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Adequacy Evaluation of Electrical Distribution System with DG using MCS

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Abstract— In the last few decades, due to the growth of load demand, the operation, maintenance and control of power system have become a challenging task. To meet the load requirements, many noticeable research activities are going on in the field of deregulation, restructuring of power system, utilization of renewable energy sources and installing small generators at the load centre referred to as Distributed Generation (DG) etc. Furthermore, among many different types of DG units, renewable DG units are widely accepted.

In this paper, adequacy evaluation of the electrical distribution system with DG has been proposed. This concept deals with installation of additional capacity with the existing capacity for supplying load, which is provided by renewable DG units. Reliability index such as average unsupplied load (AUL) is calculated using Monte Carlo technique, and it is tested by considering IEEE RTS system as a base case for analysis.

Keywords— Adequacy Assessment, Renewable wind energy, Monte Carlo simulation, Distribution system, Distributed generation, IEEE RTS, Reliability index.

INTRODUCTION

The main objective of power system is to supply electrical energy as economically as possible with an acceptable degree of reliability and quality.

For conducting reliability assessment of power system, the system is divided into three hierarchical levels. 1st level (HL1) consists of evaluation of generation system, 2nd level (HL2) consists of combined evaluation of generation and transmission systems, 3rd level (HL3) consists of combined evaluation of all the main sectors of power system, i.e. generation, transmission and distribution system. Due to the complexities in HL3, only distribution system is taken into account for analysis of reliability evaluation of power system. Fig 1 represents hierarchical levels of reliability assessment.

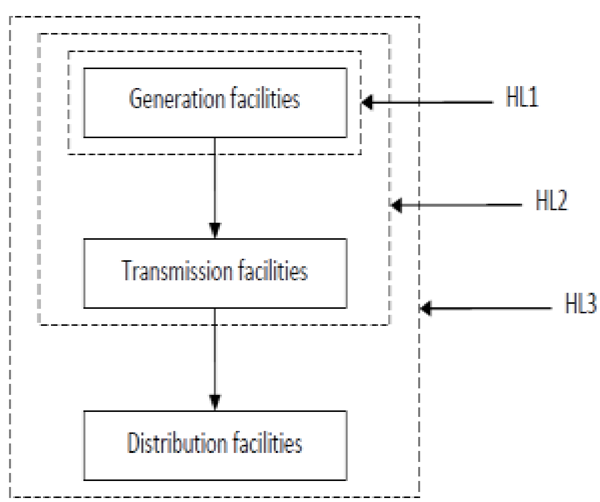

Figure 1: Hierarchical levels for reliability assessment.

The reliability assessment of a distribution system can be evaluated by two attributes: adequacy and security. Adequacy evaluation specifies the ability of the system to supply the accumulated electrical energy requirements of customers within component ratings and voltage limits, even when expected and unexpected component outages occur. Security evaluation specifies to the ability of power system to withstand the disturbances arising from faults or equipment outages. Most of the research work is carried out considering security as an aspect of reliability evaluation with DG and only a few are conducted considering adequacy requirement. In [5] adequacy of a distribution system is assessed with consideration of distributed generation. Present work concentrates on adequacy of a distribution system with renewable wind energy based DG; natural variation of wind speed assessed by sequential time series and amount of power generation calculated using probabilistic method.

Distributed generation (DG) is commonly used in small-scale (1 KW–50 MW) electric power generators that produce electricity at a site close to customers or that are connected to an electric distribution system. It includes combustion gas turbines, fuel cells, solar, wind turbine and electric vehicles etc. Due to the improvements in distributed generation technology, some amount of spare capacity is also added at the customer sites. DG assures sufficient and acceptable continuity of supply, in the event of failure in the generation, distribution, and transmission systems. The degree of redundancy has to be proportionate with the requirement, that the supply should be as profitable as possible. It is necessary that maximum reliability is achieved within a given set of economic constraints. DG units are closer to customers so that transmission and distribution costs are avoided or reduced. It is straight forward to find sites for small generators than for large ones.

Probabilistic methods are used throughout this paper to provide new substantial information to be used in design and are innovative in planning and allocation. There are two fundamental approaches for probabilistic interpretation of reliability of power systems namely a method followed by Roy Billiton (analytical method) and Monte Carlo Simulation. Analytical method performs the system by mathematical models and uses straight forward analytical solutions to perform theory based reliability indices from the model. Monte Carlo Simulation estimates an experimental reliability index by simulating the actual random behavior to the system. Whatever approach is used, the predicted indices are valuable as the derived models. In this paper, MCS approach is used for calculating distribution adequacy indices.

PROBLEM DESCRIPTION

In this section, adequacy evaluation of an electrical distribution system with DG is described. The assumptions considered are,

1. Renewable DG used is wind power generation.
2. Hourly load characteristic of Distribution system is known a priory.
3. Due to future load growth, distribution systems may not be able to supply required load and hence additional energy is required. To avoid expansion of substation, DG installed close to them.

The interpretation of ability of a distribution system for satisfying the total system load is done as a part of adequacy assessment. Certainly the average amount of energy not supplied is given as adequacy index. MCS is used for distribution system adequacy assessment to endure the randomness of power generation in wind turbines.
The subsequent control strategies are applied throughout the study.

- Unit power factor is maintained for all wind based DG.
- The data needed for MCS is naturally varying wind speed. The average hourly values are considered and the variation within the hour is not considered.
- Wind-based DG output power is regulated and used for satisfying load. Extra energy will be stepped up to grid.
- All DG ratings are considered in MW.

TIME SEQUENTIAL WIND SPEED SIMULATION

The necessary condition in time sequential simulation is to generate artificial operating histories of the wind speed (WS). The energy generated by DG depends mainly on values available at generation substation. The values such as wind speed and solar density radiation are different in various locations and are not predictable. Modeling of renewable DG plays a vital role in distribution system planning in presence of these resources. Thus, the proposed model should be able to tolerate power generation uncertainty. In this paper, wind turbines are utilized as renewable distributed generations. Research has been done by using solar energy [8], but using wind turbines does not cause any limitation for adequacy assessment. This proposed method is also applicable for other renewable based DG.

In this approach, wind speed data from various years in wind turbine location is gathered and corresponding time sequential wind speed variation is predicted. The effect of uncertain and time varying nature of wind speed profile should be modeled in distribution system adequacy assessment procedures. In this paper sequential time varying nature of wind speed with its uncertainty is considered. According to the wind speed probability density function, probabilities of each state of DG and transition rates to up and down states are calculated. After obtaining results, it is possible to calculate the sequential variation of wind speed using Monte Carlo simulation.

The following assumptions have been made,

1) The WS model is statistically stationary, i.e. random behavior of the WS is same at all points of time regardless of the point of time being considered.
2) The transition probability from a given WS state to another state is directly proportional to the average probability of the new state.
3) Transitions between WS states and Wind turbine states are independent of each other.

The sequential time series of wind speed is calculated for each simulation year as explained in fig 2.

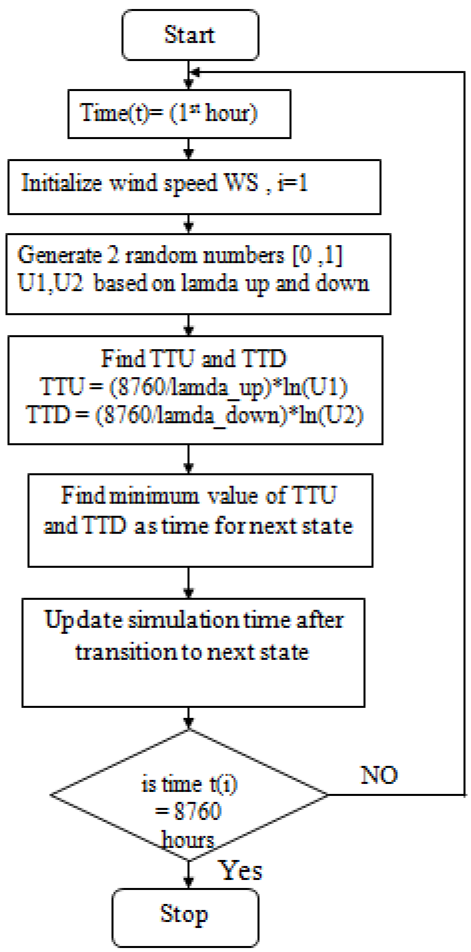

Figure 2. Flow chart to generate sequential time series wind speed

In fig 2, Lamda up and lamda down are up transition and down transition rates respectively. TTU and TTD are time to up and time to down respectively. The smallest of two values calculated defines the present WS movement and duration in a present state (example, if TTU < TTD, indicates that the current WS goes to upper state after TTU seconds).

A WS time series is thus obtained used in the Monte Carlo technique. The advantage of this approach is that it considers the natural variation of WS, and allows for a more realistic simulation. The disadvantage is the long computation time to calculate the time series based wind speed at every sampled year, but that can be overcome by defining and storing a set of artificial WS time series before simulation, and calling them during computation. Since WS series is not calculated yearly computation time would be sensibly reduced.

WIND POWER GENERATION

By using time varying wind speed depending on cut out and cut in speed, wind power generation is calculated for each turbine using (1)

$$W_P = \begin{cases} 0 & s \le s_{ci} \\ S_{rated} * \frac{(s_i - s_{ci})}{(s_r - s_{ci})} & s_{ci} \le s \le s_r \\ S_{rated} & s_r \le s \le s_{co} \\ 0 & s_{co} \le s \end{cases} \quad (1)$$

Where, S_{ci}, S_{co} and S_r are the cut-in, cut-out and rated wind speed respectively, W_P is the output power of wind turbine.

After generating hourly wind speed time series and converting it into power generation using (1) for each wind turbine and summation of all wind turbines power generation is calculated using (2). Total power generation by each wind turbine is given by

$$P_{WT} = \sum_{m=1}^{N} (1 - FOR_m) * W_{P_m} \quad (2)$$

Where, P_{WT} is the power generated by wind turbine in m^{th} node in MW, FOR_m is the forced outage rate of m^{th} wind turbine. Simultaneous outages of two or more wind turbines are eliminated.

ADEQUACY ASSESSMENT USING MCS

In order to calculate adequacy of distribution system Total available capacity is calculated by

$$P_{Total} = P_T + P_{WT} \quad (3)$$

Where, P_T is Transmission capacity of substation, P_{DG} is total power generated by DG. After getting total available capacity, unsupplied load is calculated by superimposing weekly load and the available system capacity.

Accordingly, the system available margin is calculated. If this margin is positive, system capacity is adequate to supply load. If margin is negative then the system is not adequate. The distribution adequacy indices calculated by

$$AUL = \left| \frac{\sum \text{Negative Margin in MW}}{8760 * M} \right| \quad (4)$$

M is the number of Monte Carlo experiments.

Advantage of using Monte Carlo method for simulation is that it grants to model systems that are too complex for an analytic solution and it also grants to simulate uncertainty. Even when a design has a few uncertain parameters, it will operate in almost any uncertainty condition. While designing a system that will perform over a long period, simulating how it will operate over its entire lifetime comprises all kinds of uncertainty. Monte Carlo method is used to predict the tendency of failure after a certain time.

One drawback of Monte Carlo method is that they can involve running thousands of iterations of a single model. Literally, the more composite the system being simulated or the more uncertainty it contains, the more simulations had to be run. It can sometimes take days to run a complex model hundreds or thousands of times.

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IEEE reliability test system.

The adequacy assessment of the distribution system is implemented in MATLAB Software and tested for 66/11 KV distribution substation.

The 66/11 KV distribution substation has capacity of 3400 MW to serve loads, with respect to operational limitations; the single line diagram of the system is shown in Fig. 3. This system supplies different combinations of loads. All loads are fed from 11-kV buses and weekly peak load value is considered for calculations of indices. Distribution substation peak load is 2850 MW. If the detailed value of hourly load variation is available, the proposed method can also be used for satisfying hourly load conditions. The annual peak load curve per hour is given in Fig. 4.The data required for load model is obtained from IEEE reliability test system given in reference [1].

Adequacy assessment done in two steps: 1. Determination of AUL without DG, 2. Determination of AUL with DG.

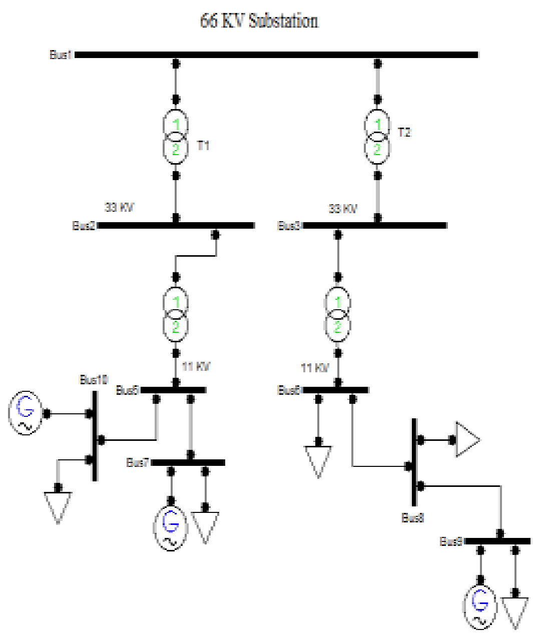

Figure 3.Single line diagram of distribution system.

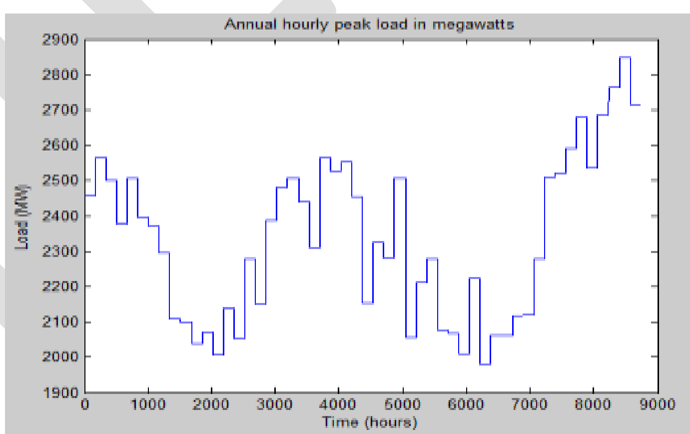

Figure 4.Peak load curve of one year.

A. Determination of the AUL Without DG

In this section, the available system margin is obtained by deducting the peak load from the transmission power P_T per hour. The estimated system margin for a sample year is shown in Fig. 5. From this figure it is noticed that substation transmission capacity is not capable of satisfying the required demand and therefore it is necessary to increase the overall system capacity. To estimate the required energy to meet the demand, hourly based negative margin at each hour during the sample year is recorded. Fig. 6 shows the distribution of the recorded negative margins per sample year. The maximum requirement of energy between the transmission capacity and peak load obtained is 380MW.

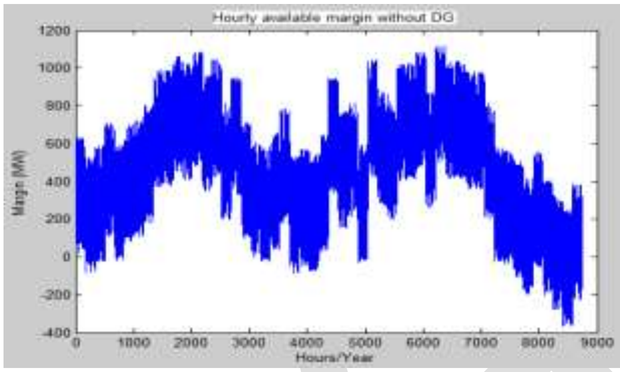

Figure 5.Hourly available system margin for one year

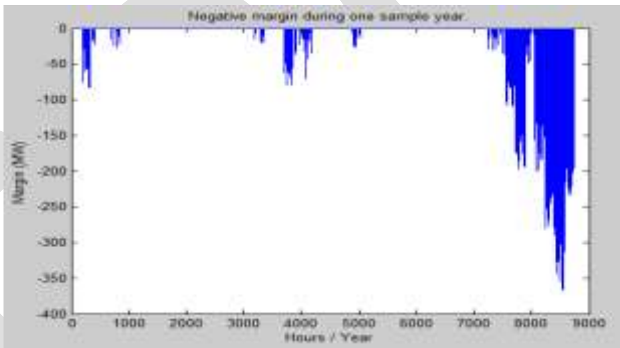

Figure 6. Negative margin without DG.

This result shows a high deficiency of the system. In order to estimate the AUL for any year, Monte Carlo Technique was performed for many sample years. The average amount of unsupplied load for each hour was calculated using (4). Fig. 7 shows calculated AUL using MCS. The AUL found to be 6.157 MW for each hour of the year. This figure shows the great need of substation capacity in order to meet the system load demand.

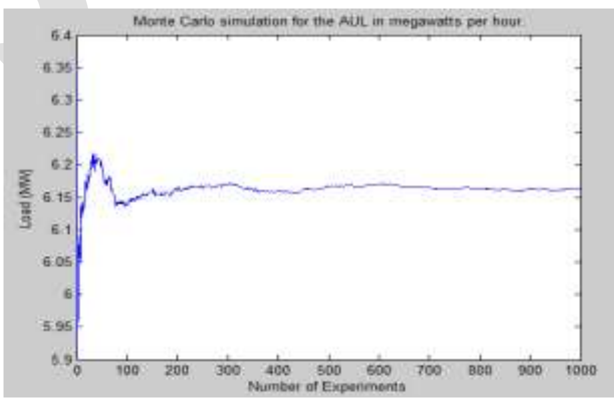

Figure 7.MCS for Average Unsupplied Load in MW

B. Determination of the AUL With DG

In this section, wind turbines are assumed to run in parallel with the existing system. In order to calculate wind power, Wind speeds are predicted for one year using fig 2, and it's shown in fig 8.

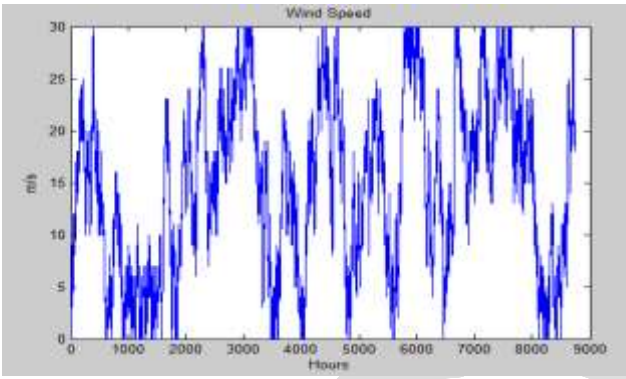

Figure 8 sequential time based series wind speed

Later, Wind speed is transformed to power generation as explained in section IV. DG location in distribution system and their failure rate, repair rate, capacities (MW) are provided in Table 1.Total available capacity P_{Total} is calculated using (3). Then the available capacity is superimposed with load curve and same procedure is followed as without DG. The results shown in Fig. 10 and those obtained from the system without DG (Fig. 7) shows that, the negative margin during the sampled year has reduced by DG running in parallel with the substation. However, the adequacy of the system calculated using indices, average amount of unsupplied load in each hour of the year.

Number	Capacity (MW)	Failure rate	Repair rate	Location
G1	20	0.001	0.003	Bus 7
G2	10	0.0024	0.005	Bus 9
G3	15	0.003	0.006	Bus 10

Table 1

The simulation for number of sample years is shown in Fig. 10. The AUL in each hour is 2.1 MW. Therefore, by implementation of wind turbines, adequacy index of distribution system has been improved by 65.89%. If DG is well managed it gives good support to the substation.

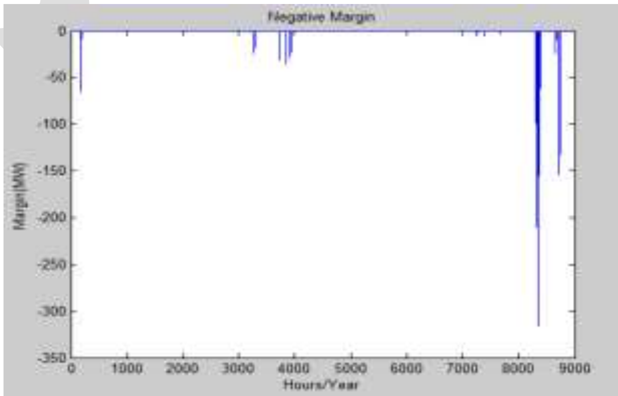

Figure 9. Negative margin with DG

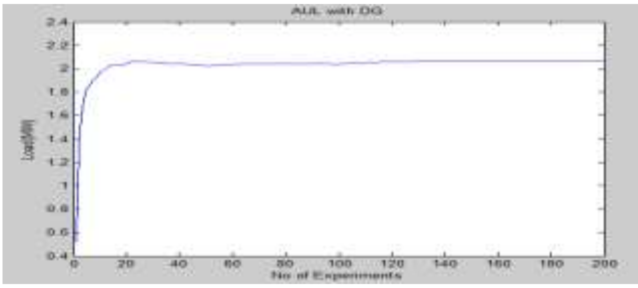

Figure 10. MCS of AUL with DG

CONCLUSION

In this work adequacy evaluation of the distribution system has been performed by considering wind energy based DG. Monte Carlo simulation technique is used for calculation of adequacy index using natural variation of wind speed. Application of the proposed approach for the test system notifies that wind energy based distributed generation can provide positive margin and could be a very good value addition to minimize the curtailment of unsupplied load value as distribution system adequacy index.

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