Optimal Sizing an SPV/Diesel/Battery Hybrid System for a Remote Railway Station in India

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Abstract- The grouping of the diesel generators with a battery storage and Solar Photovoltaic (SPV) at remote-area-railway station can overcome the inconvenience due to unavailability of power at such places to a great extent. This paper presents the development of a methodology for calculation of the sizing and optimization of a stand-alone SPV/diesel/battery hybrid system proposed for a small railway station. This approach uses three types of improved versions of particle swarm optimization algorithm to minimize the system cost including cost of available devices, and to determine the optimal sizing of SPV array, storage battery and diesel generator in terms of its size and cost. The hybrid system is analysed after the calculation of hourly data of solar radiation, by collection of sunshine hour and ambient temperature to the site of Khutwasa railway station near Seoni Malwa, Central India. Such work is helpful for designing reliable hybrid SPV/diesel system for any small railway station at a minimum cost, as indicated by the results.

Keywords- Solar Radiation, Hybrid System, Solar PhotoVoltaics, Diesel Generator, PSO, Railway Station.

1. Introduction

Solar energy systems can be considered as promising power generating sources due to availability and topological advantages for local power generations in remote areas railway stations in India. The Solar PhotoVoltaic (SPV) source of energy is inexhaustible, free from pollution fumes, and has no moving parts. The hybrid systems have been considered as attractive and preferred alternative sources for remote systems such as radio telecommunications, satellite earth stations, or at sites that are far away from a conventional power system, [1,2,3].

Currently, most of remote areas railway stations of India are electrified using stand-alone diesel generators, since they provide close to grid equivalent power supplies. In such type of electrification, for light and fan application at small railway stations the major problem faced by power generation using diesel generators is the sever fluctuation; while the diesel generator should have enough capacity to fulfil the required load although this load is required to be fulfilled only for a small portion of its operational time. Maximum efficiency of diesel generators is obtained when they are allowed to run at around 85% of their rated capacity also they become less efficient as the load decreases. Hence, such diesel generators which are sized to fulfil the required load run inefficiently for a large portion of their operating time. Wear and related maintenance needs of diesel generators also increase along with bad efficiency while they run at low loads, and with the decrease of load. This effect can reduce their operating life up to 50% [4]. Besides, the diesel generator is regarded as a source of sparse reliability. Major problem with use of the stand-alone diesel generator can be surmounted by bringing together the diesel generator with a renewable energy source such as photovoltaic and battery storage. This hybrid system will have the combined advantages of a diesel generator with a that of an SPV system, from economy and reliability point of view [1,4,5]. The largely familiar arrangement of hybrid systems SPV/Battery/Diesel standalone system is shown in fig 1. At places where all time availability of supply is required, this configuration is generally employed, also because using SPV alone in such cases will be a costly affair, it is advantageous in small railway stations where diesel generators previously dominated are already available.

Therefore even with the high initial costs of diesels, the addition of SPV modules, batteries, and controller will, to a great extent perk up the efficiency of DG as well as significantly lower the running cost of the system. Also, a diesel generator will eliminate the requirement of oversized SPV arrays, which otherwise will be costly as well as poorly utilized. Therefore Such renewable sources which are expensive in their installation costs, hybrid systems which include renewable energy sources with diesel generators often have a less overall cost than renewable or diesel only system.

Several optimization techniques for hybrid systems with energy storage have been studied in the literature. A simulation tool called SimPhoSys is developed by Schmitt [6] to simulate the performance of SPV systems, this tool is modular and flexible, model blocks integrated in Simulink library. They have considered initial and O&M cost but many other factors are to be taken care of like minimization of non utilized energy, maximization of efficiencies of all components . LingFang, W. [7] suggested a stand-alone hybrid generating system designed by combining different unconventional power sources including wind, solar, and storage systems. The optimal combination of size and storage is a complex mixed-integer combinatorial optimization problem. The optimum system configuration is derived by using a modified particle swarm optimization (PSO) algorithm. L. Zhang etal [8] have described the development of methodology for calculation of sizing and optimization of a stand alone hybrid system having wind, PV and diesel. They used DIRECT (a deterministic algorithm) to follow optimal combination of system components. The simulation results showed the number of PV arrays, wind turbines and batteries based on the minimum total cost of the system. Kourtroulis etal [9] presented an alternative methodology for optimal sizing of wind-pv. The decision variables are number and type of battery, pv panel and tilt angle, wind turbines & their height, battery chargers. The minimization of the cost (objective) function is implemented employing a genetic algorithm approach.

However all these methods are unable to achieve more accurate solutions due to non linear, complex and non convex characteristics of the hybrid system. Also they do not consider the existence of DG unit as back up power . In general, some of the models are not accurate, some models are using traditional optimization methods, but their calculation efficiency is lower. Some of the intelligent optimization algorithm used to solve these problems, improve the speed to a certain extent, but cannot avoid the possibility of the trap in the local minimum. In addition, some methods are only applicable to the constant load demand problems, which make the application of formula extremely limited. Particle Swarm Optimization (PSO) method of optimization based on evolutionary programming is used in many applications relating to power sources [1]. Some experiments have been carried out based on average weather data , and others, more precise, based on real weather data (insolation, wind speed, temperature, etc.) .

In this research work, an algorithm has been developed for calculating solar radiation and power at a given site and then for a stand-alone multi sources hybrid power system evaluation and cost optimization for a given land area. The costs include capital cost, replacement cost, operation and maintenance cost, fuel cost. Also economic aspects such as interest rate, subsidy, taxation rate, inflation, capital recovery factor, sinking fund factor have been expressed for each power sources are considered. Battery bank has been used to cover the emergency energy of the power system. The optimization problem is solved using PSO techniques which are Time Varying Acceleration Coefficients PSO (TVACPSO), Random Inertia Weight PSO (RANDPSO) and Exponentially Decreasing Inertia Weight PSO (EDPSO). The algorithm and simulation are carried out using Matlab software. Included in the study are the details of SPV modules, inverters & economic parameters. The control parameter, like the battery state of charge (SOC), is also taken into account. Comparison of results obtained by three types of modified PSO algorithm on MATLAB platform is done. This paper is structured as- introduction is given in first section, section II presents methodology (modelling of solar radiation followed by estimation of solar photovoltaic power), after which section III discusses about proposed model, followed by section IV which discusses system operation strategies, section V gives brief idea about PSO, next section VI deals with optimization procedure of system, section VII gives results & discussion followed by section VIII which is conclusion.

2. Methodology of SPV/Battery/Diesel Hybrid System Optimal Sizing

The important aspect of optimal sizing problem of a hybrid system is the formulation of practical problem in a standard mathematical optimization format which is acceptable to the optimization algorithm. Before planning for installation and operation the pre-sizing study of system is done, for which climatic condition of application site, availability of average insolation of the site are included in this study. The problem is not new and has been treated by few authors. However since unfortunately, no meteorological stations available in every location of India to measure the amount of intercepted solar radiation. So an alternative method for estimation of solar radiation is required. This approach as first part proposes analysis and estimation of solar insolation at any location. The methodology of work can be described as a succession of following basic steps :

1. Calculation of hourly insolation on a horizontal surface for all hours of an ’average day’ having the same daily global irradiance as the monthly average. This is achieved through the use of classical formulae first derived by Erbs, Collares-Pereira and Rabl, and Liu and Jordan [12]

2. Calculation of hourly values of global irradiance on the tilted surface for all hours of the day. This is done through algorithm inside the PSO algorithm on the MATLAB platform and other tools.

3. Determination of maximum power delivered by proposed SPV system and BOS, this is summed up, to obtain the total annual power.

4. Find out power dispatch strategy among SPV-B-D, during 24 hrs of a day.

5. Obtain the optimal values of PSO variables, viz number of modules, number of battery and rated capacity of DG required, from these data other BOS requirement can be calculated.

6. Obtain minimum total cost required.

To size any SPV hybrid system, it is essential to have accurate information about environmental conditions and the best available radiation data for the intended site [11]. The models developed play an important role in the sizing of the hybrid system and are studied using an hourly time step *(*δt = 1 h) for a period of one year.

Figure 1 depicts the common configuration of SPV-B-D hybrid system, SPV modules are connected to power conditioning unit (PC) and battery bank (BB), through battery charger (BC), battery charger takes care of charging limits of battery bank. Diesel generator (DG) is directly connected to load and bidirectional inverter is connected in between , mainly to convert DC to AC to feed the load.

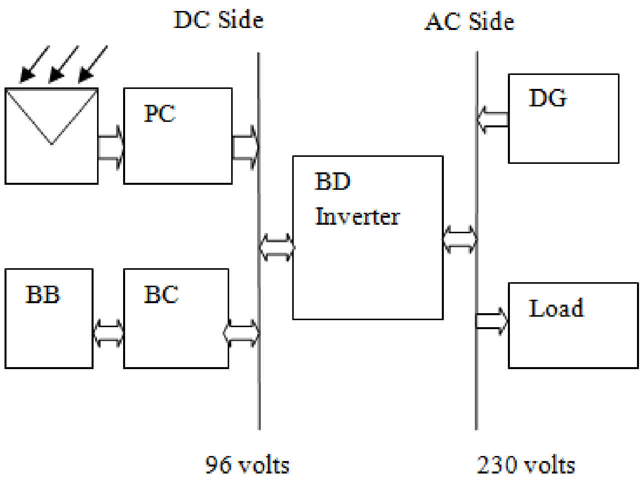

Fig. 1. Common Configuration of Hybrid Systems

2.1.1. *Sizing of the diesel generator*

Diesel generator system design simply involves selecting a locally available unit that is closest to the peak load requirements of the application. Where, the diesel generator operates most efficiently when running between 80-90% of its rated capacity and become less and less efficient as the load decreases. Therefore, to optimize the diesel generator operation during the selected period, it is selected to be loaded, in this case, with 85% of its rated power. Diesel generator has typically a maximum fuel efficiency of about 3 kWh/l when run above 80% of it's rated capacity. When Diesel Generator is run at loads below 30% of its rating, the fuel efficiency becomes very low [9,10]. Eq. (1) shows the fuel consumption cost for 1 h of running of the diesel generator.

$$F(t) = \left(0.246P_{dg(t)} + 0.08415P_{(dg)}\right) \quad (1)$$

The choice of diesel generator depends on type and nature of the load. To determine rated capacity of the diesel generator to be installed, following two cases should be considered [11]:

1.If the generator is directly connected to load, then the rated capacity of the generator must be at least equal to the maximum load, and

2. If the diesel generator is used as a battery charger, then the current produced by the generator should not be greater than C_bAh/5A, where C_bAh is the ampere-hour capacity of the battery.

In this work, we have considered the diesel generator to be directly connected to the load.

2.1.2. *SPV system sizing*

The performance of SPV system is affected by the solar radiation, environmental temperature and the characteristic of the SPV modules. For practical applications, certain number of SPV modules need to be connected to obtain the voltage demand and power demand of the consumers. The SPV panels are connected in series to form strings, where the number of panels to be connected in series *Ns* is determined by the selected DC bus voltage ($V_{\_bus}$). The number of PV modules for parallel connection determines the capacity of the SPV arrays.

- *Determination of the tilt angle and direction of modules*

In this case, the array inclination is proposed to set at 23^{o} from horizontal and facing the south direction, to maximize the incident global radiation on the array during the worst month (here, Dec.).

- *Determination of the Solar Radiation*

Since the primary requirement for the design of any solar power project is accurate solar radiation data, it is essential to know the method used for measuring data for accurate design. Data may be instantaneously measured (irradiance) or irradiation (integrated over a period of time usually one hour or day). Data maybe for beam, diffuse or total radiation, and for a horizontal or inclined surface.

Here a new method to find out the monthly averaged hourly solar radiation on horizontal and tilted surface is presented. First extraterrestrial solar radiation is calculated, which is different from radiation reaching earth, because of atmospheric effect of absorption and scattering etc. Values of clearness indices are determined from the solar radiation on the Earth's surface and calculated extraterrestrial solar radiation during those days with clear skies within a duration of few years.

As per Ashare calculation [12]

$$I_t = I_g * \left[r_t * \{1 - \left(\frac{I_d}{I_g}\right)\} \right] + \left(I_d * \frac{r_d}{I_g} \right) \quad (2)$$

The total instantaneous solar radiation on a horizontal surface 'I_t' is in expressed as the sum of the direct (beam) solar radiation on a horizontal surface 'I_b', and the diffuse solar radiation on a horizontal surface 'I_d'.

The declination angle 'd' and sunset hour angle 'w_s' for each day of the year can be calculated by using eq. (2) and (3) Monthly average daily solar radiation on a horizontal surface is represented as H_{ga}, and hourly total radiation on a horizontal surface is represented by I_g , where n is the day number counted from the 1st of January.

$$d = 23.45 * \left[\sin\{360 * \frac{(284+n)}{365}\} \right] \tag{3}$$

$$H_{ga} = \frac{[\ H_{oa} * \left(a + b * \left(s_a / s_{max} \right) \right)]}{1000} \tag{4}$$

where H_{ga} is the monthly average daily global solar radiation on horizontal surface in MJ/m^2.day. and S_{max}, H_{oa} , w_s and w_{st} are given as

$$s_{max} = (2/15)*(w_{st}) \tag{5}$$

$$H_{oa} = \left(\frac{24}{\pi} \right) * S * \left[1 + 0.033 * \cos\left(\frac{360n}{365} \right) \right] * [w_s * \sin L * \sin d + \cos L * \cos d * \sin w_s] \tag{6}$$

$$w_s = \cos^{-1}[-\tan(L) * \tan(d)] \tag{7}$$

$$w_{st} = \cos^{-1}[-\tan(L - A) * \tan(d)] \tag{8}$$

Clearness index is given as $K_T = H_{ga} / H_{oa}$ (9)

$$H_{da} = H_{ga} * (1.311 - 3.022 * K_T + 3.427 * K_T^2 - 1.821 * K_T^3) \tag{10}$$

where H_{da} is the monthly average daily diffuse solar radiation on horizontal surface. This equation holds true for value of K_T between 0.3 and 0.8 and value of w_s greater than 81.4 degree

$$t = s_t - [4 * \{L_s - L_o\}] + E \tag{11}$$

t is local apparent time

$$w = 15 * (12 - t) \tag{12}$$

here w is the hour angle

The I_b, and I_d, depend on the day of the year, the time of day, the equation of the time, the local Standard Meridian for the location, the latitude and longitude, and the weather conditions. The predicted values for the total I_t, direct I_b, and diffuse I_d, solar radiations on a horizontal surface are required for determining the total solar radiation I_t on the surface of a tilted SPV panel, with the tilt angle kept equal to latitude of the site. Azimuthal angle we have taken as zero because panels are due south.

- *Estimation of SPV power*

The design and analysis of photovoltaic modules require a tool that can predict the behaviour of photovoltaic generators under various weather conditions. The following procedure utilizes the basic solar equations and experimental models to estimate the amount of solar radiation falling on the PV arrays tilted with some angle with the horizontal.

To calculate the annual total electricity production from a PV system, we have

$$E_{out} = \eta_{inv} * \eta_{mppt} * \left(\Sigma \frac{P_m}{1000} \right) * \delta t \tag{13}$$

$$P_m = (V_{oc} * I_{sc}) * FF \tag{14}$$

$$FF = \frac{V_m * I_m}{V_{oc} * I_{sc}} \tag{15}$$

$$I_{sc} = [I_{sc}(stc) + K_i (T_c - 25)] * \frac{G}{1000} \tag{16}$$

$$V_{oc} = V_{oc}(stc) + K_v [T_c - 25] \tag{17}$$

$$T_c = T_a + \left(\frac{NOCT - 20}{800} \right) * G \tag{18}$$

Where E_{out} is the annual total electricity production (kWh), η_{inv} and η_{mppt} are inverter and MPPT efficiencies (mean power conversion efficiency coefficient for each PV technology) and δt is time step of simulation.

- *Determination of the number of series and parallel connected modules*

The number of modules Ns, which are to be connected in series string, is directly determined by the DC operating bus bar voltage and the peak-power voltage of the available module Vmp, as:

Maximum number of modules in series = round down [Vdc max(of inverter)/Voc)] (19)

number of modules in series Ns = Ns_{max} (20)

where $Ns_{max} < (P_{max} / P_{mmax})$ (21)

Maximum number of strings in parallel (Np) = inverter max dc input/max current of each module (22)

N_group = Ns * Np (23)

Number of inverters =Total number of PV modules (n_mod)/ (n_group) (24)

Total number of PV modules in a string (of a row) (n_mod_l) = floor [available length of the space/length of a module] (25)

Optimal shading distance = max of shading distance calculated for 24 hrs* 365days, by following geometrical relation

$$Dsh = (\text{width of pv module} * \sin(A) * n\_l) * \frac{[\sin(L) * \cos(d) * \cos(w(st))](\cos(L) * \sin(d)]}{[\sin(L) * \sin(d)) + (\cos(L) * \cos(d) * \cos(w(st))]} \tag{26}$$

- *Sizing of the Storage system*

Batteries in SPV systems operate under specific conditions which must be allowed for in the system design, as they affect both battery life and the efficiency of the battery operation. The most prominent feature is cycling with various cycles of different degree of regularity. Also, superimposed on the daily cycle is the climatic or seasonal cycle, due to the variable climatic conditions. Since, the energy deficiency will occur anytime when the load exceeds the energy supply from the array, thus the daily and seasonal energy deficiency can be calculated.

It must ensure, here, that the excess energy generated and not used during the sunshine periods must be stored. This analysis determines the charge/discharge percentage of the battery that usually cannot exceed a given value for safe operation.

The difference between power generated by SPV source and load demand, decides whether the battery bank is in charging or discharging state. During the charging process and discharging process of the battery bank, the battery state of charge (*SOC*) at the hour *t* is accumulated as follows [13]:

$$SOC_t = SOC_{(t-1)} * \left(1-\delta_{bat(t)}\right) * \eta_{bat} + P_{b(t-1)} \tag{27}$$

where the hourly self-discharge rate ($\delta_{bat(t)}$) is assumed to be zero since it is only 0.007% for 1 h and the battery round-trip efficiency (η_{bat}) is considered to be 0.8 and 1, respectively, during the charging process and the discharging process of the battery bank.

The value of *SOC* could not be lower than its allowable minimum limit (SOC_{min}), and it could not be higher than it has an allowable maximum limit (SOC_{max}) during charging operation. These conditions are considered the constraints under battery banks operation [13,14].

$$SOC_{min} \le SOC_t \le SOC_{max} \tag{28}$$

For longevity of the battery bank, the maximum charging rate (SOC_{max}) is given as the upper limit, and it takes the value of total nominal capacity in Ah of the battery bank which is defined by the total number of batteries (*n_bat*), and the nominal capacity of each battery ($C_b$in Ah), as follows [14]:

$$SOC_{max} = C_b * n\_bat \tag{29}$$

The minimum permissible state of charge (SOC_{min}) of battery bank during discharging may be expressed as follows[14]:

$$SOC_{\min} = n\_bat * C_b(1-DOD_{\max}) \tag{30}$$

Where DOD_{max} is the maximum depth of discharge in percentage.

3. Proposed Model

An SPV/Diesel/battery system assumed to be installed in the site of Khutwasa (Near Seoni Malwa, Madhya Pradesh) in India with geographical coordinates defined as: latitude: 22°31,46”N, longitude: 77°35’9”E and altitude: 512 m above sea level and is proposed in order to meet the 100kW power demand of this remote railway station. The calculated data of average hourly solar radiation (from our Matlab program) were used and are plotted in Fig. 2.

The specifications and the related capital as well as maintenance costs and installation costs of the SPV panels and the battery banks are listed below. These elements constitute the inputs of the optimal sizing procedure.

A. Specification of selected devices

(1) SPV module characteristics :

- V_{oc} = 29 volts
- Vm = 23.4 volts
- P = 150 watts (rated power at STC)
- Cost of module = 28325 Rs
- Maintenance cost = 238.25 Rs/yr
- Length of module = 1.29 m
- Width of module = 0.99 m

(2) Inverter characteristics :

- Inverter efficiency = 95.3%
- MPPT efficiency = 100 %
- Pmax = 12 kW
- Minimum input voltage = 335 volts
- Maximum input voltage = 560 volts
- Cost of inverter = 165440 Rs
- Maintenance cost of inverter = 2475 Rs

(3) Battery characteristics :

- Rated capacity of one battery = 1153 Ah
- Type of battery = Lead-Acid battery
- Efficiency = 85 %
- Depth of discharge = 0.8
- Number of replacements of battery & battery charger in system lifetime = 2
- Cost of battery charger per unit (5kW) = 25900 Rs

(4) Diesel Generator characteristics :

- Fuel price = 55 Rs/lt
- Capital cost of the diesel generator = 22,250 Rs/kW.
- Maintenance cost = 22 Rs/h

The lifetime of the whole system is assumed equal to the lifetime of the PV system which has a longer lifetime of 20 years. The lifetime of the battery bank and the diesel generator are to 4 years and 7486 hours respectively. The minimization of the system total cost is achieved by selecting an appropriate system configuration.

4. System Operation Strategies

The power output of SPV panel is given by

$$P_{tot}(t) = \eta_{inv} * P_{pv}(t) \quad (31)$$

in which P_{tot} is the hourly power produced by the renewable resource (SPV panels) through the inverter and η_{inv} is the DC/AC converter efficiency (%) specified by the manufacturer.

The power generated by the hybrid system and the amount of energy stored are time dependent. So, the power supplied to the load is controlled by the following equations

If value of $P_{pv}(t)>P_L$, remaining power will charge battery

$$P_{pv}(t) = (P_L / \eta_{inv}) + P_b(t) \quad (32)$$

If $P_{pv}<P_L$, and battery has enough power to supply remaining power while DG off

$$P_L = P_{tot}(t) + P_b(t) \quad (33)$$

If battery is unable to supply then DG is started

$$P_L = P_{tot}(t) + P_b(t) \quad (34)$$

If power from DG exceed the load demand then it is used to charge battery also

$$P_L = P_{dgmin} + P_{tot}(t) - P_b(t) \quad (35)$$

If load demand is more than DG capacity then Dg with full capacity along with battery will make the difference

$$P_L = P_b + P_{tot}(t) + P_{dg}\, full \quad (36)$$

5. General Idea About PSO

Particle swarm optimization is an interesting and intelligent computational technique for finding global minima and maxima with high capability for multimodal functions and practical applications. It does not require good initial solutions to start its iteration process. The particle moves towards an optimum solution through its present velocity and its individual best solution obtained by itself in each iteration and global best solution is obtained by all particles. In a physical dimensional search space, updated position and velocity of the 'ith' particle are represented as

$$v_i^{k+1} = K[v_i^k * \omega + C_1 * R_1 * \{p_{best}(i) - x_i^k\} + C_2 * R_2 * \{g_{best} - x_i^k\}] \quad (37)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (38)$$

Where $x_i = [x_{i1}, x_{i2}, ------------ x_{id}]$

$v_i = [v_{i1}, v_{i2}, -------------- v_{id}]$, here 1,2........d shows possible dimensions for i=1,2.....i particles with position 'x' and velocity 'v'

$p_{best}(i) = [x_{i1P\_best}, x_{i2P\_best} -------- x_{idP\_best}]$ represent individual best positions of particle i

$g_{best} = [x_{1G\_best}, x_{2G\_best}, ----------- x_{nG\_best}]$ represent the global best positions. k represents the iteration number for total n iterations.

ω is inertia weight, K is constriction factor, C_1C_2 are non negative coefficients called acceleration factors, R_1R_2 are two random numbers different from each other and generally distributed in the range [0,1].

In a simplified model taking into account only one dimension of particle p_{best} and g_{best} are combined into one single term, making convergence and divergence of a particle easy for some of the benchmark functions [1].

Suitable selection of ω provides a balance between global exploration and local exploitation reduces total number of iterations. Particle swarm optimization works well if maximum velocity is kept at value of dynamic range of each variable x_{max} [1].

6. Optimization Procedure

A. Objective function and constraints

The objective function taken here is the total annual system cost, obj (*x*) (Rs), which is equal to the sum of the total capital cost function AC*C* (*x*), the operation & maintenance cost function AO*M* (*x*) and the fuel cost function *AFC*(*x*) during the total life of the installation. The life of the system is assumed to be equal to the life of the PV panels that are the elements that have a longer lifetime. The objective function to be minimized is then, expressed as follows:

$$\text{ATC}(x)_{min} = [\text{ACC}(x) + \text{AFC}(x) + \text{AOMC}(x)]_{min} \quad (39)$$

where *x* is the vector of the sizing variables *x* = {*n_mod*, *n_bat*, *P_d*}, where *n_mod* is the total number of SPV modules, *P_d* is the rated capacity of diesel generator and *n_bat* is the total number of batteries.

Constraints are as follow

1) Power balance constraint For any period t, the total power supply from the hybrid generation system must supply the total demand P_L with a certain reliability criterion. This relation can be represented by :

$$(P_{PV} + P_{BAT} + P\_d) \geq P_L \quad (40)$$

2) The constraints of the number of PV modules and batteries and capacity of DG;

$$n\_mod, n\_bat, P\_d \geq 0 \quad (41)$$

3) The constraints of the capacity of batteries;

$$SOC_{min} \leq SOC_t \leq SOC_{max} \quad (42)$$

Where, minimum allowable battery capacity, which is determined by the maximum depth of discharging DOD , that calculated by

$$SOC_{min} \leq (1 - DOD) \leq SOC_{max} \quad (43)$$

7. Results

Results for optimal design for optimal design and power dispatch strategy for hybrid off-grid SPV system are discussed here. It includes the forecast of solar radiation data by various tools , and optimal power generation schedule of SPV-B-D system proposed for railway station of India using time varying acceleration coefficient PSO (TVACPSO), exponentially decreasing inertia weight PSO (EDPSO), random inertia weight (RANDPSO).

Program has been coded in MATLAB. The performance of algorithm has been checked using MATLAB 10.a on a core 2 duo, 2 GHz, 2.99 GB RAM. The convergence behavior of PSO for TVACPSO, EDPSO, RANDPSO in various trials is judged the two criteria first is the probability to get best solution or objective function (robustness), second is the solution quality. Parameter setting of PSO is shown in table I.

The predictions of insolation in the plane of the array on an annual basis are shown in figure 2 and are compared in Table II. It can be observed that 1) all tools under estimate the solar radiation in the plane of the array, 2) the PVSYST and synergy environment data have very similar data, 3) the RETScreen gives significantly higher mean bias error than MATLAB results.

The hourly output power (W/m^2)through SPV during sunshine hours for 12 months is shown is shown in figure 3. Figure 4 shows the available battery power during 24 hours of operation. Finally results obtained from all above variants of PSO are compared and are summarized in Table III .The optimization procedure resulted in the determination of the optimum numbers and of PV panels, DG capacity and of batteries, ensuring that the system total cost is minimized while guaranteeing the optimum availability of the energy. Figure 5 shows that EDPSO with population size 20 & maximum number of iteration 200 shows the early convergence & also best suitable objective function results comparatively. So this is selected as final optimal and economic solution. The obtained optimal configurations of this proposed hybrid system gives 90,25,00000 Rs total cost for 20-year (lifetime of the system) operation. As per optimal result from table III and as per equation (29) and (30) SOCmax and SOCmin will be 11674 and 3737 Ah respectively.

The stand-alone hybrid SPV-B-D system seems to be a motivating techno-economic solution to meet the energy demand of remote consumers in the site source which looks like these of the Khutwasa railway station site where the number of operating hours of the diesel generator has to be reduced.

The optimization procedure resulted in the determination of the optimum numbers and the types of SPV panels, DG and of batteries, ensuring that the system total cost is minimized while guaranteeing the optimum availability of the energy.

The stand-alone hybrid SPV-B-D system with battery bank seems to be a motivating techno-economic solution to meet the energy demand of remote consumers in the site like Khutwasa railway station where the number of operating hours of the diesel generator has to be reduced.

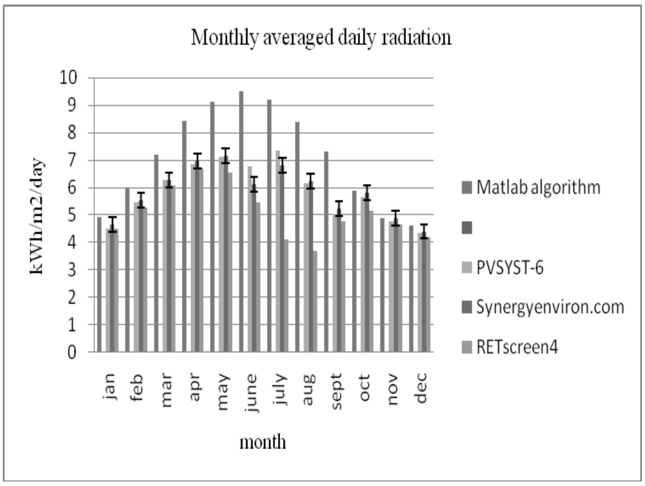

Fig 2. Solar radiation output at considered site

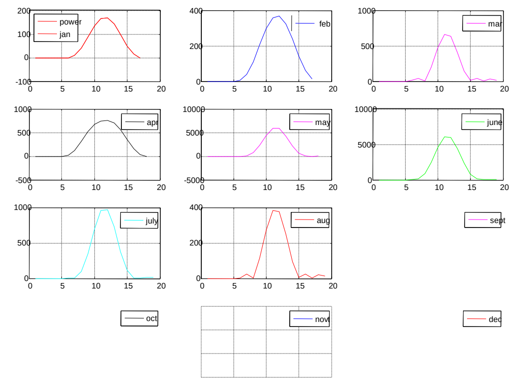

Fig. 3. SPV Power output during sunshine hours

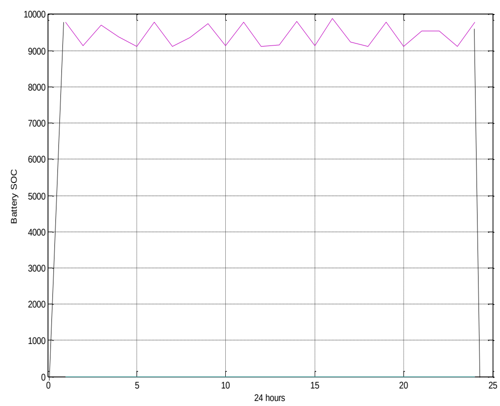

Fig. 4. Battery SOC in a day

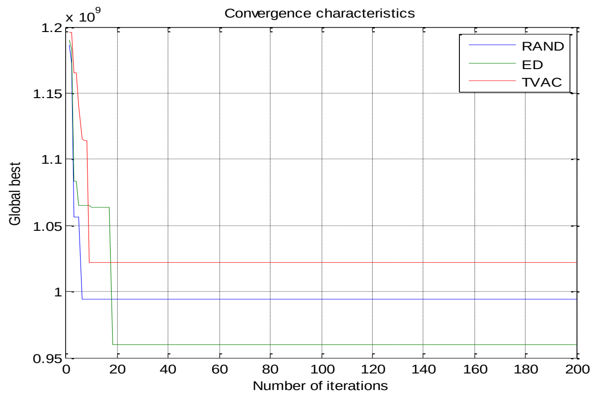

Fig. 5. Optimum value of Objective Function

Table 1. PSO Parameters Setting

Parameter	Value
Population size	20
Max no. of iteration	200
Acceleration Coefficients C1 & C2	2 ,2
$C_{1f}, C_{1i}, C_{2f}, C_{2i}$	0.5,2.5,2.5,0.5
$\omega_{min}, \omega_{max}$	0.4,0.9

Table 2. Relative error

Source	Average annual radiation (kWh/m^2)	Relative Error
MATLAB algorithm	7.117	N/A
RETScreen (PV)	5.088	28%
PVSYST	5.861	17%
Synergyenviron.com	5.840	18%

Table 3. Optimal number of devices and optimal costs as per PSO implementation result

	TVACPSO	RANDPSO	EDPSO
Population size	30	30	30
Maximum number of iterations	200	200	200
Global best fitness	$9.025X10^8$	$9.6X10^8$	$9.83X10^8$
Number of modules	488	467	493
Number of inverters	9	6	8
Nseries	19	19	19
Nparallel	2	2	2
Shadow distance between two rows (m)	3.62	3.61	3.62
ACC (Rs)	$26X10^6$	$18X10^6$	$2.4X10^7$
AOM (Rs)	9945	8562	9543
AFC (Rs)	160	160	189
Rated capacity of DG	36	39	27
Number of batteries	147	162	181

8. Conclusion

In this study, an Algorithm based on PSO and MATLAB platform is developed for the prediction of the optimal sizing of PV-B-D hybrid energy system in remote areas. The objective function for cost is constructed, which includes initial costs, yearly operating costs and maintenance costs. The hybrid system consists of photovoltaic panels, Diesel generator and storage batteries. Due to the complexity of nonlinear integral planning in hybrid energy systems, particle swarm optimization algorithm is used to solve this problem. By use of inertia eight PSO algorithm operation strategies, the global optimal searching ability of the proposed algorithm is further improved. The improved versions of PSO algorithm can avoid to the local minimum trap. The developed algorithm has been applied to design the SPV/diesel/battery hybrid energy system to supply 100kW load of a small railway station located in the area of Khutwasa, Madhya Pradesh (India). The optimal solution is achieved using proposed method and shows that the system can deliver energy in a stand-alone installation with an acceptable cost.

Obtained results shown clearly the great impact of the site energetic potential (solar radiation) as well as the load requirement on the optimal hybrid system constitution (numbers of PV panels, batteries and DG capacity) and the related cost of the hybrid system. Also, the use of longterm data of the renewable resources is very helpful to enhance the performances of the optimal solution.

A well-designed and optimized hybrid energy system can be cost effective, has a high reliability and can improve the quality of life in remote rural area railway station.

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