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Reliability Assessment of Standalone Hybrid Energy System for Remote Telecom Tower

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Abstract

In Telecommunication sector, Telecom Operators are always looking for increasing the coverage area of their networks and services to their potential customers to extend their business, thus they also install BTS Towers in remote rural areas where there is lack of central grid electricity connection and transportation difficulties which highlights a potential barrier to Telecommunication industry growth. A Reliable Power System is necessary for such a remote Telecom Tower. Reliability of Telecom Power system plays significant role in keeping the people connected all the time. Therefore, it is necessary to carry out reliability analysis of the power system for the Remote Telecom Tower for ensuring good reliability. This paper presents the reliability analysis of standalone hybrid power system using different combination of renewable energy sources and conventional energy sources for Remote Telecom CDMA BTS of Nepal Telecom in Okhaldhunga Site. In this paper, probabilistic approach of reliability evaluation using Monte Carlo Simulation is applied for the reliability evaluation of hybrid power system. For the Reliability-Cost worth study of Telecom BTS Power System, the revenue loss cost concept is introduced such that the interruption cost is expressed in terms of revenue loss cost caused by the interruption of the power supply. The reliability and cost implications of hybrid energy systems for remote Telecom Tower in Nepalese conditions are discussed. The Sequential Monte Carlo Simulation is performed in MATLAB for the reliability assessment of hybrid power system for the Remote Telecom CDMA BTS of Nepal Telecom.

Keywords

Reliability, Monte Carlo Simulation, Reliability-Cost Worth, BTS Tower, Hybrid Power System, standalone

1. Introduction

In Telecommunication sector, Telecom Operators are always looking for increasing the coverage area of their networks and services to their potential customers in remote areas to extend their business. Therefore, beside urban areas, Telecom Operators also install BTS Towers in remote rural hilly and mountainous region where there is lack of central grid electricity connection and transportation difficulties which highlights a potential barrier to Telecommunication industry growth. Continuous electricity supply for BTS Tower in such remote areas has always been a problem. To supply power to BTS Tower in such remote rural areas, one of the viable options is renewable based hybrid energy system (Solar-Wind-Battery System) depending upon the environmental conditions and availability of the energy sources in site [1]. Hybrid energy system is gaining popularity for supplying power to the telecommunication equipment in such rural areas. Such system incorporates a combination of one or several renewable energy sources such as solar, wind energy, micro-hydro, fuel cells and may be conventional generators for backup. Advantages of hybrid energy system are improved reliability, reduced emissions and pollution, reduced cost and more efficient use of power. Even with the implementation of hybrid energy system, there is a possibility of loss of load due to outage of system components and weather conditions. So reliability of the system has to be taken care of while evaluating the hybrid system performance [2].

There are many studies in literature about reliability of energy generating systems that comprises renewable energy resources. E. Isen et. al. analyzed the reliability of the hybrid energy system installed in Davutpasa Campus of Yildiz Technical University during June [3]. Similarly, Su Youli and Ken Nagasaka used Monte Carlo Simulation Method for the reliability evaluation of the laboratory based micro grid composed of renewable energy sources [4]. Various authors had analyzed the effects of using renewable energy sources in Telecom Power System. Sonali Goel and Sayed Mazid Ali did the cost analysis of various models of hybrid systems consisting renewable energy sources for powering a remote area telecom tower located at an island village Barakolikhola of Kendrapara district of Odisha in India [5].

Reliability evaluation is generally performed either by Deterministic or Probabilistic methods. Deterministic methods cannot recognize the random behavior of the system. So they cannot be applied directly to the Renewable Energy Sources. Probabilistic Methods incorporate the random behavior of the system and can be applied to the renewable energy sources. Thus, probabilistic approach is used for reliability analysis for random behavior of renewable energy sources. Monte Carlo Simulation technique is one of the probabilistic methods that can be used to simulate the random nature of the renewable energy sources. Monte Carlo simulation approach can be utilized to include a number of random variables and their interactions [6]. The sequential Monte Carlo Simulation has been performed in MATLAB for reliability study of power system in Telecommunication sector with different combination of solar, wind and battery storage system utilizing the data of Okhaldhunga obtained from Department of Hydrology and Meteorology, Nepal. In Telecom Sector, the loss of power system interrupts the communication service to the customers and degrades the quality of service to the customers [7] and ultimately causes huge revenue losses to the Telecommunication Company and this cost is to be considered for reliability cost worth analysis. Reliability cost worth of the hybrid energy system is also evaluated in this paper considering the revenue loss cost caused by the interruption of power supply to the BTS. The research for reliability analysis of hybrid energy system for Remote BTS Tower described in this paper is conducted at hierarchical level I (HL-I) and is focused on system adequacy analysis.

2. Hybrid Energy System Components

This section describes models of different components of standalone hybrid energy system such as PV system, WTG system, Battery System. By the help of these models, the output power of all the components of the hybrid energy system is determined.

2.1 Wind Energy Conversion System

The power output from a Wind Turbine Generator (WTG) depends on its rated power (P_r), cut–in speed (v_{ci}), rated speed (v_r) and cut out speed (v_{co}). WTG are designed to start generating at the cut-in speed to rated wind speed. The output wind power increases non linearly from cut in speed up to rated speed, the rated power Prated is produced when the wind speed varies from rated speed (v_r) to cut out speed (v_{co}) and the output wind power is zero for speed greater than cut out speed as the wind turbine is shut down for safety reason. The electrical power hourly generated can be calculated from the wind speed data using the wind turbine generator power curve. The Power curve gives a quantitative relationship between wind speed and wind turbine power output. It describes the operational characteristics of a wind turbine generator. Thus, to any power output, a corresponding wind speed can be found on this curve. A typical curve is shown in Figure 1.

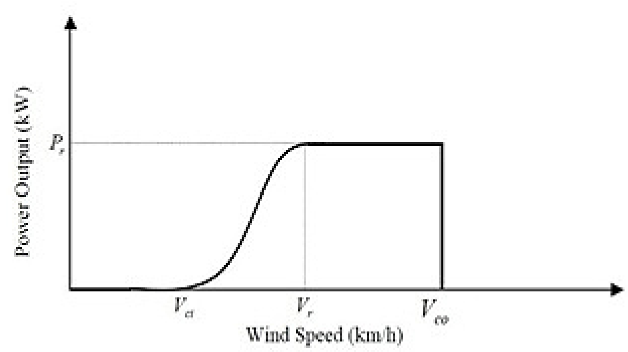

Figure 1: Wind Turbine Generator Power Curve

The mathematical polynomial equations relating the power output from a WTG with the wind speed from the WTG power curve can be written as given in equation 1 [2]

$$P_{WTG} = \begin{cases} 0 & 0 \le v \le v_{ci}, v \ge v_{co} \\ av^3 + bP_r & v_{ci} \le v \le v_r \\ P_r & v_r \le v \le v_{co} \end{cases} \tag{1}$$

where ‘a’ and ‘b’ constants are functions of v_{ci}, V_r and P_r and can be obtained by the following relations.

$$a = \frac{P_r}{{v_r}^3 - {v_{ci}}^3}$$

$$b = \frac{{v_{ci}}^3}{{v_r}^3 - {v_{ci}}^3}$$

2.2 Photovoltaic Conversion System

The output power from a PV system depends upon the solar radiation and the ambient temperature at the site. The maximum power produced by a PV module under standard test conditions (STC) can be used to evaluate the module rated power in peak-watt. This test should be performed in a radiation level of 1kW/m2 and a cell temperature of 25 deg. centigrade. The electrical powers generated by a PV array consist of N modules can be computed using equations as [8]

$$T_c = T_a + s\frac{N_{OT} - 20}{0.8} \tag{2}$$

$$I = s[I_{sc} + k_i(T_c - 25)] \tag{3}$$

$$V = V_{oc} - k_v T_c \tag{4}$$

where, T_c represents cell temperature in deg.Centigrade, I stands for PV module short-circuit current in A, k_i signifies current temperature coefficient in A/deg.C, V_{oc} stands for open circuit voltage, and k_v is open-circuit voltage temperature coefficient in V/deg.C.

The power output from a PV array, containing N modules, can be directly calculated as

$$P_{pv} = N * FF * V * I \tag{5}$$

where, P_{pv} is a function of solar radiation level 's' for calculating power output from a PV array and Fill Factor (FF) depends on the material of module and is given by the following relation:

$$FF = \frac{V_{MPP} * I_{MPP}}{V_{OC} * I_{SC}} \tag{6}$$

2.3 Energy Storage System

The output of a WTG or a PV array is intermittent because wind and sunlight are not always available when there are power demands. Therefore, energy storage facilities are useful additions in power systems using wind and solar energy in small stand-alone applications. The operating strategy of an energy storage element is that whenever the generation exceeds the load, the excess energy is stored and is used whenever there is a generation shortage. The energy storage state time series can be obtained from the load time series and the renewable energy generation time series taking into consideration the charging and discharging characteristics of the energy storage element. In the simulation, the energy storage state time series is calculated using the following steps [9]:

- Determine the surplus generation (it can be either a positive or a negative value) time series { SG_t; t=1,2,.........,T} from the load time series { L_t; t=1,2,3...........,T} and the generation time series $\{TG_t$; t=1,2,3...........T$\}$.

$$SG_t = TG_t - L_t \tag{7}$$

- Compute the energy storage state time series $\{ES_t$ t=1,2,3...............,T$\}$ using the following relation.

$$ES_{t+1} = \begin{cases} ES_{min}, & (ES_t + SG_t) \le ES_{min} \\ ES_t + SG_t, & ES_{min} < (ES_t + SG_t) \le ES_{max} \\ ES_{max} & ES_{max} < (ES_t + SG_t) \end{cases} \tag{8}$$

Where, ES_{min} and ES_{max} are the minimum and maximum allowable storage levels of the energy storage element.

2.4 Load Model

The existing Base Trans receiver Station (BTS) Tower at Okhaldhunga Nepal Telecom (NT) site has IPCDMA BTS and Microwave as transmission medium. The total power consumption by this kind of BTS and Microwave Transmission are as shown in table 1.

The load of Telecommunication equipment is almost constant. It varies from time to time according to the

Table 1: BTS Load Data Table

SN	BTS Config.	BTS	Microwave	Total Load
1	S111	540 W	120 W	660 W

high or low traffic. The daily load profile of BTS load is shown in Figure 2

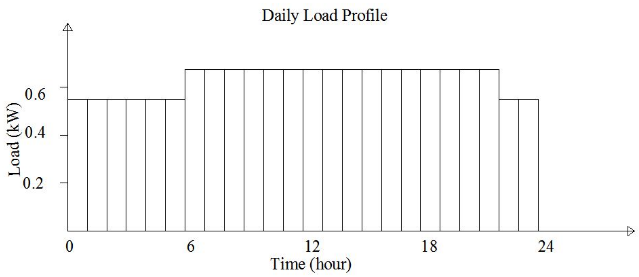

Figure 2: Daily load profile of CDMA BTS

3. Site Data Simulation

Wind is a highly variable resource at different locations. Wind power generated from a wind turbine generator depends on the fluctuation of wind speed at a wind farm. Studies on wind power need an accurate wind model to simulate the wind speed variation at different locations. The data of wind speed for a particular site in Nepal is not sufficiently available. Wind speed probability distributions are often used to describe wind characteristics of a specified location. Weibull distribution can be used to represent the wind speed probability and simulate the hourly wind speed. The probability density function of a Weibull distribution is

$$f(v) = (\beta/\alpha^{\beta})v^{\beta-1}exp[-(v/\alpha)^{\beta}] \quad (9)$$

where $\beta > 0$ is the shape parameter, $\alpha > 0$ is the scale parameter of the distribution.

The Weibull distribution is related to a number of other probability distributions, in particular, it interpolates between the exponential distribution ($\beta = 1$) and the Rayleigh distribution ($\beta = 2$). α and β can be calculated by wind speed data collected at a specified site using the following equations [10]:

$$\alpha = \bar{v}/\Gamma(1+(1/\beta) \quad (10)$$

$$\beta = (\sigma/\bar{v})^{-1.086} \quad (11)$$

where Γ is gamma function, $\bar{v}$ is mean wind speed, and σ is the standard deviation of the wind speed.

By the inverse transform method,

$$U = F(v) = 1 - exp[-(v/\alpha)^{\beta}] \quad (12)$$

$$v = \alpha(-lnU)^{1/\beta} \quad (13)$$

Where, $F(v)$ is the cumulative probability distribution function, and U is a uniformly distributed random variate between [0, 1]. The algorithm for generating Weibull distributed random variates is as follows:
Step 1: Generate a uniformly distributed random number sequence U between [0, 1].
Step 2: Calculate by 13.

The algorithm which was used to obtain wind velocity data, can also be used to achieve the solar irradiation and ambient temperature data [8]. In several studies, solar radiation has been predicted using Weibull distribution using the historical radiation data. Weibull distribution can be used to represent the solar radiation probability and simulate the hourly solar radiation. In this paper, Weibull distribution has been used to get the wind speed and solar radiation data.

4. Reliability Evaluation Methods

Reliability Evaluation Methods can be classified into two general groups (a) Deterministic and (b) Probabilistic. A basic difficulty with deterministic criteria is their inability to consider the probabilistic or stochastic nature of system behavior or component failures. They cannot recognize the random behavior of the system, thus, cannot be applied directly to the continuously fluctuating system comprising renewable energy sources. Probabilistic techniques provide quantitative risk assessments which can be used for renewable systems. The prediction of the future behavior of a power system that is influenced by different random system parameters can only be recognized using probabilistic techniques, thus, can be applied to the system consisting of renewable energy sources.

Probabilistic Method is further sub-divided into Analytical and Monte Carlo Simulation Method. Analytical techniques represent the system by analytical models and evaluate the indices from these models using mathematical solutions and use direct analytical solutions to evaluate indices. Unlike analytical technique, Monte Carlo Simulation estimates the indices by simulating the actual process and random behavior of the system over the period of interest. It repeats simulation for a large number of times until convergence criteria is met and requires a large amount of computing time. MCS can be classified into two types: Non-sequential and sequential MCS [11]. In Non-sequential MCS, system states are randomly sampled irrespective of event chronologies whereas in Sequential MCS, simulation is advanced sequentially or chronologically, recognizing the fact that the system state at a given time point is correlated with that of the previous time points. In this paper, Sequential MCS is considered for simulation in MATLAB program.

4.1 Evaluation Methodology

A general adequacy evaluation model for a power system using wind energy, solar energy and energy storage is shown in Figure3. The reliability assessment of standalone hybrid solar-wind-energy storage and Diesel Generator system is done in three steps.

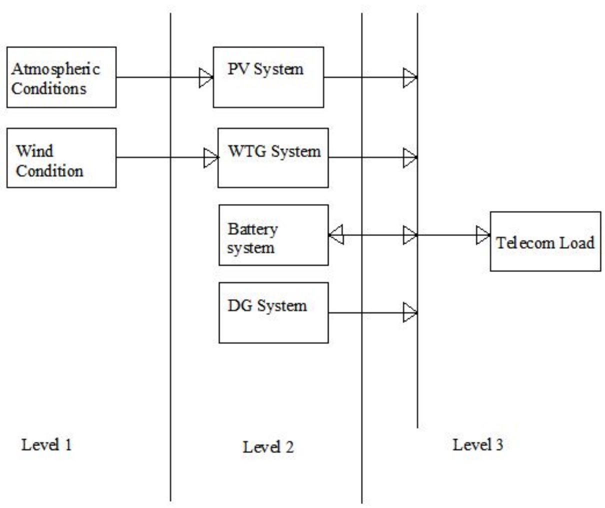

Figure 3: Reliability Evaluation Methods

In the first step, required atmospheric data such as hourly solar radiation, hourly ambient temperature and hourly wind speed are collected from sources like weather monitoring stations, meteorological department etc. In next step, hourly output power available from each type of source is obtained from respective power generation models incorporating the outage schedules generated randomly using failure rates of respective generating units. In the final step, total available generation for all hours is superimposed with hourly load data and reliability indices are obtained.

The MCS method is a general designation for stochastic simulation using random numbers. In this method the random behaviors of the system are simulated. In this study, the state duration sampling approach, which is a kind of the sequential MCS method, is applied to hybrid energy system. Consequently, a series of information in a time sequence are produced and the adequacy indices from a series of simulated experiments can be calculated.

The main parameters used to create an operational history for generating unit are unit mean times to failure (MTTF) and mean times to repair (MTTR). These parameters can be used in conjunction with random numbers between 0 and 1 to produce a state history consisting of a series of random up and down times called state residence times for each generating unit in the system. The up time and down time of PV, wind, DG are given by relation as [9],

$$Uptime = -MTTF * ln(x_1) \tag{14}$$

$$Downtime = -MTTR * ln(x_2) \tag{15}$$

assuming that failure rates of all units are exponentially distributed and x_1 and x_2 are random numbers .

The basic overall simulation methodology can be briefly described as follows:

1. Generate operating histories for each generating unit using eqns. The operating history of each unit is then in the form of chronological up-down-up operating cycles.
2. Obtain the system available capacity by combining the operating cycles of all the generating units in the system.
3. Superimpose the system available capacity obtained in step 2 on the chronological load model to construct the system available margin model.
4. Estimate the desired reliability indices by observing the margin model constructed in step 3 over a long time period.

5. The simulation proceeds chronologically from one hour to the next for repeated yearly samples until specified convergence criteria are satisfied.

The overall step of reliability assessment of hybrid energy system for remote Telecom Tower is shown in Flowchart in Figure 4

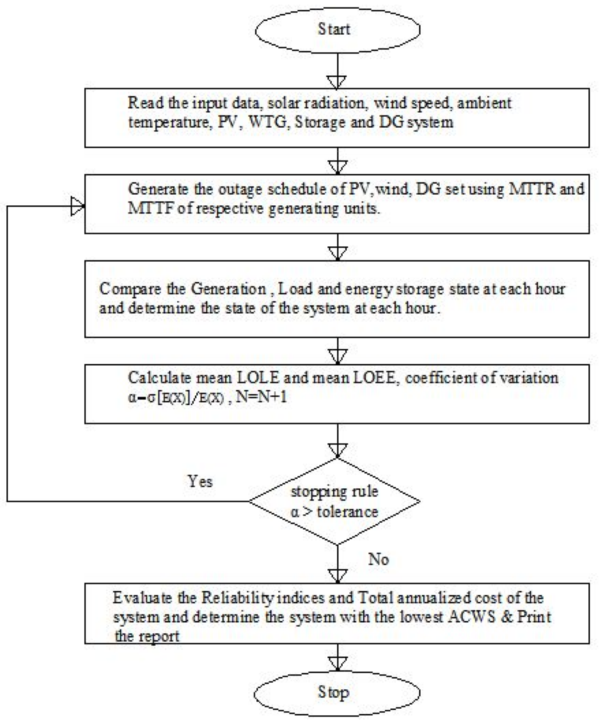

Figure 4: Flowchart of Methodology used

The reliability indices for a number of sample years (N) can be obtained using the following equations.

1. Loss of Load Expectation (LOLE), (hours/year)

$$LOLE = \frac{1}{N}\sum_{i=1}^{n} t_i \tag{16}$$

   Where, t_i -Loss of load duration in year i, N- Total number of simulated years, n – Number of load curtailments

2. Loss of Energy Expectation (LOEE), (kWh/year)

$$LOEE = \frac{1}{N}\sum_{i=1}^{n} e_i \tag{17}$$

   Where,e_i –Energy not supplied in year i, N- Total number of simulated years, n – Number of load curtailments

The Loss of Load Expectation (LOLE) and Loss of Energy Expectation (LOEE) indices provide an overall indication of the ability of the generating system to satisfy the total system load. Other indices such as the probability of health state, marginal state, frequency of interruptions and the expected duration of interruptions can also be calculated if required.

4.2 Simulation Stopping Criteria

Monte Carlo Simulation requires a large amount of computing time to simulate the actual operation of a system. The accuracy of the indices estimated by a simulation technique is improved by increasing the number of sample years. It is, however, not practical to run the simulation for a very large number of samples in order to achieve an extremely high level of accuracy. A stopping criterion (or rule) is often used to determine the most appropriate time to stop the simulation so that it not only reduces the simulation time but also provides an acceptable confidence in the results. There are different stopping criteria, which can be used to track the convergence of the simulation [11]. In this paper, the stopping criterion is used as the ratio of the standard deviation of the expected value E(X) and E(X) where X is a reliability index such as LOLE or LOEE. The mathematical expression for each statistical value and the stopping criterion are as follows: The basic reliability index is

$$E(X) = \frac{1}{N}\sum_{i=1}^{n} X_i \tag{18}$$

Where X_i is the observed value of in year i and N is the total number of simulated years.
The standard deviation of the mean is

$$\sigma[E(X)] = \frac{\sigma(X)}{\sqrt{N}} \tag{19}$$

Where $\sigma(X) = [\frac{1}{N-1}\sum_{i=1}^{n}(X_i{}^2 - E^2(X))]^{\frac{1}{2}}$

The stopping criterion is as follows:
$\frac{\sigma[E(X)]}{E(X)} < \varepsilon$
Where ε is the maximum error allowed.

4.3 Reliability Cost/Worth Evaluation at HL-I

Reliability cost refers to the additional costs needed to achieve a certain level of reliability. Reliability Cost worth evaluation incorporates both cost analysis and quantitative reliability assessment into a common framework [9]. Capital investment, operation and maintenance costs and interruption cost expressed in terms of revenue loss cost caused by outage of power supply are considered in reliability cost/worth analysis for determining the minimum total cost of the system as shown in Figure 5.

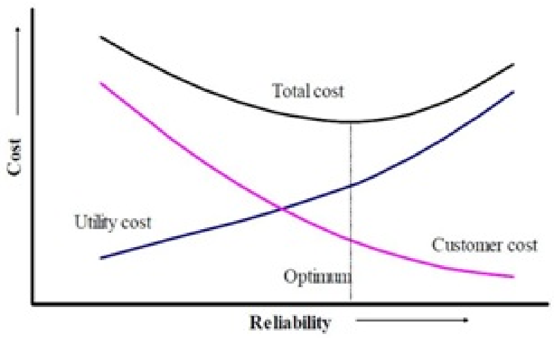

Figure 5: Reliability cost worth curve

The Figure 5 shows that as the reliability increases, the capital and operating (i.e utility) cost of the system increases while the revenue loss cost decreases and there is a point which has a minimum total cost of the system.

5. Results and Discussions

The proposed algorithm is implemented in MATLAB. The algorithm program runs with different random numbers generated for each year for the outage schedules for wind and solar, and diesel generator units. The generated power by solar and wind depends upon the environmental conditions like ambient temperature, solar radiation, wind speed etc. Hence, different combination of solar and wind has been analyzed.

In this paper, the simulation is performed such that the capacity of PV System increases from 20 Nos. of 120 watts PV module in the step interval of 4 Nos. up to 40 Nos., WTG system increases with 0 kW, 2.5 kW and 5 kW and the battery capacity starts from 800Ah in the step interval of 200Ah up to 1200Ah. The LOLE and the total annualized cost of the system including Revenue loss cost caused by power outage in the BTS is calculated for each possible combination of Solar-Wind-Battery and DG system and then compared to each other. The case with the minimum total annualized cost of the system is the best power system for the assessed site.

As for example case, the reliability of the existing power system of CDMA BTS in Bandredanda of Okhaldhunga district is also assessed from MATLAB program. The existing power system is standalone solar system with battery storage that consists of 20 Nos. of 120 watts PV module, 800Ah Battery. The obtained results indicated towards poor reliability with LOLE=2410.05 hours/year, No. of healthy states N(H)=220, No. of marginal states N(M) =6130 and EIR=73.78%. Therefore, to improve the reliability, the simulation results showed that the number of PV panels and WTG has to be added and energy storage capacity of the battery has to be increased.

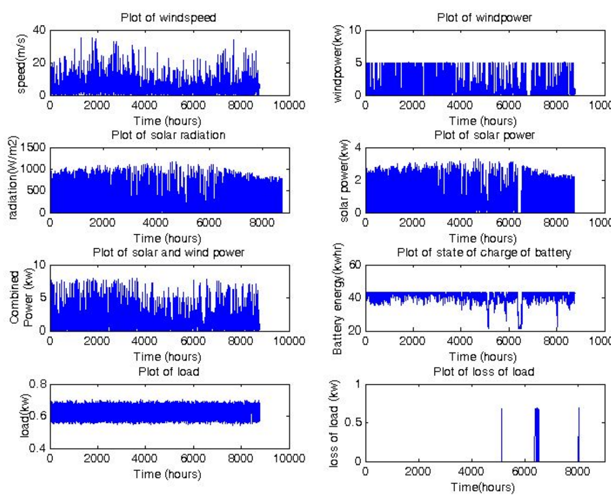

Figure 6: MATLAB output graph for PV-Wind-Battery System

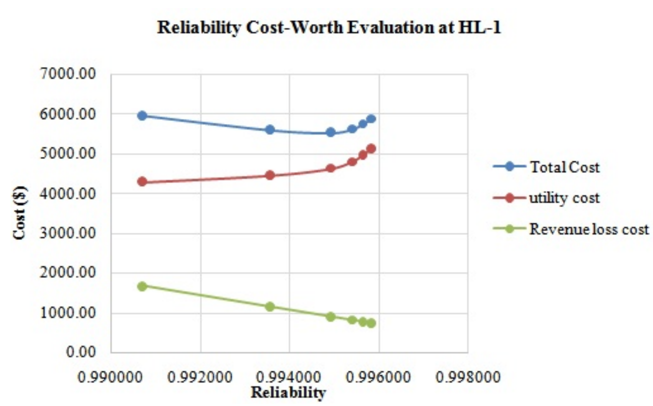

Figure 7: Reliability Cost Component graph for PV-Wind-Battery System

As discussed earlier, the best case is the case with the minimum total system cost and the best case obtained is PV=28 Nos., WTG=5 kW and Battery=1000Ah for standalone PV-Wind-Battery Hybrid System which has LOLE=45.34 Hours/year, LOEE=28.74 kWh/year, No. of healthy states N(H)=8574, No. of marginal states N(M)=141, EIR=99.49%. The MATLAB Simulation result is tabulated in Table 2 and their respective graphs are shown in Figure 6. The reliability-cost component graph for the best case of standalone PV-Wind-Battery System is shown in Figure 7.

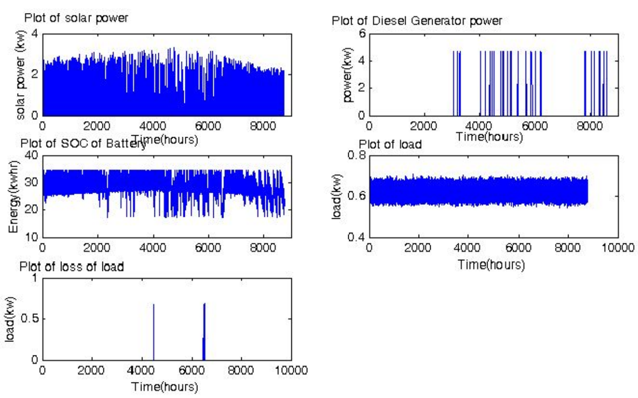

Figure 8: MATLAB output graph for PV-Battery-DG System

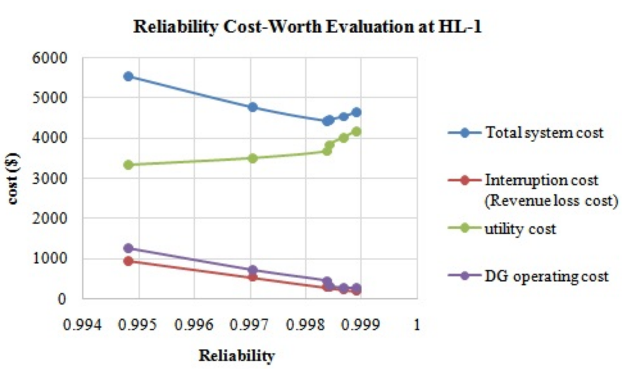

Figure 9: Reliability Cost component graph for PV-Battery-DG System

In the case if DG set is planned to be added, the best case obtained is PV=28 Nos., Battery=800Ah which has LOLE=14.45 hours/year, LOEE=9.16 kWh/year, No. of healthy states N(H)=7388, No. of marginal states N(M)=1358, DG runtime=184.68 hours, EIR=99.84%. The MATLAB Simulation results is tabulated in Table 3 and their corresponding graphs are shown in Figure 8.The reliability-cost component graph for the best case of standalone PV-Wind-Battery System is shown in Figure 9.

5.1 System risk with different energy sources added to the base system

The risk of the existing base system with the cases when 2.5kW & 5kW WTG, 2.4kWp solar PV and mix of 2.4kWp solar PV & 2.5kW WTG, mix of 2.4kWp solar PV & 5kW WTG is added to the base system separately is shown in Figure 10.

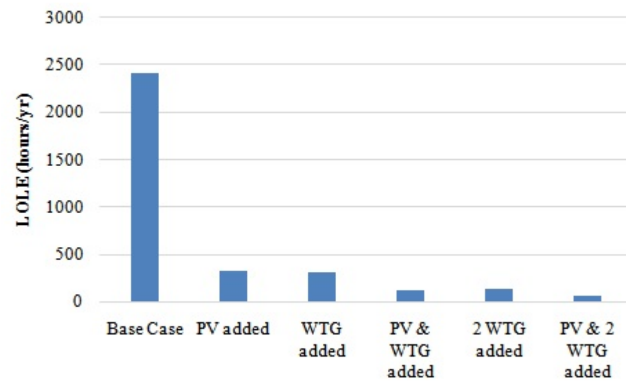

Figure 10: System risk with different energy sources added to the base system

The Figure 10 illustrates that the system reliability improves with the addition of energy sources of any type. The level of improvement is however different, despite different amounts of capacity additions, depending on the type of energy sources added to the system. From the reliability point of view, for this particular site, the WTG and PV added to the base system seems more superior to PV arrays or WTG units when comparing reliability benefits from a given capacity addition. The combination of WTG and PV improves reliability as the WTG can supply the load during the night time when the PV cannot supply the load during night time, thus maintaining enough energy storage reserve in the battery for the worst case. Such that whenever the need of the energy from the battery storage, it could be easily utilized at its utmost level. Further, it has been established that any kind of energy sources added to the base system will increase the reliability of the hybrid system. Also, the number of healthy states increases with the addition of

Table 2: MATLAB Output Results for PV-Wind-Battery System

No. of PV panels	WTG (kW)	Battery (Ah)	LOLE (hrs/yr)	LOEE (kWh/yr)	Capital & operating cost ($)	Revenue Loss ($)	Total AWCS ($)	N(H)	N(M)	N(R)	EIR
20	5	1000	83.77	52.70	4283.53	1675.44	5958.97	8280	396	84	0.990685
24	5	1000	57.60	36.48	4453.70	1152.08	5605.78	8487	215	58	0.993552
28	5	1000	45.34	28.75	4623.87	906.88	5530.75	8574	141	45	0.994919
32	5	1000	41.05	26.07	4794.04	821.04	5615.08	8605	114	41	0.995392
36	5	1000	38.84	24.68	4964.21	776.76	5740.97	8626	95	39	0.995638
40	5	1000	36.78	23.43	5134.38	735.60	5869.98	8632	91	37	0.995829

Table 3: MATLAB Output Results for PV-Battery-DG System

No. of PV panels	Battery (Ah)	LOLE (hrs/yr)	LOEE (kWh/yr)	DG runtime (hrs/yr)	DG Op. cost($)	Capital Cost ($)	Capital & operating cost ($)	Revenue Loss ($)	Total AWCS ($)	EIR
20	800	46.93	29.31	511.18	1277.95	3334.84	4612.79	938.64	5551.43	0.99482
24	800	26.56	16.68	294.04	735.09	3505.01	4240.10	531.12	4771.22	0.99705
28	800	14.45	9.16	184.68	461.71	3675.18	4136.89	288.92	4425.81	0.99838
32	800	14.06	8.92	133.90	334.76	3845.35	4180.11	281.16	4461.27	0.99842
36	800	11.79	7.47	116.54	291.35	4015.53	4306.87	235.88	4542.75	0.99868
40	800	9.76	6.17	111.78	279.45	4185.70	4465.14	195.12	4660.26	0.99891

any renewable energy. The increase in the capacity of the generation resulted in the increase of number of the healthy state which is shown in Figure 11.

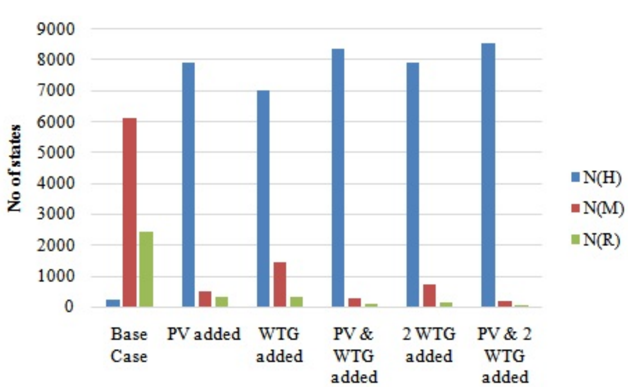

Figure 11: System risk with different energy sources added to the base system

5.2 Battery sizing variation effect on reliability

In order to appreciate the impact of the major battery capacity on the reliability of the base system, the LOLE was determined as a function of the battery capacity. It can be clearly seen from Figure 12 that the increment of the battery capacity significantly improves the reliability of the system. For the existing base case, the increment of the battery capacity did not increased the system reliability because there is not enough generation to fully charge the battery in time and store the energy in the battery in this case, thus has no effect in reliability with increase in the storage capacity. But for other cases, which have addition of PV and WTG has reliability increased for the increment in the capacity of the battery.

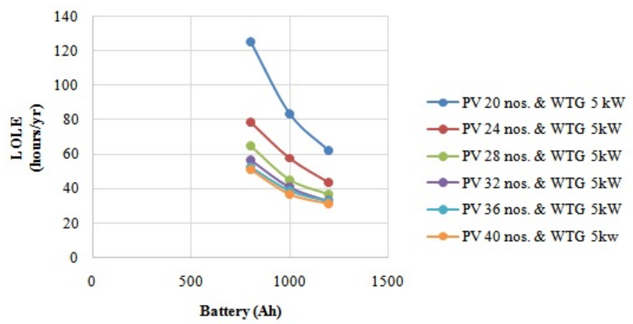

Figure 12: Effect of Battery Capacity in LOLE

5.3 Effect of Renewable Energy Penetration in DG system on LOLE and DG Run time

When DG is introduced to the standalone PV wind battery system, the LOLE is reduced. For higher battery storage capacity, the LOLE is lower and DG run time is also reduced which can be observed in Figure 13 and 14.

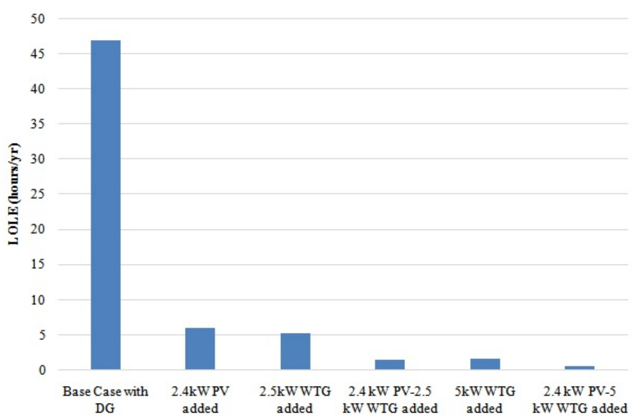

Figure 13: Effect of Renewable energy addition in DG system on LOLE

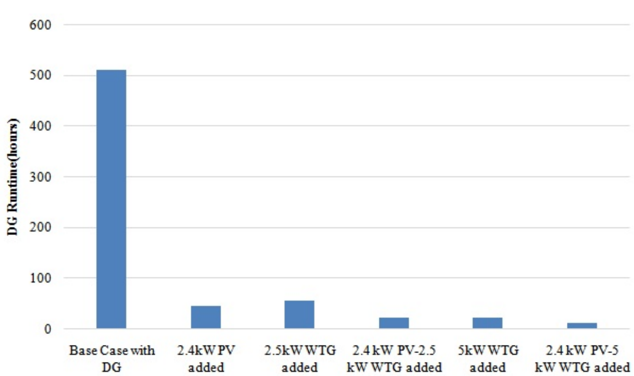

Figure 14: Effect of Renewable energy addition in DG system on DG runtime

Hence the reliability is greatly improved with the inclusion of conventional diesel generator in the hybrid system for remote Telecom BTS. It is observed that the addition of PV, WTG and PV-WTG in the base case with DG, reduced the LOLE and the DG Runtime.

5.4 Effect of Battery Capacity in DG run time

For standalone PVwindbatteryDG system, the DG runtime reduces when the battery capacity is increased from 800Ah to 1200Ah which is indicated in Figure 15. The lesser the DG runtime, the less will be the operational cost of the DG.

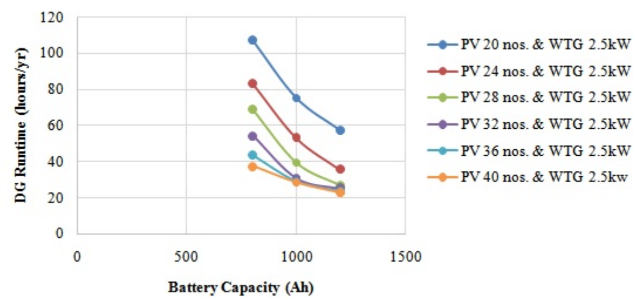

Figure 15: Effect of Battery capacity on DG runtime in PVBatteryDG System

6. Conclusion

In this paper, Reliability assessment of a standalone Hybrid Energy System for Remote Telecom Tower was performed using Sequential Monte Carlo Simulation. Monte Carlo Simulation has been implemented in the generation model by creating an artificial history of the generating units' behavior considering random operating and failure state. In this study, the models and methodologies for the reliability assessment of standalone Hybrid Energy System for Remote Telecom Tower has been proposed and implemented. MATLAB Program was developed based on proposed models and methodologies in order to calculate the reliability indices and related economic indices for each configuration of Hybrid Energy System for remote Telecom BTS and to determine the system with minimum reliability-cost worth value for the remote Telecom BTS. The proposed models and methodologies for reliability cost worth evaluation was performed for a particular site Bandredanda Nepal Telecom CDMA BTS Site, Okhaldhunga District, as an example case, which indicated towards poor reliability and high revenue loss. In the study of Reliability Cost worth of Telecom BTS Power System, the revenue loss concept was introduced such that the interruption cost was expressed in terms of revenue loss caused by the interruption of the power supply. Different possible configurations of PV-Wind-Battery were considered for the evaluation of reliability-cost worth of CDMA BTS power system and the Hybrid Energy System with minimum reliability-cost worth value of the system was determined. The reliability of the existing power system in Bandredanda CDMA BTS can be improved by adding additional solar panels, WTG and changing the capacity of the Battery. The results obtained showed that the installation of 5kW WTG, 3.36 kWp PV and 1000Ah Battery give high reliability, less revenue loss and minimum system cost. In the case of Hybrid Energy System comprising conventional Diesel Generator, the Solar-Diesel-Battery System consisting of 3.36kWp PV, 800Ah Battery and 7.5 kVA DG set showed minimum system cost, less revenue loss and high reliability.

In conclusion, the models, methodologies, results and discussion presented in this paper has provided valuable information for Telecom Companies for planning and operating power systems containing wind energy, solar energy, DG system and energy storage for isolated (non grid connection) Remote Telecom Tower.

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