Electrical Power and Energy Systems 61 (2014) 81–89

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Reliability optimization of an electric power system by biomass fuelled gas engine

F.J. Ruiz-Rodriguez, M. Gomez-Gonzalez, F. Jurado *

University of Jaén, Dept. of Electrical Engineering, 23700 EPS Linares (Jaén), Spain

ARTICLE INFO

Article history:
Received 16 May 2013
Received in revised form 10 March 2014
Accepted 18 March 2014

Keywords:
Probabilistic load flow
Reliability systems
Biomass
Gas engine
Contingency
Shuffled Frog Leaping Algorithm

ABSTRACT

This article presents a method to optimize the reliability of an electric power system by the introduction of distributed generation using biomass as fuel. The reliability index of the system is determined as the failure probability of the system. Probabilistic load flow is used to calculate the reliability index. This probabilistic load flow is solved by the method combined of cumulants and Gram–Charlier expansion. To determine the reliability index a number of contingencies should be simulated, the more the number of contingencies, the more accurate the index is. This probabilistic method uses the random variables as starting data, so both generators and loads are modelled as random variables. Generators considered for distributed generation are biomass fuelled gas engines, that are very abundant in Spain.

This paper applies a new method utilizing Shuffled Frog-Leaping Algorithm and probabilistic load flow to solve this problem. Acceptable solutions are reached in a small number of iterations. Numerical applications are presented and considered regarding the power system IEEE 14-bus and including biomass fuelled gas engines at several nodes. The results obtained show the improvement of the reliability index due to the presence of distributed generation.

Introduction

The actual electrical systems present an uncertain performance, both in terms of customer demand as to the likelihood of failure of their components. A way to collect the sources of uncertainty in the system is to represent the input data to the problem as random variables.

The solution of the load flow problem, taking as input these random variables, is called probabilistic load flow [1]. There are various approaches to estimate the load flow problem using these random variables as starting data. On the one hand there are simulation techniques such as the Monte Carlo method that still use deterministic algorithms for solving the problem. On the other hand, there are analytical techniques that operate directly with random variables.

Among the different existing simulation techniques, the Monte Carlo method emphasizes since this method can use the deterministic load flow algorithms developed, that have already been developed [2].

There are also several analytical methods to address the problem of probabilistic load flow, such as the method of cumulants [3,4], or the point estimate method [5]. In these methods are used the convolution properties of the random variables that represent the power injected at the nodes to obtain the voltage and power flow through the lines also as random variables.

The main advantage of using some of these techniques is their computational efficiency treating random variables, as can be seen in [6] to the method of cumulants, and [7] to the estimated point method.

Regarding the reform of the electricity industry, the reliability of power systems is increasingly important [8]. In the new structure of power systems, a number of independent generators supplying power to a number of independent distributors through one or more transmission networks. Some of the major constraints on system operation are related to security of the system. Sometimes the operator plans to expand the power system with more expensive generating units to reach the requirements of system reliability.

The determination of the reliability of the system is a very complex problem because it is influenced by a great number of factors. The problem depends on the availability of power plants, loads at the nodes, lines out of service (contingencies), nodes out of service, day of the week, season, weather and hour of the day. The uncertainties regarding availability of power plants and estimated load are important aspects of the system and therefore these variables should be modelled using random variables.

This paper presents a technique for optimizing the overall reliability of a power system based on the method of cumulants.

* Corresponding author. Tel.: +34 953 648518; fax: +34 953 648586.
E-mail addresses: fjruiz@ujaen.es (F.J. Ruiz-Rodriguez), manuel.gomez@ujaen.es (M. Gomez-Gonzalez), fjurado@ujaen.es (F. Jurado).

http://dx.doi.org/10.1016/j.ijepes.2014.03.019
0142-0615/

Nomenclature

A_t	availability of the component t
BFGE	biomass fuelled gas engine
BPSO	binary particle swarm optimization
BSFLA	Binary shuffled frog-leaping algorithm
b_{in}	series susceptance of branch of node i to node n
C	total number of simulated contingencies
CDF	cumulative distribution function
DG	distributed generation
$D_{\max}$	maximum allowed change in a frog's position
$D_{\min}$	minimum allowed change in a frog's position
$\mathbf{d}_k^t$	change vector of the k memeplex in iteration t
g	number of generations for each memeplex before shuffling
Gas	Genetic Algorithms
G_c	set of simulated contingencies
g_{in}	series conductance of branch from node i to node n
H_c	set of non-simulated contingencies
HHV	Higher Heating Value
$H_k(x)$	Hermite's polynomial of order k
k_r	cumulant of order r
L	number of lines of the system
L_l	transmission capability limit
L_p^{low}	voltage lower limit at node p
L_p^{up}	voltage upper limit at node p
mp	number of memeplexes
N	nodes number of the electric system
nf	number of frogs in every memeplex
OF	objective function
P	population of frogs
PDF	Probability density function
PLF	probabilistic load flow
P^d	overall probability of failure in the system
P_i	real power injection at node i
P_m	probability of occurrence of contingency m
P_m^d	probability that the system fails under the contingency m
P_{low}^d	lower limit for the probability of system failure
P_{up}^d	upper limit for the probability of system failure
p	probability that line operates
p_o	probability for the normal state
Q_i	reactive power injection at node i
q	probability of line failure
$\mathbf{rand}_k^t$	random Z-length binary vector for the memeplex k in iteration t
SFLA	Shuffled Frog-Leaping Algorithm
t	time or iteration
t_{max}	number of shuffling iterations
V_i	voltage at node i
$\mathbf{x}_i$	position of the particle or frog i
$\mathbf{x}_{best,k}^t$	frog with the best fitness of the memeplex k in iteration t
$\mathbf{x}_{worst,k}^t$	frog with the worst fitness of the memeplex k in iteration t
$\mathbf{x}_{gbest}^t$	frog with the global best fitness in iteration t
Y_1 and Y_2	constants $(0 < Y_1 < Y_2 < 1)$
Z	number of variables which is considered as a frog

Greek symbols

δ_{in}	phase angle of voltage between node i and node n
$\Phi(x)$ and $\phi(x)$	CDF and PDF, respectively, of normal distribution of mean $\mu = 0$ and standard deviation $\sigma = 1$, and $\Phi'(x), \phi'(x), \Phi''(x), \phi''(x) \ldots$ the successive derivatives
λ_t	ratio of failure for component t
μ_t	ratio of repair for component t
μ_G	mean of electrical power output of the gas engine
μ_{HHV}	mean of higher heating value
σ_G	standard deviation of electrical power output from the gas engine
σ_{HHV}	standard deviation of higher heating value
$\varsigma_{k,j}^t$	random variable between 0 and 1

The purpose of the problem is to determine the rates for electric system reliability and improve by connection of distributed generation. The most commonly used indices are the probability of system failure, failure frequency and expected duration of the failure [8]. In this paper only determine the index referring to the risk of system failure. The availability of the power generation and load variation at the nodes are modelled using random variables.

Unforeseen contingencies (equipment outages) are more difficult to include in the problem. Fortunately not all contingencies result in system failure [8]. Therefore, only the contingencies with greater impact on the system should be simulated. Substantially this reduces the set of contingencies to be considered.

The accuracy for the limits of reliability index depends on the number of simulated contingencies. Hence the number of contingencies to be simulated also depends on the desired accuracy of the results obtained [9].

The final step in the formulation of the problem is to define the set of conditions that cause a system failure. The set of conditions depends on the application. In this paper, two conditions are considered:

1. Transmission capability of lines.
2. Voltage out of range.

Generators considered for distributed generation are biomass fuelled gas engines [10], that are very abundant in Spain.

Artificial intelligence based methods do not always guarantee the optimal solution, nevertheless they provide near solutions to the optimal in short CPU times. Shuffled Frog-Leaping Algorithm (SFLA) was originally developed by Eusuff et al. [11]. It is a memetic meta-heuristic, that is designed to seek a global optimal solution by performing an informed heuristic search using a heuristic function.

In this paper, a hybrid method that uses a Binary Shuffled Frog-Leaping Algorithm, BSFLA, and probabilistic load flow are proposed to search a large range of combinations for location and size of BFGEs that minimize the reliability index (probability of failure) of the system.

Probabilistic load flow (PLF)

The load flow is represented by a system of nonlinear equations that reflect the balance at steady state in the network between the power consumed and the power produced [12]:

$$P_i = V_i \sum_{n=1}^{N} [V_n (g_{in} \cdot cos\delta_{in} + b_{in} \cdot sin\delta_{in})]$$

$$Q_i = V_i \sum_{n=1}^{N} [V_n (g_{in} \cdot sin\delta_{in} - b_{in} \cdot cos\delta_{in})] \quad (1)$$

These input values to the problem cannot be accurately determined. One way to ascertain the sources of uncertainty of the system is to represent the input data as random variables in the problem.