Optimal Economical sizing of a PV-Wind Hybrid Energy System using Genetic Algorithm and Teaching Learning Based Optimization

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ABSTRACT:In this paper, a new approach of optimal Economical sizing of a Hybrid PV-Wind energy system is presented in order to assist the designers to take into consideration both the economic and ecological aspects. This paper presentsthe various optimization techniques to design the hybrid PV-wind system. The hybrid system consists of photovoltaic panels, wind turbines and storage batteries. Genetic Algorithm (GA) and Teaching Learning Based Optimization (TLBO) optimization techniquesare utilized to minimize the formulated objective function, i.e. total cost which includes initial costs, yearly replacement cost, yearly operating costs and maintenance costs and salvage value of the proposed hybrid system. It also presents the application and performance comparison of GA and TLBO optimization techniques for optimal sizing of Hybrid PV/Wind energy system. Two computer programsare designed, using MATLAB code to formulate the optimization problem by computing the coefficients of the objective function. Finally, the optimal solution is achievedby GA& TLBO optimization method.

Keywords:GA, TLBO, solar energy, wind energy

I. INTRODUCTION

Energy from renewable sources is being considered as a viable alternative to fossil fuels. Among them, wind and solar energies have made a fast and significant breakthrough in the past 10 years. In addition, they can be consumed locally, hence reducing both impacts from high-voltage transmission lines through rural and urban landscapes and power losses. However, neither a solar nor a wind energy stand-alone system can fully satisfy load consumption because of seasonal and periodic climatic variations. Therefore it is more reliable and efficient to install a hybrid energy system with storage because of renewable energy sources intermittent character [1]. Global environmental concerns and the ever-increasing need for energy, coupled with a steady progress in renewable/green energy technologies, are opening up new opportunities for utilization of renewable energy resources. In particular, advances in wind and photovoltaic (PV) generation technologies have increased their use in wind-alone, PV-alone, and hybrid PV-wind configurations. Moreover, the economic aspects of these renewable energy technologies are sufficiently promising at present to include the development of their market [2].A hybrid energy system consists of two or more energy systems, energy storage system, power conditioning equipment, and a controller. Hybrid energy systems may or may not be connected to the grid. They are generally independent of large centralized electric grids and are used in rural remote areas [3-5]. In many remote areas of the world, the availability, reliability, and cost of electricity supplies are major issues. The standard solution is typically to use diesel or petrol generators to meet power requirements in areas distant from established electricity grids (Sustainable Energy Development Office 2010). There can be a number of problems with running stand-alone diesel or petrol generation, including noise, pollution, and high running and maintenance costs. Generators can also be inconvenient to use. Due to the high running and maintenance costs, continuous operation of a generator may not be financially viable [6]. The use of hybrid energy systems, incorporating PV and wind resources, in remote locations can overcome or at least limit some of the problems associated withgenerator only systems. The use of these renewable energy-based systems could help reduce the emissions (such as CO_x, NO_x and SO_x) [7]. But such PV-wind hybrid systems are usually equipped with diesel generators to meet the peak load demand during the short periods when there is a deficit of available energy to cover the load demand [7, 8]. To eliminate the need of a diesel generator, a battery bank can be used. Battery life is enhanced when batteries are kept at near 100% of their capacity or returned to that state quickly after a partial or deep discharge [8]. The use of PV modules only does not protect batteries against deep discharges. During periods of little or no sunshine, the load draws more energy than the PVs can replace. A more

dynamic source of energy is a wind turbine. Adding a wind turbine to a system would protect batteries against deep discharges and thus extend their life [8-10]. Many studies have been carried out in the area of sizing of PV-wind hybrid energy systems. Generally, there are three main approaches to achieve the optimal configurations of such hybrid systems in terms of technical analysis and economic analysis. These approaches are *the iteration approach* [8-14], *the probabilistic approach*[15], and *the trade-off approach*[16]. However, these approaches are time-consuming and difficult to adjust if insolation, wind speed, load demand, rating of each generator, and initial cost of each component are changed.

II. LITERATURE SURVEY

When the stand alone energy system having photovoltaic panels only or wind turbine only are compared with the hybrid PV-wind energy systems, the hybrid systems are more economical and reliable according to climate changes [17,18].Like Solar panels are too costly and the production cost of power by using them is generally higher than the conventional process, it is not available in the night or cloudy days. Similarly Wind turbines can't operate in high or low wind speeds.A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. So these non-linear problems can be solved by soft computing techniques, but which may not be accurate for multi objective functions. For example Fuzzy Logic and Neural Network are soft computing techniques, which may not provide the precise result compared to heuristic approaches like GA and PSO [13].

III.HYBRID SYSTEM STRUCTURE

The increasing energy demand and environmental concerns aroused considerable interest in hybrid renewable energy systems and its subsequent development. The generation of both wind power and solar power is very dependent on the weather conditions. Thus, no single source of energy is capable of supplying cost-effective and reliable power. The combined use of multiple power resources can be a viable way to achieve trade-off solutions. With combine of the renewable systems, it is possible that power fluctuations will be incurred. To mitigate or even cancel out the fluctuations, energy storage technologies, such as storage batteries (SBs) can be employed. The proper size of storage system is site specific and depends on the amount of renewable generation and the load. The needed storage capacity can be reduced to a minimum when a proper combination of wind and solar generation is used for a given site.The structure of the proposed PV-wind hybrid energy system is shown in Fig. 1. Because most electric appliances use alternate current (AC) power supply, an inverter is used before the load. In order to guarantee the inverter working normally, a dump load is used to consume the surplus energy generated by the system. The peak power trackers will keep the PV array and wind generator operating at their maximum power operating points. The proposed method is to optimally size a PV-wind hybrid energy system to electrify a residential remote area household as shown in Fig. 2.
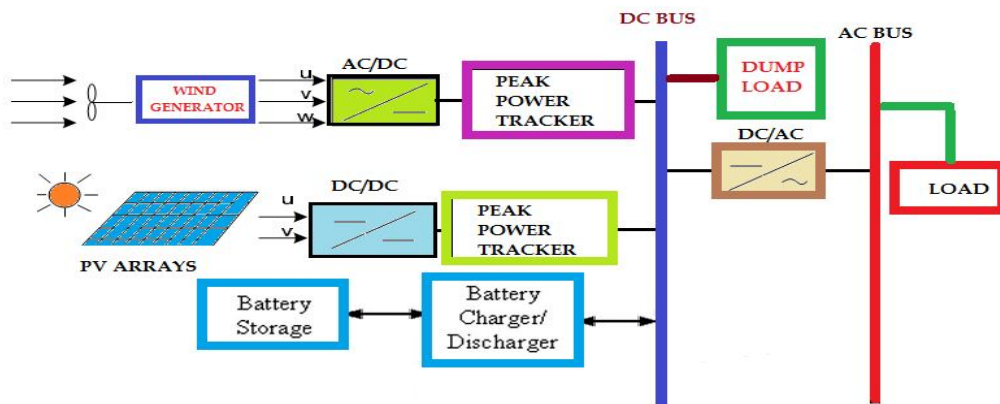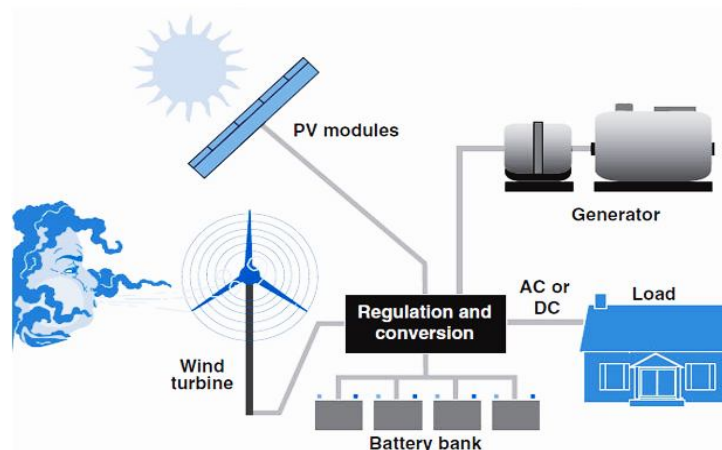

Fig.1: Block Diagram of Hybrid PV-Wind generation unit

Fig.2: The hybrid solar–wind power generation project for a house

IV.PROPOSED PROBLEM OPTIMIZATION METHODOLOGY

Because of the intermittent solar irradiation and wind speed characteristics, which highly influence the resulting energy production, the major aspects in the design of PV and WG power generation systems are the reliable power supply of the consumer under varying atmospheric conditions and the corresponding total system cost. Considering the wide range of commercially available device types, it is essential to select the number and type of PV modules, WGs and batteries, and their installation details such that power is uninterruptedly supplied to the load and simultaneously the minimum system cost is achieved. A design method forhybrid PV/WG systems, based on energy balance, has been proposed [19]. Using the hourly average data of windspeed, solar radiation and consumer power demand, the difference of generated and demanded power (P_d) any hour is calculated over a 24-h period. The numbers of PV modules and WGs are finally selected, using an iterative procedure where the system operation is simulated for various numbers of PVs and WGs, such that (P_d) has an average value of zero. The total annual cost for each configuration is calculated and the combination with the lowest cost is selected to represent the optimal mixture. A method for the selection of the optimum combination of battery and PV array in a hybrid PV/WG system has been presented by [8]. According to the methods proposed by [16] the optimal sizes of the PV and WG power sources and the batteries are determined by minimizing the system total cost function using linear programming techniques. The total system cost consists of both the initial cost and yearly operation and maintenance costs. Common disadvantage of the methods described above is that the proposed sizing methodologies do not take into account system design characteristics such as the number of battery chargers; the PV modules tilt angle and the WG installation height, which highly affect both, the resulting energy production and the installation and maintenance costs. Also, the minimization of the system cost function has been implemented either by linearly changing the values of the corresponding decision variables or employing linear programming techniques, resulting in suboptimal solutions and increased computational effort requirements.In this paper, an alternative methodology for the optimal sizing of stand-alone PV/WG systems is proposed. The purpose of the proposed methodology is to suggest, among a list of commercially available system devices, the optimal number and type of units ensuring that the 5-year round total system cost is minimized subject to the constraint that the load energy requirements are completely covered, resulting in zero load rejection. The 5-year round total system cost is equal to the sum of the respective components capital and maintenance costs. The decision variables included in the optimization process are the number and type of PV modules, WGs and battery chargers, the PV modules tilt angle, the installation height of the WGs and the battery type and nominal capacity. The minimization of the cost (objective) function is implemented employing a genetic algorithms (GA) approach, which compared to conventional optimization methods, such as TLBO has the ability to attain the global optimum with relative computational simplicity. GAs have been applied to the design of large power distribution systems and the solution of power economic dispatch problems because of their ability to handle complex problems with linear or non-linear cost functions both, accurately and efficiently. In the proposed method, GA is selected because it has shown to be highly applicable to cases of large non-linear systems, where the location of the global optimum is a difficult task. Due to the probabilistic development of

solutions, GA is not restricted by local optima. Thus, given the number of non-linearities that exist in similar problems; GA appears to be a useful approach. A general block diagram outlining the proposed methodology is shown in Fig. 3.
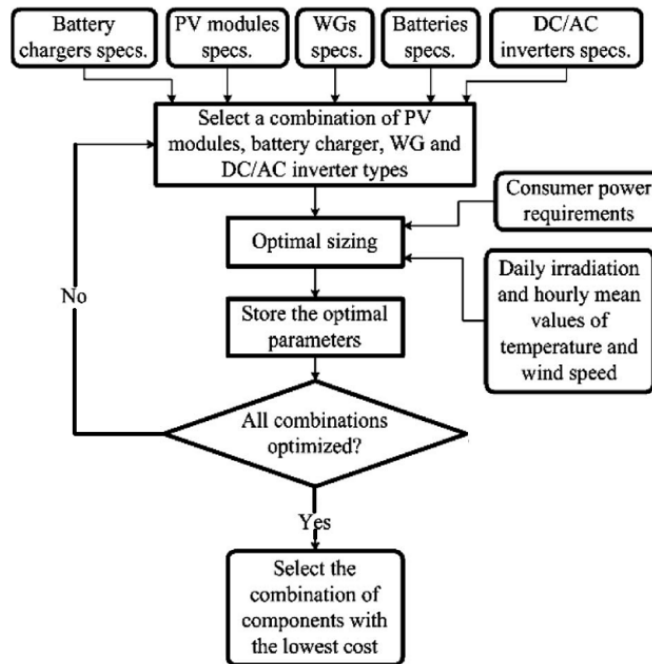

Figure-3: Flowchart of proposed optimization methodology

V. METEOROLOGICAL AND LOAD DATA

The proposed method is to optimally size a PV-wind hybrid energy system to electrify a residential remote area household near to latitude is 39.74° N, Longitude 105.18° W, Time Zone: - GMT-7, Elevation: -1829 m. MIDC/NREL Solar Radiation Research Laboratory (BMS) is a good source for the long-term monthly average daily solar radiation data (incident on both horizontal and south-facing PV array tilted by the latitude angle ϕ of the site) and wind speed data (measured at 42 feet/12.8 m height in the site).The proposed method requires a recorded long-term wind speed data and global insolation data (incident on a south-facing PV array tilted by the site latitude angle ϕ) for every day of each month in a period of 1 year. Fig.4 and 5 show these data (i.e., the global solar insolation and windSpeed, respectively) for every month in a typical year. Fig.6 illustrates the considered residential remote area load profile, during the 12 months of the year.
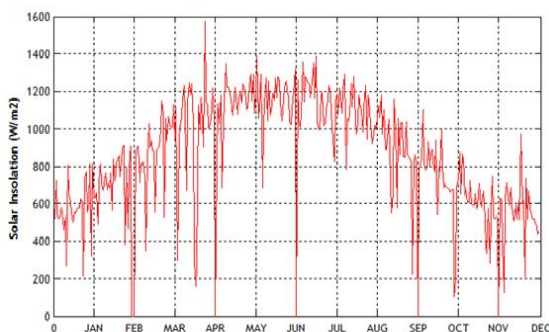

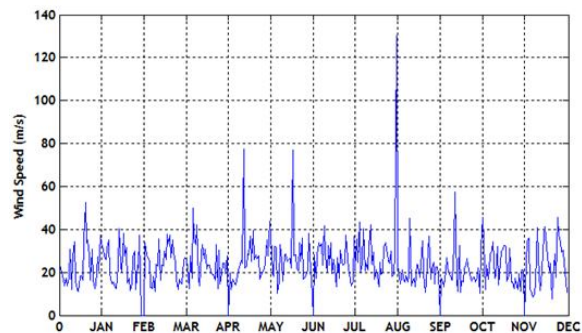Fig.4: Solar Insolation Data for Every Day in a Typical Year

Figure-5: Wind Speed Data for Every Day in a Typical Year
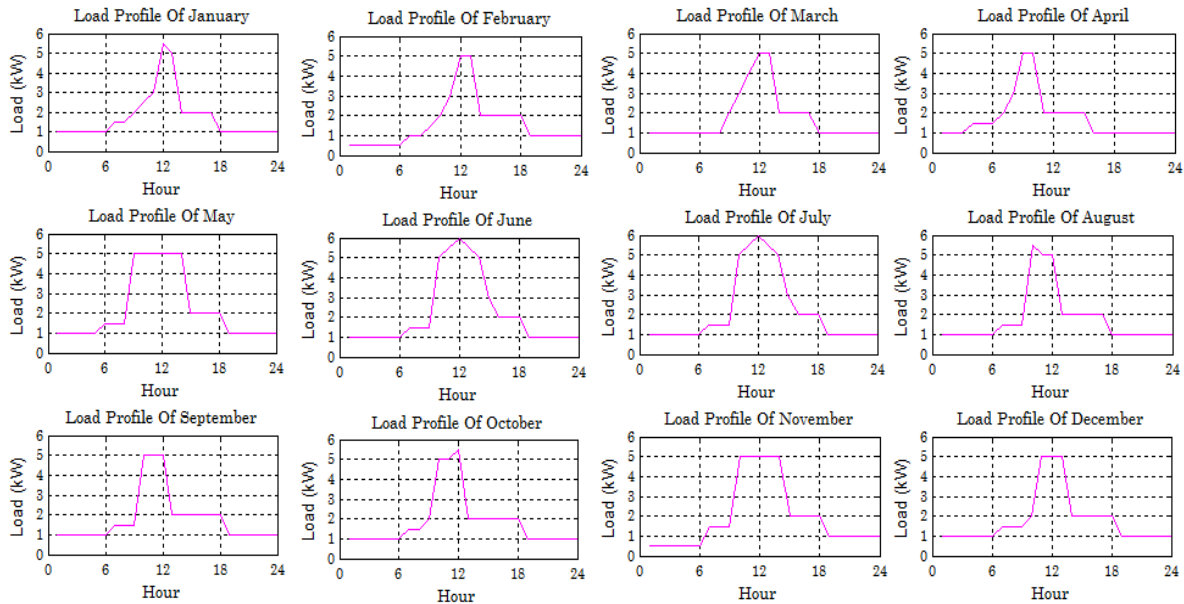
Fig.6: Load profile for all months of a typical year

VI. PROBLEM FORMULATION

The major concern in the design of the proposed PV-wind hybrid energy system is to determine the size of each component participating in the system so that the load can be economically and reliably satisfied. Hence, the system components are found subject to: 1. minimizing the total cost (C_T) of the system, 2.ensuring that the load is served according to certain reliability criteria.The objective function (C_T) is to be minimized, and this cost function is generated by the summation of the present worth (PWs) of all the salvage values of the equipment, the yearly operation and maintenance costs, the initial or capital investments, and the replacement costs of the system components. Thus, the objective function can be formulated as:

$$min.\, C\mathbf{T} = \sum_{k=1}^{3} I_k + R_{PWk} + OM_{PWk} - S_{PWk}$$

(1)

where the index k is to account for PV, wind, and batteries; I_k is the capital or initial investment of each component k; R_{PWk} is the PW of the replacement cost of each component k; OM_{PWk} is the PW of the operation and maintenance costs of each component k; S_{PWk} is the PW of the salvage value of each component k. The constraints that ought to be met, while minimizing the objective function C_T, should ensure that the load is served according to certain reliability criteria.

A. Basic Economic Consideration

As Equation (1) suggests, the PWs of some annual payments as well as of salvage values are needed. Thus, assuming a life horizon of N years for the project, an interest rate r, and inflation rate j (caused by increases in prices), the different PWs can be calculated as follows [20].

1) Salvage Value

If a component has a salvage value of S (Rs.) at present (because it is reaching the end of its total or life cycle), then the salvage value of the component is expected to be $S (1+j)^N$(i.e., N years from now provided that the component is put in service at the present time). The PW of $S (1+j)^N$, taking the interest rate into consideration is [20]:

$$S_{PW} = \frac{S.(1+j)^N}{(1+r)^N} \qquad (2)$$

Let, fac1 = $(1+j)^N$ / $(1+r)^N$, then $S_{PWk} = S_k$ facl, for all components k in the hybrid system.

2) Operation and Maintenance

If the operating and maintenance cost of a component is OM (Rs. /year), then this tends to escalate each year at a rate not necessarily equal to the general inflation rate. Thus, for escalation rate *es* the operation and maintenance costs incurred at year *y* will be *OM* $(1+es)^y$, and having a PW of:

$$\frac{OM.(1+es)^y}{(1+r)^y} \qquad (3)$$

The summation of the PWs of all the annual payments is, thus, given by:

$$OM_{PW} = OM. \sum_{y=1}^{N} \frac{(1+es)^y}{(1+r)^y} = OM. \, fac2 \qquad (4)$$

Where fac2 represents a geometric progression, and is given by:

$$fac2 = (\frac{1+es}{r-es}).\,[1-(\frac{1+es}{r-es})^N], \, r \neq es$$

$$N, \qquad\qquad r = es \qquad (5)$$

Hence, $OM_{PWk} = OM_k. \, fac2$, for all components k in the system. Note that other PW calculations will be treated in a similar manner throughout the analysis of each component.

B. Total Cost Coefficients

1) The PV Array

Assuming the design variable, in case of the PV array, to be the total array area A_{PV} in square meters. This area is constrained by both the maximum available area for the PV array(e.g., the roof surface of buildings)and thebudgetpresetfor the PV modules. With an initial cost of α_{PV} (Rs. /m^2), the total initial investment would be:

$$I_1 = \alpha_{PV}. \, A_{PV} \qquad (6)$$

Note, here, that if the project life span is assumed to be the same as the PV array lifetime, then the replacement cost of the PV modules will be negligible (i.e., $R_{PW1}=0$). With a yearly operation and maintenance cost of α_{OMPV} (Rs. /m^2/year), the total yearly operation and maintenance cost would be $OM_1 = \alpha_{OMPV}. \, A_{PV}$. Thus, the global PW of the yearly operation and maintenance cost would be:

$$OM_{PW1} = \alpha_{OMPV}. \, A_{PV}. \, fac2 \qquad (7)$$

The salvage value can be found by multiplying the selling price per square meter S_{PV} by the area A_{PV}, and the PW of the selling price would be:

$$S_{PW1} = S_{PV}. \, A_{PV}. \, fac1 \qquad (8)$$

In summary, the PWs of the PV array costs are:

$$I_1 + R_{PW1} = \alpha_{PV}. \, A_{PV} = c_1. \, A_{PV}$$
$$OM_{PW1} = \alpha_{OMPV}. \, A_{PV}. \, fac2 = c_2. \, A_{PV}$$
$$S_{PW1} = S_{PV}. \, A_{PV}. \, fac1 = c_3. \, A_{PV}$$

2) The Wind Turbine

The design variable due to the use of the wind turbine is the total rotor swept area A_w in square meters. This value is constrained by both the space available and the budget of the project. Note that if A_w is known, then it is the task of the designer to distribute A_w among several machines such that the summation of the individual areas gives A_w. Since the lifetime of a wind turbine L_w is usually shorter than that of the PVarray N, then it might be necessary to purchase additional wind turbines before the life span of the project comes to an end. The number of times, withinNyears, a wind turbine is needed is $X_w=N/L_w$ (rounded to the greater integer). If α_w is the price in Rs. /m^2 at present, the price at year

ywould be $\alpha_w.(1 + es)^y$ having the PW of $\alpha_w.(1 + es)^y/(1+r)^y$. Thus, the PW of all the initial and replacement investments in wind turbines is [20]:

$$I_2 + R_{PW2} = \alpha_w. A_w \sum_{x=1}^{X_w} \frac{(1 + es)^{(x-1).L_w}}{(1 + r)^{(x-1)_{L_w}}} \tag{9}$$

Where es is the escalation rate,r is the interest rate,L_w is the lifetime of wind turbines, and X_w is the number of times wind turbines are purchased. Note that if X_w equals 1 (i.e., the life span of the wind turbines is greater than or equal to that of the whole project), then $R_{PW2} = 0$ and $I_2 = \alpha_w.A_w$ (since the wind turbines are bought once at the beginning of the project). With a yearly operation and maintenance cost of α_{OMw} (Rs. /m^2/year), the total yearly operation and maintenance cost would be OM2=αOMw.Aw, and the PW of all the yearly costs would be:

$$OM_{PW2}= \alpha_{OMw}. A_w. fac2 \tag{10}$$

The salvage value of the wind turbine is assumed to decrease linearly from α_w (Rs. /m^2) to S_w (Rs. /m^2), when the wind turbine operates along its lifetime L_w (i.e., from its installation to the end of its lifetime, respectively). If the project life comes to an end before the wind turbines have reached the end of their life span, then the wind turbines could be sold at S_{PW} (Rs. /m^2), which is a value greater than S_w.

$$S_{pw} = \left(\frac{S_w - \alpha_w}{L_w}\right). Years + \alpha_w \tag{11}$$

where "years" indicates the number of years of operation between the installation of the last wind turbine and the end of the project life span. Therefore, the PW of all the salvage values is found by:

$$S_{PW2} = S_w . A_w \sum_{x=1}^{X_w-1} \left(\frac{(1 + j)^{x.L_w}}{(1 + r)^{x.L_w}}\right) + S_{pw}. A_w \left(\frac{(1 + j)^N}{(1 + r)^N}\right) \tag{12}$$

If N(i.e., the life span of the project) is a multiple of that of the wind turbines L_w, then Equation (12) can be reduced to:

$$S_{PW2} = S_w. A_w \sum_{x=1}^{X_w} \left(\frac{(1 + j)^{x.L_w}}{(1 + r)^{x.L^w}}\right) \tag{13}$$

In summary, the PWs of the wind turbine are:

$$I_2 + R_{PW2} = \alpha_w. A_w \sum_{x=1}^{X_w} \frac{(1 + es)^{(x-1).L_w}}{(1 + r)^{(x-1)_{L_w}}} = c_4 . A_w$$

$$OM_{PW2}= \alpha_{OMw}. A_w. fac2 = c_5. A_w$$

$$S_{PW2} = S_w . A_w \sum_{x=1}^{X_w-1} \left(\frac{(1 + j)^{x.L_w}}{(1 + r)^{x.L_w}}\right) + S_{pw}. A_w \left(\frac{(1 + j)^N}{(1 + r)^N}\right) = c_6 . A_w$$

3) The Storage Batteries

The design variable in the case of storage batteries is their capacity C_b in kilowatthours. As in the case of wind turbine, the lifetime of a battery L_b is expected to be less than that of the whole project. Hence, batteries of capacity C_b are to be purchased at regular intervals of L_b. The total PW of the capital and replacement investments in batteries is given by:

$$I_3 + R_{PW3} = \alpha_b. C_b \sum_{x=1}^{X_b} \left(\frac{(1 + es)^{(x-1).L_b}}{(1 + r)^{(x-1).L_b}}\right) \tag{14}$$

Where L_b is the battery lifetime, X_b is the number of times batteries should be purchased during the project lifetime, X_b = N/L_b (rounded to the greater integer), andα_b is the capital cost in (Rs. /kWh).The salvage value of the batteries is assumed to be negligible. With a yearly operation and maintenance cost of α_{OMb} (Rs. /kWh/year), the total yearly operation and maintenance cost would be OM$_3$ = α_{OMb}.C$_b$, and the PW of all the yearly costs would be:

$$OM_{PW3} = \alpha_{OMb}. C_b. fac2 \tag{15}$$

In summary, the PWs of the battery costs are:

$$I_3 + R_{PW3} = \alpha_b . \, C_b \sum_{x=1}^{X_b} \left(\frac{(1+es)^{(x-1).L_b}}{(1+r)^{(x-1).L_b}} \right) = c_7 . \, C_b$$

$$OM_{PW3} = \alpha_{OMb} . \, C_b . \, fac2 = c_8 . \, C_b$$

$$S_{PW3} = 0$$

C. System Modelling

Modelling is an essential step before any phase of optimal sizing. For the proposed PV- wind hybrid system with a storage battery, as shown in Figure 1, three principal subsystems are included, the PV array, the wind turbine generator (WTG), and the battery storage.

1) Modelling of the PV Array

In the proposed method, the system operation is simulated for one year with a time step of 1 h. The power produced by the PV power sources is assumed to be constant during that time period. Therefore, the power generated by the renewable energy sources is numerically equal with the energy generated within this time step.For a PV array having an efficiency η_{PV} and area A_{PV} (m^2), the output power P_{PV}(kW), when subjected to the available solar insolation R (kW/m^2) on the tilted surface, is given by [12].

$$P_{PV} = R. \, A_{PV.} \, \eta_{PV} \tag{16}$$

Here, the insolation R incident on the PV array is defined in Figure 4.

2) Modelling of the WTG

A WTG produces power P_w when the wind speed V is higher than the cut-in speed V_{ci} and is shut-down when V is higher than the cut-out speed V_{co}. When $V_r < V < V_{co}$ (V_r is the rated wind speed), the WTG produces rated power P_r. If $V_{ci} < V < V_r$, the WTG output power varies according to the cube law. The following equations are to be used in order to model the WTG [8, 14]:

$$P_w = \begin{cases} P_r . \left(\dfrac{V^3 - V_{ci}^3}{V_r^3 - V_{ci}^3} \right), & V_{ci} \leq V \leq V_r \\[2em] P_r , & V_r \leq V \leq V_{co} \\[2em] 0 , & V_{co} \leq V \text{ or } V \leq V_{ci} \end{cases} \tag{17}$$

Where

$$P_r = \frac{1}{2} C_P \, \rho_{air} \, A_w \, V_r^3 \tag{18}$$

In the above equation, C_p, ρ_{air}, and A_w are the power coefficient, air density, and rotor swept area, respectively.As the available wind speed data V_i (see Figure 5) were estimated at a height H_i =12.8 m, then to upgrade these data to a particular hub height H, the following equation is commonly used [2,8]:

$$V = V_i . \left(\frac{H^a}{H_i^a} \right) \tag{19}$$

Where V is the upgraded wind speed at the hub height H and a is the power-law exponent ($\approx 1/7$ for open land).

3) Modelling of the Storage batteries

At any hour t, the state of charge of the battery [SOC(t)] is related to the previous state of charge [SOC(t – 1)] and to the energy production and consumption situation of the system during the time from t –1 to t. During the charging process, when the battery power P_B flows toward the battery (i.e., $P_B > 0$), the available battery state of charge at hour t can be described by:

$$SOC\ (t) = SOC\ (t\text{-}1) + \frac{P_B\ (t)\ X\ \Delta t}{1000\ X\ C_b} \tag{20}$$

Where Δt is the simulation step time (which is set equal to 1 hr), and Cb is the total nominal capacity of the battery in kilowatt-hours.On the other hand, when the battery power flows outside the battery (i.e., $P_B<0$), the battery is in discharging state. Therefore, the available battery state of charge at hour t can be expressed as:

$$SOC\ (t) = SOC\ (t\text{-}1) - \frac{P_B\ (t)\ X\ \Delta t}{1000\ X\ C_b} \tag{21}$$

To prolong the battery life, the battery should not be overdischarged or overcharged. This means that the battery SOC at any hour t must be subject to the following constraint:

$$(1 - DOD_{max}) \leq SOC\ (t) \leq SOC_{max} \tag{22}$$

where $DOD_{max}$and SOC_{max} are the battery maximum permissible depth of discharge and State Of Charge, respectively.

VII. SYSTEM RELIABILITY & SIMULATION

First of all, it is assumed, in this work, that the peak power trackers, the battery charger/discharger, and the distribution lines are ideal (i.e., they are lossless). Also, it is assumed that the inverter efficiency η_{inv} is constant, the battery charge efficiency η_b is set to equal to the manufacturers' round-trip efficiency, and the battery discharging efficiency is set to be 1.The total generated power by the PV array and WTG for hour t, Pg (t), can be expressed as:

$$P_g\ (t) = P_{PV}\ (t) + P_w\ (t) \tag{23}$$

It is to be noted that the desired load demand at any hour t, $P_L^*(t)$ may or may not be satisfied according to the corresponding values of the total generated power $P_g\ (t)$ and the available battery SOC (t) at that hour. The proposed energy management of the PV-wind hybrid system can be summarized as follows:

- If $[P_g\ (\text{t})>P_L^*(t)\ /\eta_{inv}]$ and $[SOC\ (t-1) < SOC_{max}]$ then satisfy the load and charge the battery [using Equation (20)] with the surplus power $[P_B\ (t) = (P_g\ (t) - P_L^*(t)\ /\eta_{inv})\ \eta_b]$. Afterwards, check if $[SOC\ (t) \geq SOC_{max}]$ then stop battery charging, set $SOC\ (t) =SOC_{max}$, and dump the surplus power $(P_{Dump}\ (t) = P_g\ (t) - [P_L^*(t)\ /\eta_{inv}+1000\times C_b/\Delta t\times\eta_b\times (SOC_{max}-SOC\ (t-1))])$.
- If $[P_g\ (t)>P_L^*(t)\ /\eta_{inv}]$ and $[SOC\ (t-1) \geq SOC_{max}]$ then stop charging the battery, satisfy the load, and dump the surplus power $[P_{Dump}\ (t) = P_g\ (t) - P_L^*(t)\ /\eta_{inv}]$.
- If $[P_g\ (\text{t}) =P_L^*(t)\ /\eta_{inv}]$ then satisfy the load only.
- If $[P_g\ (t) <P_L^*(t)\ /\eta_{inv}]$ and $[DOD\ (t-1) < DOD_{max}]$ then satisfy the load by discharging the battery [using Equation (21)] to cover the deficit in load power$[P_B\ (t) = P_L^*(t)\ /\eta_{inv} - P_g\ (t)]$. Afterwards, check if $[DOD(t)\geq DOD_{max}]$ then stop battery discharging, set $DOD(t)=DODmax$, and calculate the deficit in load power $(P_{deficit}(t)=P_L^*(t) - [P_g(t)+1000\times C_b/\Delta t\times(\ SOC(t-1) -(1-DOD_{max}))]\ \eta_{inv}$.
- If $[P_g\ (t) <P_L^*(t)\ /\eta_{inv}]$ and $[DOD\ (t-1) \geq DOD_{max}]$ then stop battery discharging and $[P_{deficit}\ (t) = P_L^*(t) - P_g\ (t).\ \eta_{inv}$.

As it is assumed, in this work, the simulation step time Δt is equal to 1 h and the generated PV and wind powers are constants during Δt. Then, the power is numerically equal to the energy within Δt.The program for the calculation of suggested PV-wind hybrid system was written in MATLAB code in an M-file. A flowchart diagram for this program is shown in Fig. 9. The input data for this program consist of mean hourly global insolation on a tilted array R, mean hourly wind speed V_i, and desired load power during the yearP_L^*. Note, here, that for every configuration of the proposed PV-wind hybrid system, this program simulates the system.There are three additional bounds that should be imposed on the sizes of the system components, which are:

$$0 \leq A_{PV} \leq A_{PVmax} \tag{24}$$

$$0 \leq A_w \leq A_{w\ max} \tag{25}$$

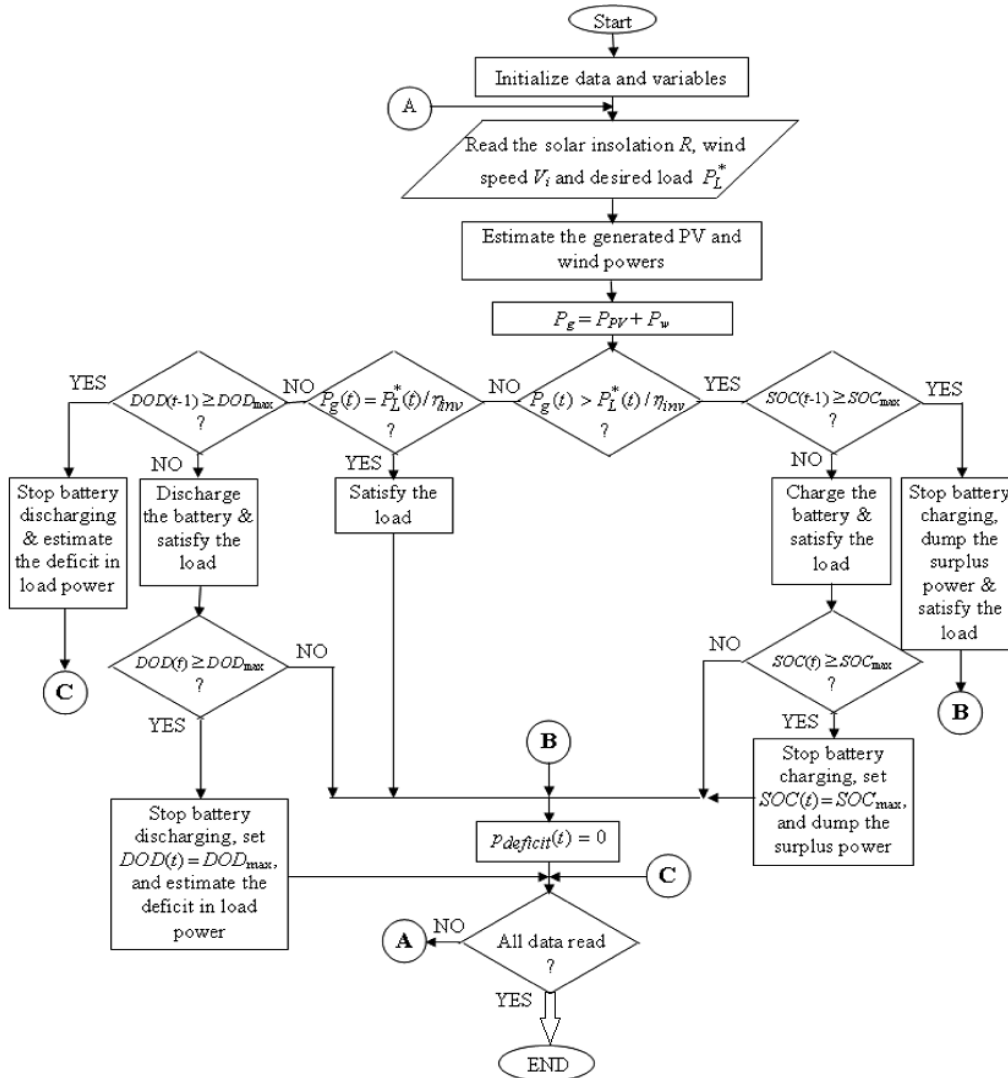$$0 \leq C_b \leq C_{b\ max} \tag{26}$$

Fig. 7. Flowchart of the simulation Program.

VIII.   FINAL FORM & OPTIMIZATION TECHNIQUES

At this stage, the optimization problem can be written in its final form as follows:
- Minimize the cost function C_T

$$(c_1 + c_2 - c_3). A_{PV} + (c_4 + c_5 - c_6). A_W + (c_7 + c_8). C_b \qquad (27)$$

- Subject to:

$$\left. \begin{array}{l} 0 \leq A_{PV} \leq A_{PVmax} \\[6pt] 0 \leq A_w \leq A_{w\,max} \\[6pt] 0 \leq C_b \leq C_{b\,max} \end{array} \right\}$$

$$(28)$$

To solve the above optimization problem, one of the *soft computing* approaches (GA) is proposed, where, in this work [21], the Genetic Algorithm Code under MATLAB software is utilized for solving the previous optimization problem. GA contains the **elitist** approach [22].This means that a solution cannot degrade from one generation to the next, but that best individual of a generation is copied to the next generation without any changes being made to it. To use the GA, for solving the formulated optimization problem, an M-file (MATLAB Code) has written, to compute the values of the *objective function* (or called *fitness function*).The M-file has to be written to accept a vector (i.e., individual) whose length is the number of independent variables for the objective function and return the corresponding scalar values of the objective function (i.e., cost).In this work, the individual of the considered optimization problem contains three variables (or genes), which are: A_{PV}, A_w, and C_b.The used GA is based uponusing the flowchart of Fig. 8, to yield the optimal solution. Initially, the GA selects individuals at random from the current population to be parents and uses them to produce the children for the next generation by using the three main operations, which are the selection, crossover, and mutation operations. Then, it can repeatedly modify a population of individual solutions, where, over successive generations, the population evolves toward an optimal solution. Note, here, that the used different settings in the GA are 100 individuals for the population size,the stochastic uniform function for the selection operation, the scattered crossover function (with a crossover probability of 80%) for the crossover operation, the adaptive feasible mutation function (with a probability rate of 1%) for the mutation operation, and an elite individual. At the same time, it is to be noted that the additional three bounds of Equation (28) can be entered directly in the dedicated positions of the GA.
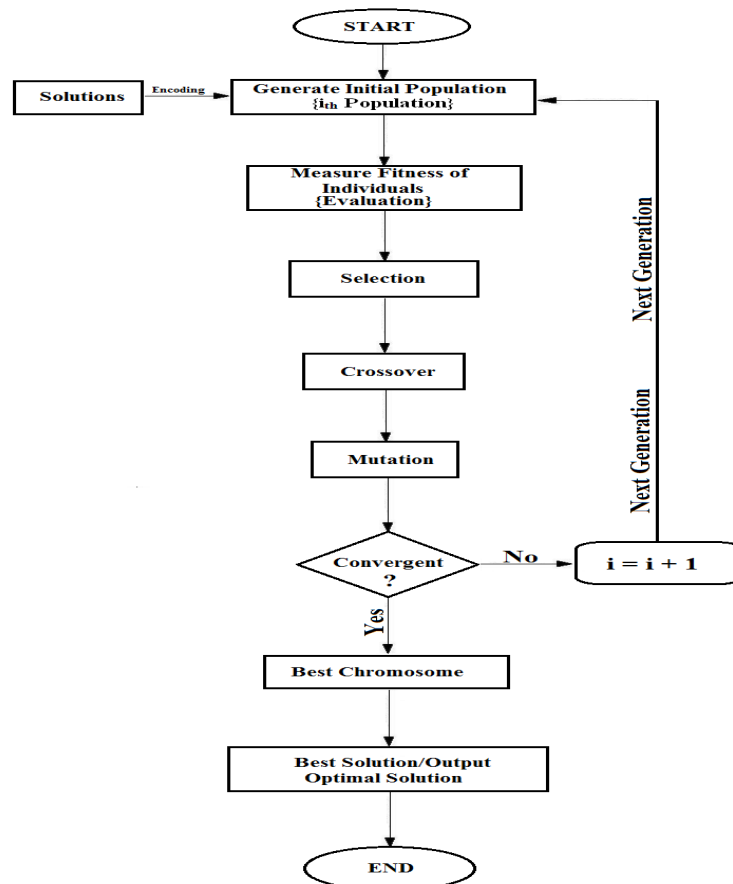

Fig.8. Flow Chart of Genetic Algorithm

A latest optimization algorithm, named Teaching Learning-Based Optimization (simply TLBO) was proposed by **R. V. Rao et al, at 2011**, for handling the optimization of mechanical design problems by considering the influence of a *teacher* on *learners*. Afterwards, some improvements and practical applications have been conducted toward TLBO

algorithm. However, as far as our knowledge, there are no such works which categorize the current works concerning TLBO from the algebraic and analytic points of view [26].This algorithm mimics the teaching–learning ability of the teacher and learners in a classroom. The teacher and learners are the two vital components of the algorithm. The algorithm describes two basic modes of the learning: (1) through teacher (known as the teacher phase) and (2) interacting with the other learners (known as the learner phase). The output in the TLBO algorithm is considered in terms of the results or grades of the learners, which depend on the quality of the teacher. A high-quality teacher is usually considered a highly learned person who trains learners so that they can achieve better results in terms of their marks or grades. Moreover, learners also learn through interaction among themselves, which also helps to improve their results. **R. V. Rao et al**. demonstrated that TLBO can obtain the better optimization performance in many fields, e.g., the constrained mechanical design optimization problems, unconstrained and constrained real-parameter optimization problems, and continuous non-linear large scale problems, in comparison with other optimization algorithms. Then, a number of improvements and applications concerning TLBO have been proposed sequentially [26].The basic procedure for implementing the TLBO algorithm is as follows:Initialize the population size, design variables and termination criterion, evaluate the initial population, Calculate the mean of each design variable and select the best solution, Calculate the difference mean (Difference$_{*, D}$ = r ($M_{new, D}$- T_F X $M_{*, D}$) and modify the solutions based on best solution, The existing solution is updated as in $X_{new, D}$ = $X_{old, D}$ + Difference$_{*, D}$, If new solution is better than existing then select the solutions randomly and modify them by comparing with each other and if not than keep the previous solution and repeat step 3-5, If termination criterion is fulfilled then take the final value of the solution. Fig 9 shows the flow chart of TLBO algorithm and its operation for non-linear problems.
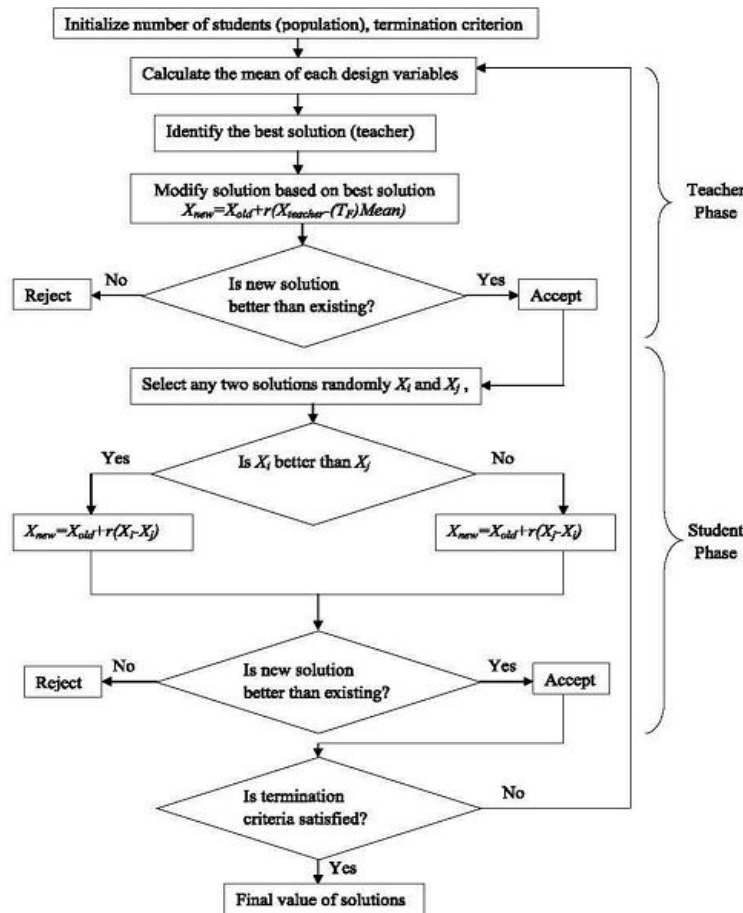

Fig. 9. Flow Chart of TLBO Algorithm

IX. APPLICATION RESULTS AND DISCUSSION

The formulated optimization problem of the PV-wind hybrid energy system is solved, in this work, by using the GA and TLBO under MATLAB software, which may provide a number of potential solutions to the given problem. The choice of the final optimum solution is left to the system's designer. The specifications and the related maintenance and installation costs of different wind turbines, PV panels and batteries, which are input to the optimal sizing procedure, are listed in Tables I-III. The maintenance cost of each unit per year and the installation cost of each component have been set at 0-1% and 5-10% respectively of the corresponding cost. The life time of Wind Turbine, PV panel and Battery is considered to be 5 years. Since the tower heights of wind turbines affect the results significantly, 12.8m meter high tower at an elevation of 1829m is chosen. The minimization of the system total cost is achieved by selecting an appropriate system configuration. In Table IV, it indicates the compared result of optimum sizes of the different components included in the hybrid system. The corresponding *fitness function optimization* (i.e., minimization of the system cost in rupees) along the successive generations of the GA is shown in Fig 10, which indicates that the system is optimized after forty iterations only. Similarly In another M-file a MATLAB code has written for proposed hybrid PV/Wind energy system using *Teaching Learning Based Optimization* (TLBO) algorithm. The corresponding *fitness function optimization* (i.e., minimization of the system cost in rupees) along the successive iterations of the TLBO is shown in Fig 11, which indicates that the system is not optimized even after hundred iterations. Table-VI shows a comparison between the costs that resulted from solving the formulated optimization problem by using the proposed GA-based technique and the TLBO algorithm using MATLAB software. Thus, Table-V indicates that the proposed GA-based technique is better than the TLBO algorithm, in solving such optimization problems, and this is due to the fact that the GA is capable to converge to the global optimum solution instead of convergent at a local optimum one. Fig 12 shows the comparison of result using GA and TLBO, where GA is most efficient than other.Figure 13, 14, and 15 illustrates the generated PV power, wind power, and the total generated power of the suggested PV-wind hybrid system, for every month during the year.

Table-I: Wind Turbine Generator Data

Power Rating (W)	2500
V_r (m/s)	30
V_{ci} (m/s)	15
V_{co} (m/s)	40
Life Time of the WTG (years)	5
Installation Cost (Rs./m^2)	17
Operation and Maintenance Cost (Rs. /yr.)	3.4

Table-II: PV Array Data

V_{oc} (V)	2500
I_{sc} (A)	30
Life Time of the PV Panel (years)	5
Installation Cost (Rs./m^2)	5.5
Operation and Maintenance Cost (Rs. /yr.)	0.65

Table-III: Battery Specifications

Nominal Capacity (Ah)	50
Voltage (V)	12
DOD (%)	80
Efficiency (%)	80
Life Time of the PV Panel (years)	5
Installation Cost (Rs./m^2)	13
Operation and Maintenance Cost (Rs. /yr.)	2.6

Table-IV: Comparison of Optimum sizes of Hybrid System

A_{PV} (m^2)		A_w (m^2)		C_b (kWh)	
GA	TLBO	GA	TLBO	GA	TLBO
40.0004	48.9090	50.0000	40.9645	30.0000	40.9871

Table-V: Cost Comparison Using GA and TLBO

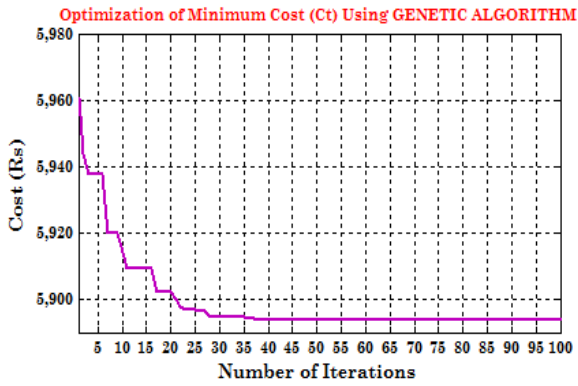| Technique	Cost (Rs.)
Genetic Algorithm (GA)	5,893
Teaching-Learning Based Optimization (TLBO)	6,990

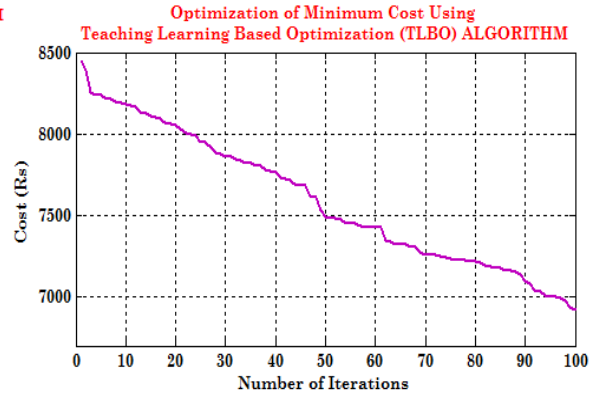Fig. 10: Optimization of the Objective function using GA

Fig. 11: Optimization of the Objective function using TLBO

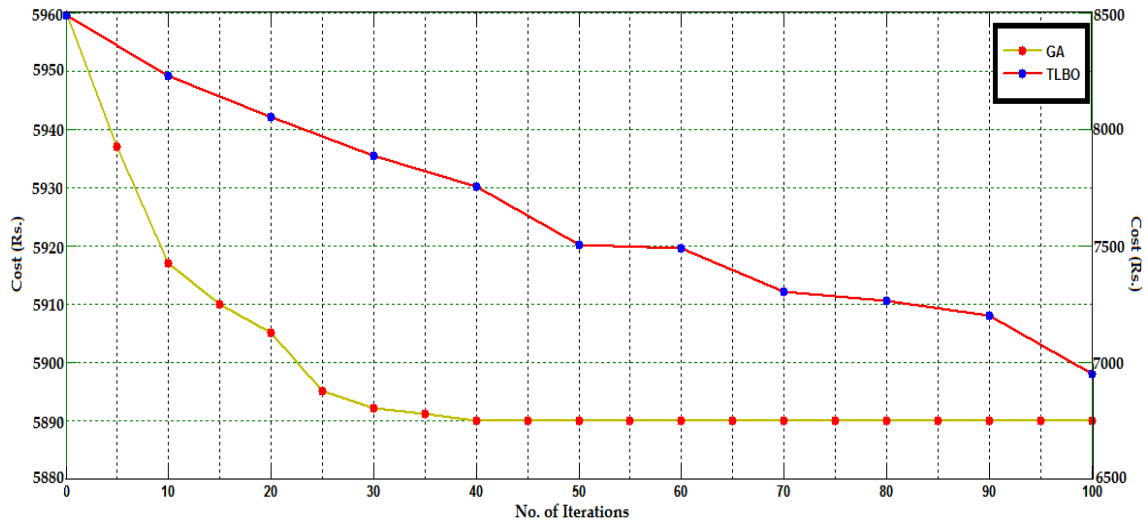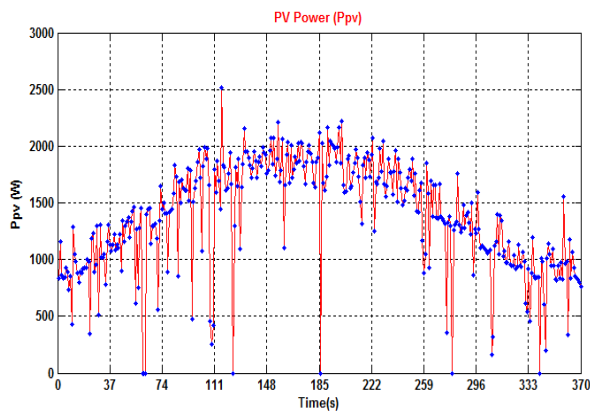Fig. 12: Comparison of Results of Optimization Techniques

Fig.13: PV Power

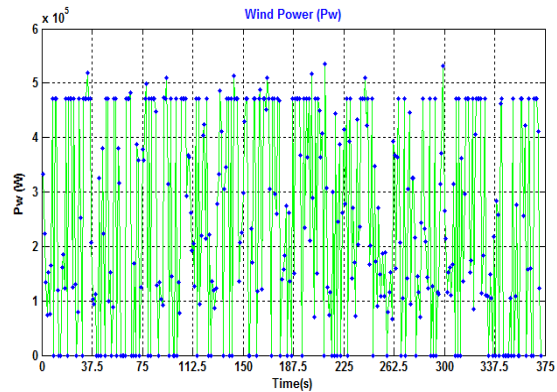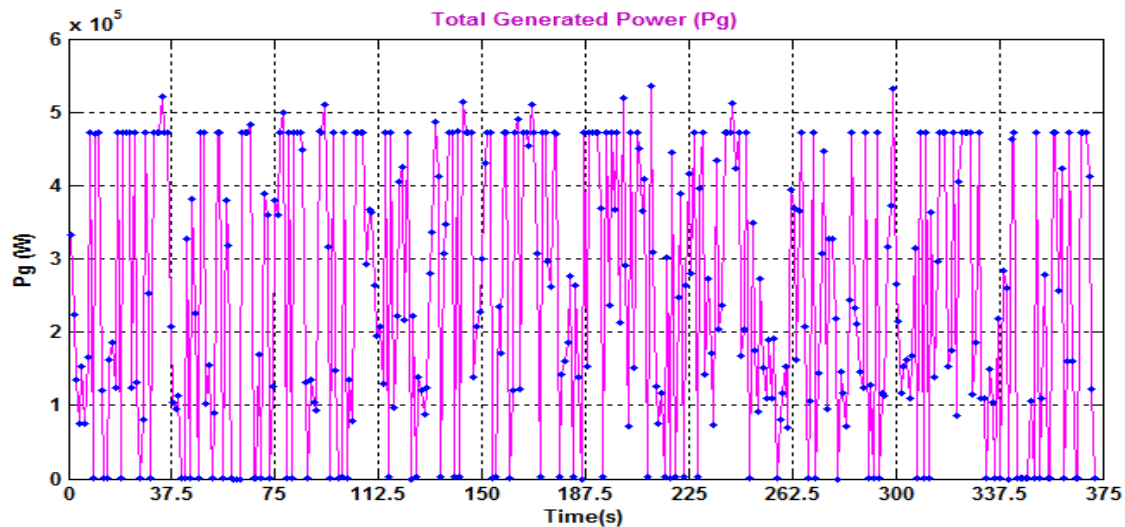Fig.14: Wind Power

Fig. 15: Total Generated Power

X. CONCLUSION

This paper presents a GA& TLBO-based optimization technique to optimally size a proposed PV-wind hybrid energy system, incorporating a storage battery. The optimization problem is formulated, in this work, to achieve a minimum total cost for the system components and to ensure that the load is served reliably. The results yield that the GA converges very well and the proposed technique is feasible for sizing either of the PV-wind hybrid energy system, stand-alone PV system, or stand-alone wind system. In addition, the proposed techniquesare able to be adjusted if insolation, wind speed, load demand, and initial cost of each component participating in the system are changed. The results yield, also, that the PV-wind hybrid energy systems are the most economical and reliable solution for electrifying remote area loads.

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