Abstract—In this paper, the optimal sizing of solar, wind hybrid system using GA and PSO optimization techniques has done to minimize the total cost of the system which comprises of investment cost, running and maintenance costs, and get back prices of the each component of the system, to cater the electrical demand of remote areas where the transmission of power from longer distances is a costlier task. And to reduce the costs incurred due to the transmission losses. The system comprises of PV Cells, wind turbines for the purpose of power generation and batteries as storage equipment for the purpose of backup instead of using conventional sources as backup. And the comparison of the performance characteristics of the system has been carried out using GA and PSO optimization techniques. With matlab software the programs of genetic algorithm and particle swarm optimization are developed to carry out the optimization in two different m-files.

Index Terms—GA, Hybrid system, PV, PSO, Wind.

I. INTRODUCTION

In general, now a days most of the electricity generation is based on the conventional energy resources. The use of these conventional energy sources like gas, oil, coal through the process of burning to generate electricity leads to the release of the greenhouse gases which leads to global warming. To save the earth and future generations we are adapting the use of non – conventional energy sources like wind energy, solar energy and several other forms of naturally available energies. The electricity which is generated at a place has to be transmitted to several long distances to cater the electrical need of the people. The transmission of electricity to the remote places where the generation of electricity through conventional forms of energy is not possible and is more costlier because, these places are in long distances from the generating stations, the transmission losses would be more. To avoid the raise in cost of the electricity supplied, it is advised to adapt the non – conventional energy sources like wind and solar. This paper deals with the use of solar energy generation in combination with wind energy and batteries to supply and store the energy during peak load and generation times. The sizing of the each energy system is most important in the consideration of initial, running, maintenance costs and supply of the connected load. The optimal and economical sizing of the entire system can be done through several optimization techniques, here we use Genetic algorithm (GA) and Particle swarm optimization (PSO) techniques to find out the optimal size of the each individual system considering both economical and technical aspects.

II. HYBRID SYSTEM MODEL

A. Hybrid system

Hybrid energy systems is more popular these days due to the raise in cost of conventional sources of energy and ever increasing demand for energy. Due to the above factors the use of hybrid systems with renewable energy sources has been increased and the systems having two or more energy sources to meet the demand and to improve the efficiency of the system. Usually most of the supply is in the form of alternating current (AC) only. Usually the energy generated using renewable energies is of the direct current (DC), to convert it into the usual AC form we need to connect an inverter in between the load and the system. To improve the working of the inverter and a dump load is connected across the inverter to consume the surplus energy.

III. PROBLEM FORMULATION

The main objective in the proposed hybrid system is to optimally size the components of the system to satisfy the connected load both economically and reliably. The system components are subject to.

1. Minimizing the cost of the system (CT)
2. Ensuring that the load is satisfied with reference to some reliability.
The objective function is to minimize the total cost of the system, the cost function is calculated by the summation of the present worth (PW) of all the get back values of the system components, initial, running and maintenance costs and replacement costs.

The objective function is as follows

\[
\text{min. } CT = \sum_{k=1}^{3} I_k + R_{PW,k} + OM_{PW,k} - S_{PW,k}
\]

Where

- \(I\) represents each individual system from 1 to 3 as PV, wind and batteries
- \(R\) represents the cost of replacement of the system components
- \(OM\) represents the cost of operation and maintenance
- \(S\) represents the salvage or get back price of the components after the life time of the project.

The constraint that has to be met while optimizing the cost function is that the load is served according to certain reliability criteria. The reliability criteria is measured using the LPSP (loss of power supply probability). This can be calculated by long time average amount of load that cannot be served. The value of LPSP varies between 0 and 1. 0 indicates the load will never be satisfied, and 1 indicates that the load is always satisfied. The constraint can be written as

\[
LPSP = \frac{\sum_{t=1}^{T} LPS(t)}{\sum_{t=1}^{T} E_L(t)} \leq LPSP^*
\]

Where

- \(LPS(t)\) represents the amount of power that has not been supplied by the system at that particular time \(t\)
- \(E(t)\) represents the amount of load at that particular time \(t\)

### A. Cost coefficients

**PV array:**

The main constraint in design of the PV array is its area and is represented by \(A_{pv}\), and this is constrained by area which is available for setting PV arrays in maximum. With an initial cost \(a_{pv}\), the PV array initial cost can be calculated as

\[
I_1 = a_{pv} * A_{pv}
\]

If the lifetime of the project is considered to be equal to the life span of the PV modules the replacement cost of the PV arrays is negligible. With yearly operation and maintenance costs of \(a_{OMPV}(Rs/m^2/\text{year})\)

\[
OM_{PV} = a_{OMPV} * A_{PV} \cdot \text{fac2}
\]

The salvage value can be found by multiplying the selling price per square meter \(SPV\) by the area \(APV\), and the PW of the selling price would be:

\[
SPW_1 = SPV \cdot APV \cdot \text{fac1}
\]

**Wind Turbine:**

The main constraint that has been considered in the designing of the wind system is its rotor swept area in \(A_w\), this value is constrained by both budget and available area for the project implementation.

Usually the lifetime of the wind turbine is shorter than the lifetime of the PV array \(N\), so, it is necessary to purchase new wind turbines to replace the existing ones. The no. of times the wind turbines need to be replaced will be \(X = N / L_w\), \(L_w\) represents the life of wind turbine. If \(a_w\) is the price in Rs./m² at present, the price after year ‘\(y\)’ would be \(a_w(1 + esy)\) having the PW of \(a_w(1 + esy)/(1 + r)\). Thus, the PW of all the initial and replacement investments in wind turbines is

\[
I_2 + R_{PW2} = a_w \cdot A_w \sum_{x=1}^{xw} \frac{(1 + es)}{1 + r} \cdot (x-1)w
\]

The yearly operation and maintenance costs is considered to be \(OMw\) then the yearly operation and maintenance costs would be

\[
OM_{pw2} = a_{OMw} \cdot A_{w} \cdot \text{fac2}
\]

The salvage value of the wind turbine is assumed to decrease linearly from \(a_w (Rs./m²)\) to \(Sw (Rs./m²)\), when the wind turbine operates along its lifetime \(Lw\)

\[
S_{pw} = S_w \cdot A_w \sum_{x=1}^{xw} \frac{(1 + j)}{1 + r} \cdot (x-1)w
\]

**Storage system (Batteries):**

The main constraint which is considered in the design of the storage system is its capacity in kilowatt-hours (KW). The battery life time is expected to be less than the life time of the project. Hence the batteries have to be replaced at a regular intervals of \(L_b\) which is the life time of the battery. Total investment and replacement at present worth can be calculated as

\[
I_3 + R_{PW3} = a_b \cdot C_b \sum_{x=1}^{xb} \frac{(1 + es)}{1 + r} \cdot (x-1)b
\]

The get back value of the batteries is expected to be negligible and the operation and maintenance costs of the batteries is to be calculated as

\[
OM_{pw3} = a_{OMb} \cdot C_{b} \cdot \text{fac2}
\]

### IV. SYSTEM MODELING

Before approaching the phase of optimal sizing of the system, the modeling of the system has to be done. For the proposed hybrid energy system consisting of storage battery, the modeling of the three subsystems which are PV array, Wind turbine system, storage battery has to be done.

**A. Modeling of PV array**

Consider a PV array of area \(A_{pv}\), having efficiency of \(\eta_{pv}\), with available solar insolation \(R\) the total amount of energy generated using PV system is

\[
P_{PV} = R \cdot A_{PV} \cdot \eta_{PV}
\]

\(P_{PV}\) is the amount power generated using the PV system in KW, and \(A_{pv}\) is the area of the PV array which is represented in \(m²\) and solar insolation in kW/m².

**B. Modeling of WTG**

The power produced by the wind turbine is represented with \(P_w\) when the wind speed lies in between the cut-in and cut-out speed of the wind turbine \(V_{ci}<V<V_{co}\)

The wind turbine generates rated power when the \(P_r\) when the wind speed is in the range of rated speed of the wind turbine \(V_{ci}<V<V_r\)

The total wind power generated is shown in the following equation

\[
P_w = \begin{cases} 
P_r \cdot \left( \frac{V^3 - V_{ci}^3}{V_r^3 - V_{ci}^3} \right), & \text{if } V_{ci} < V < V_r \\
0, & \text{otherwise} 
\end{cases}
\]

Where

- \(P_r\)
- \(V_{ci}\)
- \(V_r\)
\[ P_r = \frac{1}{2} C_p \rho_v A_w V^3 \]

C. Modeling of the storage system.

The modeling of the storage system is mainly based on the state of charge of the battery and depth of discharge of the battery. If the power is flowing towards the battery the soc of the system can be considered as

\[ SOC(t) = SOC(t - 1) + \frac{(P_b(t) \times \Delta t)}{1000 \times C_b} \]

If the battery power is flowing from battery to the load the soc of the system can be considered as

\[ SOC(t) = SOC(t - 1) - \frac{(P_b(t) \times \Delta t)}{1000 \times C_b} \]

For the long life of the battery the depth of discharge of the battery system has to maintain the following constraint which is

\[ (1 - DOD_{max}) \leq SOC(t) \leq SOC_{max} \]

where DODmax and SOCmax are the battery maximum permissible depth of discharge and SOC, respectively.

V. FINAL FORM AND OPTIMIZATION

The optimization function can be written in its final form as follows:
1. Minimize the cost function CT
\[(c1 + c2 - c3) \cdot A_P + (c4 + c5 - c6) \cdot A_T + (c7 + c8) \cdot C_b\]
2. Subject to:
\[0 \leq A_P \leq A_{P_{max}}\]
\[0 \leq A_T \leq A_{T_{max}}\]
\[0 \leq C_b \leq C_{b_{max}}\]
\[SOC(t) \leq SOC_{max}\]

A. Genetic algorithm

The evolution usually starts with individuals generated randomly to create a population. It is an iterative process, where the population in each iteration is called a generation. In each generation, for every individual population, fitness is evaluated; the fitness is usually the value of the objective function in the optimization problem being solved. The more fit individuals are randomly selected from the present population, and each individual’s genome is modified, recombined and possibly randomly mutated) to form a new generation. The candidate solutions of new generation are then used in the next iteration of the algorithm. Usually, the algorithm terminates when either a maximum number of generations are been created, or a satisfactory fitness value level has been reached for the population.

A typical genetic algorithm requires:
1. A solution domain by genetic representation,
2. A solution domain by the fitness function.

A standard representation of each candidate solution is accomplished in an array of bits. Arrays of structures and other types can be used in essentially the same way. The main property of the genetic representation is that their parts are easily aligned due to their fixed size, which makes simple crossover operations. Representations with Variable length may also be used, but implementation of crossover is more complex in this case.

Selection: In this selection procedure the solutions from each successive generation with high fitness value are selected and generate a new population. The selection is based on the fitness value of the function which is the optimal value of the function.

Crossover: In this process the population with best fitness value is selected from each successive generation and made the crossover operation by changing the bits of the each population solution. This produces the new population with best fitness value which can produce better solution.

Mutation: Mutation is an operation which is used to differ the new generation from the past generations by changing the bits of the new generation if it is same as the old generation population.

B. Particle swarm optimization

Particle swarm optimization is a meta-heuristic algorithm, which follows the procedure of fish schooling and bird flocking. Initially a random population is generated and fitness value is calculated. By taking the best fitness value into consideration the best population is selected and by updating the velocities and weights of the best population the new generation is created and checks for the new optimal solution. The process continues until the optimal solution is obtained. The population with high fitness function in each generation is taken as the local best solution and the population with high fitness value among all iterations is taken as the global best solution. The global best solution is taken as the optimal solution.

VI. RESULTS

The following are the results obtained by using the GA tool, PSO tool and the power generated through individual systems and load and power to the battery and SOC of the Battery are shown in the following figures.

Table 1: Optimum sizes of the hybrid system

<table>
<thead>
<tr>
<th>Technique</th>
<th>A_p (m²)</th>
<th>A_t (m²)</th>
<th>C_b (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA Technique</td>
<td>40.0001</td>
<td>50.0000</td>
<td>30.0000</td>
</tr>
<tr>
<td>PSO Technique</td>
<td>43.8828</td>
<td>56.2382</td>
<td>31.9077</td>
</tr>
</tbody>
</table>

Table 2: Minimum cost obtained

<table>
<thead>
<tr>
<th>Technique</th>
<th>Cost(Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA Technique</td>
<td>11096.4207</td>
</tr>
<tr>
<td>PSO Technique</td>
<td>12377.0606</td>
</tr>
</tbody>
</table>

![Wind speed data for every day in a typical year](image)
Fig 3: Solar irradiation data for every day in a typical year

Fig 4: Average daily load data for every month in a year

Fig 5: Total average load in a typical year

Fig 6: Power generated using PV system (PSO)

Fig 7: Power generated using PV system (GA)

Fig 8: Power generated using wind system (PSO)

Fig 9: Power generated using wind system (GA)

Fig 10: Total power generated (PSO)
techniques. The load is served according to the reliability criteria as observed in the acquired results.

VIII. REFERENCES

[17] Installed capacity selection of hybrid energygenerationsystem via improved particle-swarm-optimisationKong-Jong Wai; Shan Cheng; Yeu-Fu Lin; Yi-Chang Chen Generation, Transmission & Distribution, IET, Volume: 8, Issue: 4, Publication Year: 2014, Page(s): 742 – 752.

VII. CONCLUSION

The photovoltaic cells, wind turbines and storage systems (batteries) are optimally placed in a remote location taking cost and reliability as constraints. The use of meta-heuristic algorithms that are explained in this work are proved effective in the optimal utilization of the above-mentioned resources. The cost function is minimized using the Genetic algorithm (GA) and Particle swarm optimization (PSO). The iterative complexity which arises in the GA method is minimized by using PSO. The optimal solution is obtained by applying both GA and particle swarm optimization.