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MODELING OF RENEWABLE ENERGY SYSTEMS FOR POWER GENERATION

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Abstract— **Sustainable energy systems are termed as the systems which deliver energy and power, utilizing the Renewable and natural resources, which is cost effective and has an environmental concern. The Modeling of the systems and its components is itself a complex procedure. The basic Modeling through Physical law applied to each component of the system, its subsystem and the result of the overall system is more time consuming and requires thorough understanding of physical concept and the results obtained are more accurate. Alternatively, the Mathematical Modeling techniques or the procedures are simple to understand, easy to apply and more faithful in obtaining the useful results. This paper presents Various Mathematical Modeling of wind turbine and PV system and simulated for the faithfulness of the results. The deviations from the response of the models from the ideal model are represented as relative index. It shows that simple model can be accurate and it is useful in predicting the behavior of the system.**

Keywords— **Mathematical Modeling, Wind turbine system, PV system**

I. INTRODUCTION

Energy is the driving force for all the kinds of research on the systems, innovations, modifications and development of the mathematical models for its better utilization. Any system can be physically modeled by understanding the physical laws applied to it ,the accuracy and faithfulness of the model development is very crucial in obtaining the actual behaviour of the system [1].Various Renewable energy system models have been developed by the authors as optimization models for Techno-economic simulation, models in terms of Technical assessment, taking into factors technical parameters influencing the system and economic assessment including the cost parameters[2].The Modeling of the system is important in order to understand its behaviour over the range of its operation and helps in building control algorithms and hence in obtaining the performance better.

The advantage of mathematical simulation is that many simulations can be performed for obtaining the top 1% of the faithful results[3].The Modeling process consists of the physical understanding of the systems, subsystems and their integration from the input to the output. Suppose Modeling of the wind turbine involves various components, like design of the blades, shaft, gearing systems, controlling systems, generating systems, the mathematical formulation of the each component is to be carried out and simulations are done based upon the knowledge of the components and their integration with the components[4].Dynamic Modeling and controllers for small wind turbines are explained using the bin power curve method using the Matlab/Simulink environment[5]. In[6] ,a simple mathematical models of wind turbine, diesel generator, PV sytems, Micro Hydro systems, Battery bank Model of charge controller, rectifier are used for the calculation of their outputs for effective optimization of integrating the renewable energy systems. The parameters taken into consideration for Modeling may produce the differential effects in the results.

The studies are often made to simplify the Modeling process and net results are shown in terms of faithful results. The involvement of various physical laws, differential equations, solving them with necessary constraints are applied to them. The various models referred by the authors are encouraging to further development in obtaining the faithful models. The performance of the various PV systems are carried and modeled to determine the best operating with least cost of energy[7]. The Modeling process is more significant in identifying, knowing the different component characteristics and supports in decision making.However,it is too complex and time consuming to obtain a perfect model [8].The application of simple mathematical models are trust worthy in obtaining the faithful results which are beyond the case of uncertainity.Simple approaches based upon on its approximation using polynomial methods are very helpful in achieving the reliable results, even though the accuracy of the results will vary by smaller percentage with the experimental results. Simple rule in the polynomial approach is that higher the order, better will be the results in approximation.

The Modeling of each renewable energy system source referred by the cited authors involves few variances in developing the models[9]. But the models presented have to be justified by the other referred authors by setting the same input data and carry out their simulation for the faithfulness of each model. The simple model will give the result associating with practical errors. The complexity of the model may be time consuming but it can give the better results. In actual, when the models are compared with the experimental, the faithfulness of each model can be easily ascertained. Moreover, it also improves the optimization of the proposed Model. The MATLAB/SIMULINK environment used by the authors is the most promising computation tool for the simulation.

This paper presents the various simple models adopted by the authors for obtaining the results for power generation from renewable energy systems involving the wind turbines

II. MODELING STUDIES

The Modeling studies carried out are explained in the various subsections, simulations on the various models are compared using the Matlab/simulink environment. The faithfulness of the each models are checked under the same environmental conditions recorded at the choosed site and also simulated for the regular small interval steps. The models presented here gives the idea of determining the parameters to which the power generation is estimated. The models are linear, non linear and exponential form to which the expected results are assumed. Some models are based upon fitting the experimental(Power) curve from the manufacturers results. The validation of the models are based upon the details furnished by the manufacturer. The deviations in each models are taken as reference from the actual data available. The models may produce the erratic results and these are assumed to be the lie in operating range.

III. MODELING OF WIND TURBINE

The various literatures have modeled the wind turbine systems for the faithfulness of the result. Some models were quite accurate and some needed a improvement in the model.The model equations are represented as 1,2,3 from the literatures are as follows

The basic equation model from the reference[10],the power output is given by

$$p = \eta_t \eta_g \left(0.5\right) \rho C_p A v^3 \quad (1)$$

Where η_t ,η_g are the efficiencies of the transmission and generator , usually taken as 0.85 and 0.9. C_p is the the coefficient of performance , A., is the area of the rotor and v,is the velocity of the wind.

The Model (1) based on linear power curve is given by[11][12][1]

$$\left.\begin{array}{ll} P=0 & (\text{for } v<v_c) \\ P = P_r(v- v_c)/(v_r-v_c) & (\text{for } v_c \le v \le v_r) \\ P=P_r & (\text{for } v_r \le v \le v_f) \\ P= 0 & (\text{for } v > v_f) \end{array}\right\} \quad (2)$$

Where v_c is the cut in speed, v_r is the rated speed of the turbine and v_f is the cut out speed.P_r is maximum rating of power from the turbine. This equation is very simple and follow simple linearity. The power available from the turbine is proportional to the rated power and ratio of difference of change in the available velocity and the rated velocity of the turbine with respect to the cut in speed.

The Model (2) based on cubic law [13] is given by the power density

$$\left.\begin{array}{ll} P_{wd}=0 & (\text{for } v<v_c) \\ P_{wd} = av^3-bP_r & (\text{for } v_c \le v \le v_r) \\ P_{wd}=P_r & (\text{for } v_r \le v \le v_f) \\ P_{wd}= 0 & (\text{for } v > v_f) \end{array}\right\} \quad (3)$$

Where $a = \frac{p_r}{v_r^3 - v_c^3}$ $b = \frac{v_c^3}{v_r^3 - v_c^3}$ and the power P is calculated by $P=P_{wd}A\eta_o$ where A is the area turbine and η_o is the overall efficiency of the turbine which is calculated by the taking the product of c_p,efficiency of turbine generator and the transmission efficiency. This model is assumed due to the cubic nature of the power curve from the manufacturer details. V_c is the cut in speed, V_r is the rated velocity of the turbine and V_f is the cut –out speed of the turbine.

The Model (3) based on Weibull's parameter[14] is given by

$$\left.\begin{array}{ll} P=0 & (\text{for } v<v_c) \\ P=a+bv^k & (\text{for } v_c \le v \le v_r) \\ P=P_r & (\text{for } v_r \le v \le v_f) \\ P= 0 & (\text{for } v > v_f) \end{array}\right\} \quad (4)$$

Where $a = \frac{p_r v_c{}^k}{v_c^k - v_r^k}; b = \frac{p_r}{v_r^k - v_c^k}$ where k is the shape factor of the weibull distribution and it is taken as 2.1 for this turbine.

From the Model (4) based on Method of least squares[15]

$$\left.\begin{array}{ll} P=0 & (\text{for } v<v_c) \\ P = a_1v^2+b_1v+c_1 & (\text{for } v_c \le v < v_1) \\ P=a_2+v^2+b_2v+c_2 & (\text{for } v_1 \le v \le v_2) \\ P= a_3+v^2+b_3v+c_3 & (\text{for } v_2 \le v \le v_f) \\ P=P_r & (\text{for } v_r<v<v_f) \\ P=0 & (\text{for } v > v_f) \end{array}\right\} \quad (5)$$

Where a_1,$b_1$and c_1 are the coefficients of quadratic equations .The values of these constants are calculated using the least square method by fitting actual power curve.

where a_1=3.7; ,b_1=17.8; c_1=24.3: a_2=6; b_2=-41; c_2=85
a_3=-5.5; b_3=160.4; c_3=-794:a_4=-6; b_4=167.5;c_4=-810.5

The Model(5) based on cubic spline interpolation technique is given by[16]

$$\left.\begin{array}{ll} P=0 & (\text{for } v \le v_c \text{or } v \ge v_f) \\ P = a_1v^3+b_1v^2+c_1v+d_1 & (\text{for } v_c \le v < v_1) \\ P= a_1v^3+b_1v^2+c_1v+d_1 & (\text{for } v_1 \le v \le v_2) \end{array}\right]$$

$P= a_1v^3+b_1v^2+c_1v+d_1$ (for $v_2\leq v \leq v_f$)
:

$P= a_nv^3+b_nv^2+c_nv+d_n$ (for $v_{n-1}<v<v_r$)
$P=P_r$ (for $v_r<v<=v_f$)
$P=0$ (for $v > v_f$)
(6)

. where n is the number of cubic spline interpolations functions responding n+1 values of wind speed and corresponding power and a_1, b_1, c_1 and d_1 are the coefficients of the polynomials. These constants are calculated from the details of the power curve from the manufacturer using the cubic spline interpolations method upto three interpolations. Where the values of the constants determined as, a_1=0.183;,b_1=1.5.8;c_1=9.3;d_1=14:a_2=0.5;b_2=-6;c_2=52;d_2=-145:a_3=--0.083; b_3=4;c_3=153;d_3=-790.

The Fig.1 shows the comparison of above various model deviations from the actual power from the turbine. The wind

turbine is selected as **E-33** from the manufacturer of Enercon Ltd. The rated power of the turbine is 300KW, cut in speed is 3m/s,rated wind speed is 13m/s and swept area of 855.5m^2.The actual power curve of the turbine shown in the Fig.1 and the various models represented as Model 1,2,3,4 and 5.simulations are carried out using the Matlab simulations for the wind speed varying 0 -25m/s in steps of 0.5m/s.

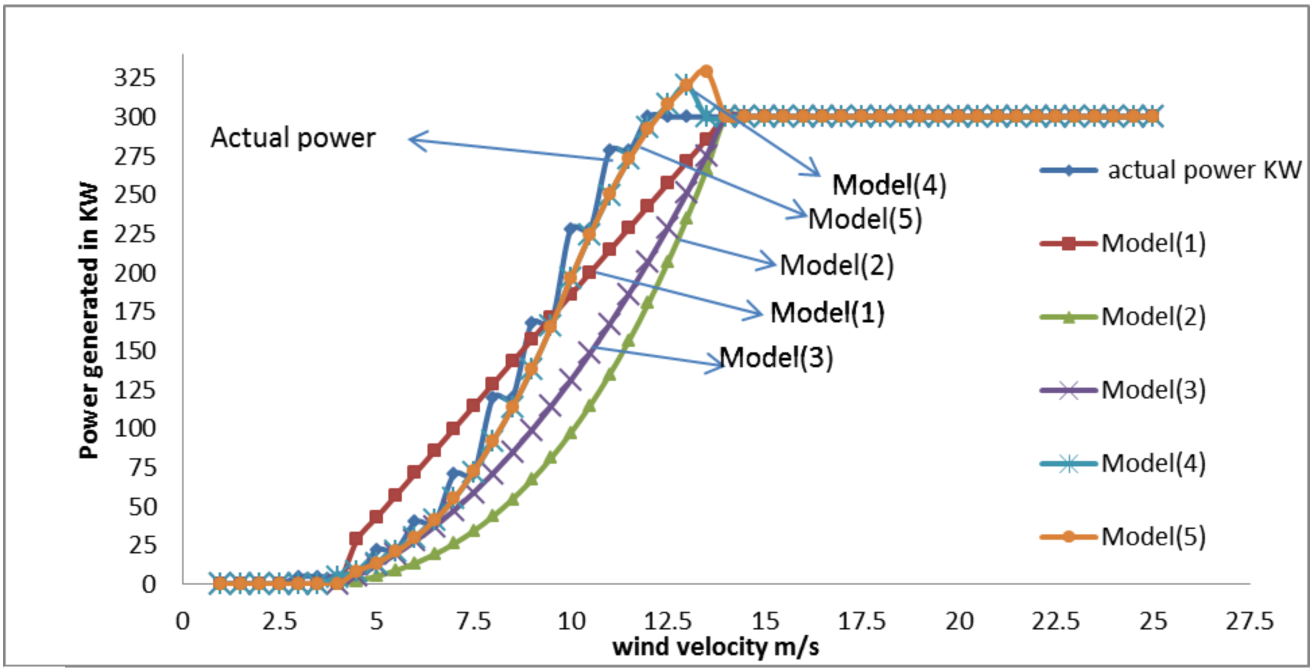

Fig.1. comparison various models from the actual power of the wind turbine

From the Fig.1 ,It can be inferred that all the models show some deviations from the actual power details. The Model(1) shows the linearity but may not give the accurate results. The Model(2) shows more deviation due to its cubic nature and is having larger deviations from the actual curve.
The model based upon the fundamental concept does not give the accurate results. The Model based on linear ,weibull, cubic law cannot be employed if accurate analysis is required ,the method of least squares and cubic spline method used can arrive at an exactly to the behavior of the turbine. This is due to , constants of the equation are obtained by fitting actual curve of the wind turbine. These models involve more computational time and obtaining the constants become difficult. Hence Model(4) and(5) are better to use if we want simulate the performance of the turbine for 8760 hours.

The complication of the model becomes when we increase the terms of the equations and increasing the more steps to calculate the coefficients. The linear Model(1) is slightly more acceptable because of its simple equation and is showing faithful towards the actual curve.

IV. RELATIVE INDEX AS A PARAMETER

Here, we represent the deviation of the models from the actual power by the term Relative Index(RI), which is nothing but percentage of faithfulness of the model from the actual results. Where

$$RI=\frac{\text{Actual power}}{\text{Model power}} x\ 100 \qquad (7)$$

RI is presented as parameter scale from 0-100, which represents as a faithfulness of the model at the respective velocity. If the RI value is beyond the value of 100, then the

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model is largely deviated from the actual result. The Fig.2 shows the RI values of the above models, where Model(2) showing the more deviation ,hence this model cannot be accepted as a good model to use for obtaining the simulation results. Model(4) and Model(5) have shown good response and are giving the accurate results in presenting i faithfulness. It is important to note that these models require higher computational time for obtaining the constants. Model(1) is very easy to adopt and give near to the values of the actual results.

More precisely the deviations can be identified from this parameter and taken as reference to adopt the referred models.

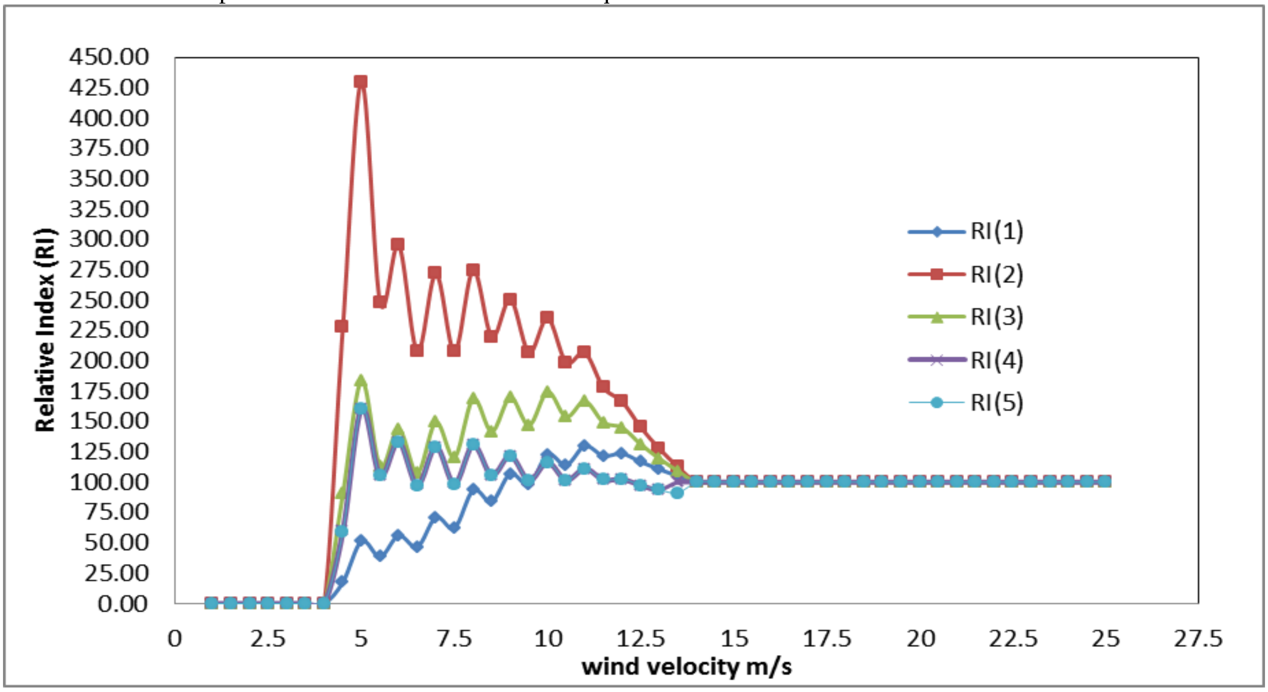

Fig.2 . Deviation of the models as Relative index(RI) parameter

V. MODELING OF PV SYSTEMS

In this section, modeling of photovoltaic systems from are compared through hourly power generated from the set of solar intensity data on a particular day measured at the location of 15.26^{0}N ,76.39^{0}E,Hosapet,Karnataka. The PV module from the manufacturer **siemens M35** is taken into consideration for the study.

The details of the PV Module are Max power output=35W,Max power voltage=17.0V,Max power current=2.12A,open circuit voltage=22V,short circuit current=2.3A,Voltage temperature coefficient =-0.1152V/c^0 and current temperature coefficient =0.000224 A/ ^{0}c.Fig 3 shows the data of variation of solar intensity at chosen site.

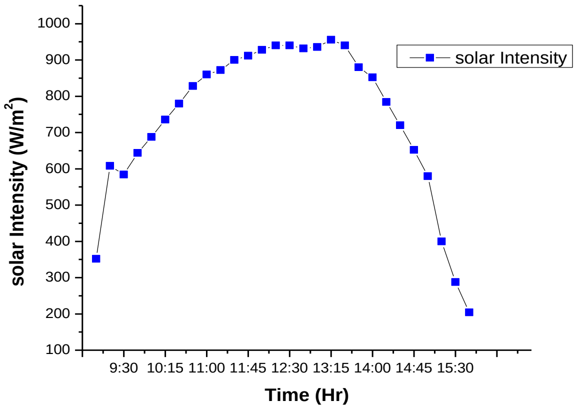

Fig.3. variation of Solar radiation at the selected site

The data of solar radiation is recorded from 9:00 AM to 4:00 PM as a better sunshine hours.The power generated during the time is simulated for all the PV models discussed here.The objective is to obtain the performance of the models with respect to the same intensity.The simulation can be made for the hourly data from the meteorological data available at the site.The idea is to simply the simulation process for ascertaining the deviation of the results.The modeling of PV system is taken here to compare the outcome of results. Models discussed here involves simple models and as well as complexive equations,which are totally based upon the basic physical sciences.The assumptions made here are very simple and according to the suitability of the values,while considering some of the constants.

The power obtained from the PV modules is given by the simple equation[17] as Model(1) is

$$P_{spv} = \eta_{SPV} * H_T(t) * A_{SPV} \quad *N \tag{8}$$

Where η_{SPV} is the efficiency of the solar panel which is taken as 18% from the manafaturer,H_T is the solar irradiance W/ at the time interval t , A_{SPV} is the active area of the PV modules (0.33X1.293) m^2 and N is the Total number of modules connected in series and parallel. This model is very simple to use involving the efficiency factor is being taken into account which deviates the error from other models. The efficiency of the module from time to time and is assumed as constant here.

The Model(2) from the reference[18] is also gives the simple equation to calculate the hourly output of the PV module which is given by

$$P_{PV} = A.I_T \eta_e.\eta_d.\eta_c.\eta_w \tag{9}$$

Where A is the active area of the PV Modules,η_e is the efficiency of the solar cell (32%),η_d is the degradation factor which is 0.8 for 25-30 years,η_c is the efficiency of power conditioning devices is 0.85 and η_w is the wiring efficiency of the PV array system taken as 90%.

The power output from the PV module or the array is modeled by considering the Maximum operating point current working at the maximum power point (MPPT) [15] is given and is represented as Model (3)

$$I_{PV} = I_{SC}\left\{1 - C_1\left[\exp\left(\frac{V_{PV} - \Delta V}{C_2.V_{OC}}\right) - 1\right]\right\} + \Delta I \tag{10}$$

Where

$$C_1 = (1 - I_{mp}/I_{sc}).\exp\left[-V_{mp}/(C_2.V_{oc})\right]$$

$$C_2 = \frac{V_{mp}/V_{oc} - 1}{\ln(1 - I_{mp}/I_{sc})}$$

$$V_{PV} = V_{mp}.\left[1 + 0.0539.\log\left(E_{tt}/E_{st}\right)\right] + \beta_o.\Delta T \tag{11}$$

$$\Delta V = V_{PV} - V_{mp};$$

$$\Delta I = \alpha_0.\left(E_{tt}/E_{st}\right).\Delta T + \left(E_{tt}/E_{st} - 1\right).I_{sc}$$

$$\Delta T = T_{cell} - T_{st}, T_{cell} = T_A + 0.02.E_{tt}$$

I_{sc}=short ciruit current,V_{PV}=maximum operating point voltage,V_{oc}=open ciruit voltage,V_{mp}=module maximum power voltage(V),I_{mp}= maximum power current(A), α_0 =temperature coefficient A/ ^{0}c. β_0 =0.1152V/c^0 . E_{tt}= solar irradiance W/m^2 as the total radiation falling on the horizontal surface,E_{st} is the standard irradiance as reference which is 1000 W/m^2.

Hourly output of the PV array is obtained as

V_{PA}=N_{PVS}.V_{PV} ; where, N_{PVP}& N_{PVS} are serial number of the modules in series and parallel connection. seriesPV modules and parallel PV modules in connection are taken as 50 each.

$$P_{PVA}=N_{PVP}.N_{PVS}.V_{PV}.I_{PV}.F_C.F_O \tag{12}$$

F_C &F_O are the connection losses and other loss factors due to dust collected over the panels. These are taken as 0.15 and 0.2 respectively

The Model(4) from the ref[19],the power output of the module is determined by the relationship between the current I_c and the voltage V_c as follows,

$$I_c = I_l - I_0\left(e^{\frac{qV_d}{mKT}} - 1\right) - \frac{V_d}{R_p}$$

$$V_c = V_d - I_c.R_s \tag{13}$$

$$I_a = N_p I_c, V_a = N_s N_c V_c$$

Where I_l is the photo generated current from the solar cell,I_0 is the diode reverse saturation current which depends on the temperature is the diode ideality factor is the coulombs electron charge current is the Boltzmann constant and T is the absolute temperature,R_p and R_s are the resistances n series and parallel connection.

I_a and V_a are the current generated from the photovoltaic array.N_c is the number of cells connected in series in a module,N_p is the number of strings connected in parallel and N_s is the number modules connected in series.

R_p value is 1.1 ohms cm^2 and R_s is 0.5ohm cm^2, calculated from the by giving the V_{oc} and I_{sc} value details from the manufacturer.I_o is 1.0X10^{-12} A/cm^2 for any typical solar cell.The detail PVModel[20] is also developed using the relation between A and resistance with respect to temperature.

The Fig.4 shows the simulation results from the MATLAB/SIMULINK for the results of power generated from each model. Here, the I-V characteristics and P-V characteristics are not simulated with respect to the solar insolation and are found to be common parameter in order to differentiate the models in various research papers. The objective is to obtain the power generated from each model during time (t), corresponding to solar insolation.

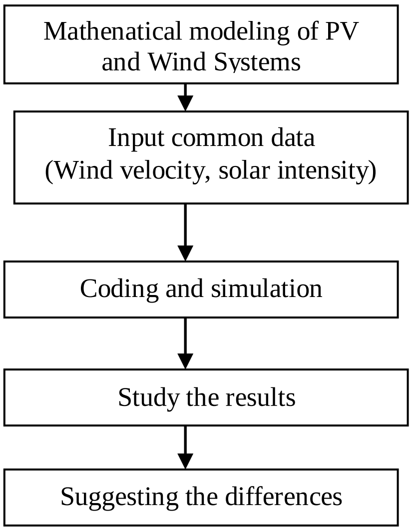

Fig.5. Flow diagram of studying the mathematical Models

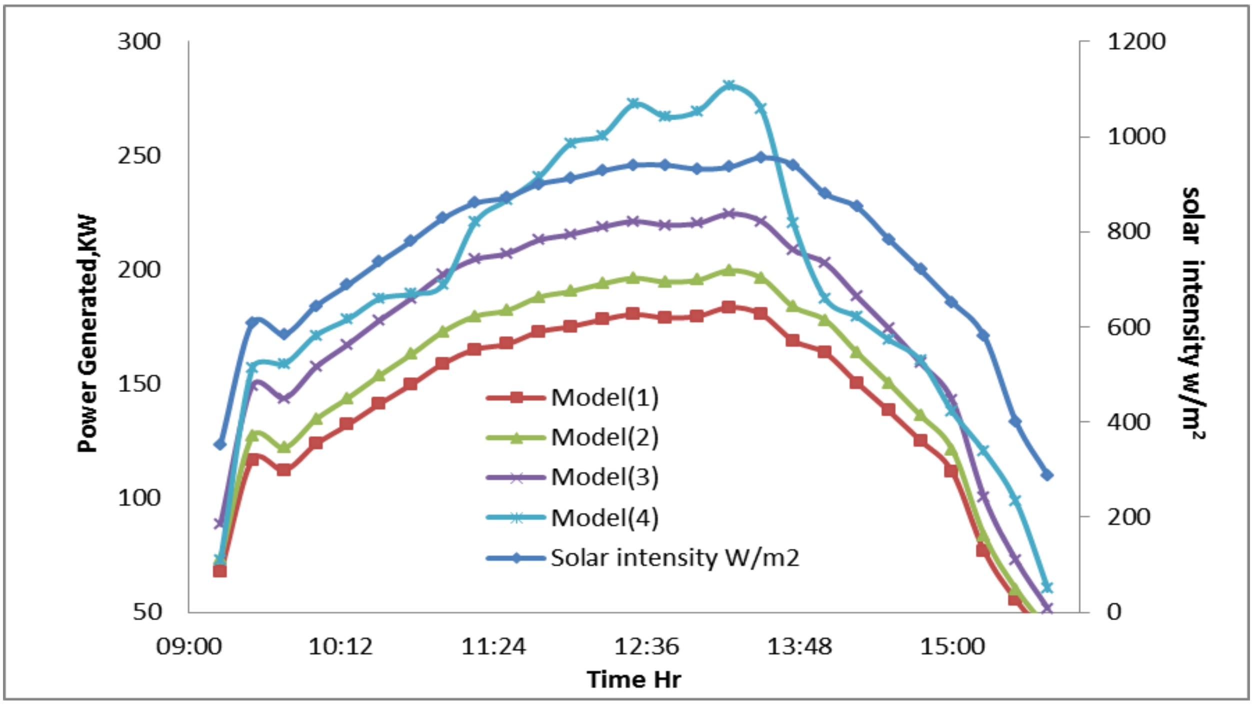

Fig.4. Power output results from the models during the time(t) Hr

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VI. DISCUSSIONS

Fig.5 represents the flow diagram of methodology adopted for studying the mathematical models. It can be seen that the trend of the power(Energy) generation curves follow the pattern of solar intensity variation. The four models presented as 1,2,3 and 4 from the references and simulated for same insolation. The Model(1) and Model(2) are simple to use and simulate ,but the accuracy of the results might fall with the actual reults.The actual P-V curve from the manufacturer is not taken consideration ,because the solar intensity is variant at different locations. Model(3) and Model(4) being complex for simulation has given more difference due to its pure theoretical modeling. These two models involve the physical laws applied and tend to give slightly more deviation, when we try to compare with actual or practical results.

the Relative Index(RI) of the models cannot be made possible, because the parameter gives the erratic results and with more deviations in each model.
Model(1) and Model(2) are very simple to use and able to give the faithful results because ,the operation of PV systems involves several losses like sudden variation in solar intensity,wind velocity, dust collected over the plates ,operation of the converter systems and others.

The mathematical models of wind turbine and PV systems presented here is to compare the results, if the models are not deviating the from required range. The faithfulness of each model cannot be explained in reference to the practicality of the results. This is due to large number contingency losses occur during the operation time of the renewable energy system. But these models help the designers for the accurate simulation of the systems. A small change in variation of the model affects the results. The selected models are very helpful obtaining and understanding the physical behaviour of the system. As the model becomes too complex, the variation of results will also be more. This suggests that the simple mathematical model is enough to predict and analyze the practicality of the system. The presented models is to seek the trends and approach of understanding the problem. The deviation of the results in all the models is due to the assumptions of certain parameters and factors which contribute to the performance of the system. These factors have to be considered very carefully in such a way to avoid larger deviations. In assessment for the Power to be generated from the Renewable systems, It is very economical and less time consuming in order to predict its behaviour. Thus, from the simulations studies it can be inferred that simple models are very helpful and easy to use and asses the systems.

Table- 1 summary of Models studied

Mathematical Model	Dependent parameter	Remarks
Wind Model(1)	Dependenton difference of $(v- v_c)/(v_r-v_c)$	Simple to use gives minimal linear deviations with the observed due to fixed difference ratio
Wind Model(2)	Cubic equation and constants av^3-bP_r	Cubic power of velocity deviates more from the actual
Wind Model(3)	linearity equation and K^{th} power component of velocity and	K is based on weibulldistribution ofwind density.Less deviations comared to model(2)
WindModel(4)	Quadratic polynomial and constants obtained from method of least squres	Accurate and more computation
Wind Model(5)	Cubic polynomial	More accurate and More computation.
PV Model(1)	Efficiency of PV panels	Very simple equation ,less accurate
PV Model(2)	η_d, η_C & η_W	slightly increase in power generation
PV Model(3)	More physical parameters involved	Complexity in computation and gives more insight in power generation
PV Model(4)	Less physical parameters	More variation of results are seen.

VII. CONCLUSIONS

This paper presents the mathematical modeling of wind turbines and PV systems and simulated for their results with respect to common parameter. The deviations in their results give the idea of applicability and adoptability to use in different conditions.
In modeling of wind turbines Model (4) and Model(5) have given the accurate results in comparison to other models. These model constants are based upon by fitting the actual power curve and hence these give accurate results. These models require some more computational time in reference to obtain the constants than others. The model(1) is very useful as it is simple and show linear trend in comparison model(2) and Model(3) which are deviating largely from the actual. The Relative Index(RI) as parameter is presented as faithfulness of the model.
In Modeling of PV systems, all the models have shown the same trend with respect to the varying insolation. RI is cannot be made as comparison to all the models. The simulation of the models having more complexity have shown higher values in comparison to simple models presented. This shows that simple models are very helpful to use and obtain faithful results. The simple the model is better will be the result, because the practical have always fluctuate from the theoretical values.so.it is suggested that simple models are better to use for obtaining the useful results.

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