MODELLING AND OPTIMISING THE VALUE OF A HYBRID SOLAR-WIND SYSTEM

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1. ABSTRACT

In this paper, a net present value (NPV) approach for a solar hybrid system has been presented. The system, in question aims at supporting an investor by assessing an investment in solar-wind hybrid system in a given area. The approach follow a combined process of modelling the system, with optimization of major investment-related variables to maximize the financial yield of the investment. The consideration of solar wind hybrid supply presents significant potential for cost reduction. The investment variables concern the location of solar wind plant, and its sizing. The system demand driven, meaning that its primary aim is to fully satisfy the energy demand of the customers. Therefore, the model is a practical tool in the hands of investor to assess and optimize in financial terms an investment aiming at covering real energy demand. Optimization is performed by taking various technical, logical constraints. The relation between the maximum power obtained between individual system and the hybrid system as a whole in par with the net present value of the system has been highlighted.

2. INTRODUCTION

Nowadays the price of fuels is increasing drastically mainly because of scarcity and high demand. Moreover these fuels eject out greenhouse gases which is slowly destroying the environment. Considering all these factors the people these days are largely depending on natural resources for energy for many applications like cooling, heating, electricity, etc. Solar, wind and Bio energy can be widely used these days if the environment or the place is rich in that source of natural resource. The availability of resources play a major factor for producing energy from this resources. Among all renewable energy sources solar and wind energy are more attractive to the people because these resources are available at the site at free of cost.

However, every venture exploring solar and wind energy trace the common drawback of its dependency on the unpredictable climatic and weather variations, alongside its mismatch with the demand load rate. By lowering the energy performance of the system, this shortcoming sharply decreases the lifetime of batteries. It should be noted that only an integrated exploitation of these energy resources helps keep the cost of system design low. A stand-alone solar or wind energy system is insufficient to supply continuous power citing the frequent seasonal and periodical changes (Yang et al, 2008). The drawbacks from solar and wind now a day the people are thinking towards hybrid technology i.e. combination of solar and wind. The hybrid system can get enough energy from both sources and even if the energy from one source is low at the point it will be compensated by the other. Hybrid systems has gained popularity in the past, for its application in remote systems such as radio telecommunication and satellite earth stations, or at localities inaccessible to the conventional power grids (Yang et al, 2009; Zhou et al, 2008; Diafa et al 2008). Today, upgrading the current single source systems (Solar, Hydro or Wind) into hybrid systems for grid-connection applications has been a major area of focus (Bakos and Tsagas, 2003).
Researchers have recommended many optimization procedurals such as graphical construction, probabilistic method and iterative techniques. Shah et al. (2015) contributed in the field of Performance of U.S. hybrid distributed energy systems: Solar photovoltaic, battery and combined heat and power. Until recently, the relatively high levelized cost of electricity from solar photovoltaic (PV) technology limited deployment; however, recent cost reductions, combined with various financial incentives and innovative financing techniques, have made PV fully competitive with conventional sources in many American regions. Their results show that conservatively sized systems are technically viable in any continental American climate and the details are discussed to provide guidance for both design and deployment of PV + battery + CHP hybrid systems to reduce consumer costs, while reducing energy- and electricity-related emissions.

Rahimi et al. (2015), studied the design and application of a novel hybrid sun–wind-tracking system. Their principal experiment was focused on comparison between dual-axes sun-tracking and hybrid sun–wind-tracking photovoltaic (PV) panels. Their results show that, the overall daily output energy gain was increased by 49.83% compared with that of a fixed system and an overall increase of about 7.4% in the output power was found for the hybrid sun–wind-tracking over the two-axis sun tracking system. Sinha and Chandel (2015) were studied photovoltaic–micro wind based hybrid systems for 12 locations of the Himachal Pradesh state to solve the problems in hydro power plants during extreme winter season. The results show that (i) ANN predicted data are close to measured/estimated data, (ii) The normalized solar and wind energy generation are found to range between 1034–1796 kWh/kWp/yr and 222–616.8 kWh/kWp/yr respectively for all locations and (iii) the state has good prospect of power generation from hybrid systems with major solar and minor wind components.

With the objective to minimize costs, Moussa et al. (2015), designed a hybrid solar-wind energy plant model, which included optimised variables namely, count of photovoltaic modules and wind turbines, wind turbine height and turbine rotor diameter. The results show that the hybrid plant delivered energy that combined the nature of the two complementary energy sources, and supplied energy reliably all along the year. Onar O.C et al. focused on integrating wind turbine, photovoltaic and fuel cell along with ultra-capacitor systems for grid-independent applications. Testing the dynamic characteristics of their suggested hybrid model under parameters such as wind speed, solar radiation and demand load, for a per day analysis, they found that their model displayed fantastic performance. The hybrid model of Chougule and Ravi integrated methodologies involving analytics and parameters to determine the early cost of castings. By testing their model in a unified industrial product and process designing environment, the cost determined by a product designer matched closely with that estimated by an experienced foundry engineer. Their study also shows that web-enabling of the entire system promotes collaboration between product designer, tool-maker and foundry engineer for cost reduction.

Konstantinos et al, studied the four important factors that influence the rising demand for electricity namely climatic changes, forecasted growth rates of EU Member State economies, variations in consumption rates and bringing in of latest technologies. They also did a framework for assessing power schemes for power from renewable energy sources considering the indeterministic competitive market milieu. They expected the modern deregulated electricity market to be ready to respond to this challenge. They based their expectation on their prediction of an adequate and economical supply of energy within this new model and promising new opportunities it would offer for incomings as well as present power producers. Celik (2008) proposed a battery operated model for hybrid wind-solar energy systems which included design factors such the time fraction necessary for the hybrid system to meet the load and the cost of the system. In his study he introduced new notions that integrated the autonomy and economics of the system employed in the optimisation of the technological and economical analysis. He suggested that rather than excessively raising the size of the hardware, an auxiliary source could be employed additionally within the system, resulting in increased technologically and economically optimum systems.
Dihrab and Sopian (2010) proposed a hybrid solar-wind system that was employed as the power source for the grid-connected applications in three Iraqi cities. A MATLAB simulation of the model using input parameters obtained from meteorological data of the three cities, along with the proposed sizes of the wind turbines and the photovoltaic arrays was carried out. Their results showed that their hybrid system would provide sufficient energy for villages in desert or rural areas. Kershman et al. (2008) worked on the model of a hybrid solar/wind system that operated the sea-water reverse osmosis (RO) desalination plant later, employed to supply potable water to a village on Libya's coast. In their studies, the reverse osmosis desalination plant operated using a grid-connected power supply system that combined the power from photovoltaic power generation (PV) and wind energy conversion (WEC). The results showed that the economic evaluation of the combined power system showed that the water from the Grid+WEC+RO cost more than that from the Grid+PV+RO. However, water from both the systems was expensive compared to that from the conventional fossil-operated plant.

Bakos and Tsagas (2003) analysed the technical and economic feasibility of using a grid-connected hybrid wind/solar system to meet the power demands of a typical residency in Xanthi, a Greek city, through electrical and thermal energy production. They evaluated the economics of their hybrid solar/wind system using the Life Cycle Savings (LCS) and the PayBack Period (PBP) techniques to calculate the input capital cost. Deshmukh and Deshmukh (2008) discussed about the techniques to model the constituent parts of the HRES, its design and analysis. They justified the increasing popularity for the hybrid solar/wind energy systems using the literary works focussing on improving the HRES design. Borowy and Salameh (1996) developed an analogy to optimise the storage capacity of a battery bank and a photovoltaic array considering a single hybrid solar/wind power system. In their study, the wind speed and irradiance data were compiled on an hourly basis per day for a span of 30 years and using these data, the average generated power was calculated for very same durations. Yang et al. (2008) developed simulation models for a hybrid wind/solar system which are used to calculate optimized combinations of PV module, wind turbine, and battery bank parameters for a given loss of power supply probability (LPSP). The proposed algorithm was found to deliver a good optimised sizing performance suggesting a hybrid solar/wind system to be the best solution.

Every effort to explore an efficient and economical renewable energy source requires at least a single optimised sizing technique. The use of photovoltaic arrays, battery banks and wind turbines shoot up the investment costs and hence, such a sizing technique ensures that the hybrid system operates at an optimum investment value and power assurance. This type of optimization includes economical objectives, and it requires the assessment of the system’s long-term performance in order to reach the best compromise for both reliability and cost.

In this paper, a single optimal sizing model for a stand-alone hybrid solar/wind system using battery banks is developed based on the loss of power supply probability (LPSP) and the annualized cost of system (ACS) concepts. The optimality procedure targets on finding out the configuration that yields the best compromise between the two considered objectives: LPSP and ACS. The decision variables included in the optimization process are the PV module number, wind turbine number, battery number, and also the PV module angle of slope and installation height of the wind turbine. In order for the hybrid system to operate and maintain the required power reliability at the least possible cost, the formulation of the model was carried out using an optimization technique – the genetic algorithm (GA), which is an advanced search and optimization technique; it is generally robust in finding global optimal solutions, particularly in multi-modal and multi-objective optimization problems, where the location of the global optimum is a difficult task.
3. MODELLING THE HYBRID SYSTEM COMPONENTS

Fig.1 shows a schematic representation of the proposed hybrid solar/wind power generation system. As per the design, the system includes a wind turbine, photovoltaic array, battery bank, inverter, controller and associated accessory devices and wires. In this case the system is setup such that during the day time solar panel extracts energy and directly supply to the power grid and in case excess energy it produced, it gets stored. Wind energy is also produced such that it goes to the battery and then the grid system to make sure the battery is not always in drained condition. During the night time wind energy is continuously produced like in the day time and also the stored energy in the battery is used to run the grid. To analyse the performance of the hybrid system, the overall system is modelled and analysed towards optimum cost.

![Block diagram of a solar / wind hybrid system](image)

There are many times the decisions are taken while going for the grades of the accessories considering the cost and optimising the life of the products. Here the experiment set up is analysed for the following three situations:

- Expensive setup using high grade instruments and materials
- Moderate cost setup using average grade instruments and materials
- Cheap setup using low grade instruments and materials

|                      | EXPENSIVE | MODERATE     | CHEAP                |
|----------------------|-----------|--------------|----------------------|
| Initial investment   | High      | Average      | Low                  |
| Maintenance          | Low       | Average      | High                 |
| Life                 | High      | Average      | Low                  |
| Battery              | Sealed battery | Low grade sealed battery | Lead acid battery |

3.1. Supply

Hybrid solar and wind power is used to run all the household appliances. This is the why the inverter plays a very important role in this system.
Since the supply doesn’t give the required output 24*7 throughout the year, hence it is necessary to use regular power supply for continuous electricity to the household appliances.

Usually there are 2 types of sources which are

- **Primary source**: Here the solar and wind energy which we extract will be the prime source of energy to run the house. Power from the electrical grid will be utilized as a backup if the battery gets drained and when battery needs to get charged again.
- **Secondary source**: Here the solar and wind energy which we extract will be a backup if the grid system supply is cut off.

Primary source has been considered for this study.

4. EQUATIONS

4.1. Optimization of variables

The important variables that describe the system are as following:

- \( P_{ME} \): The electrical capacity of the plant
- \( P_s \): The peak load capacity of the solar cell
- \( P_w \): The peak load capacity of the wind turbine

4.2. Primary or Main function

To maximise the main or the primary function, the net present value (NPV) for a specific time period of time was maximised. It is done for the investment of the project lifetime. NPV is used because of its frequently appraisal criterion in plant investment and also as theory regards it superior over other parameters. This model evaluates and determines the optimal solutions for other investment parameters.

The Net present value (NPV) function to be optimized is

\[
NPV = (R_{NETE} + R_{REINE}) \cdot DF - (I_M + I_s + I_W + I_{EC} + I_C + I_{ET}) - (A_S + A_W + A_{ET}) \cdot DF
\]

It is to be noted that the maximisation function in the above statement gives the value without the taxes. All the monetary values are multiplied with a constant coefficient DF, known as the Discount Coefficient, which results in the current expression:

\[
DF = (1 - \{1 + (i - p) (1 + p)\})^{-N} / (i - p)
\]

Where \( I \) is the interest rate, \( p \) is the inflation rate and \( N \) is the investment lifetime of the plant in a whole.

4.3. Revenues of facility

The revenues obtained by the facility are given below. \( R_{E} \) is the revenue obtained from sales of the net electricity supplied to the main grid:

\[
R_{NETE} = C_E (1 - ne) \sum ((E_{RESH} + E_{EHWL}) - E_{DC})
\]
Where \( E_{EHE} \) is the electricity produced from the solar cell and \( E_{EHW} \) is the electricity produced from the wind turbine. \( E_{DC} \) is the electricity consumed by the different apparatus present during the operation. \( n_e \) is the electricity transmission losses and \( t = 1, \ldots, T \) is the time period. \( E_{DC} \) is given as

\[
E_{DC} = C_i \left( \sum E_{MSt} + E_{GTT} \right) + C_W \left( \sum E_{WT} + E_{CT} + E_{St} + E_{It} \right)
\]

Where \( C_i \) is the cost per capacity of solar energy lost and \( C_W \) is the cost lost in wind turbines. \( E_{MSt} \) is the energy lost in the solar panel in period of time and \( E_{GTT} \) is the energy lost in grid time inverter. Similarly \( E_{WT} \) is the energy lost in wind turbine during conversion, \( E_{CT} \) in the controller, \( E_{St} \) in the storage. Basically all these losses are transmission losses in different electrical equipment’s.

\( R_{EP} \) is the electricity capacity available for reimbursement:

\[
R_{EP} = C_E P_{ME}
\]

Where \( C_E \) is the income from the capacity availability (₹/kW).

### 4.4. Expenses

Energy conversion related expenses

\( I_M \) is the base plant investment cost subtracted from the public subsidy given by government:

\[
I_M = C_{MPME}(1 - S_{MB})
\]

Where \( S_{MB} \) is the public subsidy of investment for the base plant and \( C_M \) is the specific investment cost (₹/kW) calculated from a known cost criterion.

\( A_S \) is the solar cell plant O&M:

\[
A_S = O_S C_s P_S
\]

Where \( O_S \) is the annual operation and management cost of the cell as a percentage of investment cost.

\( A_W \) is the wind turbine O&M:

\[
A_W = O_W C_W P_W
\]

Where \( O_W \) is the annual operation and management cost of the wind turbine as a percentage of the investment cost.

\[
I_S = C_S P_S (1 - S_{MB})
\]

\( I_S \) is the peak load solar cell cost minus the public subsidy.

\[
I_W = C_W P_W (1 - S_{MB})
\]

\( I_W \) is the peak load wind turbine cost minus the public subsidy.

\( I_{E_T} \) is the investment cost of connecting the power plant to the national grid:

\[
I_{ET} = (L C_{ETV} + C_{ETF})(1 - S_{ET})
\]

where \( L \) is the total length of the transmission line (km), \( C_{ETV} \) is the changing investment cost (₹km^{-1}), \( C_{ETF} \) is the fixed connection cost and \( S_{ET} \) is the subsidy.

\( A_{ET} \) is the electricity transmission line operation and management cost as a percentage of the investment cost.
IET is the investment cost of connecting the power plant to the national grid:

\[ I_{ET} = (LC_{ETV} + CETF)(1 - S_{ET}) \]

where LC is the length of the transmission line (km), CETV is the variable investment cost (V km\(^{-1}\)), CETF is the fixed connection cost (V) and SET is the subsidy.

### 4.5. Constraints

As with any modulation, many constraints had to be included in the mathematical formulation of the problem.

#### 4.5.1 Energy Constraints

The energy produced because of the solar and wind must be enough to satisfy the consumer demand otherwise there would be no use of setting up the plant and giving so much investment to it.

The constraints based on this parameter would be as the follow

\[ ES + EW >= EDT \text{ where } T = 1, 2, 3, \ldots, t \]

#### 4.5.2. Legislation constraints

The legislation of Indian government says that subsidy for the particular project may be provided only if the energy produced by the plant is at least 70% or more than that of the customer demand.

#### 4.5.3. Logical constraints

The independent variables were considered non-negative. Additionally, upper limits were placed for many of the variables.

### 5. CASE STUDY

The case study is done in Coimbatore which is a small city in Tamil Nadu, India. This place is selected because of uniform wind and solar energy available in this area throughout the year. Here useful inputs are used in the NPV equation and hence figures have been plotted using Mat lab to get the results. Here to account into the NPV equations few assumptions are made based on the Coimbatore environment. Those technical and financial data are given below in Table 1.

#### Table 1. Technical Financial data

|                          |        |
|--------------------------|--------|
| Total efficiency of plant | 55     |
| Interest rate %          | 9      |
| Inflation %              | 4      |
| Investment lifetime (yr.)| 15     |
6. RESULTS

Figure 2 represents the change in Solar power ($P_s$) with net present value (NPV) for the given range of input. It shows the change of NPV value with respect to the solar power generated.

Here the different colours represent the difference in values of NPV for the given input.
Similarly this figure 2 below represents the change in Wind power ($P_w$) with net present value (NPV). For the given range of input it shows how the NPV value changes for the wind power generated.

Since the system is a hybrid system NPV changes with both wind and solar, so both the above figures, figure 1 and figure 2 are merged into Figure 3.
Here in figure 3 value of power both the figures merge, but there are a set of values for NPV for the optimum power. So now to get an optimum NPV value for the optimum power an need account into the maintenance, life of the components and the profit earned in the process.

For figure 1 and figure 2 the top, middle and bottom lines of the NPV which are blue, red and yellow lines respectively.

These lines represents:

Blue : Expensive setup using high grade instruments and materials

Red: Moderate cost setup using average grade instruments and materials

Yellow: Cheap setup using low grade instruments and materials

Now considering all the expenses a maintenance figure is plotted.

**6.1 Maintenance figure**
Here,

Maintenance 3 represents the maintenance for the cheap setup (i.e Yellow line)

Maintenance 2 represents the maintenance for the moderate setup (i.e red line)

Maintenance 1 represents the maintenance for the expensive setup (i.e blue line)

From figure 5 if cheap product is selected maintenance is high and it maintenance starts at a early period of time.

So, from the figure 5 selecting maintenance1 is optimum. Therefore the blue line has been selected

Next taking the life expectancy of all the component put together. It shows depending on the cost and quality of the product, how long it will last.

6.2 Life Expectancy

Figure 6 shows that more the cost of the product, better will be the components used and hence better will be the life time of the component.

![PRODUCT LIFE](image)

Figure 6: life time vs. cost of the products

Hence it is better to go with the blue line (expensive setup) according to Figure 6. Next is the comparison between the investment cost and profit gained in a period of 10 years using the hybrid system.

Therefore blue line is more optimum.
Table 2. Income gained over years

| Initial Investment | Final Gain in 10 Years | Losses % |
|-------------------|------------------------|----------|
| 4                 | 1.708                  | 57.3     |
| 3.8               | 1.707                  | 55.05    |
| 3.6               | 1.706                  | 52.611   |
| 3.5               | 1.705                  | 51.285   |
| 3.4               | 1.704                  | 49.885   |
| 3.2               | 1.703                  | 46.78    |
| 3.1               | 1.702                  | 45.09    |
| 2.9               | 1.701                  | 41.344   |
| 2.7               | 1.7                    | 37.03    |
| 2.5               | 1.7                    | 32       |

From the data it is found out that over the span of 10 years the profit attained is almost similar. Looking at the profit prospective, from this data it is optimum to choose the yellow line. Since, after 10 years they have got back 68% of their investment, whereas blue line have got only 42.7% of their investment. Therefore choosing yellow line is more optimum.

7. CONCLUSION

From the obtained results it can conclude that the maintenance and life expectancy of the system dictate the type of the device been chosen. In case of a low costing system it is noticed that the maintenance cost is more and the life expectancy is more. Where as in case of a system where a higher costing appliance is taken into considerations the maintenance cost is lower and the life expectancy of the product is higher. From the maintenance and life expectancy figures selecting blue line is most optimum and selecting yellow line is least optimum. Whereas when the profit attained in a span of 10 years is compared, it is profitable to go with the yellow line and least profitable to go with the blue line. Since the optimum solution for the whole system is required, we have to take into account of the above 2 situations, hence it is better to choose the red line. The red line accounts into the profit factor as well as the maintenance and life factor. So the red line which uses the moderate cost setup and average ranged instruments and components is the most optimum. So it’s better to go with the red line to attain the highest NPV and power.

The reason of going with the red line is that, in this scenario all the above mentioned parameters are in the most optimum state and this will lead to the best result.

8. REFERENCES

[1] Yang, H., Zhou, W., Lu, L., and Fang, Z 2008, Optimal Sizing Method For Stand-Alone hybrid Solar-Wind System With LPSP Technology By Using Genetic Algorithm, Solar Energy, Vol. 82, pp. 354.
[2] Yang HX, Zhou W, Lou CZ 2009 Optimal design and techno-economic analysis of a hybrid solar–wind power generation system. Appl Energy;86:163–9.
[3] Zhou W, Yang HX, Fang ZH 2008, Battery behavior prediction and battery working states analysis of a hybrid solar–wind power generation system. Renew Energy;33(6):1413–23.
[4] Diafa S, Belhamel M, Haddadac M, Louchea A 2008, Technical and economic assessment of hybrid photovoltaic/wind system with battery storage in Corsica Island. Energy Policy;36(2):743–54.
[5] Bakos GC, Tsagas NF 2003, Technoeconomic assessment of a hybrid solar/wind installation for electrical energy saving, *Energy Build.*, **35**(2):139–45.

[6] Shah, K.K., Mundada, A.S and Pearce, J.M 2015, “Performance of U.S. hybrid distributed energy systems: Solar photovoltaic, battery and combined heat and power,” *Energy Conversion and Management*.

[7] Rahimi Masood, Meisam Banybayat, Yaghoub Tagheie, Peyvand Valeh-e-Sheyda 2015, “An insight on advantage of hybrid sun–wind-tracking over sun-tracking PV system”, *Energy Conversion and Management*, Pages 294–302.

[8] Sinha Sunanda and S.S. Chandel 2015. “Prospects of solar photovoltaic–micro-wind based hybrid powerystems in western Himalayan state of Himachal Pradesh in India”, *Energy Conversion and Management*, Pages 1340–1351.

[9] K. Mousa, Ali Diabat, Hamzah S. Alzu'bi 2010. “Design of hybrid solar and wind power plant using optimization”. *Engineering Systems Management and Its Applications*, IEEE explore, Abu Dhabi, Pages 1-6.

[10] Onar O.C., Uzunoglu, M., and Alam, M.S 2008. “Modeling, Control And Simulation Of An Autonomous Wind Turbine/Photovoltaic/Fuel Cell/Ultra-Capacitor Hybrid Power System”, *Journal Of Power Sources*, Vol. **185**, No. 2, pp. 1273-83.

[11] R. G. Chougule and B. Ravi 2005. “Casting cost estimation in an integrated product and process design environment” Vol. 3, No.6 *IJICIM*.

[12] Celik, A.N 2003. “Techno-Economic Analysis Of Autonomous PV-Wind Hybrid Energy Systems Using Different Sizing Methods”, *Energy Conversion And Management*, Vol. **44**, pp. 1951-1968.

[13] Dihrab, S.S. And Sopian, K. 2010 “Electricity generation of hybrid PV/wind systems in Iraq”, *Renewable Energy*, Vol. **35**, pp. 1303-1307.

[14] G.C Bakos and N.F Tsagas 2003, Techno economic assessment of a hybrid solar/wind installation for electrical energy saving, *Energy and Buildings*, Volume **35**, Issue 2, Pages 139–145

[15] Deshmukh M.K, S.S Deshmukh 2008. “Modeling Of hybrid Renewable Energy Systems”, *Renewable and Sustainable Energy Reviews*, Vol. **12**, No. 1, pp. 235-249.

[16] Borowy, B.S., and Salameh Z.M 1996. “Methodology For Optimally Sizing The Combination Of A Battery Bank And PV Array In A Wind/PV Hybrid System”, *IEEE Trans. Energy Convert.*, Vol. **11**, No. 2, pp. 367-73.

[17] Konstantinos Venetsanosa, Penelope Angelopouloua, Theocharis Tsoutsosb 2002, “Renewable energy sources project appraisal under uncertainty: the case of wind energy exploitation within a changing energy market environment”, *Energy Policy* Greece.

[18] Yang, H., Zhou W. and Lou C 2009. “Optimal Design and Techno-economic Analysis of a Hybrid Solar-Wind Power Generation System”, *Applied Energy*, vol. **86**, No. 2, pages 163-169.

[19] H.X. Yang, L. Lu, J. Burnett 2003. “Weather data and probability analysis of hybrid photovoltaic–wind power generation systems in Hong Kong”, *Renewable Energy*, vol. **28**, No. 11, pages 1813-1824.

[20] Amit Kumar Yadav, S.S. Chandel 2015. “Solar energy potential assessment of western Himalayan Indian state of Himachal Pradesh using 348 algorithm of WEKA in ANN based prediction model”, *Renewable Energy*.

[21] Chandel SS, Agarwal RK 2011 “Estimation of hourly solar radiation on horizontal and inclined surfaces in western Himalayas”. *Smart Grid Renew Energy,SGRE*, Vol.2 No. 1.

[22] Parita G Dalwadi, Chintan R Mehta 2012, “Feasibility Study of Solar-Wind Hybrid Power System”, *International Journal of Emerging Technology and Advanced Engineering*. Vol. **2**, No. 3.

[23] Olaf Goebel, Sultan A. Kershman 2005. “Hybrid wind/PV and conventional power for desalination in Libya”, *Centre for Solar Energy and Hydrogen Research* Vol. **4**, No. 3.