

Computer Aided Optimal Sizing of Hybrid Photovoltaic Wind System for Rural Electrification in India

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Abstract -The sizing and techno economical optimization of a stand alone hybrid system is presented in this paper the main objective is to find the optimum size of system, able to fulfill the energy requirements of a given load distribution at a rural place in India In the optimal sizing procedure the first step is modeling of a hybrid pv/wind system with mathematical models that characterize pv module, wind generator and the battery. The second step is to optimize the sizing of a system according to loss of power supply probability (LPSP) and the levelized cost of energy (LCE). The configuration which meets the desired system reliability with the lowest LCE gives the optimal choice By Applying the optimization model to a hybrid plant which is assumed to installed at a rural place called Nekkanti in India which is almost in Nallamalla forest, the simulation results show the optimal configuration which meet the desired system reliability requirements with the lowest LCE. The proposed system simulated using the MATLAB solver, the input parameters to the solver was the meteorological data for the selected locations and the sizes of the Photovoltaic cells and the wind turbines. The results shows that (sites) can use the solar and wind energy to generate power enough to power some village in the rural area.

Keywords- LPSP, LCE, CAD, HPWS, Optimum sizing

I. INTRODUCTION

Electric energy plays an important role for the development of nation. It is the factor responsible for industrial and agricultural development for the development of agricultural sector rural electrification plays main role According to IEA (2009) worldwide 1.456 billion people do not have access to electricity, of which 83% live in rural areas. The technologies are developed to produce energy and satisfy the needs of the nation. The scarcity of fossil fuel resources on a world wide basis has necessitated an urgent search for alternative sources. The problem can be overcome by the use of renewable energy to meet the energy demand. Using solar and wind energy is one of the best options to generate electricity since these energies are inexhaustible and pollution free. For remote areas i.e., The areas which are far away from the grid hybrid systems have been considered as attractive and preferred alternative sources [3-4]

In India agriculture play dominant role in the development of nation, most of the people live in rural areas whose occupation is agriculture. In India nearly more than 70,000 villages are unelectrified. 400 million people have no access of electricity. In Andhra Pradesh for the areas which are nearer to, or under Nallamalla forest that are very far away from the grid it is difficult to supply electricity due to their inherent location and economy. The cost to install lines and bus bars are considerably high for remote areas. In most of the remote areas ,extension of utility grid experiences several problems like poor regulation high capital investment etc., For long time, the choice of diesel power generation for these regions has been considered as the most economical and reliable alternative. Now a days due to several practical problems induced for the user (high operating costs, fuel transportation problems, complicated maintenance, etc.), the diesel power generation is not always the most profitable solution. On the other hand, with more concerns about environmental issues and the steady progress in renewable energy technologies, renewable energy resources appear to be one of the most efficient and effective solution for sustainable energy development and environmental pollution prevention. The use of different energy sources allows improving the system efficiency and the reliability of the energy supply and reduces the energy storage requirements compared to systems comprising only one single renewable energy source. On the other hand, with the complementary characteristics between solar and wind energy resources for certain locations, hybrid solar/wind power generation systems with storage banks offer a high reliable source of power.

To use solar and wind energy resources more efficiently and economically, the optimal sizing of hybrid PV/wind system with battery plays an important role in this respect. In [15] this context, Biomass-based fuels are being steadily replaced with modern fossil fuels and electricity in cities of developing countries. The latter energy sources are more convenient and efficient to use, and produce less local pollutants. This fuel transition has accompanied economic growth in many cities. In [1] this context, an optimization sizing model is developed. It consists of three sub models; system components sub models, technical sub model based on the loss of power supply probability (LPSP) and the economical sub model based on the levelised cost of energy (LCE). Applying the developed model, a set of configurations meeting the desired LPSP is obtained. The configuration with the lowest LCE gives the optimal one. In this based on the desired LPSP the number of wind generators, photovoltaic modules, batteries are increased

In [2] this context modeling a hybrid PV/wind system is considered as the first step in the optimal sizing procedure. In this paper, more accurate mathematical models for characterizing PV module wind generator and battery are proposed. The second step consists to optimize the sizing of a system according to the loss of power supply probability

(LPSP) and the levelised cost of energy (LCE) concepts. In [4] this paper deals with the modeling of an electrical local network supplied with energy provided by renewable resources. Its purpose is to implement and develop a software application to analyze and simulate a real hybrid solar-wind system connected to a local grid using Matlab Simulink environment. Blocks like wind model, solar model, local grid model are implemented and the results of simulation are also presented.

In this paper it is assumed to install HPWS at a place called Nekkanti in Andhrapradesh. The optimization sizing is done first by calculating the wind potential based on it the wind generator capacity is chosen. Later based on the desired LPSP the number of photovoltaic modules and batteries are increased. This optimal sizing is done by developing a software program using Matlab Simulink environment.

II. PROPOSED HYBRID PV/WIND CONFIGURATION

The following architecture is an improved version of the centralized DC-bus architecture shown in Fig.1. The improvement exists mainly in the addition of a DC/DC converter for each energy conversion system (including the storage battery) before connecting them to the main DC bus (Fig. 1). By this addition of the DC/DC converters, the state values of the energy conversion sources become completely decoupled from each other and from the state values of the grid. The power production of the different sources becomes now freely controllable without affecting the state values of the grid.

Decoupling the state values means that the variations of the renewable resources like the velocity of the wind and the intensity of the solar radiation will not influence the state values of the electrical grid. These values are only controlled by the inverter. On the other hand, changes in the loads, which influence the state values of the grid, will not affect the generation side.

In order to meet the energy requirements of isolated consumers, the stand-alone PV/wind system, similar to the one of Fig.1, is proposed. It consists of a PV generator, a wind generator, a battery storage system, a DC/DC converter, an AC/DC converter, a DC/AC inverter able to meet the consumption peak load demand and an uninterruptible power supply (UPS) used to stabilize the wind turbines output as well as to protect the sensitive devices from undesired power fluctuations. The proposed configuration permits to the energy produced by the wind generator to be sent directly to consumer via the UPS and the energy surplus is transformed to DC current and it is subsequently stored in the batteries.

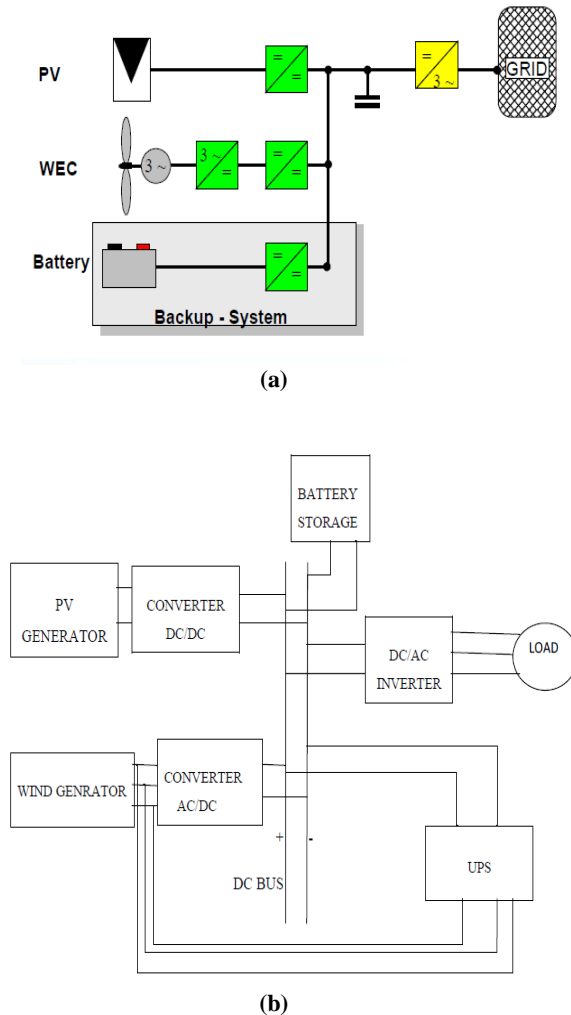


Fig1: Schematic diagram of Hybrid PV/Wind system with battery storage

III. MODELLING OF THE HYBRID PV/WIND SYSTEM COMPONENTS

Modelisation is an essential step before any phase of optimal sizing. Various modeling techniques are developed, to model HPWS components, in previous studies. For a hybrid PV/wind system with storage battery, as shown in Fig.1, three principal subsystems are included, the PV generator, the wind turbine and the battery storage. A methodology for modeling HPWS components is described below.

A. Modeling of PV generator

As the operation and the performance of PV generator is interested to its maximum power, the models describing the PV module's maximum power output behaviours are more practical for PV system assessment.

For estimating the power output of PV modules a mathematical model is used. The estimation is carried out using a computer program which uses a subroutine for determining the power output of a PV module. Using the solar radiation available on the tilted surface, the ambient temperature and the manufacturers data for the PV modules as model inputs, the power output of the PV generator, P_{pv} can be calculated according to the following equations[11]

$$P_{pv} = \eta_g N A_m G_t \quad (1)$$

Where,

η_g is the instantaneous PV generator efficiency,

A_m is the area of a single module used in a system (m^2),

G_t is the global irradiance incident on the titled plane (W/m^2) and

N is the number of modules.

All the energy losses in a PV generator, including connection losses, wiring losses and other losses, are assumed to be zero. The instantaneous PV generator efficiency is represented by the following equation [12]

$$\eta_g = \eta_r \eta_{pt} [1 - \beta_t (T_c - T_r)] \quad (2)$$

Where

η_r is the PV generator reference efficiency,

η_{pt} is the efficiency of power tracking equipment which is equal to 1 if a perfect maximum power point tracker is used,

T_c is the temperature of PV cell ($^{\circ}C$),

T_r is the PV cell reference temperature and

β_t is the temperature coefficient of efficiency, ranging from 0.004 to 0.006 per $^{\circ}C$ for silicon cells.

Based on the energy balance proposed by the PV cell temperature can be expressed as follows:

$$T_c = T_a + \left(\frac{NOCT - 20}{800} \right) G_t \quad (3)$$

Where

T_a , is the ambient temperature ($^{\circ}C$),

NOCT is the nominal operating cell temperature

Consequently, the instantaneous PV generator efficiency can be expressed as follows:

$$\eta_g = \eta_r \eta_{pt} \left\{ 1 - \beta_t (T_a - T_r) - \beta_t G_t \left(\frac{NOCT - 20}{800} \right) (1 - \eta_r \eta_{pt}) \right\} \quad (4)$$

η_{pt} , β_t , NOCT, A_m are parameters that depend on the type of module, and given by the manufacturer of the modules

B. Modeling of wind generator

The speed of wind is described in terms of statistical methods ,as it is a random process. Generally the wind speed data were recorded at ground surfaces .The following equation is used to determine the wind speed at a particular hub height

$$V = V_{ref} \left(\frac{H}{H_{ref}} \right)^{\alpha} \quad (5)$$

Where

V is the wind speed at hub height H ,

V_0 is the wind speed measured at the reference height H_0 and

α is the power law exponent which varies with the elevation, the time of day, the season, the nature of the terrain, the wind speed and the temperature.

The wind speed distribution is assumed to be a weibull distribution. Hence the probability of wind speed during any time interval is given by [8]

$$f(v) = \left(\frac{k}{c} \right) \cdot \left(\frac{v}{c} \right)^{k-1} \cdot \exp \left[- \left(\frac{v}{c} \right)^k \right] \quad (6)$$

$$c_{bat}(t) = c_{bat}(t-1) + \left(p_{pv}(t) - \left(\frac{p_{load}(t) - p_{wg}(t)}{\eta_{inv}} \right) \right) \Delta t \eta_{cha} \quad (12)$$

2)Case2: when the battery is in discharging process, the energy discharged by the battery is given by the following expression:

$$C_{bat}(t) = c_{bat}(t-1) + \frac{1}{\eta_{dech}} \left(p_{pv}(t) - \left(\frac{p_{load}(t) - p_{wg}(t)}{\eta_{inv}} \right) \right) \Delta t \quad (13)$$

where

η_{dech} =Battery discharging efficiency which set equal to 1

η_{inv} =Inverter efficiency (in this study considered as constant and equal to 95%).

At any time, the storage capacity is subject to the following constraints:

$$C_{bat\ min} \leq C_{bat}(t) \leq C_{bat\ max}. \quad (14)$$

Where

$C_{bat\ max}$ and $C_{bat\ min}$ are the maximum and minimum allowable storage capacity.

$C_{bat\ n}$ = Storage nominal capacity

$C_{bat\ min}$ = Minimum allowable storage capacity can be determined by

$$C_{bat\ min} = DOD.C_{batn} \quad (15)$$

where DOD (%) represents the maximum permissible depth of battery discharge. Here it is taken as 50%

IV. MODELING OF SYSTEM RELIABILITY

Loss of power supply probability (LPSP) : It is defined as the long term average fraction of the load that is not supplied by a stand alone system.

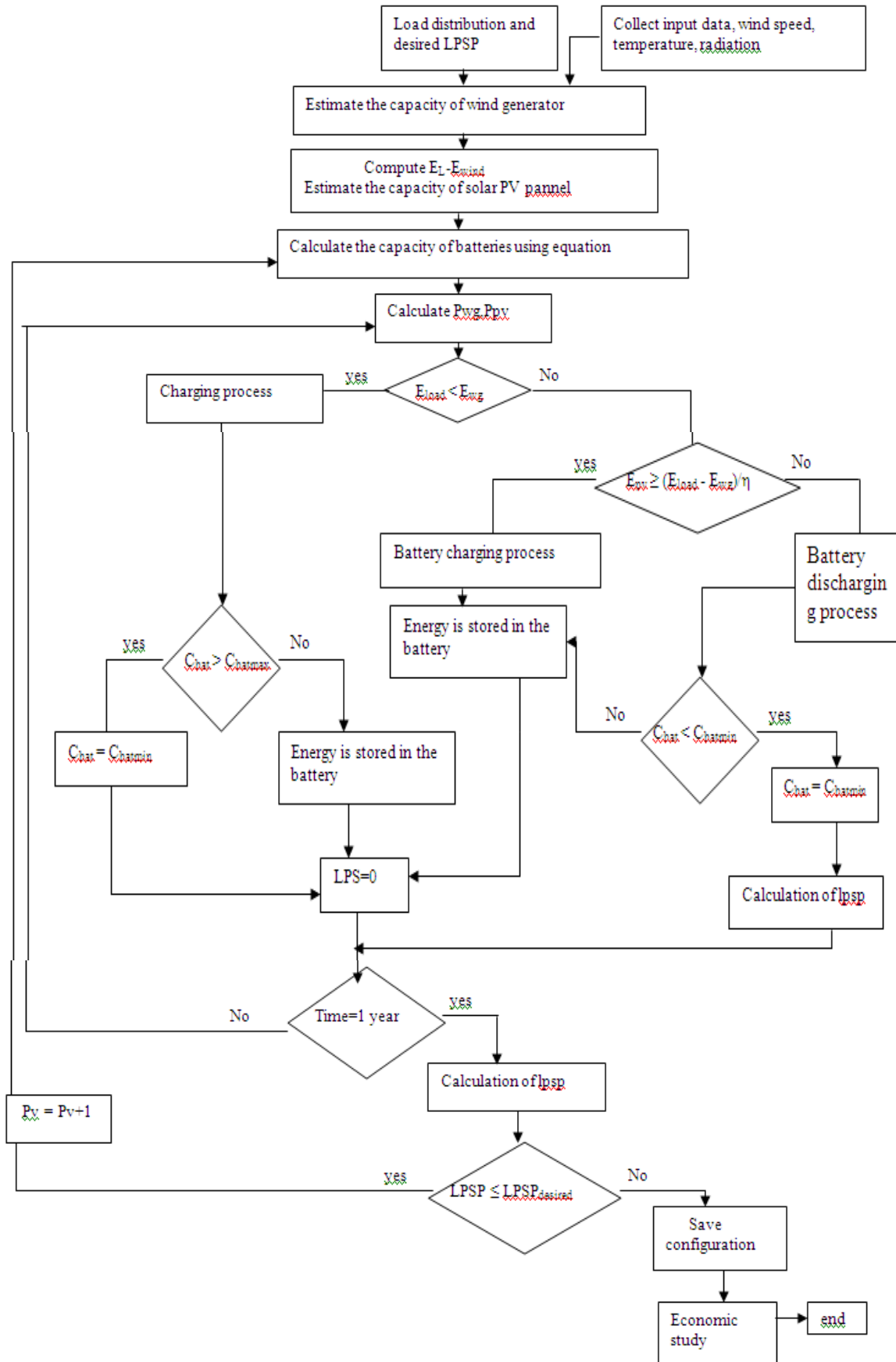


Fig 2: Flow chart for Optimal sizing of HPWS

LPSP of 0 means the load will be always satisfied , and the LPSP of 1 means the load will never be satisfied

The LPSP technique is a technical implemented criterion for sizing and evaluating an Hybrid Photovoltaic Wind System with storage batteries. In this study, the technical model for hybrid system sizing, based on the LPSP concept, is developed During the system operation, the following situations appear:

A. Case 1:

The output power of the wind generator, is greater than the power demand ($P_{wg} \geq P_{load}$).

In this case, the energy surplus ($P_{wg} - P_{load}$) and the energy generated by the PV generator (P_{pv}) are stored in the batteries. The storage capacity of batteries is calculated using Eq. (11). If the battery storage is maximum ($C_{bat} \leq C_{max}$) the residual energy is forwarded to low priority loads.

B. Case2:

The wind generator output power demand is lesser than the power demand ($P_{wg} < P_{load}$).the energy deficit ($P_{load} - P_{wg}$) is covered by the PV generator If this precondition is not fulfilled ($P_{pv} \leq (P_{load} - P_{wg})/\eta_{inv}$) then the energy deficit is covered by the batteries under the condition $C_{bat} = C_{bat.min}$ and the amount of energy discharged by the battery using Eq.(10)

In case the energy generated by PV and wind generators and stored energy in batteries is insufficient to satisfy the energy load requirements at any time t , then there is a deficit of energy which results in power loss .The loss of power supply LPS(t), can be expressed as follows:

$$LPS(t) = (P_{load}(t) - P_{wg}(t))\Delta t - (P_{pv}(t)\Delta t + C_{bat}(t-1) - C_{bat.min})\eta_{inv} \quad (16)$$

In the above two cases the battery stops discharging or charging process when it reaches a minimum or maximum value respectively.

The ratio of all LPS(t) values to the total load required during a period T (1 year for this study) defines the LPSP. This can be defined as[4]

$$LPSP = \frac{\sum_{t=1}^T LPS(t)}{\sum_{t=1}^T P_{load}(t) \Delta t} \quad (17)$$

T is the operation time

V. DETERMINATION OF THE OPTIMUM NUMBER OF BATTERIES AND PV MODULES BASED ON THE ECONOMIC APPROACH

The number of photovoltaic modules and the number of batteries are determined based on the desired LPSP. To obtain minimum cost of the system it is necessary to determine pv/battery combination . The initial cost of the system can be defined as [6]

$$IC = \alpha \cdot N_{pv} + \beta \cdot N_{batt} + c_0 \quad (18)$$

Where

IC-initial capital of the plant

α - cost of the PV module

β - cost of a battery

c_0 - the total constant costs including the cost of design , installation, wind turbine etc

The condition to obtain optimum solution is

$$\frac{\partial N_{pv}}{\partial N_{batt}} = -\frac{\beta}{\alpha} \quad (19)$$

VI. ECONOMICAL MODEL

Levelised cost of energy(LCE): It is the ratio of the total annualized cost of the system to the annual electricity delivered by the system . it is given by

$$LCE = (PVC.CRF)/E_{load} \quad (20)$$

Eload is the yearly output in kWh,

PVC the total present value of actual cost of all system component and CRF the capital recovery factor,

CRF can be expressed as follows

$$CRF = d(1+d)^T / ((1+d)^T - 1) \quad (21)$$

where,

d is the annual discount rate,

T is the system life in years,
The present value of costs (PVC) can be calculated as follows:

$$PVC = IC + C_m + RC, \quad (22)$$

Where,
IC = Initial cost,
C_m = Present value of system life of maintenance costs of the hybrid system
RC= Present value of the replacement of parts of the installation costs.

The initial cost of the system consists of the components prices (wind generator including tower and controller, PV generator, battery bank, inverter), the cost of civil work, installation and the connections cables. In this study, the civil work and installation costs are taken as 20% of the price of wind generator (turbine+tower+controller) for wind part and 40% of price of PV generator for PV part.

The replacement cost mainly depends on the replacement of some parts of the installation. Since the wind generator and PV generator have the life of the system, their replacement costs can be considered as zero, while the batteries and the inverter must be replaced.

The present value of replacement cost can be determined as follows

$$RC = U_c C_n \sum_{i=1}^{N_{rem}} \left(\frac{1+g_1}{1+d} \right)^{(T_i/N_{rem}+1)} \quad (23)$$

C_n=Nominal capacity/power (battery/inverter), (Wh or W),
U_c =Unit cost (RS/Wh),
N_{rem}=Number of component (battery or inverter) replacements over T year
g₁=inflation rate of component replacement
The present value of maintenance costs (25 years of maintenance) of the hybrid system c_m expressed as

$$C_m = C_{m0} \left(\frac{1+i}{d-i} \right) \left[1 - \left(\frac{1+i}{1+d} \right)^T \right], \quad d \neq i, \quad (24)$$

Where,
i =Inflation rate for operations,
d =Interest rate,
T =System life in years (25 years).
C_{m0} =Maintenance cost in the first year.

C_{m0} is expressed as a fraction of the component cost. Here , it is assumed to be 1% of cost for PV generator and inverter and 3% of cost for wind generator. For battery storage, the annual maintenance cost is considered to be zero. The annual discount rate is considered as 8%

VII. RESULTS AND DISCUSSION

The presented analysis is applied to load distribution assumed at a place called Nekkanti in Andhra Pradesh it almost comes under Nallamalla forest where tribal people lives . it is located at a latitude of 16.9 and longitude of 79.98 . To install a hybrid photovoltaic wind system at this place it is necessary to collect the metrological data for one year . Here the metrological data for the year 2011 is collected. Wind speed

Solar radiation and temperatures are the input parameters. Fig 3. shows the monthly solar radiation, daily average wind speed and temperatures. The Wind energy & solar energy are assumed to be constant during the time step. The load is taken between 3.5kwh to 35kwh/day. The electrical loads are assumed to be light ceiling fan and an agricultural pump. In these areas during March and April peak loads are noted for agricultural pumps and the load is zero during June and July months and a load of 3.5kwh/day is assumed to be present during the months June and July

Here in this context the objective is mainly to analyze the hybrid photovoltaic wind system from the techno-economical point of view which is assumed to be installed at Nekkanti. The wind generator rating is chosen based on wind potential/month. . The wind potential is obtained by plotting wind density function curve for every month in a year using weibull distribution.

From the results obtained by simulation, the wind generator rating is chosen to have a Energy potential of 40kwh/month. As per the load requirements the difference energy is generated by pv modules. Here pv modules rated 75w is used .A battery of 36AH is used. The system components specifications, ratings, prices and their lifetime is given in Tables I,II,III respectively. As per economic point of view for optimal sizing the no of pv modules and number of batteries

are obtained using equation (19) The simulation results shows to get the desired LPSP i.e., zero and to have minimum LCE three pv modules and two batteries are needed .The present value of cost is Rs. 2,02,540/-The cost/kwh by considering the average energy generated for 25 years is Rs.3.35/- i.e., nearly Rs.3.5/-

Table I. SYSTEM PARAMETERS its SPECIFICATIONS

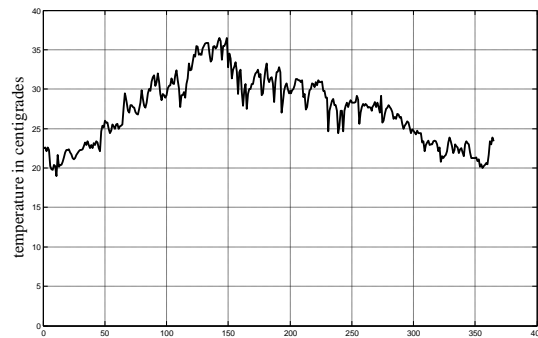
s.no	Parameters and its specifications
1	Battery DOD - 0.5
2	Silicon module efficiency - 13%
3	General inflation rate - 7.5%
4	Discount rate - 20%

Table II. COMPONENTS RATINGS and THEIR PRICES

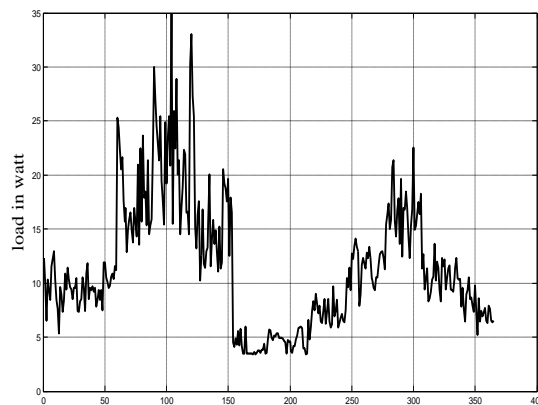
s.no	Parameters	Life time (in Years)
1.	Wind Generator	25
2.	PV Module	25
3.	Battery	7-8
4.	Inverter	10

Table III. COMPONENTS and its LIFETIME

s.no	parameters	ratings	Cost (in rupees)	Cost (in \$)
1	Pv modules cost	75 W	6225	-
2	Wind generator	400 KWH/month	50000	895
3	Lead acid battery	36AH	10200	97



day



day

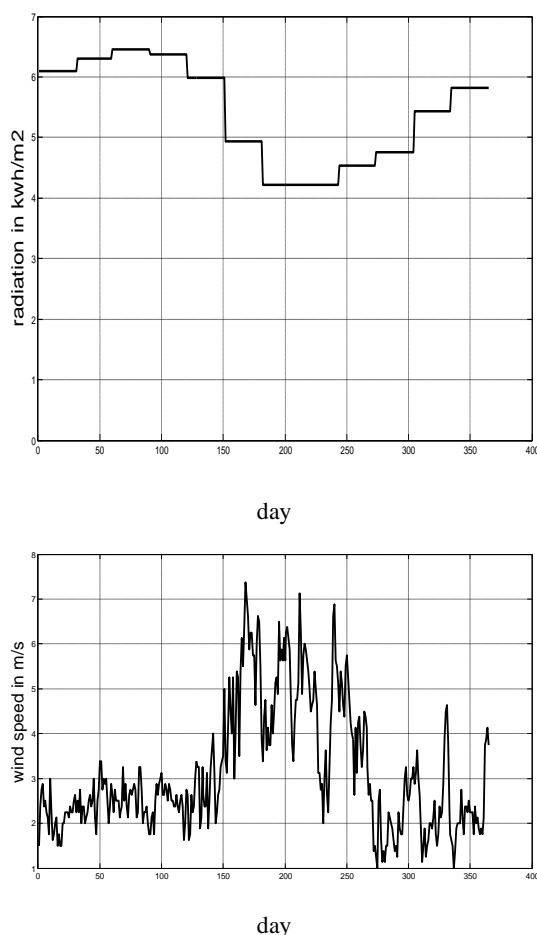


Fig3: Temperature,Load,Radiation,Wind speed at Nekkanti for the year 2011

VIII. CONCLUSION

The optimal sizing of autonomous hybrid PV/wind system with battery storage, using an optimization model can be obtained in terms of a system power supply reliability requirement by using the LPSP concept. The one with the lowest levelised cost of energy is considered as the economical optimal configuration.

It can be concluded that:

1. The optimal configuration system size depends on the available wind and solar potential at a site.
2. In india due to the adequate available of potential and solar energy the LCE of using HPWS is found to be economical.
3. It is very economical to install this plant in rural areas as the cost of transmission lines is deducted
4. The ratings of wind generator depends on the wind potential at a particular site
5. The ratio of number of pv modules and batteries depends on its cost ratio
6. The optimal configuration depends on the LPSP. When the desired LPSP is less then the LCE cost raises.

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