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Study on day-ahead optimal economic operation of active distribution networks based on Kriging model assisted particle swarm optimization with constraint handling techniques

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HIGHLIGHTS

- Presenting the optimal economic operation and schedule model of the ADN.
- Developing a Kriging model assisted modified fuzzy adaptive PSO algorithm.
- A constraint-handling method based on the basic principle of PSO is developed.
- A dynamic update method is developed in KMA-MFAPSO to rebuild the Kriging model.

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ABSTRACT

The distribution system is demanded to be more efficient, more flexible and more intelligent due to the continued growth of the electricity loads, the high efficiency of energy utilization and the environmental protection. The traditional distribution systems are facing the challenge of evolving from passive networks to the active distribution networks (ADN) with the integration of multiple controllable resources. This paper presents an optimal operation and schedule model of the ADN, considering a variety of controllable resources such as distributed generations, battery storages and interruptible loads. To solve the optimization problem, a modified fuzzy adaptive PSO assisted by Kriging model (KMA-MFAPSO) is developed in this paper. In KMA-MFPSO, a novel constraint handling technique (CHT) based on the PSO is proposed to handle the constraints effectively. In addition, under the premise of ensuring the accuracy of the calculation, the Kriging model is used in KMA-MFAPSO to calculate the power flow the ADN approximately, which greatly speeds up the solving process. Finally, the effectiveness of the proposed algorithm is tested on a modified IEEE-123 system. The optimal results obtained by the proposed method are compared with the results obtained by using other solving algorithms. The simulation results indicate that KMA-MFAPSO is very robust and fast to solve the optimization problem so that it can be used in practical systems.

1. Introduction

Nowadays, the power system is demanded to be more efficient, more flexible and more intelligent due to the continued growth of electricity loads and the shortage of traditional energy sources. What is distinct about the modern distribution system is the large-scale integration of distributed generations (DGs), especially the integration of wind turbines and photovoltaic power generations. However, high penetration rate of DGs will have a huge influence on traditional distribution system mainly in the following aspects: changing the voltage profiles of distribution system, increasing the difficulties of relay protection, deteriorating the power quality and influencing the reliability of the system and so on [1,2]. Although the maturing technology of micro-grid has provided a solution to the integration of DGs, due to the capacity

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Nomenclature

T total scheduling periods
Δt time interval
$C_{i,t}^{\text{buy}}$ electricity price of substation i at time interval t
C_i^{dg} generating cost of distributed generation i
C_i^{batcha}, C_i^{batdis} charging and discharging costs of battery storage i
C_i^{IL} cost of the interruptible load i
C_i^{tap} operating cost of voltage regulator i
C_i^{cap} operating cost of capacitor bank i
N_{sub} number of substation
N_{dg} number of distributed generations
N_{bat} number of battery storages
N_{IL} number of interruptible loads
N_{tap} number of voltage regulators
N_{cap} number of capacitor banks
$P_{i,t}^{\text{buy}}$ active power of substation i buying from the transmission system at time interval t
$P_{i,t}^{\text{dg}}$ generated active power of the ith DG at time interval t
$P_{i,t}^{\text{bat}}$ charging and discharging power of the ith battery storage at time interval t
$P_{i,t}^{\text{IL}}$ load curtailment of interruptible load i at time interval t
$tap_{i,t}$ actual tap position of the voltage regulator i at time interval t
$tap_{i,t}^{\text{c}}$ the mapped continuous tap position of the voltage regulator i at time interval t
$cap_{i,t}$ actual switch status of the capacitor bank i at time interval t
$cap_{i,t}^{\text{c}}$ the mapped continuous switch status of the capacitor bank i at time interval t
$s_{i,t}^{\text{batcha}}$, $s_{i,t}^{\text{batdis}}$ charging and discharging states of battery storage i at time interval t
$P_{i,t}^{G,p}$, $P_{i,t}^{L,p}$ active power and active load of node i at time interval t of phase p
$Q_{i,t}^{G,p}$, $Q_{i,t}^{L,p}$ reactive power and reactive load of node i at time interval t of phase p
$V_{i,t}^{p}$ voltage magnitude node i at time interval t of phase p
$V_{j,t}^{m}$ voltage magnitude node j at time interval t of phase m
V^{low},V^{upp} the minimum and the maximum allowable bus voltage magnitude
G_{ij}^{pm}, B_{ij}^{pm} real and imaginary parts of node admittance matrix
$\theta_{ij,t}^{pm}$ voltage phase angle difference
N_{bus} number of bus
$S_{l,t}$, S_l^{upp} transmission power of line l at time interval t; the upper limit of transmission capacity of line l
N_l number of transmission lines
$pf_{i,t}^{\text{dg}}$ power factor of DG i at time interval t
$pf_i^{\text{dg,low}}$, $pf_i^{\text{dg,upp}}$ lower and upper limits of power factor of DG i
P_i^{maxdis}, P_i^{maxcha} maximum discharging and charging power of battery storage i
$SOC_{i,t}$ state of charge (SOC) of battery storage i at time interval t
SOC_i^{low}, SOC_i^{upp} lower and upper limits of SOC of batter storage i
η_i^{cha}, η_i^{dis} charging and discharging efficiencies of battery storage i
B_i battery capacity of battery storage i
tap_i^{low}, tap_i^{upp} actual lower and upper limit of tap positions of voltage regulator i
MT_i maximum tap operating number of voltage regulator i during the scheduling periods
MC_i maximum switch operating number of capacitor bank i during the scheduling periods
$P_{i,t}^{\text{IL,upp}}$ upper limit of load curtailment of interruptible load i at time interval t
MIL_i maximum load curtailment amount of interruptible load i during the scheduling periods
N_{swarm} the population size of particles
$pbest_i$, the best positon recorded by particle i
$gbest$ the best position among all particles
$\boldsymbol{x}_i^k$,$\boldsymbol{v}_i^k$ the position and the velocity of particle i at iteration k
ω inertia weight
c_1,c_2 the individual and social acceleration coefficients
$v_{i,j}^{\min,k}$, $v_{i,j}^{\max,k}$ variable range of the velocity of the jth decision variable of particle i at iteration number k
$v_{i,j}^{\text{upp},k}$,$v_{i,j}^{\text{low},k}$ the upper and lower boundaries of particle's velocity at iteration k.
$x_{i,j}^{\text{upp}}$, $x_{i,j}^{\text{low}}$ the lower and upper boundaries of the jth dimension of particle i
$x_{i,j}^{\max,k}$, $x_{i,j}^{\min,k}$ the flying range of the jth decision variable of particle i at iteration k
$\Delta soc_{i,j,t}^{k}$ variation of SOC of the jth battery storage of particle i at iteration number k
$\Delta soc_j^{\text{low}}$, $\Delta soc_j^{\text{upp}}$ the lower and upper boundaries of the jth dimension of variation of SOC
$\Delta E_{i,j,t}^{k}$ the excessive amount of SOC constraint for the jth battery storage of particle i at iteration number k
$MR_{i,j,t}^{k}$ the maximum reduction amount of SOC without interfering the natural process of PSO
$\Delta LE_{i,j}^{k}$ the excess amount of load reduction of the jth interruptible load of particle i at iteration number k
$\Delta IL_{i,j}^{\max,k}$ the maximum reduction amounts for all time intervals in the flying range of the jth interruptible load of particle i at iteration number k
$\lambda_{i,j}^{k,m}$ the tap positions adjustment coefficient of time period m of the jth voltage regulator of particle i at iteration number k
$t_{i,j,\text{ini}}^{k,m}$,$t_{i,j,\text{end}}^{k,m}$ the firs and the last time intervals of period m
$\alpha_{i,j,t}^{k,m}$,$\beta_{i,j,t}^{k,m}$ forward-adjustment coefficient and backward-adjustment coefficient of the tap position at time interval t in the period m
$\sigma_{i,j,t}^{k,m}$ the adjustment coefficient of switch state of the time interval t in time period m of the jth capacitor bank of particle i at iteration number k
$\varphi_{i,j}^{k,m}$ the adjustment coefficient of switch state of time period m of the jth capacitor bank of particle i at iteration number k
KMA-MFAPSO Kriging model assisted modified fuzzy adaptive PSO
CHT-MFAPSO constraint handling technique based modified fuzzy adaptive PSO
FAPSO fuzzy adaptive particle swarm optimization
GA genetic algorithm
ACO ant colony optimization

limitation of it, the large scale DGs' integration problem still cannot be settled effectively [3]. With the great development of the distributed generation technologies, energy storage technologies and power electronics, the grid-connection problem of DGs has been settled to a large extent [4]. However, owing to the lack of efficient optimization strategy, the low degree of automation and the lack of demand response in the traditional distribution system, the renewable energy consumption capability of the system is greatly limited, which restricts the development and the application of the clean and renewable energy sources and is not conducive to the energy structure adjustment [5]. In this situation, the active distribution network (ADN) technology emerges and is