Electrical Power and Energy Systems 33 (2011) 1470–1478

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Reliability based optimum location of distributed generation

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ARTICLE INFO

Article history:
Received 18 August 2010
Received in revised form 4 March 2011
Accepted 3 June 2011
Available online 19 July 2011

Keywords:
Optimum location
Value based
Distributed generation
Reliability

ABSTRACT

The increasing penetration of distributed generation and changing electricity industry necessitates that maximum benefit is obtained from distributed generators. Due to the importance of reliability of supply, the optimum location to maximise reliability has been investigated. A value based approach is used so that costs associated with levels of reliability may be used as an indicator. These are determined using probabilistic approaches which is a departure from the traditional deterministic criteria currently used.

1. Introduction

Deregulation and restructuring of the electricity industry is one of the major changes that occurred in the last few decades. Most of the literature describes the aim of deregulation as being to open up the market to the private sector [1]. In a deregulated market, the price of energy is determined by economic factors of supply and demand as is the case with most consumer products in a free economy. Additionally, consumers are free to choose their energy supplier. Generally this leads to increased competition and better quality of supply. It also leads to a shift from the traditional vertically integrated utilities to a more distributed structure [1,2].

Environmental factors have become a major factor in most industrial activities and sustainable alternatives are being sought. The same applies to the power industry. There is a push from various utilities around the world to source 20% of the generated energy from renewable energy. An example of this is the European 2020 targets. Hence there is a need to use an increasing mix of renewable energy in the system. The nature of renewable energy sources is such, that large scale centralised generation plants cannot be used as the sole mode of power generation. Distributed generation (DG) is ideal for incorporating renewable energy sources into the generation mix. Apart from this factor, distributed generation can be used to improve system reliability, reduce transmission losses and hence directly reduce greenhouse emissions, global warming and other environmental impacts of electricity generation [3–5]. Puttgen et al. [6] point out that distributed generation is not necessarily renewable generation. However, given the nature of renewable sources such as wind or photovoltaics, it is much more feasible to use these as small scale DG sources rather than large centralised power plants.

Due to these changes in the electricity industry it is inevitable that traditional centralised power systems will be replaced by more decentralised systems with many more entities involved in the power system planning. This is leading to an increased interest in distributed generation [4,7].

In traditional centrally planned systems, reliability planning was carried out using deterministic criteria based on past experience. However, this does not account for the stochastic nature of outages. Thus, it is highly likely that the system may be over or under built if deterministic criteria are used [8,9]. Allan and Billinton [8] further notes that in the present deregulated environment investors entering the industry will want to know the performance of the sector for which they or their shareholders are responsible, which cannot be measured with deterministic criteria. Deterministic criteria are based on meeting certain adequacy requirements and cannot provide an actual indication of system performance. The aforementioned factors provide the need to move from deterministic criteria to using a probabilistic or stochastic approach based on statistical data collected on various system components and it inherently accounts for the uncertainty.

Haghifam and Hadian [3] have already shown that distribution system adequacy can be improved when DG is connected. This occurs even if the DG source is of a variable nature such as wind turbines. Characteristics of a distribution system, such as reliability, vary depending upon the point at which the DG source is connected to the distribution feeder [10]. Therefore it is vital that the maximum benefit in terms of reliability is obtained from the DG by choosing the appropriate location. In the new deregulated

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doi:10.1016/j.ijepes.2011.06.029

environment, increased competition is expected to make the end customer reliability the most important factor. Hence the focus of this study is to determine the optimum DG location to maximise the distribution system reliability.

The innovations in this study involve finding the optimal location of distributed generation in a distribution system from a reliability perspective. Studies till now have focussed on optimum location based on minimising system power losses and other aspects of system performance. Ding et al. [11] considers the stochastic nature of DG but determines the optimal location with respect to energy loss and network investment costs. Other examples of optimal location include studies by Dasan et al. [12] and Sedighi et al. [13]. While the former considers optimisation with respect to only total system losses, the latter also accounts for voltage profile and total harmonic distortion (THD). None of these studies try to optimise the DG location to maximise system reliability.

System reliability has not been investigated adequately prior to this. Furthermore, probabilistic and value based means of evaluating system reliability have been used. While there is some research into this approach [11], it is still common industrial practice to use deterministic criteria in reliability planning.

2. Background

Most of the reliability analysis for power systems carried out in literature uses Monte Carlo simulation. This is based on random number generation and averaging out failure statistics over a large number of simulations. Monte Carlo simulation is an accepted method for reliability studies especially when large and complex systems are under consideration. However, a major disadvantage of this method is the large amount of simulations needed to obtain long term averages and estimates. It is highly time consuming and resource intensive [14].

Analytical approaches were preferred as opposed to Monte Carlo simulation for evaluation of reliability indices. The system under consideration was quite simple and analytical methods would provide a rapid and accurate solution. For a system of this type it was deemed unnecessary to use Monte Carlo simulation. The analytical state space method is based on the assumption that the system and any component in the system can be in a given state at a time. The time spent in a state is assumed to be a random variable. Homogenous Markov processes are used to model power systems using the state space method.

Even though the amount of computation required in the state space method can be quite large for complex systems, algorithms are easy to implement and the method is quite versatile. It can account for a wide range of situations. For these reasons, state space methods or variations of it have been proposed and used in a number of similar studies [8,10]. It appears that this is the most widely used analytical method for reliability evaluation.

In the state space model used, it is assumed that the system can be in one of many states and it may transition between states. For a simple model there would be states where the system is in service or out of service. An additional state may be added where it is being switched in or out of the system.

The time spent in each state is a random variable and assumed to follow an exponential probability distribution. It is also assumed that the probability of transition between states do not depend on previous states occupied and hence homogenous Markov processes may be used i.e. the long term transition rates are considered which are independent of time. Detailed discussion on homogenous Markov processes and derivations of equations are presented in Endrenyi [14]. Some of the relevant outcomes are summarised here.

Transition rate from a state and time spent in the state are inversely related. State probabilities can be determined by solving the below equation [14]

$$\boldsymbol{pA} = \mathbf{0} \tag{1}$$

where $\boldsymbol{p}$ is a row vector such that any element p_i represents the probability of the system being in state i. $\boldsymbol{A}$ is the state transition matrix. The state transition matrix contains elements such that element a_{ij} represents the transition rate from state i to state j. The transition rate per unit of time can be obtained by dividing the transition frequency within fixed duration, by that duration of time. The diagonal elements must be such that the sum of elements in each row is zero. $\boldsymbol{0}$ represents the zero matrix having same dimensions as $\boldsymbol{A}$.

From state probabilities, the state frequency for each state can be determined. Frequency for a state i denoted as f_i is determined by

$$f_i = p_i \sum_{i \neq j} (\lambda_{ij}) \tag{2}$$

where λ represents the corresponding element of the transition matrix.

3. State based system reliability model

3.1. Component model

A three state model was used to describe general system components such as sections of cable and circuit breakers. The state transition diagram for a single component in the system is in Fig. 1.

The normal state was the state of operation when there was no failure. The switching state was the state following an active fault. This state was not reached if the fault was passive. If the component was upstream of a load point (LP) then it was considered to interrupt this LP but it did not affect other components within the protection zone. Rate of active and passive failures are represented by λ_A and λ_B, respectively and time spent in repair and switching states are represented by r_p and r_s, respectively.

Temporary faults were ignored in this model since only sustained interruption indices were calculated. Therefore, it was assumed that a component must go to the repair state from the switching state. From the repair state the component returned to the normal operating state after the repair interval. If a passive fault occurred, the component went into the repair state directly without any need for switching to isolate the fault.

It must be noted, that this was a fairly generalised model and may not apply for all components. For example, Circuit breakers have failures to operate as well as false operations, which are not encountered in other components. Since the available data for the circuit breaker did not outline specific amounts of failures to operate for circuit breakers faults, it was assumed that active and passive faults accounted for these accurately. Adverse weather conditions are ignored since a large percentage of the installation is underground and relatively unaffected by bad weather.

3.2. Conventional distributed generator model

Conventional DG sources are those who have a fixed controllable output. A two state model was used where the generator could apply no power or rated power. It was assumed that DG has a forced outage rate (FOR) of 0.01 and a repair time of 44 h [15]. FOR is the probability of being in the failure state. It was also assumed that the DG was disconnected immediately following an active fault by the operation of protection devices, due to large