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Optimal sizing of grid-connected PV-systems using PSO

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Abstract: *This paper presents an ideal estimating calculation for a sustainable power source framework utilizing shrewd lattice load the executives application dependent on the accessible age. This calculation intends to augment the framework vitality generation and satisfy the heap need with least expense and most astounding unwavering quality. This framework is shaped by photovoltaic cluster as a reinforcement wellspring of vitality. Request profile forming as one of the brilliant network applications is presented in this paper utilizing burden moving based burden need. Particle swarm optimization is utilized in this calculation to decide the ideal size of the framework segment. The outcomes acquired from this calculation are contrasted and those from the iterative enhancement strategy to survey the ampleness of the proposed calculation.*

Keywords: *optimal sizing, Renewable Energy System, Positioning, Grid Integration, Demand Profiling*

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I. Introduction

In recent years, interest in renewable energy sources (RES) for power generation is progressively gaining significance in the entire world due to fossil fuel depletion, high cost, and increasing environmental concerns. Therefore, there is a big trend to use RES to address the power generation especially for the isolated or remote areas. Utilization of different RES with storage and backup units to form a hybrid renewable energy system (HRES) can give a more economic and reliable source of energy [1]. But, due to the non-linear response of system components and the random nature of RES and load profile, smart grid is utilized to suit and incorporate these units in order to move the power around the system as efficiently and economically as possible [2].

One of the most prominent aspects in the recent studies is to optimize the components of HRES to meet the load requirements with possible minimum cost and highest reliability. In view of the complexity of optimization of the HRES, it was imperative to discover effective optimization methods ready to get accurate optimization results. Particle swarm optimization (PSO) algorithm is recommended as a standout amongst the most valuable and promising methods for optimizing the HRES because of using the global optimum to locate the best solution [3].

PSO algorithm is designed based on swarm intelligence and used to handle the complex optimization problems [4]. Like other population-based optimization algorithms, PSO begins with a random initialization of particles in the search space. Every particle is invested with a random position and a random velocity at the beginning, and then adjusts its search patterns in view of its own experience and experiences of other individuals [5].Owing to its simplicity, effectiveness and low computational cost; PSO has gained significant popularity and improvements [6]. The optimization constraint was that the hourly energy demand must be satisfied by the amount of generated energy. A PSO algorithm was applied for optimum sizing of a hybrid energy system for supplying a certain load. The optimization objective was to minimize the system cost with the constraint of having specific reliability for the system.

II. Methodology

The algorithm's input is a database containing the technical and economic characteristics of commercially available devices along with meteorological data for the selected for the installation site and a series economic parameters. The economic characteristics of the system's devices are the installation and annual maintenance costs per unit [7].

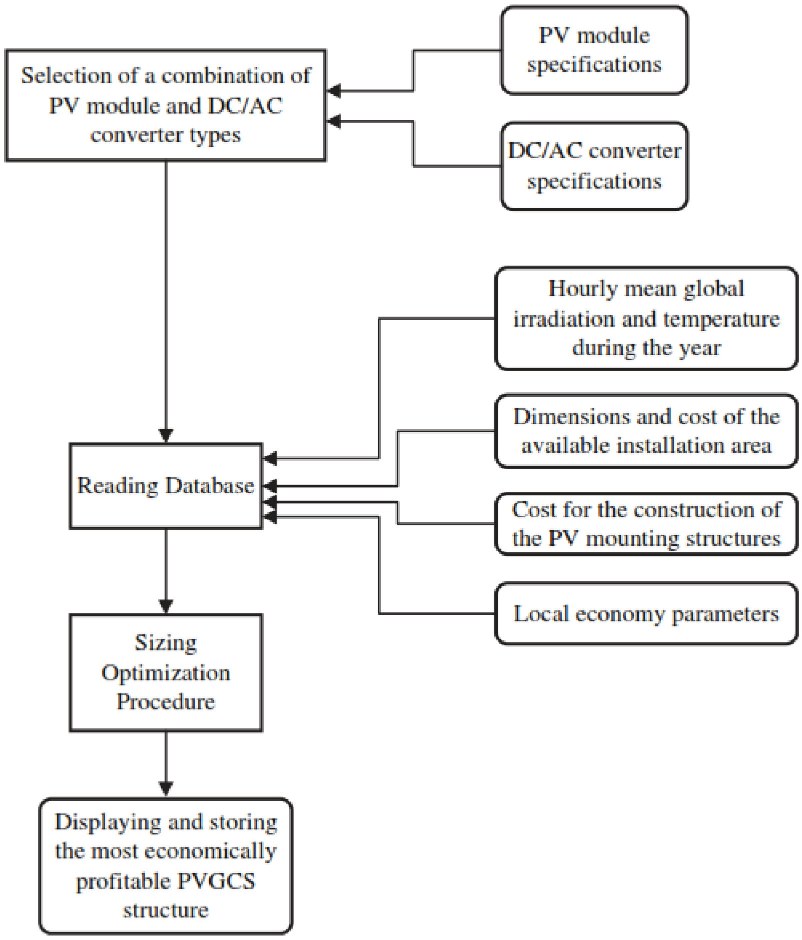
Initially a combination of devices (PV module and DC/AC converter) is selected and their characteristics are loaded from the database. The rest of parameters loaded from the database are the hourly solar irradiation and ambient temperature values during the year, the available area dimensions, the local economy's parameters and finally, parameters used for the computation of the cost of the land and the mounting structures of PV modules [8]

The next step is the sizing optimization procedure. This step is comprised of the PSO operands, as well as appropriate algorithms for handling the problem's limitations and evaluating the potential solutions. In case that a solution is infeasible a suitable repairing algorithm is applied [9]. The criterion of the objective function is the maximization of the PV SYSTEM total net profits achieved during the system operational lifetime period. The yearly energy production and the corresponding cash inflows resulting from selling the generated energy are calculated by simulating the system's operation for a one-year time period[10].

Finally, the optimal value located, achieving the highest net profit, and the overall optimal PV SYSTEM structure are displayed along with the calculated economic viability indicators which are the discounted payback time and the Internal Rate of return (IRR) [11].

III. The PV SYSTEM Flowchart and Modeling

The methodology in this paper is applicable for PV SYSTEMs and, therefore, it is considered that the total energy produced is injected to the electric grid. The flowchart of the proposed methodology's algorithm is as follows:



Solar PV system consists of number of arrays mounted on a solar panel [13]. These arrays are made up of series and parallel combination (as per output voltage and current requirement of load) of solar modules, whereas solar modules consists of number of solar cells, each cell usually produces 0.5-0.6 V [14].

Short circuit current of PV module is given by,

$$Isc = [Isc\ (STC) + K\ I\ (T-T\ (STC)] \times G/G\ (STC) \qquad [i]$$

Open circuit voltage of PV module is given by,

$$V\ oc = [V\ oc\ (STC) + K\ V\ \{T - T_{STC}\}] \qquad [ii]$$

Output power of PV module is given by,

$$P = V\ oc \times I\ sc \qquad [iii]$$

Substituting the values of Voc and I_{SC}

P = [Voc (STC) + K V{T – T(STC)oc }] × [I and Isc (STC)sc + Ki(T-T_{STC})] × G/ G $_{STC}$ [iv]

Therefore net Power output from PV module at load end is given as,
$P_{PVM} = f_{PV} \times (P \times \eta_{MPPT})$ [v]

Where
Voc = Open circuit voltage of solar PV module (Volt)
Voc (STC) = Open circuit voltage of solar PV module at Standard Test Condition (Volt)
Isc = Short circuit current of solar PV module (Amp)
Isc (STC) = Short circuit current of solar PV module at Standard Test Condition (Amp)
Kv = Temperature coefficient of voltage of solar PV module (Volt/ degree C)
Ki = Temperature coefficient of current of solar PV module (Amp/C)
ηMPPT = Efficiency of MPPT device of solar PV module
fPV = Derating factor considering shading, wiring losses and snow cover
G STC = Solar radiation (1000 W/m2) on solar PV module under Standard Test Condition (STC)
TSTC = Temperature on solar PV module (25 degree C) under Standard Test Condition (STC)
G = Solar radiation on solar PV module (kW/m)
T = Solar PV module temperature (degree C)
The PV modules are connected in series to form a panel and the numbers of module to be connected in series (N PVs) is given by,

NPVs = V_{DC} /Voc [vi]

Where,
V_{DC}= Required DC voltage at the input terminals of inverter (volt)
Based on the inverter input voltage and open circuit voltage of the PV module, the number of PV modules to be connected in series is fixed and need not to be optimized.

Whereas the number of parallel PV panels (NPVp) depends on the total output current required by solar PV and is a design variable which needs to be optimized. So the output power of solar PV at any time t is calculated by following equation,

P(t) = ηPV× NPVs × NPVp × PPVM) [vii]

ηPV= Conversion efficiency of solar PV [viii]

IV. PSO Optimization Algorithm

The PSO is a multi-agent parallel search optimization technique; it is an evolutionary technique which is inspired by the social behaviour of bird flocking, fish schooling and swarm theory [15]. The PSO idea relies on imposing various particles for searching the optimum solution. Each particle in the PSO algorithm represents a potential solution; these solutions are assessed by the optimization objective function to determine their fitness.

In the next iteration, the solutions number doubles [16, 17] until it gets the optimum one. Imposing more particles in each iteration encourage coming to the optimum solution, furthermore decreases the number of optimization iterations. In order to move to the optimum solution, particles move around in a multidimensional search space. [18]. The best experience for each particle is stored in the particle memory (pbest) and the best global obtained among all particles is called as a global best particle (gbest). During flight the current position (xi) and velocity (vii) of each particle (i) is adapted according to its own experience and the experience of neighbouring particles as described by the following equations [19]:

$$v_i^{(g+1)} = \omega v_i^{(g)} + c_1 a_1 (pbest_i - x_i^{(g)}) + c_2 a_2 (gbest - x_i^{(g)})$$

$$x_i^{(g+1)} = x_i^{(g)} + v_i^{(g+1)}$$

Where, g is the counter of generations, and ω is the inertia weight factor in a range of [0.5, 1] and almost 1 encourages the global search [11]. C 1 and c are positive acceleration constants in a range of [0, 4], designated as self-confidence factor and swarm confidence factor, respectively, a1and a2 are uniform randomly generated numbers in a range of [0, 1] [20]. Swarm size, number of particles, ω, c1 and c2 are the main parameters of the PSO algorithm, which are initialized by the users, based on the problem being optimized. The process of the PSO algorithm is shown below [21].

Standard gbest PSO algorithm

```
begin
for each particle i
   initialize position and velocity
end-for
while (not maximum number of iterations)
      for each particle i
         determine fitness value ψi
         if ψi is better than current local best fitness
            then local best fitness=ψi, local best=current
 particle position
         if ψi is better than current global best fitness
            then global best fitness=ψi and global
 best=current particle position
      End-for
      for each particle i
         calculate particle velocity based on Eq.
         update particle position based on Eq.
      End-for
      update the inertia factor based on Eq.
end-while
end
```

V. Economic viability analysis

The economic efficiency of each optimally sized PV SYSTEM is investigated using the methods of computing the discounted payback time (PBT) and the Internal Rate of Return (IRR). Initially, a PV SYSTEM investment is considered to be economically profitable only if the corresponding NPV is positive. The discounted payback time, PBT, (years), is equal to the time period for which the system NPV is set to zero. [22]

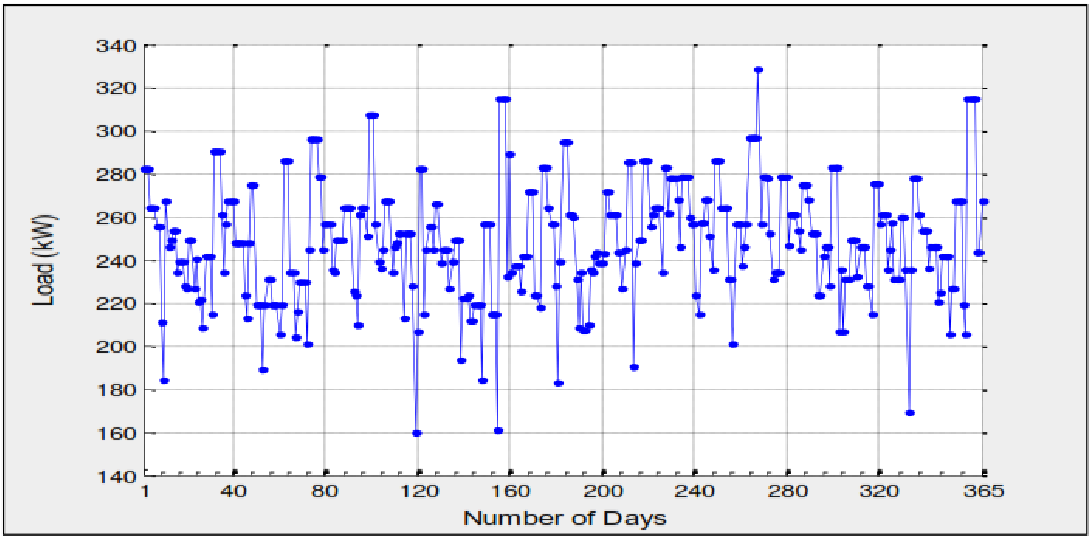
PV SYSTEM is considered to be profitable if f(x) >0, PBT <n and the IRR is higher than the nominal annual discount rate, i.

$$f(\boldsymbol{x}) = 0 \text{ for } n = \text{PBT}$$

The IRR is defined as the discount rate value that sets the NPV equal to zero:

$$f(\boldsymbol{x}) = 0 \text{ for } i = \text{IRR}$$

VI. Results and Discussion



Fig, 1 Daily Average Load Profile

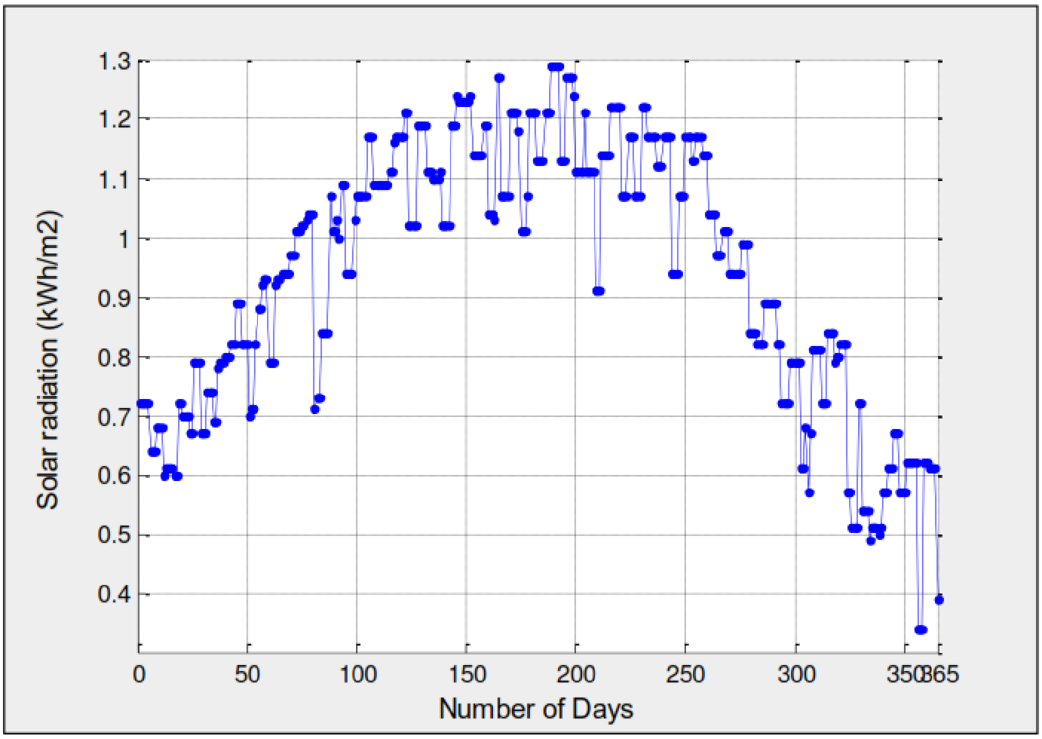


Fig 2: Daily Average Solar Illumination (kW/m^2)

Rated power	Open circuit voltage	Short circuit current	Optimum voltage	Optimum current	Investment cost (Rs/single unit)	Operational and maintenance cost (Rs/single unit)
200 W	30.8 V	8.7 A	24.5 V	8.16 A	26178	935

Table 1: Solar PV Panel Specification and Cost

				Reference paper					PSO algorithm	
Component	**Capital**	**O & M**	**Capacity**	**Units**	**Total**	**Capital**	**O & M**	**Capacity**	**Units**	**Total**
PV Panel	607281	129646	5 kW	23	65 kW	562070	120000	5 kW	20	60 kW

Table 2 : Results Comparison

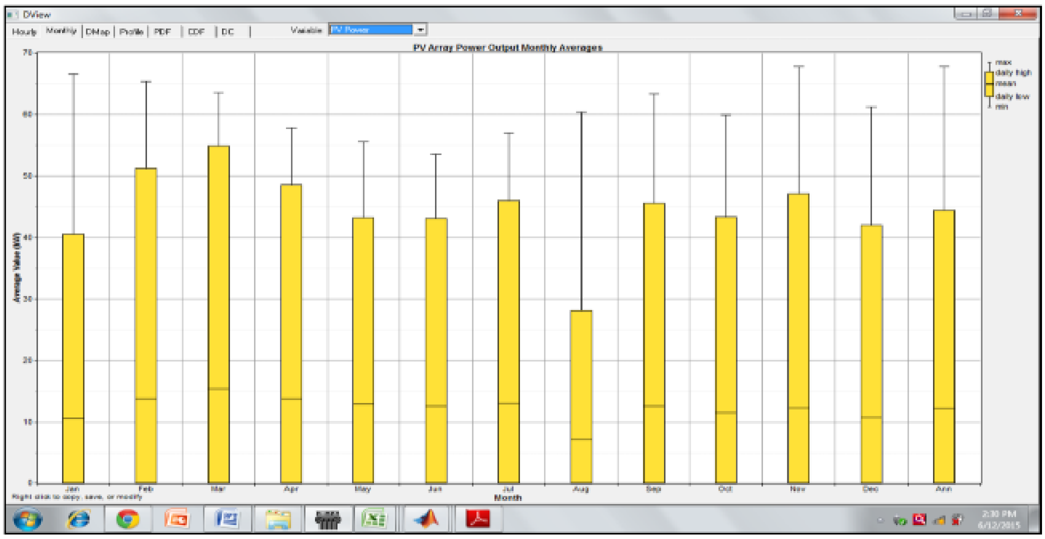


Fig 3: Monthly Output Power Generated from Solar PV

VII. Conclusion

A methodology for optimum sizing of stand-alone hybrid PV energy systems utilizing PSO has been presented in this paper. The optimization goal was to minimize the system cost with the state of insuring the load demand and satisfying a set of optimization constraints. Load shifting as one of smart grid applications has been introduced to get a distributed load profile, reduce the entire system cost and reduce CO_2 emission. Moreover, a methodology to characterize, manage the dummy energy and their exploitation has been presented.
Sensitivity analysis has been carried out in this paper to predict the system performance under varying operating conditions. The PSO technique has been implemented in this paper to carry out the optimization process. The simulation results affirmed that PSO is the promising optimization techniques due to its ability to reach the global optimum with relative simplicity and computational proficiency contrasted with the customary optimization techniques. Finally, parallel implementation of PSO has been utilized to speed up the optimization process, and the simulation results confirmed that it can save more time during the optimization process compared to the serial implementation of PSO.

VIII. Future Scope

This study gives a direction towards the future work to further enhance the overall performance of the system. Other renewable source like biogas and biomass can also be included along with solar PV. Further the other configurations can be designed only for renewable energy sources including diesel generator.
The dynamic modelling of the complete system can also be carried out as the future work. If sudden changes occur in any part of the system; load or source, then how system is regaining its original state can also be studied.

The component cost is considered same for the whole project life of 25 years. So considering the variation in component cost by time, the analysis and cost of the energy can be re-examined.
For the optimal sizing of HES, the problem can be formulated as multi–objective function and various evolutionary techniques can be applied to reach to the solution.

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