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Verification of Dependability on Parallel Differential Evolution Based Voltage and Reactive Power Control

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Abstract: This paper evaluates dependability on parallel differential evolution (DE) based voltage and reactive power control (Volt/Var Control: VVC). Considering large penetration of renewable energies and deregulated environment of power systems, VVC requires fast computation even for larger-scale problems. One solutions to increase the computation speed is to use parallel and distributed computing. Since power system is one of the infrastructures of social community, not only fast computation, but also sustainable control (dependability) is strongly required for VVC. The simulation results with IEEE 14, 30, 57, and 118 bus systems indicate that parallel DE is superior to parallel Particle Swarm Optimization (PSO) especially for dependability on VVC.

***Keywords**:* Voltage and reactive power control, Parallel and distributed computing, Meta-heuristics, Parallel differential evolution, Dependability

1. INTRODUCTION

In order to maintain high quality customer services, one of the important operating tasks of power utilities is to keep voltage within an allowable range. Various equipment such as automatic voltage regulators (AVRs) of generators, on-load tap changers (OLTCs), static condensers (SCs), and shunt reactors (ShRs) should be handled in control centers, so that they can inject reactive power and control voltage directly in target power systems. VVC determines on-line control strategies in order to keep voltage of target power systems using the above equipment considering the load change and reactive power balance in target power systems.

Reduction of operational costs is one of the current interested issues of power utilities because of deregulated and competitive environments. Therefore, in steady state operation conditions, optimal control strategies in order to minimize power transmission losses are required for VVC. Consequently, VVC can be formulated as a mixed-integer nonlinear optimization problem (MINLP) with continuous state variables such as AVR operating values and discrete state variables such as tap positions of OLTCs and the number of reactive power compensation equipment such as SCs and ShRs. The objective function can be minimization of power transmission losses of the target power system for steady state operating conditions.

For the VVC problem, various methods have been developed such as fuzzy control, expert system, mathematical programming, and sensitivity analysis (Tomsovic, et al., 1992; Cova, et al., 1995; Ramos, et al., 1995; Le, et al., 1997). After PSO has been recognized as one of the practical methods for the VVC problem formulated as a MINLP with continuous and discrete variables (Fukuyama et al., 2000), various meta-heuristic techniques have been applied to the VVC problem such as Genetic Algorithm (GA) (Subbaraj, et al., 2009), advanced PSOs (Miranda, et al., 2002; Badar, et al., 2012), DEs (Wong, et al., 2007a; Ramirez, et al., 2011), Seeker Optimization (Dai, et al., 2009), Artificial Immune System (AIS) (Honorio, et al., 2007), Artificial Bee Colony (ABC) algorithm (Ayana, et al., 2012), and Harmony Search (Khazali, et al, 2011).

Considering high penetration of renewable energies and deregulation of power systems, power flow can be changed suddenly and operators in control centers have to control voltage in wider power systems. Therefore, VVC is required to shorten the control interval and handle larger-scale power systems. Namely, VVC is required to realize faster computation to larger-scale problems than ever before. Since one of the solutions for the problem is applications of parallel and distributed computing, some researchers have already applied parallel and distributed computing techniques to VVC using meta-heuristic techniques only for realization of fast computation (Wong, et al., 2007b; Li, et al, 2009; Zhang, et al, 2010).

Power system is one of the infrastructures of social community, and sustainable voltage control is crucial for keeping various activities of the social community such as maintaining production of factories, operation of commercial buildings, daily life support in residential areas, and so on. Namely, not only fast computation, but also sustainable control (dependability) is strongly required for VVC. From the viewpoint of dependability, meta-heuristic techniques with multiple searching points have a big advantage. Since the algorithms share information among the searching points, they have a possibility to get good solutions even if information from some searching points is not obtained sometimes during the searching processes. This feature is crucial for practical applications of parallel and distributed computing techniques to VVC using parallel meta-heuristic techniques.

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Considering the above background, the authors have already proposed dependability on parallel PSO based VVC (Fukuyama, 2015). Following the research, this paper evaluates dependability on parallel DE based VVC. The results are compared with that on parallel PSO and it is found that parallel DE is superior to parallel PSO especially for dependability on VVC through simulations with IEEE 14, 30, 57, and 118 bus systems.

This paper is organized as follows: Section 2 describes a problem formulation of the VVC problem. Section 3 briefly explains a basic DE, Parallel DEs and dependability. Section 4 describes a parallel DE algorithm for VVC. Section 5 shows numerical examples and conclusions are finally drawn in Section 6.

2. PROBLEM FORMULATION OF A VVC PROBLEM

This paper treats VVC formulated as a MINLP with continuous and discrete variables in steady state operation conditions as follows:

2.1 State Variables

The following control equipment is considered as state variables in the VVC problem.
(a) AVR operating value (continuous variable)
(b) OLTC tap position (discrete variable)
(c) The number of reactive power compensation equipment (discrete variable)
Namely, state variables include both continuous and discrete variables. The problem formulation using the above state variables can be expressed as follows.

2.2 Objective Function and Constraints

(1) Objective Function
The objective function is to minimize active power losses in the target power system in steady state operating conditions.

$$\text{minimize } f_c(\boldsymbol{x},\boldsymbol{y}) = \sum_{i=1}^{n} Loss_i \quad (1)$$

where n is the number of branches, $\boldsymbol{x}$ is composed of continuous variables, $\boldsymbol{y}$ is composed of discrete variables, $Loss_i$ is active power loss (Ploss) at branch i.
(2) Constraints
a) Voltage constraint
Voltage magnitude at each node must lie within its permissible range in order to maintain power quality.

$$V_{min} \le V_i \le V_{max} \quad (2)$$

where V_i is a voltage at node i ,V_{min} is a minimum allowable voltage, V_{max} is a maximum allowable voltage.
b) Power flow constraint
Power flow of each branch must lie within its permissible range.

$$Pflow_j \le Pflow_{max} \quad (3)$$

where $Pflow_j$ is a power flow at branch j, $Pflow_{max}$ is a maximum allowable power flow.

The above state variables are treated in load flow calculation as follows. AVR operating values are treated as voltage specification values at PV specific nodes. An OLTC tap position is treated as a tap ratio to each tap position and impedance of the transformer can be calculated using the tap ratio. The number of reactive power compensation equipment is treated as a corresponding susceptance value at PQ specific nodes.

3. PARALLEL DIFFERENTIAL EVOLUTION

3.1 A Basic Differential Evolution (Swagatam et al, 2011)

DE is a method to find a near global optimal solution by repeating operations of mutation, crossover, and selection using base vectors and difference vectors.

Each method of DE is expressed by the form of DE/X/Y/Z, where, X is a decision method of the base vectors, Y is the number of difference vectors, and Z is a crossover method.

This paper utilizes DE/rand/1/bin with rank information. For each decision variable, DE/rand/1/bin decides a base vector randomly, and utilizes one difference vector and the binominal crossover. DE/rand/1/bin algorithm can be expressed as follows:
Step1: Generation of initial searching points
Initial conditions of searching points are usually generated randomly within their allowable ranges. Scaling factor F and crossover probability Cr are set. Generation k is set to 1.
Step2: Mutation
$v_{i,k}$, an ith donor vector at generation k, is generated by the following equation:

$$v_{i,k} = x_{r1,k} + F(x_{r2,k} - x_{r3,k}) \quad (4)$$

where r_1, r_2, and r_3 are randomly selected from N individuals ($r_1 \neq r_2 \neq r_3 \neq i$), *N* is the number of individuals, $\boldsymbol{x}$ is a decision vector, k is the current generation number, $x_{r1,k}$ is a base vector at generation k, and $x_{r2,k}$ and $x_{r3,k}$ form a difference vector at generation k.
Step3: Crossover
$u_{i,k}$, an ith trial vector at generation k, is generated by crossover with $v_{i,k}$ and $x_{i,k}$, the original ith state variable at generation k. d is a randomly chosen index, which ensure that $u_{i,k}$ gets at least one component from $v_{i,k}$. For other indices $(i \neq d)$, $v_{i,k}$ is selected if $rand \le Cr$. Otherwise $x_{i,k}$ is selected.

$$u_{i,k} = \begin{cases} v_{i,k} & (if\ rand \le Cr\ or\ i = d) \\ x_{i,k} & (otherwise) \end{cases} \quad (5)$$

Step4: Selection
The object function values of $u_{i,k}$ and $x_{i,k}$ are compared. When the value of $u_{i,k}$ is better than that of $x_{i,k}$, $x_{i,k}$ is changed to $u_{i,k}$.
Step5: Stop Criterion
If the generation number reaches the pre-determined maximum generation number, then stop. Otherwise, k = k+1 and go to Step 2.

Rank information is a kind of order information which can be obtained by sorting the objective function values of individuals. If the rank of the base vector $x_{r1,k}$ is high, F become small and Cr become big using the following equation (Takahama, et al, 2012):