OPERATIONAL ANALYSIS OF GRID INTEGRATED WIND ENERGY CONVERSION SYSTEM USING GENETIC ALGORITHM

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Abstract: The increasing environmental concern has drawn the attention of system operator to integrate more renewable powered units with conventional grid . In this context, wind energy conversion systems (WECS) have emerged as reliable alternative for being integrated. This work attempts to model, simulate and analyze the operation of WECS integrated power system so that system may be operated in a cost effective manner. Genetic Algorithm (GA) has been used to find the optimal operational paradigm.

***Index Terms*: *Wind integration; Power system operation; Genetic Algorithm; Cost effective system operation*.**

I. INTRODUCTION

The global electrical energy consumption is rising and there is a steady increase in the demand of power generation. So, in addition to conventional power generation units a large number of renewable energy units have to be integrated into the power system. The most desirable renewable source would be one that is non-pollutant, available in abundance, capable of supplying substantial amount of power and can be harnessed at an acceptable cost. The most promising source satisfying these entire requirements is the wind. However, wind is intermittent and unpredictable, posing serious threats to power system security. Despite the changes in generation mix and the market operation of power systems, priority remains on maintaining system security and minimizing the operation costs. This poses a fundamental challenge to the traditional generation scheduling methodologies. So when WECS are introduced in electrical power system it becomes necessary to find the steady state operation point which can minimize the cost of meeting the load demand while finding optimal allocation of power among various generating units to serve the system load. As the primary problem associated with incorporation of wind power with conventional power system is the fact that the future wind speed which is the power source for WECS is intermittent and unpredictable, so steps should be taken for reliable, secure and satisfactory operation of wind power integrated system[1]. In this point of view, decision regarding proper scheduling of generators plays a vital role so that optimum allocation of power output among the available generators can be taken while meeting the constraints. Due to the inconsistent and variable nature of wind, it can never be predicted that the scheduled power from wind turbine generator (WTG) and actual available power will be the same value. This difficulty can be analyzed under two scenarios. Those are (i) Under Estimation, (ii) Over Estimation [1-4]. If the available wind power at a particular time is found to be more than the predicted/scheduled wind power, then there will be a surplus amount of power which is the difference between available and scheduled value. Unless it is properly utilized, it is simply going to be wasted. In that case the system operator has to pay a cost corresponding to the surplus amount of power to the wind power producer for not using the all available power. Generally the surplus amount power [5,6] is not allowed to be wasted. Two possible solutions may be adopted to prevent the wastage of power. Firstly, the surplus amount of power can be sold to adjacent utilities. Secondly, by fast redispatch and automatic gain control (AGC) the output of non wind generators can be correspondingly reduced. The excess amount of power is also termed as Expected Surplus Wind Power (ESWP) and the cost corresponding to ESWP is called Penalty Cost. Over estimation is a scenario which comes into the picture when the available wind power at a particular time is lesser than the predicted wind power [7-10]. In other words certain amount wind power which is assumed is not available at the particular time. Then a premium has to be paid to conventional generator for regulation up as a result of production fall behind the forecast and some reserve unit has to be called .That cost of calling the reserve unit is termed as reserve cost [11].

II. FITNESS FUNCTION FORMULATION

Taking into consideration of the additional cost for managing wind power intermittency along with cost of thermal power generation an optimization model can be formulated which can be represented as : Minimize F =

$$\sum_i^{N_g} C_i(P_{gi}) + \sum_j^{N_w}[C_{wj}(P_{wj}) + C_{p,wj}(P_{wj,av} - P_{wj}) + C_{r,wj}(P_{wj} - P_{wj,av})] + Pf1 \qquad (1)$$

Where

N_g number of conventional generator.

N_w number of wind-powered generators.

P_{gi} power from ith conventional generator.
P_{wj}scheduled wind power from jth wind powered generator.
$P_{wj,av}$ available wind power from jth wind powered generator
This is a random variable with a value range of $0 \leq P_{wj} \leq P_{r,j}$ and probabilities varying with the given
Pdf. We considered Weibull pdf for wind variation. C_i - cost function for the ith conventional generator.

C_{wj} cost function for jth wind powered generator. This factor will typically take the form of a payment to the wind farm operator for the wind generated power actually used. $C_{p,wj}$ penalty cost function for not using all available power from the jth wind-powered generator.$C_{r,wj}$ required reserve cost function , relating to uncertainty of wind power. This is effectively a penalty associated with over estimation of the available wind power.

Analyzing the objective function, it can be stated that the first term represents the traditional sum of the fuel costs of the conventional generator. The second term is the operating cost for the power drawn from the wind generator. This cost depends upon the ownership of the wind farm. For example, if the wind farm is owned by the system operator itself, then this term may not exist but if it is owned by independent power producer IPP then system operator has to pay for the wind farms[5]. The third term is the cost due under estimation of wind power. Generally it comes in the form of penalty made to the wind power producer for not using all the available wind power. The last term relates to the cost that must be paid for over-estimation of the available wind power. This cost accounts the possibility of reserve need to be drawn.

For the conventional generator, a quadratic cost function will be assumed, which is practical for most of the cases, and is given by $C_i\left(P_{gi}\right) = a_i P_{gi}^2 + b_i P_{gi} + c_i$ (2)

Where a_i, b_i, c_i are the cost co-efficient for the ith conventional generator, the quadratic function will varies depending upon different fuel used. The detail mathematical modelling of wind power cost formulation may be followed from (1).

The most challenging issue for the integration of the wind power into the grid is its variability. So wind power prediction plays an important part in the system integration of the large-scale wind power. Wind power production is highly dependent on the wind resources at the site. So the wind distribution depends upon the seasonal and the geographical area. Wind prediction has been investigated by many authors in variety of ways. Each predicting method based on time series, fuzzy logic, neural network, artificial intelligence etc has some unique features and certain degree of accuracy. Unfortunately, the statistical data are not stationary and there are weak variations and changes, which may lead to very inaccurate results. All current prediction programs use at least one of the two kinds of methods of prediction wind power- physical and statistical methods. Physical methods try to model the wind farm equations according to the aero dynamical behavior of wind turbines in the actual site, and local effects of wind speed and direction. Statistical methods try to reproduce the behavior of the wind farm from past data under different condition. Physical models usually require long computational time compare to the statistical method. Recent researches have investigated the fitting of specific distribution to wind speed. Various probability distribution models were used or proposed for the statistical analysis of recorded wind speeds. Among them the most widely used probability density function (pdf) to describe the wind speed is the Weibull functions [8] because wind speed profile at a given location most closely follow a Weibull distribution over time. The pdf for Weibull distribution is given by

$$f_v(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} (e)^{\left(-\left(\frac{v}{c}\right)^k\right)}, 0 < v < \infty \qquad (3)$$

Where
v wind speed
c scale factor at a given location (units of wind speed);
k shape factor at a given location(dimensionless).

The Weibull distribution function with a shape factor (k) of 2 is also known as the Rayleigh distribution. In [9], the advantages of the Weibull distribution are noted as (i) it provides a good fit to observed wind speed data and (ii) if the shape factor (k) and scale factor (c) parameters are known at one height, methods exist to find the corresponding parameters at another height. Normally the shape parameter varies from 1 to 3 and the scale factor range from 5 to 25 for any wind speed characteristics.

From the knowledge of scale and shape parameter we can easily estimate the mean and standard deviation of the distribution curve. The mean of the weibull function is given by

$$E(V) = c * \Gamma(1 + k^{-1}) = \frac{c}{k} * \Gamma\left(\frac{1}{k}\right) \qquad (4)$$

and variance is given by $var(V) = E(V^2) - E^2(V)$

$$= \frac{c^2}{k}\left[2\Gamma\left(\frac{2}{k}\right) - \frac{1}{k}\left[\Gamma\left(\frac{1}{k}\right)^2\right]\right] \qquad (5)$$

Due to the fact that the WECS power output has a constant zero value below the cut-in wind speed and also above the cutout wind speed, and due to the fact that the power output is constant between rated wind speed and cut-out wind speed, the power output random variable will be discrete in these ranges of wind speed. The WECS power output is a mixed random variable, which is continuous between values of zero and rated power, and is discrete at values of zero and rated power output.

If it is assumed that the wind speed has a given distribution such as weibull, then it becomes necessary to convert that distribution to a wind power distribution. The linear transformation is accomplished with V as the wind speed random variables. A linear transformation of X is the quantity aV + b for some constants a and b. Then the linear transformation in general can be described as

$$P = g(V) = aV + b \qquad (6)$$

$$\text{Then } f_p(p) = f_v[g^{-1}(w)]\left[\frac{dg^{-1}(w)}{dw}\right]$$
$$= f_v(v)\big|_{v=\frac{p-b}{a}} * \left[\frac{dg^{-1}}{a}\right]$$
$$= f_v\left(\frac{p-b}{a}\right) * \left|\frac{1}{a}\right| \qquad (7)$$

Where
g: a transformation function
P: wind power random variable
V: wind speed random variable.

It may be seen that there is a linear increase in the wind power output in the region between the cut-in speeds to the rated-speed. Hence it is continuous distribution so random variable transformation is accomplished from the wind speed random variable to the wind power output random variable. The linear variable transformation discussed in equation (15) then takes the form

$$p = p_r * \frac{(v - v_i)}{(v_r - v_i)}, \qquad for\ v_i \le v \le v_r$$

$$f_p(p) = f_v\left(\frac{p + \frac{(v_i)}{(v_r - v_i)}}{\frac{p_r}{(v_r - v_i)}}\right)\left[\frac{1}{\frac{p_r}{(v_r - v_i)}}\right] \qquad (8)$$

The OPF can be considered as a constraint optimization. The objective aims at minimizing the cost associated with operation of the conventional generator, purchase of wind power from the private owner, and reduce the risk involved in the wind power uncertainty when WECS is integrated with existing power system. So the system operator (SO) ensures security of supply from a technical point of view and scheduled the wind power with certain fixed tariff paid to the wind farm owner. The OPF model is developed in the most general case, so that it is adaptable to all situations, no matter of who owns the generation facilities. But due to the wind power variability, it may not produce the exact amount according to the power forecast. So before proceeding to the optimal power flow model, it becomes important to understand the factors involved due to the wind power variability. Over-estimation and under-estimation [5-8] are the two factors associated with wind power uncertainty are discussed in section (I). The cost associated with under estimation is the penalty cost where as the cost associated with over estimation is the reserve cost. Along with this, another cost called ‘‘direst cost’’ has been incorporated in the model which is discussed in section (II).

The optimal power flow dispatching with a wind generator is subjected to a variety of constrain which include equality constrain (power balance) and inequality constrain as reactive power constrain, voltage constrain, line flow constrain, etc. The equality constraints of the OPF contemplate the law of physics in the power system. The physics of the power system are enforced through the power flow equations which require that the net injection of real and reactive power [18-20] at each bus sum to zero. Alternately, the sum of power generated by the conventional and wind farms is equal to the sum of the total demand in the network and losses in the system.

$$\sum_{i}^{N_g} P_{gi} + \sum_{j}^{N_w} P_{wj} = P_{loss} + P_{load} \qquad (9)$$

$$\sum_{i}^{N_g} Q_{gi} + \sum_{j}^{N_w} Q_{wj} = Q_{loss} + Q_{load} \qquad (10)$$

The inequality constraints of the OPF reflect the limits on generators in the power system as well as the limits created to ensure system security. This section will lay out all the necessary inequality constraints needed for the OPF implementation. Each generator has maximum and minimum power outputs, but in wind generators the minimum output will be zero and maximum output is equal to the rated capacity of the wind generators.

$V_i^{min} \le V_i \le V_i^{max} \qquad i \in N_g$
$P_{wj} \le P_{wj}^{max}$
$0 \le P_{wj} \le P_{r,j} \qquad j \in N_w$

III. SIMULATION, RESULTS AND DISCUSSION

Genetic Algorithm [12] is an evolutionary computation techniques that work with a population of potential solutions to a problem and can be used to solve search and optimization problems. Over many generations, natural populations evolve according to the principles of natural selection and survival of the fittest. By mimicking the process, genetic algorithms are able to evolve solutions to the real world problems. Genetic algorithms are very different from most of the traditional optimization methods. They need design space to be converted into genetic space. So GA work with coding of variable. The advantage of working with coding of variable is that coding discretizes the search space even though the function may be continuous. A more striking difference between GA and most of the traditional optimization methods is that GA uses a population of points at one time in contrast to the single point approach by traditional optimization methods. It means that GA processes number of designs at the same time. The system under consideration, i.e IEEE-30 bus system consists of six generators which includes a slack bus at node1. Node 2, 5, 8 and 11 represents four thermal generators. Node 13 represents a wind farm. In other words generator 6 (G6) represents a wind farm of 20MW installed capacity. The wind farm includes five wind generators with the same type, each of which is having a rated capacity of 4MW.

Fig.1. shows the variation of total cost with generations. It can be seen that GA has almost converged by generation 10000. So it can be concluded that increased number of generations provides an average improvement in the total cost and solution quality is improved in terms of accuracy of optimal solution. From this it is found that minimum value of total cost is achieved and its value is 1173.711$/hr.

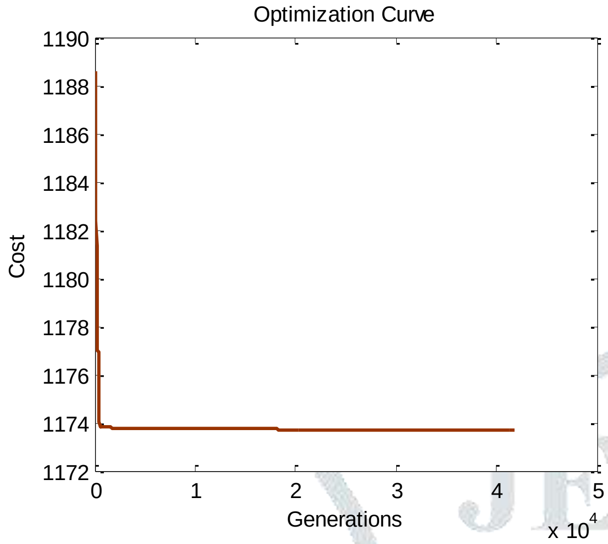

Fig.1. Variation of wind-thermal operating cost

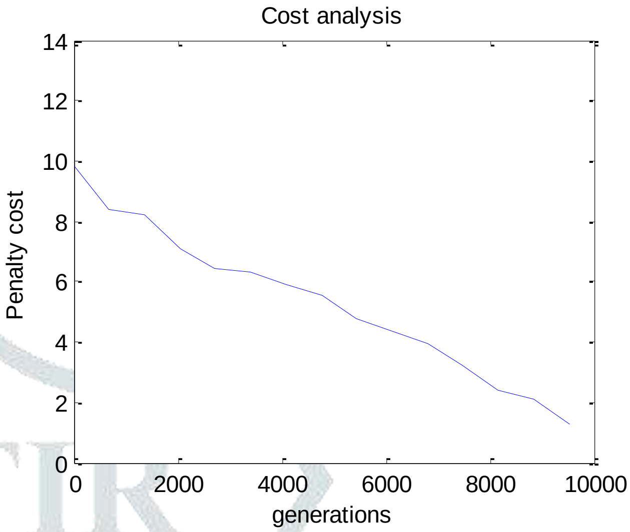

Fig.2. Variation of penalty cost

Fig.2. shows the variation of penalty cost. The value of penalty cost has been reduced from a higher value i.e. 9.7947 to 1.2747 during optimization process.

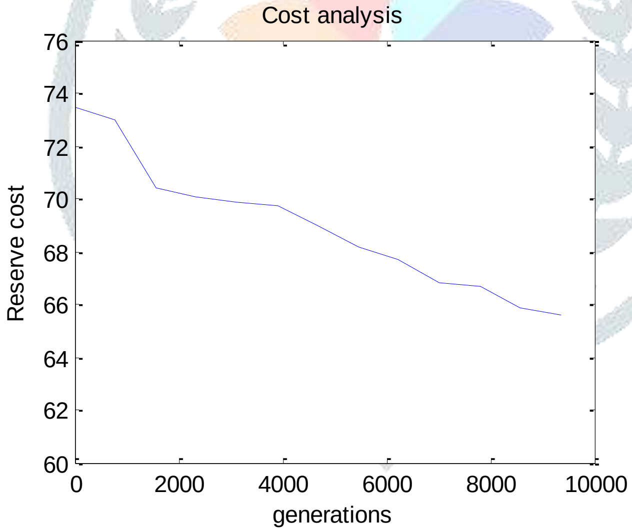

Fig.3. Variation of reserve cost

Fig.3. shows variation of system's reserve cost with number of generations. It can be concluded from the figure that at the start of optimization process the value of reserve cost was 73.4836 $/hr but with advancement of optimization it is gradually reduced and when optimal solution is reached the value of reserve cost is found as 65.6290$/hr.

IV. CONCLUSION

This work develops a model to include WECS in the optimal power flow problem along with thermal systems. The stochastic nature of the wind speed and wind power is represented by weibull probability distribution function. In addition to the classical economic dispatch formulation, factors to account for both overestimation and underestimation of available wind power have been included apart from the direct cost of wind energy. Further the optimal power flow problem is then numerically solved for IEEE-30 bus test system where in the bus no 13 the conventional system is replaced with a wind farm which consists of five WTG. To solve the OPF problem and for the optimization work Genetic Algorithm is applied. The solution of the OPF problem presented is dependent on the various factor involved, such as weibull scale factor, reserve cost for overestimating the wind power, and the penalty cost for under estimation of the wind energy. This OPF solution also indicates the minimum real and reactive power requirement in the wind farm to maintain a satisfactory voltage profile.

From the optimized solution of the problem following few points are observed from which few inferences can be derived

- The penalty cost has been found to be zero in the solution where as the reserve cost remains at some non zero value, which means that an over estimation of wind power may be beneficial compared to under estimation as this encourages the wind energy to be utilized to its maximum level.
- The penalty/reserve cost coefficients play an important role in the overall optimized results.

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