Article

Techno-Economic Assessment of a Standalone Hybrid System Using Various Solar Tracking Systems for Kalpeni Island, India

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Abstract: Achieving electrification in an island considering less emission and levelized energy cost is a challenging goal on developing islands such as Kalpeni Island. This work exhibits the techno-economic assessment of a standalone hybrid system to generate power to Kalpeni Island, India through sensitivity and optimization analysis using HOMER software. Various system configurations like solar/DG, wind/DG, solar/wind/DG, and solar/wind are analyzed based on cost and electrical parameters. Based on the optimization results, the best hybrid system is chosen for Kalpeni Island considering different solar tracking methods. Then, multi-year and sensitivity analysis are performed to analyze the effect of load growth, rising diesel price, rising battery minimum SOC, rising PVS derating, rising photovoltaic cell temperature, and changing inverter and rectifier efficiency. The system operated with a solar photovoltaic system (PVS) and diesel generator (DG) with a tracking system on a vertical axis (TSVA) shows the best optimization result compared to other hybrid configurations with a low levelized energy cost (LEC) of 0.222 \$/kWh and net present cost (C_{NP}) of \$448,269 for the chosen location. The TSVA plays a vital role on power production in the system operated with solar and DG sources, which produces 9.77% more power compared to fixed system without tracking (FSWT). The total emission produced in the system operated with solar and diesel generator with TSVA is 88.2% less compared to an WT/DG configuration operated with FSWT.

Keywords: hybrid energy system; solar tracking system; levelized energy cost; total emission; net present cost; multi-year analysis; sensitivity analysis

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1. Introduction

The electrical demand increases in proportion to an increase in population, residence, new industries, and the establishment of various commercial outlets. The increased use of various electrical appliances in household such as geysers, air conditioners, computers, etc. are inclined to raise the daily energy demand. The two types of generating power are stand-alone and the system with grid-connection. According to recent data from the Ministry of New and Renewable Energy, India, the capacity installed of conventional sources such as coal is 53.4%, non-conventional sources are 36.2%, and other sources are 10.4% in India [1]. Andaman and Nicobar Islands and Lakshadweep Island are two primary islands of India. Kalpeni Island is a part of Lakshadweep Island, which is considered to be the focus of this study. Furthermore, for electricity generation, renewable energy is the finest option for reducing global carbon emissions. The solar and wind power will satisfy the load demand at a low cost [2]. To satisfy the different load demands on Kalpeni Island, the system with different energy sources based on various tracking systems are analyzed based on levelized energy cost (LEC), loss of generation probability (LGP), expected energy not served (ENS), and emission. Thus, the techno economic assessment is carried out using the HOMER software.

The growth of remote energy production technologies is a useful alternative energy generation from non-conventional sources [3]. The microgrid is in charge of supplying

power to the users that are considered. In most cases, a standalone microgrid is made up of non-conventional sources and diesel generators. Wind and solar power systems are frequently employed renewable sources in this difficult terrain. This is owing to the environmental impact while generating power. Emissions are produced by traditional sources such as power generation from fossil fuels. This polluted emission will have an impact on the people who live nearby as well as the overall environment. To combat the huge greenhouse effect, non-conventional sources have been implemented a lot over the last decade. In remote areas, instead of connecting the transmission line to the load, small microgrids are used [4]. The studies emphasize the benefits of microgrids. They all suggest that microgrids are dependable and effective [5–10]. The load demand is predicted to rise by 30% by the year 2030 while comparing the 2012 load level, owing primarily to population and economic expansion [11]. In this study, different analyses are conducted on Kalpeni Island in order to transform the scenario to a green environment at a cheap cost, less emission, and a higher reliability factor. The combination of numerous clean energy technologies can improve system performance without requiring the integration of a backup power system [12]. In practice, the location of solar systems installation should take advantage of a variety of circumstances that will have an impact on the system [13]. The sun's light and heat are a preferable type of renewable, pure, and unlimited energy. In addition, it is generally believed to be the preferable source of energy [14]. A standalone solar-wind with a battery becomes an interrupted system with complicated evolution and several restrictions [15]. The non-conventional sources are becoming increasingly popular in urban and rural areas [16]. The hybrid system consisting of wind and solar will not match with hourly or timely load demand [17]. For a residential load demand, methodology was developed [18]. It is simple to control the DC microgrid. The intermittent nature of renewable sources can be avoided when some microgrids are available in operation [19]. The main disadvantage of a standalone system that uses solar and wind energy is power variance, which results in discontinuous power delivery and causes problems if a stable and consistent supply is required. As a result, standalone hybrid systems with diesel generator could be used to solve such issues [20].

The renewable energy source is the best solution to reduce emission when a system is operated with renewable and diesel generators in islands. The total number of households on Kalpeni Island is 934 [21]. In this study, estimated load consumption data for 25 households, 3 grocery shops and 12 LED street lights on Kalpeni Island are considered to investigate the performance of a hybrid non-conventional system with a diesel generator. This study focuses mainly on solar/wind/DG sources with different tracking systems. The comparative analysis for the system operating with different tracking systems are conducted to understand the use of solar trackers. The hybrid energy system with solar tracking techniques for Kalpeni Island are not investigated in previous research. The novelty of this work helps the researcher to identify the operation of different sources consisting of solar trackers with less cost on an island. The tracking systems helps to operate solar panels in an effective manner with more power production when compared to traditional solar panels. The reliability indices like expected energy not served (ENS) and loss of generation probability (LGP) are the main challenges of a hybrid system operating on an island. When the ENS/LGP is high, the system will not be able to supply sufficient power to Kalpeni Island. This problem can be solved by incorporating feasible sources operating in a suitable time period with low cost and less emission. The system is simulated using HOMER software since it is one of the best optimization tools in the decade. The HOMER is the most widely used software package among several since it does optimization and sensitivity analysis more efficiently in analyzing the different configurations of the system [22]. The rest of the article is organized as follows: Section 2 shows the detailed survey of hybrid non-conventional sources based on reliability, emission, cost factors, and a survey on comparative study of various tracking systems. In Section 3, the description of the proposed site, detailed load profile, environmental data of the chosen site, specification and modelling of various configurations in hybrid systems are discussed.

The optimization results of different hybrid configurations with various solar trackers and the best system based on a solar tracking technique are analyzed in Section 4. Moreover, multi-year and sensitivity analysis of various parameters was also performed in this section. The conclusions are given in Section 5.

2. Literature Review

2.1. Survey of the Hybrid Renewable Energy System

In recent days, a hybrid system using a solar photovoltaic system (PVS) and a wind energy system has been evolving for standalone applications. Several studies on microgrid systems operating in standalone mode to build a green environment are performed. When using solar or wind power, the battery plays a vital role in the microgrid system. When there is a poor environmental condition and the battery state of charge is less than the minimal value, the diesel generator can be employed as a backup source. Because solar and wind systems work completely randomly in nature, the microgrid must operate in such a way that the load demand should satisfy for each instant of time. Tribioli and Cozzolino [23] investigated, for an isolated system, a photovoltaic microgrid with different storage techniques was constructed and the performance of a power management plan was tested using HOMER Energy software. Cetinbas et al. [24] concluded that, for the given load pattern, a PV power supply of 2.500 MW, two batteries of 110 kWh capacity, and a diesel power generator of 2.100 MW were found to be the best solution. The suggested study investigated the impact of PV module degradation, rising demands, system disruptions and rising diesel fuel prices. Garg et al. [25] examined the solar output variation, operation of diesel generator and battery output for different cases in the combined energy system. Akinyele et al. [26] presented a proposed microgrid system with a diesel generator which can offer full energy for households in the selected sites, according to the results. Al-Ammar et al. [27] reveal that a hybrid source with wind/PVS is the suitable option for the particular location of the study, and the effective system component sizing is also evaluated with \$ 28.620K net present cost (C_{NP}) and 0.311 \$/kWh levelized energy cost (LEC), resulting in a cost reduction more than 80% and a 100% reduction in harmful pollutants while meeting 100% power requirements with 67.3 percent surplus power. Vera et al. [28] study the detailed literature on an energy management microgrid system with battery storage. The correct direction in suitable modelling for batteries was also included in the literature. Chambon et al. [29] presented PVS-biomass or PVS-diesel hybrid systems which provided the maximum reliability and the lowest cost for standalone electricity. Solar photovoltaic systems were determined to offer the least levelized energy cost (LEC) of 0.20 \$/kWh among standalone choices for a 4% annual capacity deficit. The reliability is an important parameter in calculating the microgrid system performance. Many works of literature were conducted for assessing the reliability in a microgrid energy system [30–33]. Priyadharshini et al. [34] worked on the objective to satisfy the consumers by generating continuous power using solar and wind systems at minimum cost. Ali et al. [35] investigated the simulation which demonstrates that the hybrid micro may reduce a carbon footprint by over 90% when compared to the traditional system, according to the techno-economic framework. Ahmad et al. [36] developed the algorithm for feasible operation of the proposed system. The objective of the work is to run a microgrid system with optimal configuration. A proper microgrid design requires a thorough analysis of the electricity system. Lee et al. [37] suggested a method that yields an optimal microgrid configuration that meets the design goal in terms of financial efficiency and power system performance restrictions. Alturki et al. [38] suggested a hybrid photovoltaic/biomass/wind/pump-hydro system would be perfect for a tiny village, local hospital, education, and industrial sites. The suggested system's economic viability and sustainable development are also in accordance with the international energy market. Hinokuma et al. [39] conducted a sensitive analysis to determine the effectiveness of the suggested system using 2030 costs for non-conventional energy technologies. The study indicates that lowering the commercial cost of solar panels, which is the major unit in the

microgrid system, is critical for lowering the cost of electricity. Riou et al. [40] suggested that boosting reliability of the microgrid at the preliminary level can be done for the less amount of money. Fathy et al. [41] conducted an analysis of a hybrid renewable system with a diesel generator for determining reliability indices like loss of generation probability (LGP) index. Yu et al. [42] summarized about reduction of carbon emission in a year, load profile alignment by considering cost parameter, and performance of battery storage optimum operation. To assess the standalone system cost, various literature works have been reviewed [43–47]. Rashid et al. [48] investigated different configurations in microgrid system design using HOMER. The levelized cost are compared for different scenarios. Table 1 shows the survey of a hybrid system using HOMER. The different sources like photovoltaic system (PVS), wind turbine (WT), fuel cell (FC), diesel generator (DG), hydro and tidal operated to analyze the reliability and cost of energy. The battery operated in the system when the system operated with renewable sources.

Table 1. Survey of the hybrid system using HOMER.

Operating Mode	System Considered	Parameter	Details	Ref.
Stand-alone	PVS/WT/FC/DG	LEC	The objective of this study is to create a stand-alone microgrid with implementation in rural island and rural electricity.	[49]
Stand-alone	PVS/DG, PVS alone, PVS/WT, DG alone	LEC	The survey shows that the PVS/diesel/battery can provide adequate energy to the island of Ethiopia throughout the duration of the work.	[50]
Grid connected	WT/FC	Emission, C_{NP}	The system's total income and return are calculated and examined for saving energy, decarbonization, and green infrastructure.	[51]
Stand-alone	PVS/WT/DG	LPSP, LEC	The result determined based on reliability, cost, technical feasibility, and ecological responsibility are all important factors to consider	[52]
Stand-alone	PVS/FC	LEC, C_{NP}	The result shows that the system operate without emission and the reliability index like loss of generation probability (LGP) is 0.05% and levelized energy cost (LEC) is 0.22 \$/kWh	[53]
Stand-alone	WT/DG/SPV, WT/PVS/DG, WT/PVS	LEC, C_{NP}	The system operated with 0% excess power flow and the levelized energy cost as 0.24 euro in the island	[54]
Stand-alone	DG, PVS/WT, PVS/WT/FC	LEC, LPSP	The cost and reliability factor for the different system configuration are analysed and compared	[55]
Grid-connected	WT/tidal, WT/tidal/DG	LEC, C_{NP} , emission	The wind turbine is operated 90% annual for the site considered	[56]
Grid-connected	PVS/Hydro	LEC, emission	The system operated with low cost and emission and higher degree of renewables	[57]
Stand-alone	PVS/WT/DG, PVS/DG, WT/DG, PVS/WT, PVS alone, WT alone	LEC, emission, C_{NP}	The levelized energy cost analysed according to the different level of renewable %. The system with PVS/wind/DG has less emission compared to the system only operated with diesel generator	[58]
Stand-alone	PVS/WT/DG	LEC, emission, C_{NP}	The sensitivity analysis is performed for variation in temperature to know about the effect of levelized energy cost (LEC) and net present cost (C_{NP})	[59]

Iqbal et al. [60] designed a microgrid based on institutional level and determined the best solution for the site considered. The capacity of storage element changes the levelized energy cost and net present cost. Sadat et al. [61] proposed a new strategy for the price in Iran while designing a microgrid system using HOMER. Rousis et al. [62] presented a sensitivity analysis for different values of diesel prices in the hybrid microgrid system. Then, a sensitivity analysis was performed for different solar radiation using HOMER. Olatomiwa et al. [63] performed a sensitivity analysis for different wind speed and diesel price in the microgrid system. Sanwar et al. [64] investigated the electricity

generation in Bangladesh for a standalone system using HOMER software. Different hybrid system configurations are examined for capacity cost, levelized energy cost, net present cost and production of wind power. Xia et al. [65] performed a sensitivity assessment for the influence of 10% variations in speed of wind, radiation from the sun, temperature and flow rate on yearly electricity output, unmet load demand, levelized energy cost (LEC) and net present cost (C_{NP}). A remote community consists of fifteen families has been chosen as the relevant example. Rezaei et al. [66] examined the uncertainty analysis for cost. The result of uncertainty operation shows that there is a variation in discount price. Sanjay et al. [67] proposed a microgrid system with less energy cost for agricultural application. Shahzad et al. [68] conducted a study on a microgrid using HOMER for cost reduction. To reflect the simulation result, the surface plot for levelized energy cost plotted with net present cost. Aziz et al. [69] investigated the results for a renewable system based on different dispatch strategies like combined, load following, and cycle charging strategy. The result shows that levelized energy cost is 0.21 \$/kWh for combined strategy, which is less compared to the other two dispatch strategies. Beitelmal et al. [70] analyzed four different hybrid microgrid configurations for the proposed and existing case study for power supply. The result shows that the levelized energy cost and net present cost is less in photovoltaic battery energy sources while comparing the other three hybrid configurations. Chauhan et al. [71] examined the optimization model for the microgrid system with different reliability and cost constraints. The levelized energy cost is less in 0.225\$/kWh in the configuration like three diesel generators, one photovoltaic system and one battery. Yadav et al. [72] discusses about transfer of power to the load in various environmental conditions. Thirunavukkarasu et al. [73] evaluated three different parameters in a microgrid system. The three parameters are reliability, levelized energy cost and emission. The objective is to achieve 0% unmet load with less levelized energy cost (LEC). It was found that the levelized energy cost for photovoltaic system (PVS) with a diesel generator (DG) is 0.319 \$/kWh.

2.2. Survey of Various PV Tracking Systems

The different tracking systems like fixed system without tracking (FSWT), tracking system on a horizontal axis (TSHA), tracking system on a vertical axis (TSVA) and tracking system on a dual axis (TSDA) are studied in various works of literature to understand the performance of various solar trackers in the system as shown in Table 2. Ruelas et al. [74] proposed a methodology for tracking PVS based on different points of tracking. Comparing the traditional tracking system, the proposed tracking method collected 24% more energy. González-Peña et al. [75] evaluated the prediction of PVS power production using different software tools. When there is a big storm, the PVS trackers' increased error rate, and a safe location decreased the quantity of electricity generated. Seme et al. [76] reviewed the various tracking systems used in PVS. A multi axis and tracking system with one axis collected 22% to 56% more energy compared to the ideal tracking system. Kuttybay et al. [77] proposed a new tracking system with the efficiency of 57.4 % compared to the existing tracking methods. The one axis tracking system is the better way to generate power using PVS when the PVS operated with less capacity [78–81]. Babatunde et al. [82] compared different tracking system with and without coefficient of temperature. Sá Campos et al. [83] proposed a model of rotation of a tracking system on a single axis. As a consequence, the efficiency in comparison to tracking continuously was validated, exposing a loss of roughly 0.73 % in the position seven approach, which could not be verified easily in the presence of errors, particularly on a cloudy weather day when such a gap can be lower.

Table 2. Review of various Tracking systems (TS) used in PVS.

TS	Details	Ref.
TSDA	Investigated the planning of solar tracker cost of investment and compared the TSDA with FSWT. The result shows that the tracking system on dual axis (TSDA) collected 35.6% and 44.7% more energy during the 1st and 2nd year compared to a fixed system without tracking (FSWT).	[84]
TSDA	Implemented a simple model of multi axis tracking PVS. The proposed model of two axis PVS collected 36.2% more energy than the traditional fixed tracking model of PVS.	[85]
TSDA	Reviewed the tracking system on dual axis and determine the efficiency which is ranging from 35% to 43%.	[86]
Single axis TS	Presented the results of power generation evaluations of bifacial PVS with fixed angle and tracking system on a horizontal axis (TSHA) in contrast to their mono facial equivalents. Furthermore, the projected information is compared to the existing results.	[87]
TSVA, TSHA, TSDA	The result shows that tracking system on a vertical axis (TSVA) produces less emission while compared with a two axis tracking system	[88]
Single axis TS	Various orientations of a single axis tracking system are studied for each day	[89]
Single axis and TSDA	The result shows that 27 to 30% and 30 to 34% more power produced using single and dual axis tracking systems respectively when compared to FSWT	[90]
Single axis and TSDA	The result shows that in a single and tracking system on dual axis (TSDA), the efficiency of tracking are 99.1 and 89.2%	[91]
TSDA	In the proposed method of tracking sun position, the result shows that 28% to 43% energy from solar captured	[92]
TSVA, TSHA, TSDA	The result shows that 28.8% extra power is generated from the photovoltaic system compared to an ideal tracking system	[93]
Single axis and TSDA	The efficiency analysis comparison of single and two axis tracking system are obtained in the result	[94]

Pelaez et al. [95] investigated a model of a tracking system with one axis in the bifacial mode of solar panels. The energy increases by 4–15% in this mode of operation. The tracker is analyzed for different conditions of clouds. Rodriguez-Gallegos et al. [96] examined the two different algorithms, namely sun tracking and best inclination tracking. The result concluded that best inclination tracking has good results compared to the sun tracking algorithm. Saeedi et al. [97] presented the advantage of using a tracking system on a dual axis (TSDA) compared to traditional tracking systems based on solar photovoltaic power output. Zaghba et al. [98] demonstrated the system efficiency for two axis and inclined fixed systems without tracking (FSWT). The performance result shows that the tracking system on a dual axis collects more power compared to the inclined fixed system without tracking.

3. Methodology

A thorough assessment of any non-conventional project requires the use of relevant factors in the chosen location to guarantee that the actual performance of various situations can be effectively examined.

3.1. Site Description

Kalpeni Island is located 287 km west from the city of Kochi, India in the Arabian sea as shown in Figure 1. This island is one among the islands of Lakshadweep. The geographical location of this island is 10°4.0' N, 73°38.7' E. As per the data of the last census, 4419 people are living in this island.

Figure 1. Location of Kalpeni Island, India (satellite view).

3.2. Load Profile

The estimated average daily load consumption for 1 household and electric load-2 throughout a year are shown in Table 3. The electric load-2 consists of 1 commercial load (1 grocery shop) and 12 LED street lights. Consider the Kalpeni Island as consisting of 25 households, 3 grocery shops and 12 LED street lights for this study and the required data for this are developed from Table 3.

Table 3. Average daily consumption for domestic load and electric load-2 during summer and winter seasons of Kalpeni Island.

Domestic Load (1 Household)						Electric Load-2 (12 Street Light and 1 Grocery Shop)					
Type of Load	PL _D (W)	Summer		Winter		Type of Load	PL _D (W)	Summer		Winter	
		Hrs	Wh	Hrs	Wh			Hrs	Wh	Hrs	Wh
Ceiling fan (3 Nos)	60 W (each)	12, 4, 4	1200	12, 4, 4	1200	LED street light (12 Nos)	100W (each)	12 * 13	15,600	12 * 13.5	16,200
Air conditioner	1510	5	7550	0.1	151	Refrigerator-1	550	24	13,200	24	13,200
Laptop	60	1	60	1	60	Refrigerator-2	290	24	6960	24	6960
LED TV	40	7	280	7	280	Ceiling fan (2 Nos)	60W (each)	15, 15	1800	15, 15	1800
Water geyser	2000	0.3	600	0.6	1200	LED tube light (5 Nos)	20W (each)	4, 4, 0, 0	160	5, 5, 1, 1	240
Grinder	150	0.5	75	0.5	75	Domestic load (1 household)					
Washing machine	500	0.5	250	0.5	250	Iron box	1000	0.1	100	0.1	100
Electric motor	1511	0.5	755.5	0.5	755.5	Refrigerator	250	24	6000	24	6000
Mobile charging (3 Nos)	5 W (each)	1, 1, 1	15	1,1,1	15						
LED tube light (5 Nos)	20 W (each)	5, 2, 1, 0.1, 0.1	164	6, 2.5, 2, 0.1, 0.1	214						
LED bulb (3 Nos)	9 W (each)	0.1, 4, 0.1	37.8	0.1, 5, 0.1	46.8						

Each street consists of a minimum of 8 households, 1 grocery shop and 4 street lights. Six months (March–August) and the next six months (September–February) are considered as summer and winter seasons, respectively. These load data are imported into the HOMER software. In HOMER software, the random variability values are given to achieve the reality of the load profile. For domestic load, random variability for time step is considered as 15% and day to day as 10%. Similarly, for electric load-2, load time step is considered as 20% and day to day as 5%. From Table 3, the hourly data for 24 h are given based on the following details. During the summer season, the air conditioner is used from 12:00 a.m. to 3:00 a.m. The refrigerator is operating for the whole 24 h. Thus, from 12:00 a.m. to 3:00 a.m., load increases since both the air conditioner and refrigerator are switched on. It decreases after 3:00 a.m. once the air conditioner is auto-switched off. On an average day, the ceiling

fan is considered to be operational for at least 20 h. At 7.00 a.m., most households use a water geyser which consumes 2000 W power, an iron box for 6 mts which consumes 1000 watts and 1.5 HP electric motor for pumping water to the tank. From 8.00 a.m. to 6.00 p.m., children will be off to schools and colleges and adults will be off to work. Within this time, LED Television, washing machine and grinder will be used by people at home. From 6.00 p.m. to 9.00 p.m., laptop and mobile charging, LED tube lights and bulbs are used. From 10.00 p.m. to 12.00 a.m., the air-conditioner was switched ON. Now, during the winter season, the use of an air conditioner decreases significantly while the use of a water geyser increases significantly at 7.00 a.m. In electric load-2, the street lights are operated from 6.00 p.m. to 6.00 a.m. with the extension of 30 mins during winter. In three grocery shops, the refrigerators are operational for 24 h, the ceiling fans are operating from 7.00 a.m. to 10.00 p.m. and the LED tube lights are operating from 6.00 p.m. to 10.00 p.m. Thus, there is a constant load demand most of the time in electric load-2.

Figure 2 shows the monthly mean scaled load profile for January to December. Figure 2 shows the monthly mean scaled load consumption of 25 households, 3 grocery shops and 12 LED street lights. The maximum load, minimum load, daily average maximum, daily average minimum and mean load are shown for each month of a year. The maximum load is 74.81 kW during the month of June and the minimum load is 55.06 kW during the month of October. Since June is summer for Kalpeni Island, there is maximum load demand in this month due to usage of additional appliances by each household, but October is winter, and there is a minimum load demand due to non-usage of different appliances, in particular, the air conditioners. The daily average maximum load, daily average minimum load, and average load vary every month in a year as shown in Figure 2. The scaled average energy consumption, average load and peak load for domestic load is 346.43 kWh/day, 14.43 kW, and 68.99 kW, respectively, and, for electric load-2, it is 80.87 kWh/day, 3.37 kW and 7.44 kW, respectively.

Figure 2. Monthly average scaled load profile for January–December.

3.3. Solar Radiation and Speed of Wind

The longitude, latitude data of Kalpeni Island is given to HOMER software for downloading the average speed of wind and solar radiation resource. The monthly average speed of wind and solar radiation data in a year are graphically represented in Figure 3a,b. The annual average wind speed and solar radiation for the selected site are 5.38 m/s and 5.68 kWh/m²/day, respectively. The average solar radiation is higher during the month of March at 6.920 kWh/m²/day and lower during June at 4.680 kWh/m²/day as shown in Figure 3a. The sky is clear during November–May when compared with June–October. The average speed of wind is higher during the month of June at 8.930 m/s and lower during the month of February at 3.480 m/s as graphically represented in Figure 3b.

Figure 3. (a) Average solar radiation; (b) average speed of wind.

3.4. Hybrid System Block Diagram for Different Configurations

The schematic diagram of the hybrid system in various configurations such as PVS/DG, WT/DG, PVS/WT and PVS/WT/DG are given in Figure 4. To evaluate the result accurately, the system is studied under various configurations. This system is developed to satisfy the load demand of Kalpeni Island.

Figure 4. Schematic diagram of hybrid system (a) PVS/DG; (b) WT/DG; (c) PVS/WT; (d) PVS/WT/DG.

The domestic load refers to the households and the electric load-2 refers to the grocery shops and street lights. The diesel generator (DG) and wind turbine (WT) are linked to the AC bus and solar photovoltaic system (PVS) and Lithium ion (LI) battery are linked to the DC bus for supplying power to Kalpeni Island. When there are excess power flows from PVS and WT, the battery gets charged. The battery is discharged when there is insufficient solar radiation and wind speed for a time 't' to satisfy AC load demand through the inverter. For each configuration, the lithium-ion battery is included to overcome the power shortage due to environmental conditions. The diesel generator is also used for supplying power to

the island as a backup source when the output of renewable energies is insufficient to fulfill the AC load demand. The converter is used either as an inverter or a rectifier between AC and DC bus. The converter converts Direct Current (DC) to alternating current (AC) during inverter operation and from alternating current (AC) to direct current (DC) during rectifier operation.

Table 4 shows the specification of solar PVS, wind turbine, diesel generator (DG), converter, battery and other parameter inputs given to HOMER software. The replacement cost, capital cost, operation and maintenance (O&M) cost for each component in the hybrid system are given in Table 4. Based on the inputs given to HOMER software, the optimization results obtained with the best optimum value based on less levelized energy cost (LEC).

Table 4. Specification of the hybrid system.

Components	Description	Specification	Components	Description	Specification
Solar PVS [69]	Capacity	1 kW	Converter [23]	Capacity	1 kW
	Capital cost	640 \$/kW		Efficiency	96%
	Replacement cost	640 \$/kW		Capital cost	300 \$/kW
	O&M cost	10 \$/year			
	Lifetime	25 years			
Wind turbine [65]	Capacity	1 kW	Converter [23]	Replacement cost	300 \$/kW
	Hub height	16 m		O&M cost	0 \$/year
	Capital cost	2000 \$/kW		Lifetime	15 years
	Replacement cost	1200 \$/kW			
	O&M cost	100 \$/year			
	Lifetime	20 years			
Li-Ion battery [99]	Nominal voltage	6V	Diesel generator (Autosize) [69]	Minimum load ratio	25%
	Nominal capacity	1 kWh/ 167 Ah		Fuel price	1 \$/liter
	Roundtrip efficiency	90%		Capital cost	220 \$/kW
	SOC _{min}	20%		Replacement cost	200 \$/kW
	SOC _{max}	100%		O&M cost	0.020 \$/operating hrs
	Capital cost	140 \$		Lifetime	15,000 h
	Replacement cost	140 \$	Other inputs [23]	Lifetime of project	25
	O&M cost	10 \$/year		Inflation rate	2%
	Lifetime	8 years		Nominal discount rate (%)	8%

3.5. Mathematical Model of Each Component

3.5.1. Modelling of Solar PVS

Photovoltaic system (PVS) output 'P_{PVS}' is critical for modelling solar array into renewable energy generating systems, and it must be estimated.

The output power of solar PVS is evaluated using Equation (1) [57]:

$$P_{PVS} = \left(\frac{S}{S_s} \right) D_F P_R \quad (1)$$

Based on temperature effect, the output power of solar PVS is evaluated using Equation (2) [42]:

$$P_{PVS} = \left(\frac{S}{S_s} \right) D_F P_R [S_C (T_{PVC} - T_{SPVC}) + 1] \quad (2)$$

where S is the radiation from the sun that falls on the ground in kW/m^2 , S_s is the standard radiation in kW/m^2 , D_F is known as derating factor, P_R is the rated PVS capacity in kW, S_C is termed as a coefficient of solar power in $\%/^\circ\text{C}$, T_{PVC} is the PVS temperature of cell in $^\circ\text{C}$ and T_{SPVC} is the standard photovoltaic cell temperature. The derating of solar is 80% and standard radiation ' S_s ' is 1 kW/m^2 . The temperature effect on power is $-0.500\%/^\circ\text{C}$, standard test condition efficiency is 13%.

The photovoltaic cell temperature ' T_{PVC} ' is evaluated from Equation (3):

$$T_{PVC} = S \left(\frac{t_a}{H_c} \right) \left(1 - \frac{\eta_{PVC}}{t_a} \right) + T_a \quad (3)$$

where t_a is the transmittance absorbance, $\frac{t_a}{H_c}$ is evaluated from the producer data, η_{PVC} is the photovoltaic cell efficiency in % and T_a is the temperature on atmosphere in $^\circ\text{C}$.

The ratio $\frac{t_a}{H_c}$ is assumed to be constant, and it can be evaluated using Equation (4):

$$\frac{t_a}{H_c} = \frac{T_{NC} - T_{aNC}}{S_{NCT}} \quad (4)$$

where T_{NC} is the nominal cell temperature in $^\circ\text{C}$, T_{aNC} is the ambient temperature with nominal temperature of cell in $^\circ\text{C}$, and S_{NCT} is the solar radiation with nominal temperature of the cell in kW/m^2 .

To evaluate the photovoltaic cell temperature ' T_{PVC} ' with the ratio $\frac{t_a}{H_c}$, then substitute Equation (4) in Equation (3):

$$T_{PVC} = S \left(\frac{T_{NC} - T_{aNC}}{S_{NCT}} \right) \left(1 - \frac{\eta_{PVC}}{t_a} \right) + T_a \quad (5)$$

The efficiency of the photovoltaic cell depends on photovoltaic cell temperature. Equation (6) below is the modified equation from Equation (5) by considering the efficiency of maximum power under operating standard conditions:

$$T_{PVC} = (T_{NC} - T_{aNC}) \left(\frac{S}{S_{NCT}} \right) \left(1 - \frac{\eta_{pvm,STC}[1 + \alpha(T_{PVC} - T_{PVC,STC})]}{t_a} \right) + T_a \quad (6)$$

where α is the temperature power coefficient.

In most cases, the value of α is negative, which implies the photovoltaic cell efficiency ' η_{PVC} ', is inversely proportional to the photovoltaic cell temperature ' T_{PVC} '. Then, the photovoltaic cell temperature ' T_{PVC} ' represents on the basis of Equation (7):

$$T_{PVC} = \frac{(T_{NC} - T_{aNC}) \left(\frac{S}{S_{NCT}} \right) \left(1 - \frac{\eta_{pvm,STC}(1 - \alpha T_{PVC,STC})}{t_a} \right) + T_a}{(T_{NC} - T_{aNC}) \left(\frac{S}{S_{NCT}} \right) \left(\frac{\alpha \eta_{pvm,STC}}{t_a} \right) + 1} \quad (7)$$

3.5.2. Modelling of Wind Turbine System

Wind turbines (WT) are erected to catch the kinetic energy of air flow and then use a rotor with n number of blades attached to a generator to convert mechanical energy supplied in wind into electrical energy. Since the speed of winds change with height, estimating wind speed at the height of the hub is critical. The hub height wind speed of wind turbine ' W_{hub} ' is estimated using the following Equation (8) [66]:

$$W_{hub} = \frac{\ln(WT_{hub}/L_S)}{\ln(WT_{ane}/L_S)} \cdot W_{ane} \quad (8)$$

where WT_{hub} is the WT hub height in meters, WT_{ane} is the anemometer height in meters, L_S is the roughness surface length, and W_{ane} is the speed of wind at the anemometer height in m/s.

The area swept is the area which the rotation of wind turbine blades covers. The wind speed 'w' is also an important parameter in estimating the power output of the WT. The cut-in speed of wind, rated speed of wind and cut-out speed of wind are 4 m/s, 14 m/s, and 24 m/s, respectively. The power output of wind turbine (WT) 'P_{WT}' is evaluated based on Equation (9) [42]:

$$P_{WT} = \left(\frac{w^3 \rho_a A_c C_w}{2} \right) * 10^{-3} \quad (9)$$

where w is the speed of wind in m/s, ρ_a is the density of air ($0.01225 * 10^{-2}$ kg/m³), A_c is the area swept of WT in m² and C_w is the wind turbine power coefficient.

3.5.3. Modelling of Battery

The required number of batteries is evaluated from Equation (10) [52]:

$$N_{bat} = \frac{n_{ad} * P_d}{C_{nb} * \eta_b * DOD} \quad (10)$$

where n_{ad} is the autonomy days by battery, P_d is the daily average consumption of power in kW, C_{nb} is the battery nominal capacity, η_b is the battery roundtrip efficiency in % and DOD is the depth of discharge.

The product of nominal voltage and storage element in each string is known as bus voltage. The storage element in series is termed as string. The total string count is evaluated based on suitable battery count, battery voltage rating and DC bus voltage. The total string count is inversely proportional to the DC bus voltage. Then, this total string count 'N_{str}' is determined by Equation (11):

$$N_{str} = \frac{N_{bat} * V_{bat}}{V_{DCV}} \quad (11)$$

where V_{bat} is the battery voltage rating and V_{DCV} is the voltage on DC bus.

The battery state of charge (SOC) under charging condition is evaluated by Equation (12):

$$SOC(t) = SOC(t-1) + ((P_{PVS}(t) + P_{WT}(t)) - (E_{res}(t) + E_{el2}(t))) dt \eta_{cb} / C_b \quad (12)$$

where SOC (t - 1) is the battery SOC in a previous time period, $P_{PVS}(t)$ is the power output of PVS for a time 't', P_{WT} is the power output of WT, $E_{res}(t)$ is the residential load for time 't' in a year, $E_{el2}(t)$ is the commercial and street light load for time 't' in a year, and C_b is the battery capacity.

The battery charging and discharging efficiency η_{cb} and η_{db} , respectively, are evaluated based on the square root of round trip efficiency.

The battery state of charge (SOC) under a discharging condition is evaluated by Equation (13):

$$SOC(t) = SOC(t-1) - ((E_{res}(t) + E_{el2}(t)) - (P_{PVS}(t) + P_{WT}(t))) dt / \eta_{db} C_b \quad (13)$$

The constraints considered during the optimization process to obtain the result with a certain limit. For SOC, the constraints followed are given in Equation (14):

$$SOC_{min} < SOC(t) < SOC_{max} \quad (14)$$

where SOC_{min} is a minimum state of charge and SOC_{max} is a maximum state of charge.

3.5.4. Modelling of Converter

The hybrid non-conventional source generates output voltage in either DC or AC. Thus, to satisfy the power supply of load requirement, the converter is essential for converting either DC input to AC output or AC input to DC output. The converter will either act as an inverter or a rectifier based on the requirement. In this analysis, the efficiency of converter is kept constant in HOMER for converter operation in the system. Thus, the output of the converter is based on its input and efficiency (96%).

The load side power given from converter output is given in Equation (15) [65]:

$$P_{ls}(t) = P_{input}(t) * \eta_{conv} \quad (15)$$

where $P_{input}(t)$ is the converter input power, and η_{conv} represents the converter efficiency.

3.5.5. Modelling of Generator

The fuel is essential for operating a diesel generator. The consumption of fuel on an hourly basis is taken for consideration to operate a diesel generator in HOMER. The rate of fuel consumption in a diesel generator is evaluated using Equation (16) [52]:

$$F_{DG}(t) = F_C * P_{RDG} + F_S * P_{ODG}(t) \quad (16)$$

where F_C is the intercept coefficient, F_S is the fuel curve slope, P_{RDG} is the rated power output of DG and $P_{ODG}(t)$ is the real power output of DG. F_C and F_S are represented as constants.

3.6. Economic and Reliability Features

The net present cost (C_{NP}) is one of the main parameters in a system optimization process using HOMER. The feasible result of optimization process will be decided based on C_{NP} and levelized energy cost (LEC). The C_{NP} depends on annualized cost and capital recovery factor. The net present cost ' C_{NP} ' is represented by Equation (17) [65]:

$$C_{NP} = C_{annual,T} \left(\frac{1}{RF_C(r_i, l)} \right) \quad (17)$$

where C_{NP} is the net present cost in \$, $C_{annual,T}$ is the annualized total cost in \$, RF_C is the capital recovery factor, r_i is based on inflation discount rate in %, and l is the project lifetime.

The capital recovery factor $RF_C(r_i, l)$ is evaluated based on Equation (18):

$$RF_C(r_i, l) = \left(\frac{r_i (r_i + 1)^l}{(r_i + 1)^l - 1} \right) \quad (18)$$

where

$$r_i = \frac{r_d - i_f}{r_d + i_f} \quad (19)$$

where r_i is the interest rate annually, r_d is the discount rate in % and i_f is the inflation rate in %.

The total annualized cost ' $C_{annual,T}$ ' is the sum of capital cost ' C_{ca} ', replacement cost ' C_{rep} ' and operation and maintenance cost ' C_{mo} ' of all components in the hybrid system in \$. This cost is evaluated from Equation (20):

$$C_{annual,T} = C_{ca} + C_{rep} + C_{mo} \quad (20)$$

The capital cost is the sum of capital cost of photovoltaic system ' C_{cpvs} ', wind turbine ' C_{cwt} ', battery ' C_{cbat} ', converter ' C_{ccon} ' and diesel generator ' C_{cdg} '. This cost is evaluated from Equation (21):

$$C_{ca} = C_{cpvs} + C_{cwt} + C_{cbat} + C_{ccon} + C_{cdg} \quad (21)$$

The replacement cost is the sum of the replacement cost of photovoltaic system ' C_{rpvs} ', wind turbine ' C_{rwt} ', battery ' C_{rbat} ', converter ' C_{rcon} ' and diesel generator ' C_{rdg} '. This cost is evaluated from Equation (22):

$$C_{rep} = C_{rpvs} + C_{rwt} + C_{rbat} + C_{rcon} + C_{rdg} \quad (22)$$

The operation and maintenance cost is the sum of operation and maintenance cost of photovoltaic system ' C_{mopvs} ', wind turbine ' C_{mowt} ', battery ' C_{mobat} ', converter ' C_{mocon} ' and diesel generator ' C_{modg} '. This cost is evaluated from Equation (23):

$$C_{mo} = C_{mopvs} + C_{mowt} + C_{mobat} + C_{mocon} + C_{modg} \quad (23)$$

The levelized Energy cost (LEC) is the total annualized cost ' $C_{annual,T}$ ' to the sum of residential $E_{res}(t)$ and electric load-2 $E_{el2}(t)$. The LEC is calculated from Equation (24) [65]:

$$LEC = \frac{C_{annual,T}}{\sum_{t=1}^{8760} E_{res}(t) + E_{el2}(t)} \quad (24)$$

In this study, two reliability indices are evaluated in HOMER software. The expected energy not served (ENS) and Loss of generation probability (LGP) are evaluated during the optimization process.

The Energy not served (ENS) is the reliability index used to evaluate the expected generation $E_G(t)$, which is not generated to satisfy load demand for each time period ' t '. This index is represented in kWh/yr, and it is represented by Equation (25)

$$ENS = \sum_{t=1}^{8760} E_d(t) \quad (25)$$

where

$$E_d(t) = (E_{res}(t) + E_{el2}(t)) - (P_{PVS}(t) + P_{WT}(t) + P_{DG}(t)) \quad (26)$$

The loss of generation probability (LGP) is the ratio of expected energy not served (ENS) to the total load demand $E_{res}(t)$ and $E_{el2}(t)$. This index is represented in %, and it is represented by Equation (27):

$$LGP = \frac{\sum_{t=1}^{8760} E_d(t)}{\sum_{t=1}^{8760} E_{res}(t) + E_{el2}(t)} \quad (27)$$

3.7. Electrical Features

The electrical parameters like capacity factor, PVS penetration and renewable fraction are evaluated during the process of optimization.

Capacity factor 'CF' is defined as the ratio of mean power output of PVS/WT/DG to the total capacity of PVS/WT/DG as represented in Equation (28):

$$CF = \frac{\text{Mean output power of PVS/ WT/ DG (kW)}}{\text{Total capacity of PVS/ WT/ DG (kW)}} \quad (28)$$

PVS penetration is the ratio of mean power output of the photovoltaic system (PVS) to the average load demand. Mathematically, it is represented by the following Equation (29):

$$\text{PVS penetration} = \frac{\text{Mean output power of PVS} \left(\frac{\text{kWh}}{\text{day}} \right)}{\text{Average load demand} \left(\frac{\text{kWh}}{\text{day}} \right)} \quad (29)$$

Renewable fraction 'RF' is termed as the energy fraction in which the energy is delivered from a non-conventional source to load. Mathematically, it is represented by following Equation (30):

$$RF = 1 - \frac{\text{Total DG power generation} \left(\frac{\text{kWh}}{\text{yr}} \right)}{\text{Total load consumption} \left(\frac{\text{kWh}}{\text{yr}} \right)} \quad (30)$$

4. Optimization Results and Discussion

4.1. Analysis of Various Tracking Systems Used in Different Hybrid Configurations Based on Various Aspects

Table 5 shows the levelized energy cost (LEC), net present cost (C_{NP}), loss of generation probability (LGP), Expected energy not served (ENS) and emissions analysis for different configurations like PVS/DG, WT/DG, PVS/WT/DG and PVS/WT with fixed axis without tracking system (FSWT), tracking system on a horizontal axis (TSHA), tracking system on a vertical axis (TSVA) and tracking system on dual axis (TSDA). The results obtained from HOMER based on the input parameters are given in this Table 5. The LEC is low in PVS/DG and PVS/WT/DG configuration at 0.223 \$/kWh in FSWT. The net present cost is low in PVS/WT/DG. The LGP and ENS are nil in all configurations except PVS/WT. This is due to the random nature of renewable source since it depends on environmental effects. The advantage of PVS/WT configuration is to supply power without emissions, but the other three configurations produce emissions between 12,228.4 kg/yr and 119,538.9 kg/yr. The cost of a tracking system on the horizontal axis, vertical axis and dual axis are \$90, \$100 and \$180, respectively, and are used for performing optimization results. While using TSHA in PVS/DG, PVS/WT/DG and PVS/WT, the LEC is less in PVS/DG and PVS/WT/DG at 0.224 \$/kWh, but the total emission is more in these two configurations at 12,449 kg/yr. The total emission is the sum of CO₂ emission and other emissions. The other emissions include carbon monoxide, sulphur dioxide, particulate matter, unburned hydrocarbons and nitrogen oxides which emit less from a diesel generator compared to CO₂ content. The net present cost is increased by 49.42% in PVS/WT while comparing the result with PVS/DG and PVS/WT/DG. The LGP and ENS for PVS/WT are 0.0722% and 113 kWh/yr.

Table 5. Cost, reliability and emission analysis for various configurations with different TS.

TS	Parameters	PVS/DG	WT/DG	PVS/WT/DG	PVS/WT	TS	PVS/DG	PVS/WT/DG	PVS/WT
FSWT	LEC (\$/kWh)	0.223	0.410	0.223	0.361	TSVA	0.223	0.222	0.383
	C_{NP} (\$)	449,574	827,473	449,573	727,327		448,532	448,269	771,189
	LGP (%)	0	0	0	0.0673		0.0330	0.0323	0.0628
	ENS (kWh/yr)	0	0	0	105		51.5	50.3	97.9
	CO ₂ emission (kg/yr)	12,048	117,775	12,148	0		13,552	13,836	0
	Other emission (kg/yr)	180.47	1763.9	182	0		203	207	0
	Total emission (kg/yr)	12,228.4	119,538	12,330	0		13,755	14,043	0
TSHA	LEC (\$/kWh)	0.224	-	0.224	0.336	TSDA	0.226	0.226	0.400
	C_{NP} (\$)	452,516	-	452,516	676,153		455,751	455,327	806,655
	LGP (%)	0	-	0	0.0722		0	0.0168	0.0635
	ENS (kWh/yr)	0	-	0	113		0	26.1	99
	CO ₂ emission (kg/yr)	12,449	-	12,449	0		14,055	15,590	0
	Other emission (kg/yr)	186.5	-	186.5	0		210.6	233.6	0
	Total emission (kg/yr)	12,635.5	-	12,635.5	0		14,265.6	15,823.6	0

The levelized energy cost and net present cost are low in PVS/DG and PVS/WT/DG using TSVA when compared with PVS/WT configuration. The LEC is low at 0.222 \$/kWh in PVS/WT/DG when compared with other configurations using TSVA. Compared with other configurations, the LGP and ENS are high in PVS/WT even when used with TSVA. However, only in PVS/WT is there no emission due to the absence of DG. The net present cost is low at \$455,327 in the PVS/WT/DG system using TSDA when compared with other models. The wind turbine system representing WT/DG is simulated with a fixed axis without a tracking system (FSWT) only since a solar source is necessary while analysing using solar trackers.

The above Figure 5 shows the levelized energy cost (LEC) and net present cost (C_{NP}) in PVS/DG, WT/DG, PVS/WT/DG and PVS/WT. The optimization results given in Figure 5a show that the LEC is low in PVS/WT/DG configurations using TSVA at 0.222 \$/kWh, which is 42% less than the system with PVS/WT and 0.44% less than the

system with PVS/DG. For the system with other tracking systems and FSWT, the LEC is higher than 0.222 \$/kWh. The optimization results given in Figure 5b shows that the net present cost is higher in WT/DG and PVS/WT. In PVS/WT/DG with FSWT, the net present cost (C_{NP}) is 45.66% lower when compared to the C_{NP} of WT/DG. In the hybrid system consisting of PVS/DG or PVS/WT/DG using TSHA, the net present cost is 33.07% lower when compared to net present cost of PVS/WT. In the PVS/WT/DG configuration with TSVA, the net present cost is 41.87% lower when compared to net present cost of PVS/WT. Similarly, TSDA used in PVS/WT/DG configuration has a net present cost which is 43.55% lower when compared to the net present cost of PVS/WT.

Figure 5. Cost for different tracking systems in various configurations (a) LEC (\$/kWh); (b) net present cost ' C_{NP} ' (\$).

The above Figure 6 shows the total emissions for various configurations with different tracking systems. The optimization results show that the emissions are significantly more in the system with WT/DG using FSWT at 119,538.9 kg/yr. In FSWT, the system consisting of PVS/DG has less emission of 12,228.4 kg/yr, which is 89.68% lower than WT/DG. However, for PVS/WT configuration, the emission is nil for the system with various tracking techniques. The system consisting of PVS/DG and PVS/WT/DG with TSHA produces the same emission of 12,449 kg/yr. The system consisting of PVS/DG and PVS/WT/DG with TSVA produces emission of 13,755 kg/yr and 14,043 kg/yr, respectively. The system consists of PVS/DG and PVS/WT/DG with TSDA produces emission of 14,265.6 kg/yr and 15,823.6 kg/yr, respectively.

Figure 6. Total emission for different tracking systems in various configurations.

Table 6 shows the electrical parameters analyses for various configurations with different tracking systems. In a fixed system without tracking (FSWT), the PVS production and PVS penetration are high in PVS/WT configuration. Since the diesel generator is not included in this configuration, PVS capacity of 519 kW is used to meet the load demand.

Similarly, the PVS production is high in PVS/WT configuration for TSHA, TSVA and TSDA as shown in Table 6. The 19 kW wind turbine capacity is used in WT/DG configuration along with the diesel generator of 85 kW capacity to meet the load demand. The usage of 82 kWh capacity lithium-ion battery is less in WT/DG configuration only, while, in other configurations, solar plays an important role which increases the use of battery. The usage of diesel generator for electricity production is less (5–6.96%) for various configurations using different tracking systems except WT/DG with FSWT. The optimization results obtained for production of different sources in kWh/yr are shown in Table 6. The capacity factors evaluated for each method are summarized in Table 6. Only in WT/DG configuration is the fuel consumption more at 44,993 L/yr since the production of DG for this case is 154,310 kWh/yr. The usage of a converter in the different model is highlighted, which is used based on the power flow of AC and DC bus. The renewable fraction for each case varies from 87–100% except WT/DG configuration. The PVS/WT has 100% renewable fraction since the system uses only solar and wind systems.

In Figure 7, the comparison of different configurations for various tracking systems. PVS production growth in % when compared to fixed system without tracking (FSWT) is shown. When compared with FSWT, 7.78% power production is increased in PVS/DG, 7.30% is increased in PVS/WT/DG and 7.38% is increased in PVS/WT while using a tracking system on a horizontal axis (TSHA). When compared to FSWT, 10.73% power production is increased in PVS/DG, 9.77% is increased in PVS/WT/DG and 10.35% is increased in PVS/WT while using a tracking system on a vertical axis (TSVA). Finally, when compared to FSWT, 33.40% power production is increased in PVS/DG, 32.91% is increased in PVS/WT/DG and 32.78% is increased in PVS/WT while using a tracking system on a dual axis (TSDA).

Figure 7. Comparison of different configurations for various tracking systems—PVS production growth in % when compared to FSWT.

4.2. Analysis of Best System Based on Solar Tracking Technique—Optimization Results

From the previous section, using HOMER software, the system with solar and diesel generators consisting of a tracking system on a vertical axis (TSVA) is suitable for Kalpeni Island with low levelized energy cost (LEC) at 0.222 \$/kWh and net present cost (C_{NP}) at \$448,269.5. The tracking system on a vertical axis (TSVA) increases solar power production between 9.77% and 10.73% while comparing solar power production from FSWT. Based on LEC cost, TSVA is preferred even though the solar production of power using TSDA is greater. The best optimization results of solar, wind and diesel generator reveal that only the solar and diesel generators are operated during the optimization process with less levelized energy cost as shown in Figure 8.

Table 6. Electrical parameters' analyses for various configurations with different TS.

TS	Components	Parameters	PVS/DG	WT/DG	PVS/WT/DG	PVS/WT	TS	PVS/DG	PVS/WT/DG	PVS/WT
FSWT	PVS	Capacity (kW)	146	-	146	519	TSVA	135	136	495
		Production (kWh/yr)	245,487	-	246,575	874,855		251,356	252,135	920,740
		Capacity factor (%)	19.3	-	19.3	19.3		21.2	21.2	21.2
		PVS penetration (%)	157	-	158	561		161	162	590
	WT	Capacity (kW)	-	19	-	-		-	-	-
		Production (kWh/yr)	-	17,939	-	-		-	-	-
		Capacity factor (%)	-	10.8	-	-		-	-	-
	LI battery	Nominal Capacity (kWh)	527	82	526	703		517	512	687
		Energy out (kWh/yr)	99,278	79,458	99,080	100,714		97,468	97,690	98,182
	DG	Capacity (kW)	85	85	85	-		85	85	-
		Production (kWh/yr)	13,039	154,310	13,103	-		17,636	18,058	-
		Fuel consumption (L/yr)	4603	44993	4641	-		5177	5286	-
FSWT	Converter	Capacity (kW)	70.3	52.2	68.3	81.9	TSVA	60.7	60.8	129
		Energy output (kWh/yr)	143,978	76,280	143,884	155,861		146,110	146,206	155,868
		Capacity factor (%)	23.4	16.7	24.1	21.7		27.5	27.5	13.8
	Renewable fraction (%)		91.6	1.06	91.6	100		88.7	88.4	100
	PVS	Capacity (kW)	135	-	135	243		115	121	419
		Production (kWh/yr)	244,647	-	244,647	439,843		257,949	271,603	937,777
		Capacity factor (%)	20.7	-	20.7	20.7		25.5		25.5
		PVS penetration (%)	157	-	157	282		165	174	601
	WT capacity	Capacity (kW)	-	-	-	38		-	-	-
		Production (kWh/yr)	-	-	-	35,877		-	-	-
		Capacity factor (%)	-	-	-	10.8		-	-	-
TSHA	LI battery	Nominal Capacity (kWh)	519	-	519	716	TSDA	519	510	894
		Energy out (kWh/yr)	96,054	-	96,054	91,090		93,231	95,881	99,047
	DG	Capacity (kW)	85	-	85	-		85	85	-
		Production (kWh/yr)	13,472	-	13,472	-		15,317	20,328	-
		Fuel consumption (L/yr)	4756	-	4756	-		5369	5956	-
	Converter	Capacity (kW)	69.7	-	69.7	87.4		70.6	63	82.3
		Energy output (kWh/yr)	143,633	-	143,633	130,279		142,119	145,778	155,867
		Capacity factor	23.5	-	23.5	17.0		23	26.4	21.6
	Renewable fraction (%)		91.4	-	91.4	100		90.2	87	100

Architecture										Cost
PVS (kW)	WT	DG (kW)	LI	Converter (kW)	COE (\$)	NPC (\$)
136		85.0	512	60.8	\$0.222	\$448,270
136	2	85.0	509	60.6	\$0.224	\$450,981
495			687	129	\$0.383	\$771,190
343	1		1,093	83.5	\$0.394	\$794,739
19	85.0	82	52.2	\$0.410	\$827,474
85.0	95	63.9	\$0.421	\$848,861
108		85.0		30.7	\$0.485	\$978,827
110	1	85.0		30.2	\$0.487	\$981,531
32	85.0			\$0.674	\$1.36M
85.0			\$0.678	\$1.37M

Figure 8. Optimization results from HOMER for solar, wind and generator with TSVA.

4.3. Benefits of Solar DG Source with TSVA on Kalpeni Island

The simulation results of PVS/WT/DG configuration using HOMER shows that only PVS DG is operated with less levelized energy cost (LEC).

The comparison of a tracking system on vertical axis (TSVA) in various configurations is shown in Figure 9. The result on the tracking system on vertical axis for PVS DG WT configuration shows that only PVS DG are operating and show a better result when compared to other configurations. The levelized energy cost (LEC), net present cost (C_{NP}) and loss of generation probability (LGP) are less in PVS/WT/DG configuration when compared to other results. The levelized energy cost (LEC), net present cost (C_{NP}) and loss of generation probability (LGP) are 0.222 \$/kWh, \$448,269 and 0.0323%, respectively, which are less when compared to other configurations as shown in Figure 9. Thus, solar and DG using TSVA are suitable sources to use on Kalpeni Island. Thus, based on the benefits of the system considered, various analyses are performed in the following sections.

Figure 9. Comparison of TSVA in various hybrid configurations.

4.4. Reliability Assessment for Solar DG Source Configuration with TSVA

In Figure 10, the reliability indices for tracking system on a vertical axis (TSVA) are used in various configurations. The optimization results show that the expected energy not served (ENS) for PVS/DG, PVS/WT/DG and PVS/WT are 51.5 kWh/yr, 50.3 kWh/yr and 97.9 kWh/yr, respectively. Similarly, the loss of generation probabilities (LGP) for the above configurations are 0.033%, 0.0323% and 0.0628%, respectively. The result shows that ENS using PVS/WT is 90.09% more when compared to PVS/DG and 94.63% more when compared to PVS/WT/DG. Summarizing the above results, the PVS/WT/DG has lesser expected energy not served and loss of generation probability.

4.5. Cost Assessment for Solar DG Source Configuration with TSVA

The net present costs ' C_{NP} ' for different components in solar DG configuration with TSVA technique are shown in Figure 11. The total net present capital cost is \$208,988, net present operating cost is \$89,659, net present replacement cost is \$100,012, net present salvage is −\$18,721 and net present resource is \$68,332. Thus, the total net present cost ' C_{NP} ' is \$448,269. From Figure 11, it is noted that the capital cost for solar PVS is \$100,379.78, which is high compared to other components. The replacement cost for 1 kWh lithium-Ion battery is \$92,278.23, which is high compared to other components since the lifetime of battery is only eight years. The operating cost for 1 kWh lithium-Ion battery is high at \$66,188.88 compared to other components.

Figure 10. Reliability indices for TSVA used in various configurations.

Figure 11. Cost assessment of different components in solar DG configuration with TSVA.

4.6. Energy Balance of Solar DG with TSVA

In Figure 12, the daily time-stamped analysis for the month of October using solar DG source with TSVA tracking technique is shown. The hourly data for PVS output power, load demand, autosize DG power output, 1 kWh Li-Ion charge power and 1 kWh Li-Ion discharge power are recorded on 12 October. The month of October is winter for the Kalpeni Island and as such the 25 households had not used air conditioners much. In addition, many households use water geysers. They use water geyser between 6.00 a.m. and 8.00 a.m. and consequently the load demand increased from 13.29 kW to 44.29 kW as shown in Figure 12. The LED Street lights and grocery shop refrigerators are switched ON between 12.00 a.m. and 6.00 p.m. From 12.00 a.m. to 6.00 a.m., the solar PVS does not generate output due to insufficient solar radiation, but, at 7.00 a.m., it starts generating output to satisfy the load demand. The Li-Ion battery discharges power between 12.00 a.m. and 7.00 a.m. to satisfy residential and electric load-2 demand. The discharging power is overlapping with the load demand from 12.00 a.m. to 7.00 a.m. and from 7.00 p.m. to 11.00 p.m. At 8.00 a.m., the diesel generator generated 44.49 kW to satisfy load demand of 44.49 kW and solar PVS generated 11.57 kW, which is used to charge the battery. Between 8.00 a.m. and 6.00 p.m., the Li-Ion battery gets charged based on the output of solar PVS. On 12 October, solar PVS generated peak power of 97.30 kW at 1.00 p.m. Since sufficient solar radiation is available to generate power using solar PVS between 9.00 a.m. and 6.00 p.m., the diesel generator is not operated to avoid emission. After 6.00 p.m., there is

no solar PVS output due to insufficient solar radiation. Thus, from 6.00 p.m. to 11.00 p.m., the Li-Ion battery discharges power.

Figure 12. Daily time-stamped analysis for the month of October.

In Figure 13, the daily time-stamped analysis for the month of June using a solar DG source with TSVA tracking technique is shown. The hourly data for PVS output power, autosize DG power output, 1 kWh Li-Ion charge power, 1 kWh Li-Ion discharge power and load demand are recorded on 20 June. The month of June is the summer for Kalpeni Island and as such the 25 households used air conditioners more, while the use of the water geyser reduces significantly. From 10.00 p.m. to 11.00 p.m. and 12.00 a.m. to 2.00 a.m., the air conditioner is used so that the load demand is more between this period as shown in Figure 13. Due to insufficient solar radiation between 12.00 a.m. and 6.00 a.m., the Li-Ion battery discharges power from 12.00 a.m. to 2.00 a.m. and 4.00 a.m. to 6.00 a.m. and the diesel generator generated 51.21 kW power at 3.00 a.m. to satisfy the load demand. Between 7.00 a.m. and 8.00 a.m., PVS produces output between 9.08 kW and 27.40 kW and diesel generator produces 85 kW power output. The Li-ion battery is charged from the output of solar PVS and diesel generator during this period. Between 9:00 a.m. and 7:00 p.m., only the solar PVS is operated to satisfy the load demand while the diesel generator is not operated to avoid emission. The Li-Ion battery gets charged from 7.00 a.m. to 2.00 p.m. Finally, from 8.00 p.m. to 11.00 p.m., the Li-Ion battery discharges power. The discharging power is overlapping with the load demand from 12.00 a.m. to 2.00 a.m. and from 8.00 p.m. to 11.00 p.m.

Figure 13. Daily time-stamped analysis for the month of June.

In Figure 14, the operation of inverter on 20 June using a solar DG source with TSVA tracking technique is shown. The inverter input is DC source and the output is AC source. The 1 kWh Li-Ion battery SOC varies between 20% and 100%. The battery discharges till 20% only as per the constraints. When the battery discharges till 0% or less than 20%, then it affects the lifetime of battery. The household and electric load-2 requires AC supply.

Thus, to receive power from the photovoltaic system (PVS), a converter is essential to provide power to household and electric load-2 since the output of solar is DC supply. From 12.00 a.m. to 2.00 a.m., an inverter is operating based on a 1 kWh Li-Ion battery discharge. The 60.10 kW, 37.60 kW and 53.06 kW discharge power of battery from 12.00 a.m. to 2.00 a.m. is given as input to the inverter as shown in Figure 14. The inverter input power and battery discharge are overlapped in Figure 14. Then, the inverter is operated from 4.00 a.m. to 6.00 a.m. based on 1 kWh Li-Ion battery discharge. From 12.00 a.m. to 6.00 a.m., the solar panels can not generate power due to insufficient solar radiation, so the battery helps to satisfy the load demand through inverter. However, after 9.00 a.m. till 11.00 p.m., the operation of inverter is purely based on the output of PVS. The input power of inverter at 1.00 p.m. is 12.42 kW; then, the inverter output power is 11.93 kW since the inverter efficiency is 96%. The excess power from photovoltaic system (PVS) for each hour is stored in the battery. Similarly, the inverter output power is evaluated every time, and it is connected to load demand to fulfil it.

Figure 14. Inverter operation for the month of June.

In Figure 15, the operation of rectifier on 20 June using solar DG source with TSVA tracking technique is shown. The input and output of rectifier are AC and DC, respectively. The rectifier is operating only between 7.00 a.m. and 8.00 a.m. as shown in Figure 15. The rectifier is used to convert the AC input to DC output, which is connected to DC bus. The input and output power of rectifier at 7.00 a.m. are 55.07 kW and 52.87 kW, respectively. At 8.00 a.m., the rectifier input and output power are 56.54 kW and 54.28 kW, respectively. The diesel generator (DG) output from 7.00 a.m. to 8.00 a.m. is 85 kW. Since the output of DG is AC source, the rectifier receives 55.07 kW and 56.54 kW at 7.00 a.m. and 8.00 a.m., respectively, from the diesel generator. The battery SOC in % shows the performance of battery during this period.

Figure 15. Rectifier operation for the month of June.

4.7. Multi-Year Analysis for Solar DG with TSVA

Effect of Load Growth

The load will change every year as various appliances are used in residence and electric load-2. The domestic load growth for a period of 25 years is assumed to be 3%, and, for electric load-2, load growth 2% is considered in this study. Search space given for solar PVS, wind turbine, battery and converter in HOMER are 0–136 kW, 0–50 kW, 0–512 kWh, 0–60.8 kW, respectively.

In Figure 16, the variation of PVS generation (kWh/yr), DG generation (kWh/yr), energy out of battery (kWh/yr) and total emission (kg/yr) for a period of 25 years are shown. The diesel generator produces 23,065 kWh during the first year. The usage of diesel generator increases every year to satisfy the load demand. Compared with the first year, the production of diesel generator is increased by 18.42% in the second year. The diesel generator produces 139,911 kWh during the 25th year. The solar PVS power produces 252,789 kWh every year. The energy out of the battery varies between 97,730 kWh/yr and 101,095 kWh/yr during the period of 25 years. The load consumption increases from 155,858 kWh/yr to 304,417 kWh/yr within a period of 25 years based on the input given to HOMER. The total emission produced during the first year is 18,646 kg. The total emission increases each year due to an increase in diesel generator production to satisfy the varying load growth. During the 25th year, the diesel generator produces total emission of 111,097 kg.

Figure 16. Variation of generation, load and total emission using a HOMER multi-year model.

In Figure 17, the load variation with renewable fraction and PVS penetration in a HOMER multi-year model is shown. The renewable fraction depends on DG power generation and load consumption. The renewable fraction for the first year is 85.2%, and the renewable fraction decreases till the 25th year as shown in Figure 17a. The renewable fraction for the 25th year is 54%, which is less compared to the first year. For every year, as the load increases, the renewable fraction decreases. The PVS penetration is the ratio of mean output power of PVS to average load demand. For every year, as the load increases, the PVS penetration decreases as shown in Figure 17b. The PVS penetration decreases from 162% to 83% during the 25-year load consumption.

Figure 17. HOMER multi-year model (a) variation of load consumption with renewable fraction; (b) variation of load consumption with PVS penetration.

4.8. Sensitivity Analysis for Solar DG with TSVA

4.8.1. Effect of Rising Diesel Price

On Kalpeni Island, the diesel price varies between 1 \$/L and 1.2 \$/L during 2020 and 2021 with monthly variation. As per the diesel price history in India, the diesel price varies between 0.41 \$/L and 1.2 \$/L from the year 2007 to 2021. In this study, the diesel price variation is assumed as 5%. Thus, to analyze the performance of the system, diesel price varies between 0.85 \$/L and 1.15 \$/L for performing sensitivity analysis. The net present cost is \$440,579.6 when diesel price is 0.85 \$/L, \$448,269 when diesel price is 1 \$/L and \$458,677 when diesel price is 1.15 \$/L. The net present cost varies according to diesel prices, which is also shown in Figure 18. Comparing the diesel prices 0.85 \$/L, 0.90 \$/L and 0.95 \$/L with 1 \$/L, the net present cost (C_{NP}) decreases to 1.71 %, 0.98% and 0.42%, respectively. Comparing the diesel prices 1.05 \$/L, 1.10 \$/L and 1.15 \$/L with 1 \$/L, the net present cost (C_{NP}) increases to 0.85%, 1.67% and 2.32%, respectively. The diesel power production and CO₂ emission vary erratically when the diesel price is between 0.85 \$/L and 1.15 \$/L as shown in Figure 18. The diesel generator production and CO₂ emission are recorded as the highest at 18,751.15 kWh/yr and 14,335.66 kg/yr when diesel price is 0.95 \$/L due to a low renewable fraction of 88%. The diesel generator production and CO₂ emission are recorded as the lowest as 14,076.13 kWh/yr and 10,803.75 kg/yr when diesel price is 1.15 \$/L due to high renewable fraction of 91%.

Figure 18. Effect of rising diesel price on CO₂ emission, DG production and net present cost.

4.8.2. Effect of Rising Battery Minimum SOC

The performance of hybrid PVS-DG system can be analyzed by increasing the minimum SOC of the battery. The battery minimum SOC is considered as 20%, 25%, 30% and 35% for analyzing sensitivity results.

Figure 19 shows the effect of rising battery SOC_{min} on replacement cost of battery, net present cost and PVS penetration, PVS production and levelized energy cost. Since the battery should be replaced every eight years, the replacement cost of battery is significantly higher. The battery SOC_{min} should be maintained at at least 20% to increase the lifetime of the battery and to avoid damaging the battery elements. When the system is required to discharge the battery below 20% for a particular time 't', the system will operate with a diesel generator to satisfy the demand when there is insufficient solar output. The replacement cost of battery is \$92,278.23 when SOC_{min} is 20% but at 25%, 30% and 35%, the replacement cost of battery is \$98,406, \$105,075 and \$111,202, respectively. The replacement cost of battery is increased by 20.50% when SOC_{min} of battery increased from 20% to 35%. When the battery SOC_{min} is 35%, the battery will operate only from 100% to 35%. As SOC_{min} increases (20–35%), the PVS penetration increases. When SOC_{min} of battery is 20% and 25%, then PVS penetration is 162%. The PVS penetration increases to 165% and 170% when SOC_{min} increased to 30% and 35%. Similarly, there is an impact on rise in SOC_{min} of battery on net present cost (C_{NP}). The 'C_{NP}' increases from \$448,269 to \$498,490 when SOC_{min} of battery is set from 20% to 35%. The PVS production increases from 252,135 kWh/yr to 265,180 kWh/yr when SOC_{min} of battery increased from 20% to 35%. The levelized energy cost also increases from 0.222 \$/kWh to 0.247 \$/kWh when SOC_{min} of battery increases from 20% to 35%.

Figure 19. Effect of rising battery SOC_{min} (a) effect of SOC_{min} on replacement cost of battery, net present cost and PVS penetration; (b) effect of SOC_{min} on PVS production and levelized energy cost.

4.8.3. Effect of Rising PVS Derating

The PVS derating is essential in estimating the output power of solar PVS 'P_{PVS}'. The output of solar PVS is proportional to PVS derating. Practically, PVS derating cannot be 100% due to several factors. While fixing the solar panels on Kalpeni Island, the PVS derating depends mainly on shading effect, wiring loss, deposition of soil over the solar panel layer, etc. Thus, the PVS derating factor 'D_F' is assumed to be 84% and 88% to analyze the performance of the studied area.

Figure 20a shows the effect of 84% and 88% PVS derating for PVS production and levelized energy cost, and Figure 20b shows the effect of 84% and 88% PVS derating for capital cost of PVS, net present cost and levelized energy cost. The result shows that the PVS production increases when PVS derating increases. The PVS production is 251,004 kWh/yr when PVS derating is 84%, but it increases to 251,577 kWh/yr when the derating factor is considered as 88%. The levelized energy cost (LEC) reduced from 0.221 \$/kWh to 0.218 \$/kWh when the PVS derating factor is increased from 84% to 88%. All cost parameters (levelized energy cost, net present cost, capital cost of PVS) decreases

when PVS derating increases as shown in Figure 20b. The net present cost decreases from \$444,689 to \$439,564 and capital cost of PVS decreases from \$95,171 to \$91,052 when PVS derating is increased from 84% to 88%.

Figure 20. Effect of rising PVS derating (a) Effect of 84% and 88% PVS derating for PVS production and levelized energy cost (LEC); (b) effect of 84% and 88% PVS derating for capital cost of PVS, net present cost and levelized energy cost (LEC).

4.8.4. Effect of Rising Photovoltaic Cell Temperature

The sensitivity analysis performed for different photovoltaic cell temperature ' T_{PVC} ' is shown in Figure 21. The net present cost (C_{NP}) increases from \$452,219 to \$455,041.3 when photovoltaic cell temperature is increased from 38 °C to 44 °C. Similarly, the levelized energy cost (LEC) increases from 0.2244 \$/kWh to 0.2258 \$/kWh considering the above temperature change. When the photovoltaic cell temperature is increased from 38 °C to 40 °C, then 0.48% of net present cost is increased. Likewise, from 40 °C to 42 °C, 0.06% of net present cost is increased and, from 42 °C to 44 °C, 0.07% of net present cost is increased. Thus, the change in photovoltaic cell temperature has an impact on cost parameters.

Figure 21. Effect of rising photovoltaic cell temperature on LEC and net present cost.

4.8.5. Effect of Changing Inverter and Rectifier Efficiency

This section discusses the effect of inverter and rectifier efficiency on net present cost, PVS power production, loss of generation probability and expected energy not served.

In Figure 22, the variations of net present cost considering the fluctuation of inverter and rectifier efficiency are shown. The values entered inside the surface plot are PVS power production. The PVS power production for the system (solar DG with TSVA) operating with 96% rectifier and 96% inverter efficiency is 252,135 kWh/yr. However, when there are changes in efficiency for inverter and rectifier, then the PVS power production changes. When efficiency increases to 98%, the PVS power production is 243,676 kWh/yr. The net

present cost ' C_{NP} ' is less when the converter (inverter and rectifier) efficiency is maintained between 96% and 98% but increases when the efficiency reduced to 95% to 96%.

Figure 22. Variation of net present cost considering fluctuation of inverter and rectifier efficiency (superimposed: PVS power production).

In Figure 23, the variation of loss of generation probability (LGP) considering the fluctuation of inverter and rectifier efficiency is shown. The values entered inside the surface plot are expected energy not served (ENS). When the inverter and rectifier efficiency are 96% (Solar DG with TSVA), then the ENS is 50.3 kWh/yr. When the efficiency decreases, the ENS and LGP increases. The ENS is 74.82 kWh/yr when rectifier efficiency is 96% and inverter efficiency is 95%. When rectifier efficiency is 96% and inverter efficiency is 97%, then the ENS is 31.10 kWh/yr. From the surface plot, it is understood that, when the inverter and rectifier efficiency are high, then reliability is improved. From the surface plot, there is no loss of generation probability (LGP) when the inverter and rectifier efficiency are 96% and 97%, respectively.

Figure 23. Variation of LGP considering fluctuation of inverter and rectifier efficiency (superimposed: ENS).

5. Conclusions

The standalone solar/DG, wind/DG, solar/wind/DG and solar/wind with fixed system without tracking (FSWT), tracking system on a horizontal axis (TSHA), tracking system on a vertical axis (TSVA) and tracking system on dual axis (TSDA) were analyzed and compared using HOMER software based on the estimated load profile for residential and load profile for commercial with street lights and environmental conditions of Kalpeni Island. The best optimization result shows that the solar photovoltaic system (PVS) with a tracking system on a vertical axis and diesel generator are the suitable sources to meet the electricity demand with low levelized energy cost (LEC) of 0.222 \$/kWh on Kalpeni Island. When compared to FSWT, 10.73% power production is increased in PVS/DG, 9.77% is increased in PVS/WT/DG and 10.35% is increased in PVS/WT while using TSVA. The different multi-year and sensitivity analysis like effects of load growth, diesel price,

battery minimum SOC, PVS derating, photovoltaic cell temperature, changing inverter and converter efficiency are performed.

From multi-year analysis, the renewable fraction for the 25th year is 54%, which is less when compared to the first year. Compared with the first year, the production of diesel generator increased by 506.59% to satisfy the future load demand on the 25th year based on multi-year input given to HOMER.

Comparing the diesel prices 0.85 \$/L, 0.90 \$/L and 0.95 \$/L with 1 \$/L, the net present cost (C_{NP}) decreases to 1.71%, 0.98% and 0.42%, respectively. The replacement cost of battery is increased by 20.50% when SOC_{min} of battery increased from 20% to 35%. The C_{NP} of battery is increased by 11.20% when SOC_{min} of battery increased from 20% to 35%. The LEC also increases from 0.222 \$/kWh to 0.247 \$/kWh when SOC_{min} of battery increases from 20% to 35%. The PVS power production is increased by 0.228% when PVS derating increases from 84% to 88%. The LEC reduced from 0.221 \$/kWh to 0.218 \$/kWh when PVS derating factor is increased from 84% to 88%. The C_{NP} and capital cost of PVS reduces by 1.152% and 4.32%, respectively, when PVS derating increases from 84% to 88%. When photovoltaic cell temperature is increased from 38 °C to 44 °C, C_{NP} is increased by 0.62% and, when increased from 38 °C to 44 °C, LEC is increased by 0.61%. The C_{NP} is less when the inverter and rectifier efficiency is maintained between 96% and 98%. There is no loss of generation probability (LGP) when the inverter and rectifier efficiency are 96% and 97%, respectively, in the system operating with solar DG with TSVA on Kalpeni Island. For future research, additional sources can be incorporated into the system located on Kalpeni Island to analyze the performance in terms of levelized energy cost and reliability indices. Furthermore, several regions with different sunlight conditions could be compared for analyzing an efficient microgrid system. To summarize, these results will be helpful in motivating stakeholders of renewable energy to build similar initiatives in order to generate power at a cheap cost with minimal emissions for islands.

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