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Application of DEPSO to Maximizing Margin to Saddle Node Bifurcation in Power System Voltage Instability

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Abstract

In this paper, a new method is proposed to maximize a margin to the saddle node bifurcation in power system voltage instability. In recent years, the emergence of power markets with renewable energy brings about a lot of uncertainties to power system voltage instability. There is high possibility that voltage instability occurs for lack of nodal power injections. To make power system more secure, it is necessary to know how much current power system conditions are close to the bifurcation point and take control of power systems to escape from it appropriately. This paper proposes a new method for maximizing a margin to the bifurcation with capacitor banks of discrete variables. The problem formulation may be expressed as one of combinatorial optimization problems. After evaluating the bifurcation with the continuation power flow calculation, the optimal control of the capacitor banks is made by DEPSO (Discrete Evolutionary Particle Swarm Optimization) of evolutionary computation. To take account of uncertainties of power system conditions, MCS (Monte Carlo Simulation) is carried out for a power system with wind power generation unit. The proposed method is successfully applied to the modified IEEE 30-node system.

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Keywords: evolutionary computation, optimization, bifurcation analysis, power systems, voltage instability, continuation power flow calculation, MCS ;

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Nomenclature

d	distance index between current power system conditions and bifurcation
f	cost function to maximize distance index for power system condition
g	cost function to maximize distance index for a set of power system conditions
g_{best}	best solution of swarm
i	node number

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j	particle number
k	iteration number of CPFLOW
m	number of the nodal specified values of power flow calculation
n	number of nodes
$N(0,1)$	standard Gaussian random numbers with mean of 0 and standard deviation of unity
P_i	nodal active power at node i
P_i^0	initial load conditions of P_i
P_i^M	maximum load conditions or singular point of P_i
P_{s_i}	nodal specified value of active power at node i
$P_{best\ j}$	best solution of particle j
Q_i	nodal reactive power at node i
Q_{s_i}	nodal specified value of reactive power at node i
q_j	threshold function of particle j for binary coding
q_j^{t+1}	transformed speed of particle j at iteration $t+1$
$rand(\ )$	standard uniform random numbers
s_j^t	location of particle j at iteration t
t	iteration number of EPSO and PSO
U	a set of control variables
u	control variables
v_j^t	speed of particle j at iteration t
w_{jr}	weights of particle j (r = 0, 1, 2)
x_i^k	k-*th* element of voltage vector at iteration i
z_j^t	location of particle j in binary at iteration t
Δa	variation of pseudo arc length
λ	load parameter
τ, τ'	learning rates
$\cdot^*$	muted parameters of $\cdot$

1. Introduction

In recent years, the emergence of power markets with renewable energy such as wind power and photovoltaic generation brings about uncertainties to power systems. Although renewable energy has advantage to provide clean energy with power systems, it has a drawback that generation output is affected by the weather conditions so that the power system frequency and voltage fluctuate significantly. As a result, the degree of power system uncertainties increases in comparison with the regulated power systems. There is high possibility that power systems become insecure in spite of Smart Grid environment.

This paper focuses on voltage instability assessment under such environment. Voltage instability is related to the singularity of the Jacobian matrix of the power flow calculation [1]. For lack of nodal power injections, power systems are inclined to approach the saddle node bifurcation [2] that corresponds to the limitation of the feasible power flow solutions. To detect such a behavior, it is necessary to examine how much the current power system conditions are close to the bifurcation. So far, a lot of methods were developed to measure a margin to the bifurcation [3-10]. Among them, the continuation power flow calculation is more effective in a way that the distance index between the current power conditions and the bifurcation is measured in active or reactions power rather than the abstract numerical expression, say, interval [0, 1]. The continuation power flow method developed by Ajjaparu and Christy was based on the predictor-corrector method with the tangent vector in numerical in analysis [8]. Afterwards, Chiang, *et al.* proposed CPFLOW to speed up the computational time with the secant method significantly [10]. Mori and Yamada presented modified CPFLOW to reduce computational effort by using a nonlinear predictor rather than linear one [11]. Some variants of modified CPFLOW with the nonlinear predictor were developed [12-14]. After evaluating the bifurcation, it is necessary to take control of power system conditions to escape from approaching the bifurcation. In this paper, DEPSO (Discrete Evolutionary Particle Swarm Optimization) is proposed to maximize the margin with capacitor banks. EPSO [16, 17] is an extension of PSO [15]