A NOVEL ALGORITHM FOR THE ADEQUACY ASSESSMENT OF DISTRIBUTION SYSTEMS WITH DISTRIBUTED GENERATION

Yasser G. Hegazy
Ain Shams University –Egypt
Y_hegazy@yahoo.com

ABSTRACT

A novel algorithm to evaluate the reliability of electric distribution systems including distributed generation is proposed. This algorithm addresses the stochastic nature of the operation of these systems. The proposed algorithm employs Monte Carlo simulation to estimate the random operating cycles of the installed distributed generators and the ability of the system power capacity to meet the total demand. A typical case study is presented in which several distributed generation units are running in parallel within a distribution system and both the system margins and the average amount of unsupplied loads are estimated. The results obtained are presented and discussed.

INTRODUCTION

Distribution system reliability is the ability of the system to provide adequate electrical energy to the loads, with an acceptable continuity and quality. System reliability can be subdivided into two basic aspects namely, system adequacy and system security [1]. System adequacy relates the presence of sufficient facilities within the system to satisfy the customer load requirements whereas; system security involves the ability of the system to respond to disturbances arising within the system suitably. In order to remain competitive, the electric utility companies attempt to secure the highest reliability standards in their systems. Among the avenues, which recently become available to provide promising reliability solutions, is the integration of distributed generation (DG) with the existing distribution systems. DG can be installed within the distribution system or at a customer's site, as a separate solution or in combination with market-driven incentives to improve reliability. DG can improve reliability by adding system generation capacity, adding generation capacity at the customer site for continuous power and backup supply, relieving transmission and distribution bottlenecks and supporting power system maintenance and restoration operations with generation of temporary backup power [2-4].

Recently, the assessment of the reliability of distribution systems with DG has become an important research topic and received a great deal of attention. Among the recent studies in this area are, the investigations of the impact of the DG on the distribution system reliability and the estimation of the new structured system reliability indices [5-9], the reliability modeling of DG for conventional distribution system planning and analysis [10,11], and the adequacy assessment of the distributed generation system using Monte Carlo simulation [12].

The analyses performed in all these publications were based on the assumption that the DG units have known locations and running all the time, however, in the real life systems, the operation of these units undergoes different scenarios according to the strategies of the electricity producers and the needs of the consumers. Therefore, uncertainties are introduced in the operation of such units and thus, stochastic modeling of systems involving DG units for reliability analysis becomes of great interest. The sources of the uncertainties in the operation of systems involving distributed generation at any hour of the day include, the number of the running DG units at this hour, the locations of these units and the power imported to the system by these units. These variables affect the modeling and the evaluation of the system capacity, security and reliability.

This paper investigates thoroughly the impact of the uncertainties in the operation of the DG units upon the adequacy of the distribution system. The state duration sampling approach and Monte Carlo simulation are combined in a novel algorithm to perform the system reliability analysis. The structure of the paper is as follows, Section II discusses the adequacy assessment problem. Section III presents the proposed algorithm to simulate the operating cycles of the DG units, Section III formulates the distribution system adequacy assessment problem of a typical distribution system, and finally the main conclusions are offered in Section VI.

ADEQUACY ASSESSMENT PROBLEM

Adequacy assessment implies the determination of the actual distribution system power capacity and the ability of this capacity to meet the total system demand. The term distribution system power capacity is introduced to account for the generating power from the available DG units plus the received power from the transmission system. Mathematically, distribution system power capacity (P_S) is defined by:

$$P_S = P_T + P_{DG} \tag{1}$$

Where: P_T is the power received from transmission system in megawatts and P_{DG} is the power generated by the DG in megawatts. P_T can be treated as a large generated power located at the substation site. P_{DG} is the expected contribution of all the online DG where,

$$P_{DG} = \sum_{i=1}^{N} P_{G,i} \quad (2)$$

$P_{G,i}$ is the power output of DG unit i and N is the number of DG units in their "on" state.

The adequacy assessment of distribution system requires the prediction of the operating state of each DG and its contribution to the system capacity. The system state will be determined accordingly. The procedure carried out to perform this assessment and to estimate the power capacity of the system is summarized as follows:

Step I: A two-state model is generated for each DG unit employing the proposed algorithm. This model is used to provide a simulated operating history of each DG unit in the form of an up-and-down cycle.

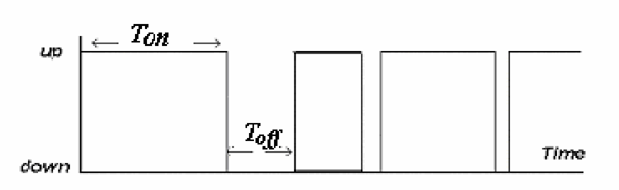

Figure 1. Two state model of a DG unit

Step II: The operating cycles of all the DGs are combined to obtain the power capacity of the DG (P_{DG}). This P_{DG} is then added to the P_T in order to obtain the overall available capacity of the system. P_T is assumed to be the power capacity of a large substation. This capacity is considered to be a random value ranging from 80% to 100% of the nominal substation capacity.

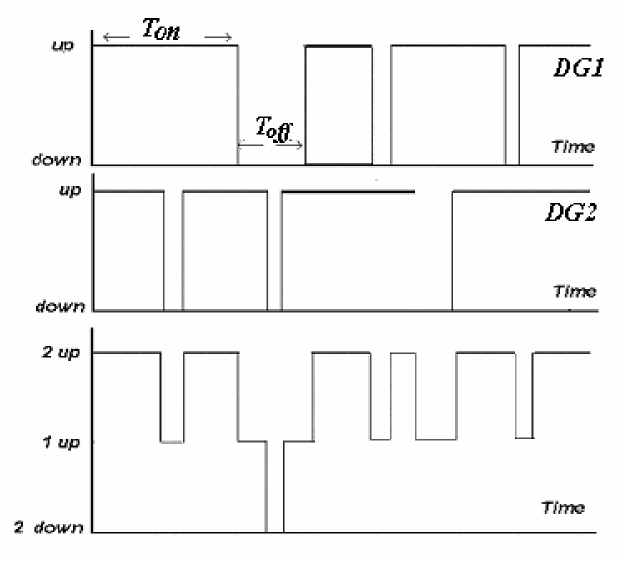

Figure 2. Combined operating cycles of two DG units

Step III: The system available capacity curve is superimposed on the chronological hourly load curve to obtain the system available margin model. A positive margin indicates that the system generation is sufficient to meet the system load, while a negative margin denotes that the system demand is not satisfied. The average amount of the unsupplied load per hour during each year ($\overline{P}_{us}$ kW/hr) is estimated in this step by running Monte Carlo simulation for a large number of sample years and evaluating the following equation:

$$\overline{P}_{us} = \frac{\left|\sum \mathrm{P_{nm}}\right|}{8760 \times J} \quad (3)$$

Where $\mathrm{P_{nm}}$ is the system negative margin (KW) and J is the number of Monte Carlo experiments.

THE PROPOSED ALGORITHM

Assume a primary distribution system with M buses and several meshed feeder sections. Each bus may have a load, a synchronous condenser, a shunt susceptance, and/or a DG unit connected to it. The maximum number of the DG units is the same as the number of buses N (N $\in$ M) that have DG connection feasibility. However, the number of DG units in their "on state" at any given hour is random. Therefore, the bus identity whether it is a load bus or a generator bus and, its loading value will also be a random one. To formulate the adequacy assessment problem, the bus loading state and its identity must be identified first. To carry out this step, a random-number generator is employed to generate an integer **k** where $k \in [1,....,N]$ to represent the expected number of DGs in their "**on state**". The locations of these DGs are then identified, by generating a random sequence of k integers, where $k \in [1,....,N]$, this sequence represents the buses' number where the DGs are connected. Each DG is considered to be in its "ON" or "OFF" state for the full hour where the DG state is estimated.
The random process of assigning DGs in their on state to certain buses in the system is repeated and the system capacity margin equations are updated. The process of updating the system equations leads to the calculations of total DG contribution power, total system centralized power generation, and the average amount of the unsupplied load per hour. The final values of variables are achieved by running Monte Carlo simulation. Monte Carlo simulation entails the repetition of the aforementioned steps until the convergence for all variables have been reached. The updating process here refers to the inclusion of the new number, new locations and the exported power of each DG unit in the solution.

CASE STUDY

The structure of the distribution system under consideration is shown in figure 3. This system is supplied from a 3100 kW, 132/33 kV substations and comprises customer-controlled distributed generators. This system is supplying different combinations of loads. All loads are aggregated at the 11 kV busses. The annual hourly peak load curve is given in figure 4. The starting hour of this figure is the first hour of the year (1am of January 1st). The peak system load is 2850kW. The data required to construct this load model is presented as a part of the IEEE reliability test system in reference [13]. The analysis of this case study is done in two phases. In the first phase, the adequacy assessment is performed on the system with the system P_S represented by only its P_T . In the second phase, the DG units are included in the analysis with the distributed generation power (P_{DG}) is represented by (3) and the system power capacity (P_S) is represented by (4). The results of the two phases are presented in the following subsections.

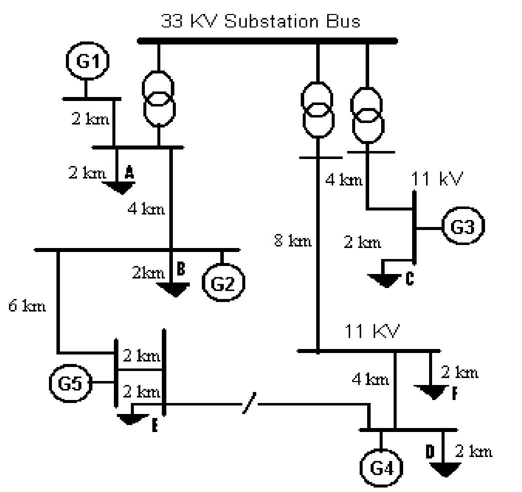

Figure 3. The distribution system under study

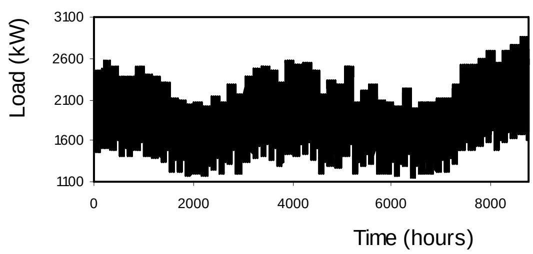

Figure 4. The annual hourly peak load

PHASE I RESULTS

The goal of this step is to determine whether the substation received power will be enough to cover the demand of the system all year round or there is a need for a substation expansion. To achieve this goal, P_T is assumed to be varying randomly in the range from 80% to 100% of the substation nominal capacity (3100 kW). The system margin is estimated by subtracting the peak load from the received power every hour. The obtained system margin for a sample year is depicted in Fig.5. The maximum difference between P_T and the load peak is 380 KW during the end of year holiday season. The adequacy of the system cannot be assessed based on the calculated negative margin at each hour for one sample year since during this sample year, P_T is considered to be a random variable and different margin patterns will be expected for different sample years. In order to determine the actual estimate of the amount of the unsupplied load for any sample year, Monte Carlo simulation was performed for a large number of sample years. The average amount of unsupplied load for each hour was calculated using (3). Fig.6 portrays the Monte Carlo convergence process. The average unsupplied load is estimated to be 5.689 KW for each hour of the year. This figure reflects the great need for system capacity increase and the inadequacy of the system in its current structure to meet the installed demand. In the next phase, the effects of running some customer-controlled DG in parallel with the existing substation upon the system overall capacity are presented.

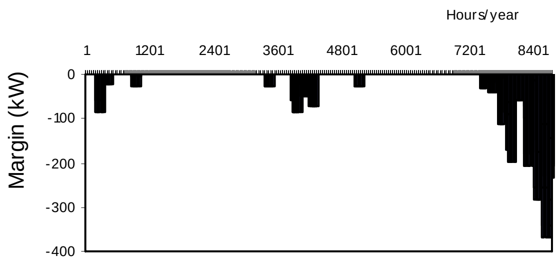

Figure. 5. The negative margin during one sample year

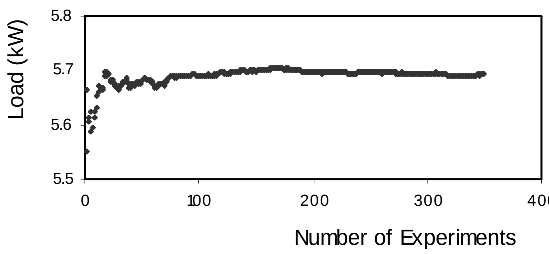

Figure 6. The average unsupplied load in KW per hour

PHASE II RESULTS

In this phase, identical DG units are assumed to be running in parallel with the existing substation. Each 11kV bus was assigned a DG unit. The ratings of each DG unit can be in the range from 200 kW to 100 MW depending on the function of this unit. For example, a residential DG system would comprise small units in the range of 100 kW whereas, an industrial DG system would involve larger units in the range of 100 MW or even higher. In this study, large DG units of 100 MW ratings are selected to examine the extreme operating conditions of the system under study.

The following assumptions were made to ensure the credibility of the results:

1. All the DG units are of the same type and size.
2. The system cables and switchgear are well designed to carry the expected demand.

Although all the DG units are identical, the operating cycle of each unit will be different in varying degrees because of the random nature of their on and off periods. The procedure explained earlier is used to generate artificial history of the operating cycle of each DG for a given sample year. The generated artificial operating cycles of all the DG are combined together to obtain the system P_{DG}. Then, the P_T is superimposed on the available P_{DG} to determine the overall P_s. The system margin is estimated by subtracting the hourly demand from the hourly available power. The obtained system margin for a sample year is depicted in Fig.7. The negative margin in any hour indicates that there is an unsupplied load at this hour. The comparison between the results of this phase and those obtained for the system with no DG reveals that having the DG running in parallel with the substation has eliminated most of the negative margins during the year.

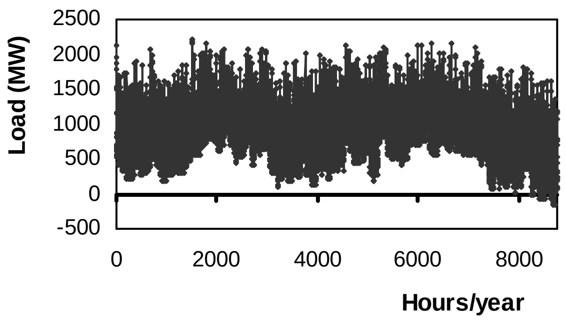

Fig.7. The hourly available margin with DG.

The criteria to judge the adequacy of the system in this case still the average amount of unsupplied load in each hour of the year. The amount of unsupplied load in each hour for any sample year is found to be 0.8 MW. This value constitutes 0.028% of the maximum load and 0.0407% of the average load. Therefore, the available capacity of the system in this case is considered sufficient to meet the system demand. The conclusion drawn directly from this result is that distributed generation units if well managed can give a good support to the existing system

CONCLUSIONS

A novel algorithm to evaluate the reliability of electric distribution systems including distributed generation is *presented in this paper*. This algorithm *employs* Monte Carlo simulation to estimate the random operating cycles of the installed distributed generators and the ability of the system power capacity to meet the total demand. A typical case study is presented in which several distributed generation units are running in parallel within a distribution system and both the system margins and the average amount of unsupplied loads are estimated. The results showed that distributed generation units if well managed can give a good support to the existing system

REFERENCES

[1] R.Billinton, and R.N.Allan, “Reliability Assessment of large electric power systems” Kluwer Academic Publisher, Massachusetts, U.S.A, 1988.

[2] T. Ackermann, G. Andersson and L. Soder 2001, “Distributed Generation: A definition” Electric Power System Research, Vol. 57, pp. 195-204.

[3] R.H.Lasseter, 1998 “Control of Distributed Resources”, Proceedings of Bulk Power Systems Dynamics and Control IV, organized by IREP and National Technical University of Athens, Santorini, Greece, Aug, pp323-329.

[4] F. V. Edwards, G.J.Dudgeon, J.R.McDonald and W.E.Leithead, 2000 “Dynamics of Distribution Networks with Distributed Generation”, Proceedings of the IEEE PES summer meeting, pp.1032-1037.

[5] Y.G. Hegazy, M.M.A. Salama and A.Y. Chikhani, 2002, “Distributed Generation and Distribution System Reliability” Proceedings of the power systems conference: Impact of Distributed Generation, Clemson, SC, March 2002.

[6] R.E.Brown, 2002, “Modeling the reliability impact of distributed generation” Proceedings of IEEE Power Engineering Society Summer Meeting, Volume: 1, Page(s): 442 –446.

[7] A. A. Chowdhury, S.K. Agarwal, and D.O. Koval, 2002, “Reliability modeling of distributed generation in conventional distribution systems planning and analysis”, Conference Record of the 37th IAS Annual Meeting, Volume: 2 Page(s): 1089 –1094 A.

[8] R.C. Dugan and McDermott, 2002 “Distributed generation impact on reliability and power quality indices” Proceedings of the IEEE Rural Electric Power Conference, Page(s): D3 -1-7.

[9] R.E.Brown and L.A.A Freeman, 2001, “Analyzing the reliability impact of distributed generation”, Proceedings of the IEEE Power Engineering Society Summer Meeting, Volume: 2, Page(s): 1013 -1018 vol.2.

[10] P.P Barker and R.W De Mello, 2000, “Determining the impact of distributed generation on power systems. I. Radial distribution systems”, IEEE Power Engineering Society Summer Meeting, vol. 3, Page(s): 1645 -1656

[11] G. Celli, F. Pilo, 2001, ”MV network planning under uncertainties on distributed generation penetration “, IEEE Power Engineering Society Summer Meeting, Volume: 1, Page(s): 485 -490.

[12] Y.G.Hegazy, M.M.A Salama and A.Y. Chikhani, 2003, “Adequacy Assessment of Distributed Generation Systems Using Monte Carlo Simulation**”,** *IEEE Transactions of Power Systems,* Vol. 18, No. 1, February, pp. 48-52.

[13] R.Billinton and W. Li, “Reliability Assessment of Electric Power Systems Using Monte Carlo Methods” Plenum Press, N.Y. 1994.