small & medium enterprises (MSME) form the backbone of the Indian economy and play pivotal role in growing economy by leap and bounds. Jaggery making is one of the most popular agriculture business enterprises those are tremendously creating job opportunities in rural India. In F.Y 2018-19, India has exported 3, 13,869.84 Mt of jaggery to 168 countries. Though India is supplying more than 80 % of global jaggery demand, most of these jaggery units are located in remote rural areas; lacking of grid infrastructure and going through one of the tough phases, thus actions are required immediately. Therefore, almost all jaggery-making units are fulfilling their energy need by using diesel generators (DG) which are causing immense environmental and noise pollution. Moreover, price of diesel is always rising thereby increasing the overall manufacturing cost. However, India is located in the equatorial sun belt of the earth, thereby receiving tremendous solar energy throughout the year. Therefore, solar energy can be optimally utilized to meet the energy demand of such remotely located rural business units. This research paper is aiming at hybridization of energy resources specifically solar energy technologies with existing energy resources like DG sets for performance improvement of jaggery making units. Research work aims to provide technology up gradation to these conventional DG powered jaggery making units that helps in reducing green house gas (GHG) emission. Moreover, performance analysis of the proposed system is carried out using PVsyst simulation tool

Keywords: Solar PV System, Solar Inverters, Meteonorm, PVsyst, Performance index, Energy improvements, GHG emission, Jaggery Unit, Rural MSME, PMKUSUM

1. INTRODUCTION

Jaggery, the most popular sweetener used worldwide is produced by removal of water from sugarcane juice using conventional open earth furnace-pan heating system. Most of these units are run by farmer's self help groups and are located in remote rural areas. Thus, these small scale business enterprises are facing serious problem of frequent electricity outages and therefore forced to make use of DG sets to match the gap between demand and supply of electricity. Uses of DG sets not only create severe environmental and energy security issues but also increase production cost of electricity. However; India receives an average solar radiation of 4-7 Kwh/m2/day, almost throughout the year and has tremendous scope for generation of electricity by solar energy. Recently India has set a target to rise grid connected solar power generation from 20,000 MW to 100 GW by 2022. Moreover, Government of India has recently launched ambitious project -Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan (PM KUSUM) Scheme with provision for of Setting up of 10,000 MW decentralised renewable energy plants, 17.50 Lakh Solar agriculture water pumps and solarisation of 10 Lakh existing grid connected agriculture pumps. All components of the scheme aim to add solar capacity of 25,750 MW by 2022.[1] Therefore, all individual farmers, group of farmers, cooperatives, panchayats and farmer producer groups those are facing scarcity of electricity to run their agriculture based business enterprises can take advantage of this project and become self reliance of electricity.

2. LITERATURE REVIEW

A substantial literature is available on energy improvement measures using design-based modifications are considered by various researchers for conversion of conventional jaggery units into energy efficient jaggery units. Reversible heat pumps are used for pre-concentration of sugarcane juice from 20°Brix to 40° Brix for separation of water from juice. By this method energy, equivalent to 15% of heat addition during evaporation is conserved, which helped in huge saving of bagasse. However, at eutectic point, sugarcane juice completely became solid and therefore separation of concentrated juice from ice was not possible. Similarly, huge amount of sugar loss took place in ice [2]. An energy optimization model of conventional four pan jaggery units is presented and uniform bagasse firing, over non-uniform firing throughout the manufacturing batch time is suggested. Mathematical modelling and experimental analysis reported that, bagasse firing rate play crucial role in improvement of thermal performance of jaggery units [3]. Similarly few researchers conducted field survey of conventional jaggery units and concluded that the amount of airflow inside the furnace is very crucial in deciding efficiency thermal system, and suggested provision of dampers either at furnace air inlet or in flue gas passage in chimney [4]. Authors have proposed techno-economically sized solar thermal system for removal of water from juice thereby reducing total quantity of thermal energy required in jaggery making process. Similarly solar driers and solar air heaters are also suggested to preheat bagasse and input air supplied to pan-furnace system and claimed that use of solar energy techniques not only

makes these jaggery units energy independent but also helps in reducing green house gas (GHG) emission, offering economic, environmental and strategic advantages [5]. Hybridization of solar photovoltaic (SPV) and solar thermal system is reviewed as emerging technology in solar energy system which supply both electricity and process heat requirement. Author addressed decrease of Solar PV output power with rise in cell temperature and reported emerging solar photovoltaic-thermal (SPVT) hybrid system that collects heat from solar cells and delivers to other heating loads, thus improves overall performance of solar system[6].

Implementation of solar PV-DG hybrid system is suggested to meet the demand of electricity in remote rural areas; those are lacking conventional utility grid supply. Integration of solar PV with DG sets overcomes the problem of large fluctuation of PV output during bad weather condition. Performance of solar PV-DG hybrid system along with battery energy storage systems is studied under different loading conditions and concluded that integration of energy resources greatly helped in maintaining service reliability and improved power quality [7]. A hybrid solar PV-DG-Wind system is suggested for standalone microgrid system. Single voltage source converter (VSC) used in this topology has the capability to suppress power quality issues such as harmonic distortion, load unbalancing and voltage fluctuation. Simulation results of the proposed hybrid topology confirmed its environmental and economical suitability for rural and isolated areas [8]. Similarly, experimentations are carried on integration of solar PV-DG hybrid system without storage facility for standalone system. Using load daily load curve of given area, optimum sizing and scheduling of generators are performed that maximizes the generator efficiency [9]. Researchers have also proposed use of ultra capacitors along with BESS for exchange of power during load dynamics that ultimately reduces battery size and improves the overall efficiency of the system. Finally, authors conclude that, grid deployment of renewable energy resources with energy storage elements can drastically reduce power generation costs and flattens the generation curve of conventional bulk power generation. Thus, it reduces transmission and distribution losses, and assures service reliability to end users [10-11]. This research paper presents detailed research methodology like site engineering assessment and technical design in section 3. Performance assessment of proposed PV system using PVsyst software tool will be presented in section 4. followed by conclusion and acknowledgement in Section 5.

3. RESEARCH METHODOLOGY

A. Need of study:

Though jaggery making-an agriculture MSME sector, has tremendous capability of providing employment for rural people, is facing a severe problem of power shortage and power quality issues. Therefore, this sector fulfilling its energy need by DG sets which is causing life threatening carbon emission, noise pollution and global warming issues. Also dynamic diesel price is always rising, thereby increasing running cost of this manufacturing sector. Therefore, huge demand of combined heat and power makes a convincing case for study of energy optimization and use of renewable energy resources in jaggery manufacturing sector, making them more cost effective and environment friendly. The work presented in this article is carried in following manner.

B. Site Engineering Assessment:

Several jaggery units are surveyed and studied at different locations of Indian states Viz. Maharashtra, Karnataka and Gujarat but detailed study of only one unit that is claimed to be the most efficient and technically advanced among all is presented here. This modified energy efficient jaggery unit is located at Post-Maindargi, Dist-Solapur, MH, India. Latitude and longitude of selected site is 17.46° N, and 76.30° E respectively. Monthly meteonorm report of the site, showing values such as horizontal global irradiation, horizontal diffused irradiation, extraterrestrial irradiation, clearness Index, ambient temperature and wind velocity are shown in Fig.1 Sun Path diagram of the proposed site, which is mainly used for determination of sun at any time of the day, and year is shown in Fig.2.

Geographical Site **Maindargi** Country **India**

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Situation Latitude 17.46° N Longitude 76.30° E
Time defined as Legal Time Time zone UT+5.5 Altitude 446 m

Monthly Meteo Values Source Meteonorm 7.2 (1994-2013), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	148.7	157.1	190.2	196.0	204.0	158.2	138.9	142.5	148.3	159.8	139.6	142.7	1926.0	kWh/m².r
Hor. diffuse	48.5	54.4	69.1	78.2	79.6	88.1	85.9	90.9	74.1	63.5	58.2	48.1	838.5	kWh/m².r
Extraterrestrial	244.5	248.7	305.4	317.0	335.3	324.8	334.4	329.3	303.1	285.1	244.4	234.4	3506.5	kWh/m².r
Clearness Index	0.608	0.632	0.623	0.618	0.608	0.487	0.415	0.433	0.489	0.561	0.571	0.609	0.549	
Amb. temper.	24.5	27.3	30.5	32.7	32.8	28.5	27.7	26.8	26.5	27.0	25.3	23.9	27.8	°C
Wind velocity	0.8	0.8	0.8	1.0	1.3	1.3	1.2	1.1	0.8	0.6	0.7	0.6	0.9	m/s

Fig. 1. Monthly Meteo Values:: Maindargi,(MH) India

A study of meteonorm reports, indicate that proposed site receives average solar irradiation of 6-7 Kwh/m2/day with tremendous scope for electricity generation using Solar PV system for the entire year. Moreover, the operational period of jaggery units span between September-May during which plant absorbs more solar radiation and thus solar PV system will contribute more as compared to DG set.

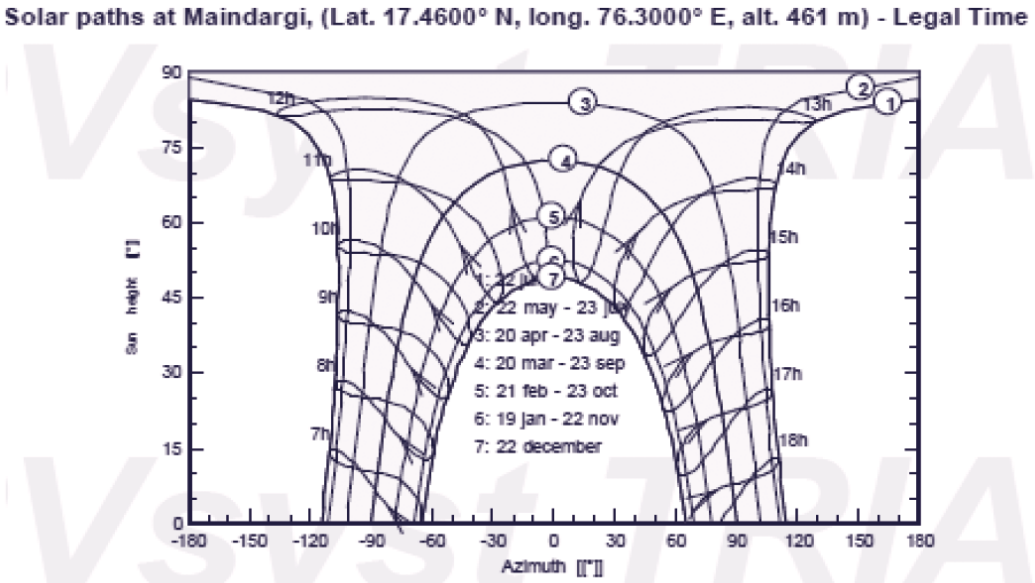

Fig. 2. Sun Path Diagram: Maindargi, (MH), India

C. Design of Solar PV-DG Hybrid System:

The schematic diagram of solar PV-DG hybrid system is shown in figure.3. The system consists of solar PV system with three phase solar inverter, DG set, PV-DG system controller, current sensors, three-phase electrical load and grid.

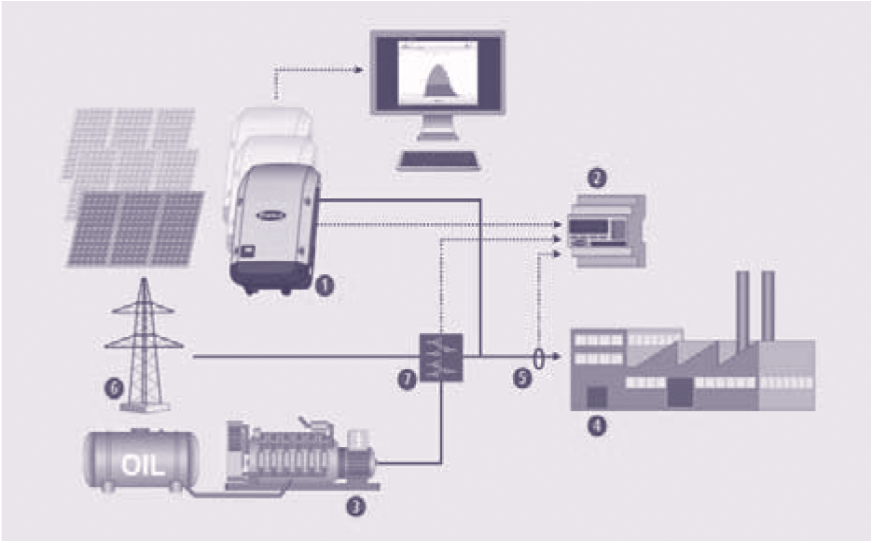

Fig. 3. Schematic Diagram of Solar PV-DG Hybrid System

The hybrid system is designed in such a way that, load power demand is satisfied at any given time. Detailed specifications of major elements of the proposed system are discussed as below:

- Solar Panels: There are mainly two types of PV panels with numerous variations within each type with respect to size, shape, and substance and cell materials. These are mono/poly-silicon crystalline and thin film. Both mono/poly-silicon crystalline panels have higher efficiency and produce more energy but heavier and costlier as compared to thin film panels. Silicon crystalline PV panels are responsive to long wave solar radiation, where as thin film modules are superior in making use of short and medium wave range of the solar spectrum. In general, silicon crystalline modules are suitable where space is at premium and thin-film modules are ideal for sites which experience cloudy weather, severe pollution, dirt and temporary/partial

shadings. Hence solar PV designer has to make judiciously select type of module depending on the site conditions and cost aspects. For the proposed site, ground mounted solar PV system of 10 KW with fixed tilt angle of 18°, equal to the latitude of the site are selected that harnesses maximum solar radiation throughout the year. The solar modules mounted at this site are of 330Wp rating and made up of polycrystalline technology. At standard test conditions (STC) of 1000 W/m2 irradiance, 25°C cell temperature, these panels give an efficiency of 17.52 %, with Open Circuit Voltage (Voc) of 46.3 V and Short Circuit Current (Isc) of 9.24 A. These modules have 72 polycrystalline cells/ panel and are suitable to work in wide temperature range of -40°C to + 85°C.

- Solar PV Inverter: The inverter converts the direct current from the solar modules into alternating current and provides the PV-Genset system with as much PV energy as possible. Smart solar inverter of "Fronious International" Symo 10.0-3-M model is used for this plant. These inverters have multi flow technology that loads can be supplied with solar energy and battery can be simultaneously charged during power outages. This enables long lasting back up power supply and high degree of self-sufficiency. Similarly, these inverters are featured with integrated data communication facility with WLAN, Ethernet, web server and wide range of interfaces. Moreover, these inverters are equipped with PLC based Solar PV-DG controller that control and monitor power generation of hybrid system in optimum manner.
- Diesel Generator: A three phase, 15 KVA, 1500 rpm, 50 Hz, 380-440V, water-cooled DG set of "Greaves Power" make DG is used as backup source of energy in the proposed Solar PV-DG hybrid system.
- Load Profile: The plant is divided into two sections; Milling Section, that includes cane cutter, cane carrier and bagasse carrier, and boiler section, which includes, juice pumps and juice filter motors. Total connected load of the plant is 8 KW (AC capacity). However, plant DC capacity is kept 25 % more than AC capacity to accommodate future expansion and losses in the system. Thus, solar PV system of 10 Kwp is designed for selected jaggery unit.

4. SIMULATION RESULTS

In this study, PVsyst V-6.70 is used to for detailed performance assessment of proposed solar PV-DG hybrid system. It predicts the daily input/outputs and performance indexes of solar PV system. PVsyst is simulation software highly useful for preliminary and detailed design of Solar PV plant. It can easily pre-size solar PV plant of any configuration like grid connected, Standalone, pumping system and dc grids as shown in fig.4. It is capable of importing meteo data from various sources like Meteonorm, NASA-SSE as well as personnel database. Moreover, software is highly useful use for computing numerous system parameters like system yields, energy injected into the grid, various performance indexes, solar fraction, performance ratio and system losses and energy flow at different stages of the system [12].

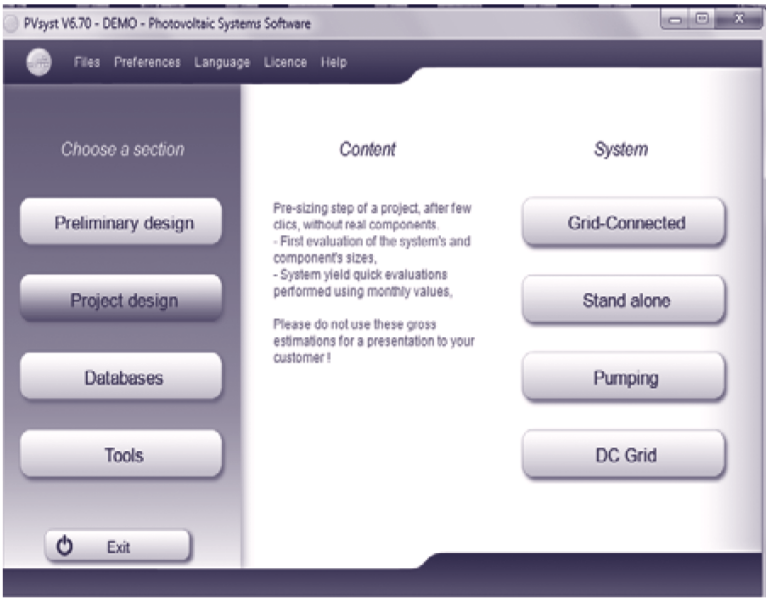

Fig. 4. Features of PVsyst

Various system parameters contributing to the performance of the PV plant are detailed as below:

A. *Daily Input-Outputs*

Daily Input-output diagram of the plant is shown in Fig.5. Daily Input-Output diagram shows variation of solar energy injected into the grid (Kwh/day) with respect to solar global incident over the year. Solar energy generated is directly proportional to solar global incident on PV modules. Each dot corresponds to the output of the array with respect to the global incident solar energy in collector plane on a particular day. The diagram shows that, the proposed PV system is capable of generating at least 50 KWh solar energy during maximum number of days in a year.

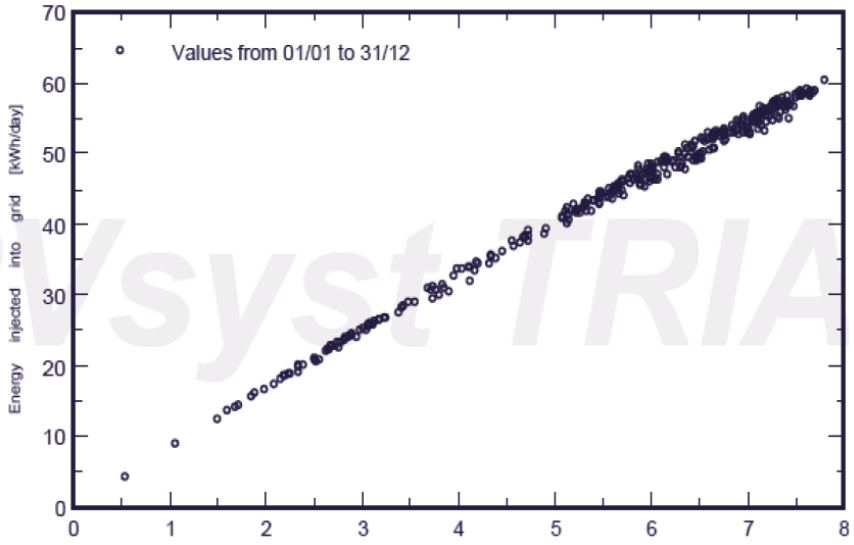

Fig. 5. Daily input/ out puts of the PV plant

B. ***Performance Indexes of the PV system:***

Various performance indexes of the PV plant are shown in Fig.6. They are described in detail as below:

- Collection loss (Lc): Collection loss or array capture loss includes thermal, wiring, module quality, mismatch IAM losses other losses due to inefficiencies. Collection loss of the plant is 0.88 Kwh/Kwp/day.
- System Losses (Ls): Losses in the inverter in grid tied system and losses due to batteries in standalone systems are termed as system losses. System losses of 0.15 Kwh/Kwp/day are found in proposed PV system
- Produced Useful Energy (Yf): It is the system useful AC output energy referred to the nominal power of PV array. Useful output energy of the system is 4.59 Kwh/Kwp/day.
- Performance ratio(PR): It is the ratio of final yield to reference yield. Thus, performance ratio is an indication of overall effect of losses on a PV array's normal power output. Average annual Performance ratio of the proposed system is 81.7%.

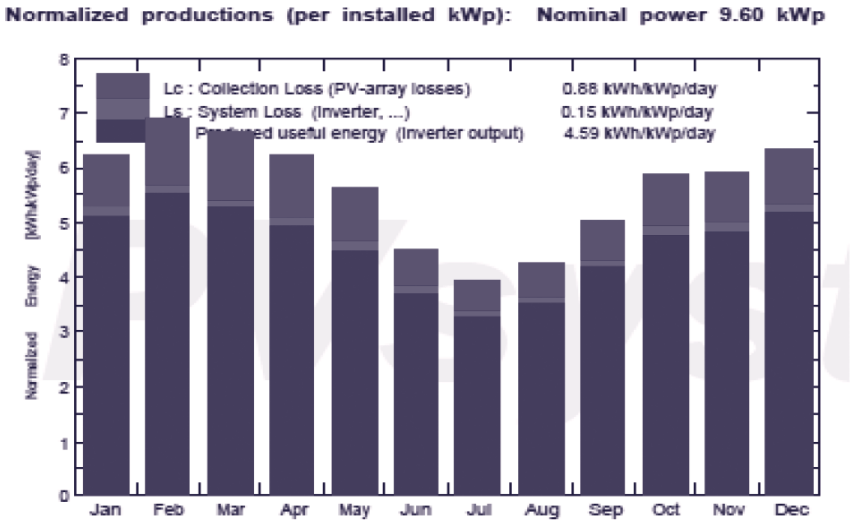

Fig. 6. Performance Indexes of the proposed PV plant

C. ***Loss and Energy flow diagram:***

Energy losses occur in PV system through various sources as shown in Fig.7. Solar energy available for the selected site is 1962 Kwh/m2. The actual energy available to the collector plane, considering incident angle modifier (IAM) factor and 18.26% PV conversion efficiency at STC is 19.35 MWh. Considering different losses such as irradiance losses, temperature losses, mismatch losses, module and string losses, and energy available at MPP is 16.60 MWh. After considering the inverter losses, energy available at the inverter output is 16.08 MWh that can be injected into the grid [13-15].

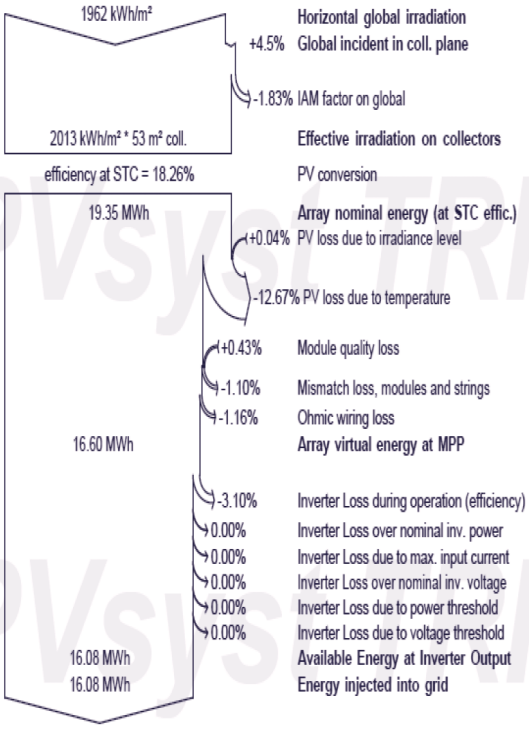

Fig. 7. Loss diagram of proposed PV system

D. *Green House Gas Balances of PV system*

Generation of electricity using solar PV system will save equal amount of electricity generated by fossil fuels like DG set. GHG emissions of DG sets are tremendously higher as compared to emission of equivalent solar PV systems. In this case, GHG emission of conventional jaggery unit run by DG set only(base case) would have been 14.8 tCO2, while of proposed case, is just 1.0 tCO2. Thus, GHG emission reduction of 13.8 tCO2 or 93% is achieved by implementing proposed system as shown in Fig.8.

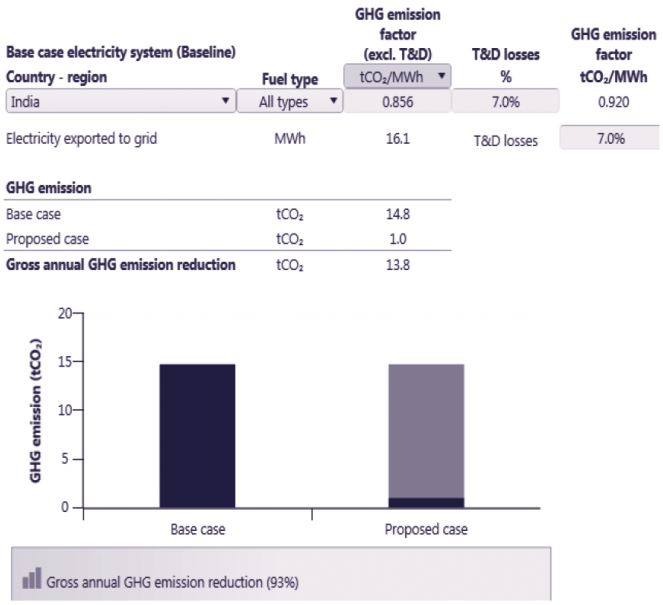

Fig. 8. GHG emission balances of proposed PV-DG Hybrid system

5. CONCLUSION AND FUTURE SCOPE

This research paper aimed at designing solar PV-DG hybrid system that minimizes the operational cost as well as greenhouse gas (GHG) emission and provides solution for intermittent nature of solar PV system and fluctuating load demand. In this paper hybrid system of solar PV plant of 10 Kwp and DG set of 15 KVA is techno-economically sized for jaggery making unit -Shiv-Samarth Agro-Tech Foundation, Maindargi, India, located in remote rural area. Further more energy modelling

of proposed system is performed using PVsyst simulation software. The following conclusions are drawn from the study.

- Annual electricity generated by the plant is 16.08 MWh. Its normalised production is 4.59KWh/Kwp/day.
- By proper design and optimum selection of tilt angle, plant achieved Performance ratio of 81.7%.
- Green house gas emission reduces from 14.8 tCO2 to 13.8 tCO2 or 93%.
- Further study could be done to develop tracking system for optimization and improvement of system efficiency.
- Hence it can be concluded that solar PV-DG hybrid technology can be economically and effectively used as an alternative source of energy to provide continual electricity to agriculture based MSME sectors those are generally lacking grid infrastructures.

ACKNOWLEDGEMENT

Authors would like to acknowledge the overwhelming support of Shiv-Samarth Agro-Tech Foundation-Farmer produce group, located at Maindargi, Dist-Solapur, (MH) India, for providing site access and detailed information about jaggery making process. We are also thankful to management authority of Bharati Vidyapeeth University Pune India for their support during research study.

7. REFERENCES

[1] MNRE GOI Report on "Pradhan Mantri Kisan Urja Suraksha evem Utthan Mahabhiyan" https://mnre.gov.in/img/documents/uploads/c01a8c19c786436ab33ed3e1136b935c.pdf

[2] M.Rane, D.Uphadea, "Energy Efficient Jaggery Making using Freeze Pre-Concentration of Sugarcane Juice", ELSVIER ,Energy Procedia, ICAER 2015, pp 15-17, December 2015

[3] V. Sardeshpande, D. Shendage, I. Pillai , "Thermal performance evaluation of a four pan jaggery processing furnace for improvement in energy utilization", ELSVIER, Energy 35 , pp 4740-4747, October 2010

[4] K.Shiralkar, S.Kancharla, N.shah, S.Mahajani, "Energy improvements in jaggery making process", ELSVIER, Energy for Sustainable Development, pp 35-48, December 2013

[5] L.Jakkamputi, M.Mandapati, "Improving the performance of jaggery making unit using solar energy", ELSVIER, Perspective in science, Vol 8, pp146-150 May 2016

[6] R.Kulkarni, S.chavan,D.Talange, "A Green House Electricity and Heat Generation:Solar PV/Thermal panel-Review" IEEE Transl, ICIC,pp680-682,May 2015

[7] J. Philip, C.Jain, K.Kant, B.Singh, S.Mishra, "Control and Implementation of a Standalone Solar Photovoltaic Hybrid System", Proc. of IEEE,Industrial Applications Society, Annual Meeting, Addison,TX,18-22 Oct-2015,pp.1-8

[8] K.Kant, C.Jain, B.Singh, "A Hybrid Diesel-Wind – PV based Energy Generation System with Brushless Generators" Proc. of IEEE,Industrial Informatics, 2016, pp.

[9] D. Yamegueu, Y. Azoumah, X. Py and N. Zongo, "Experimental study of electricity generation by Solar PV/diesel hybrid systems without battery storage for off-grid areas", Journal of Renewable Energy, vol. 36, no. 6, pp. 1780-1787, June 2011

[10] K.Kusakana,"Optimal Scheduled Power Flow for Distributed Photovoltaic/wind/diesel generators with battery storage system" Proc. of IET Renew. Power Generation,Vol.9, Iss.8, April 2015,pp.916-924.

[11] T.Adefarati, R.Bansal, J.Justo, "Techno-economic analysis of a PV–wind–battery–diesel standalone power system in a remote area", 6th International Conference on Renewable Power Generation, 19-20 Oct 2017, Iss.13,pp.740-744.

[12] Namita P. Deodhe, Deepak.Bankar, "Design of a grid connected PV system and effect on various parameters on energy generation", i-manager's Journal on power Systems Engineering, Vol.6,No-1, Feb-April 2018

[13] B. Shiva Kumar, K. Sudhakar "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India", ELSVIER, Energy Reports 1 (2015) , pp 185-192, December 2015

[14] KumariAshwini, Ashish Raj, Manoj Gupta, "Performance Assessment and Orientation Optimization of 100 kWp Grid Connected Solar PV System in Indian Scenario", IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2016)

[15] T.Hasarmani, R.Holmukhe,N.Ganer, "Techno-Economic Sizing of Renewable Energy Resources for Energy Improvements in Jaggery Making Process", IEEE International conference on data science and analytics (IEEE PuneCon-2018)(Conference proceedings)

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