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Probabilistic optimal allocation of biomass fueled gas engine in unbalanced radial systems with metaheuristic techniques

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ABSTRACT

This paper shows that in order to solve a probabilistic three phase load flow in radial distribution networks, it is necessary to apply effective techniques that take into account their technical constraints. Among these constraints, voltage regulation is one of the principal problems to be addressed in distributed generation. To evaluate the performance of this distribution system, this paper has developed a probabilistic model that takes into account the random nature of lower heat value of biomass and load. This paper applies a new method utilizing shuffled frog-leaping algorithm and three phase probabilistic load flow combined with the Monte Carlo method to solve this problem. The proposed method determines the nodes where biomass fueled gas engines are connected and their mean power output in order to minimize the voltage unbalances at the nodes.

Acceptable solutions are reached in a small number of iterations. Results prove that the proposed method can be applied for the keeping of voltages within desired limits at all load buses of a distribution system with biomass fueled gas engines. Numerical applications are presented and considered regarding the unbalanced distribution system IEEE 13-nodes. The results obtained show the decrease of the unbalance factor due to the presence of distributed generation.

1. Introduction

Many researchers have suggested that the benefits of distributed resources could be substantial. However, these distributed advantages are site specific [1–3]. In addition, distributed generation (DG) with renewable energies (bioenergy, wind, hydro, solar, geothermal energies, etc.) provides environmental benefits. In this paper, the chosen DG system is biomass fueled gas engine (BFGE).

To assess the unbalanced voltages of the electric distribution systems, the uncertainties that are relevant for the modeling must be considered. Hence, the right valuation of the impact of renewable sources on current systems of distribution must be faced by means of a probabilistic approach [4] that also considers the voltage unbalance of the electrical systems.

In addition, probabilistic approaches seem to be particularly useful to study in depth the influence of voltage unbalance on the performance of induction machines in stationary condition, with the objective to set up recommendations for their functioning [5].

The probabilistic load flow was enunciated in [6,7], and further developed at a greater extent in [8]. In [9,10] the probabilistic load flow was extended to the three-phase field to evaluate the uncertainties which affect the steady-state operating conditions of an unbalanced power system. Various distribution system load flow algorithms, based on the forward/backward sweeps, were reviewed, and their convergence ability was quantitatively evaluated for different loading conditions in [11]. A new analytical approach is explored to formulate and solve the probabilistic load flow, which shows the voltage profile of a network including uncertainties of power injections and consumption in [12].

A three-phase power flow solution method for real-time analysis of primary distribution systems was presented in [13]. For asymmetrical three-phase load-flow study, two methods based on symmetrical component theory, the node admittance method and the decoupling compensation method were proposed in [14].

A multiobjective formulation for the siting and sizing of DG resources into existing distribution networks is proposed in [15,16]. 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), originally developed by Eusuff and Lansey [17], 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 three-phase

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Nomenclature

BFGE	biomass fueled gas engine
BPSO	binary particle swarm optimization
$c_{1,k}$	random *S*-length binary vectors
$c_{2,k}$	random *S*-length binary vectors
CDF	cumulative distribution function
$cn_{j,k}$	customer number who belong to the *j*-th customer class for the *k*-th node of a feeder
DG	distributed generation
D_{max}	maximum allowed change in a frog's position
D_{min}	minimum allowed change in a frog's position
d_k^t	change vector of the *k* memeplex in iteration *t*
g	number of generations for each memeplex before shuffling
GAs	genetic algorithms
BSFLA	binary shuffled frog-leaping algorithm
mp	number of memeplexes
N	length of binary vector
nf	number of frogs in every memeplex
n	number of simulations
nn	number of nodes of the distribution system
OF	objective function
P	population of frogs
$\bar{P}_G^j$	expected value of generation power at node *j*
$P_{G,\min}^j$	lower limit of generation power at node *j*
$P_{G,\max}^j$	upper limit of generation power at node *j*
PDF	probability density function
PRTPLF	probabilistic radial three phase load flow
$rand$	random number between 0 and 1.
$S_t^{\max}$	thermal capacity of the line
SFLA	shuffled frog-leaping algorithm
t	time or iteration
$t_{\max}$	number of shuffling iterations
V_{average}^i	average value of the voltages of the three phases at node *i*
V_{base}	base of voltage in the system
V_b^i	voltage at node *i*
$\bar{V}_b^i$	expected value of the voltage at node *i*
$V_{b,\min}^i$	lower limit of the voltage at node *i*
$V_{b,\max}^i$	upper limit of the voltage at node *i*
x_i	position of the particle or frog *i*
$x_{\text{best},k}^t$	frog with the best fitness of the memeplex *k* in iteration *t*
$x_{\text{worst},k}^t$	frog with the worst fitness of the memeplex *k* in iteration *t*
x_{gbest}^t	frog with the global best fitness in iteration *t*
Z	number of variables which is considered as a frog

Greek symbols

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 of the gas engine
σ_{HHV}	standard deviation of higher heating value

load flow are proposed to search a large range of combinations for location and size of BFGEs that minimize the unbalance between phases. This method reduces the time of computation and it provides a good performance in comparison to Monte Carlo simulation.

2. Probabilistic model of biomass fueled gas engine and probabilistic load model

Olive pruning will be the primary fuel. It is estimated that this type of biomass, very abundant in Spain, has a higher heating value (HHV) about 3.90 MWh/ton [18–20]. This estimated HHV presents some randomness due to several factors, such as area of cultivation, moisture and nutrients in the ground. It is guessed that the calorific value varies between a minimum of 3.69 MWh/ton and a maximum of 4.11 MWh/ton.

This randomness can be modeled by a normal random variable, as shown in [10]. Thus, the following equations are obtained:

$$\mu_G = k \cdot \mu_{\text{HHV}} \tag{1}$$

$$\sigma_G = \sqrt{k} \cdot \sigma_{\text{HHV}} \tag{2}$$

These values are the mean and standard deviation of normal distribution, which represents the electrical power. Probabilistic load model is explained in paper [21].

3. Probabilistic radial three phase load flow (PRTPLF)

In this work the probabilistic load flow is solved using the Monte Carlo simulation method. This method has been used for its ease of implementation compared to other methods of resolving the PRTPLF.

Although this is not the case, the proposed method can implement system control laws, correlations among random variables, non-Gaussian PDFs and more complex PDFs, and so on. As can be seen in [22], the photovoltaic generators are modeled using complicated PDFs.

The analytical methods can be considered as exact and approximate. The exact methods used the convolution of random variables to solve the problem. However, the convolution is quite complex [7]. There are other analytical methods such as the method of cumulants [23] or the point estimate method [24]. The cumulants method and the point estimate method are approximations, the results are validated against Monte Carlo method [23,24].

The proposed three-phase probabilistic load flow for radial networks is a combination of the three phase load flow purposed in [25] with the Monte Carlo simulation method [26].

This technique is basically to select values of input variables randomly from their distribution functions, and with these values to solve a deterministic radial three phase load flow. After a certain number of simulations, the probabilistic solution of the problem is reconstructed from deterministic data obtained for each simulation. The number of simulations that has been estimated as adequate for this problem and has also been used in several articles to solve probabilistic load flow is 10,000 [27,28]. A convergence study of Monte Carlo method has been carried out in [22]. The IEEE-13 node test feeder system has been used in this paper. Also, the same system was used in [22].

4. Shuffled frog-leaping algorithm

4.1. Classical approach

Shuffled frog-leaping algorithm (SFLA) was originally developed by Eusuff and Lansey [17]. SFLA is a memetic meta-heuristic that is designed to seek a global optimal solution by performing an informed heuristic search using a heuristic function. It is based on evolution of memes carried by interactive individuals and a global exchange of information among the population. SFLA progresses by transforming "frogs" in a memetic evolution. In this algorithm, frogs are seen as hosts for memes and described as a memetic vector.