Electrical Power and Energy Systems 102 (2018) 393–400

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Multi-time scale optimal dispatch in ADN based on MILP

Guibin Zou[a], Yuwei Ma[a,*], Jingjing Yang[b], Meiyi Hou[a]

[a] *Key Laboratory of Power System Intelligent Dispatch and Control of Ministry of Education (Shandong University), Ji'nan, Shandong Province, China*
[b] *State Grid Weifang Electric Power Company, Weifang, Shandong Province, China*

A R T I C L E I N F O

Keywords:
Active distribution network
Day-ahead dispatch
Mixed-integer linear programming (MILP)
Multi-time scale
Short-term dispatch

A B S T R A C T

With the development of active distribution network (ADN) and the increase of penetration rate of new energy such as wind power and photovoltaic, the optimal operation problem of ADN is facing challenges. So, this paper proposes a multi-time scale optimal dispatch method based on mixed-integer linear programming to improve the calculation speed of the traditional dispatching model. First, the linear branch power flow of distribution network is introduced, and the main elements in ADN are modeled, meanwhile, the linearization method is used to simplify the non-linear components. Then, the day-ahead dispatch model is established by considering the active and reactive power coordination. In addition, in order to reduce the influence of the stochastic power from DG and FL on dispatch results, taking the results of day-ahead dispatch as reference, an auxiliary short-term dispatch model is also constructed to maximize the consumption of wind and photovoltaic (PV) power. Finally, the validity and reliability of the proposed method are verified by a modified IEEE 33-node distribution system.

1. Introduction

In order to reduce the negative impact of distributed generators on the distribution network, the active distribution network (ADN) came into being [1]. With the increase of the distributed energy resources (DER) in types and penetration rate, the decentralized and intermittent DERs, such as wind power and photovoltaic, bring an enormous challenge to ADN optimal dispatching [2]. In order to further improve the energy management potential of ADN, it has become a research focus to realize the coordinated and optimized operation of the DERs in ADN [3,4].

In recent years, scholars around the world have been studying the optimal dispatch of DER in ADN. An optimal dispatch model based on the characteristics of DERs and ADN is proposed in [5]. The model takes the minimum cost of scheduling in one cycle as the objective function, realizes the control of the distributed power generation unit and the energy storage unit in the active distribution network, and completes the optimal dispatch of ADN, but the model does not consider the output characteristics of reactive power compensation device and its economic benefits. In [6], the minimum power loss is taken as the objective function to realize the reactive power optimization of the distribution network with DERs. The number of capacitor banks (CB) and the reactive power output of DERs can be obtained from the model, but it does not consider the effect of the DG power factor, because the low power factor will lead to high reactive power flow. Obviously, this does not meet the economic requirements.

The energy storage component is detailed in [7], and the optimal power flow of distribution network is determined by the four-quadrant operation, where the active power and reactive power are all considered at the same time. In [8], the optimal situation of on load tap changer (OLTC) and the optimal output of static var compensators (SVC) are calculated from the robust optimization perspective. In order to reduce the effect of the strong randomness energy (such as wind power), a multi-time scale optimal dispatch method is proposed in [9], which takes the advantage of ADN to amend the long-time scale plan and, by reducing the dispatch step and improving the prediction accuracy, the maximum consumption of DERs can be achieved.

The solving algorithm and its operation speed are the key issues of optimal dispatch. Because of the nonlinear characteristics of objective function and component models, some artificial intelligence algorithms are used to solve the problem in [10–12], such as the particle swarm optimization (PSO), ant colony algorithm (ACA), genetic algorithm (GA), etc. These algorithms have the advantages of group intelligence, inherent parallelism, simple iterative format and easiness to express complex constraints, but traditional algorithms have some weakness, such as slow solving speed, easiness to fall into the local optimal. The second order conic relaxation (SOCR) based on basic dynamic optimal power flow model is presented in [13], and the solving speed has a significant improvement through SOCR, but there are still some nonlinear components in this model, so it should be further relaxed. In [14], the distribution network power flow equations are linearized, and it is an important contribution to realizing the linearization of ADN

---

[*] Corresponding author.
E-mail address: masayhehe@163.com (Y. Ma).

https://doi.org/10.1016/j.ijepes.2018.04.036
Received 20 November 2017; Received in revised form 8 April 2018; Accepted 30 April 2018

Nomenclature

j	node
$P_j + iQ_j$	apparent power from node j to node $j + 1$
$p_j + iq_j$	apparent power production at node j
$p_j^c + iq_j^c$	apparent power consumption at node j
$p_j^g + iq_j^g$	apparent power generation at node j
r_j,x_j	line impedance between node j and $j + 1$
V_j	voltage magnitude at node j
$P_{i,t}^{DG}$,$Q_{i,t}^{DG}$	active and reactive power of DG i at time t
$F_{i,\min}$	minimum power factor of DG i
$P_{i,\min}^{DG}$, $P_{i,\max}^{DG}$	minimum and maximum active power of DG i
T	optimal dispatching time horizon
$P_{i,t}^{ES,c}$, $P_{i,t}^{ES,d}$	charge and discharge active power of ES i at time t
$E_{i,t}^{ES}$	remaining energy of ES i at time t
$E_{i,min}^{ES}$,$E_{i,max}^{ES}$	minimum and maximum remaining energy of ES i
$z_{i,t}^c$, $z_{i,t}^d$	status variable of charge or discharge of ES i at time t
$\eta_{i,t}^c$,$\eta_{i,t}^d$	charge or discharge efficiency of ES i at time t
$Q_{i,t}^{ES}$,$S_{i,\max}^{ES}$	reactive and apparent power of ES i at time t
$\tau_{q,t}^{CB} P_{i,t}^{MG}$,$Q_{i,t}^{MG}$	active and reactive power of MG i at time t
$P_{i,\min}^{MG}$, $P_{i,\max}^{MG}$	minimum and maximum active power of MG i
$Q_{i,\min}^{MG}$, $Q_{i,\max}^{MG}$	minimum and maximum reactive power of MG i
γ	abandonment rate
R	prediction value of DERs
D	dispatching value of DERs
$S_{i,\max}^{MG}$	apparent power of ES i
$P_{i,t}^{FL}$, $Q_{i,t}^{FL}$	active and reactive power of FL i at time t
$P_{i,\max}^{FL}$	maximum active power of FL i
F_i^{FL}	minimum power factor of FL i
$Q_{i,t}^{SVC}$, $Q_{i,t}^{CB}$	reactive power of SVC i and CB i at time t
$Q_{i,\min}^{SVC}$, $Q_{i,\max}^{SVC}$	minimum and maximum reactive power of SVC i
$c_{ik,t}$	status variable of capacitor k in CB i at time t
$q_{i,k}$	capacity of capacitor k in CB i
$N_{i,\max}^{CB}$,$N_{\max}^{OLTC}$	operation number of CB i and OLTC in an operation cycle
$\alpha_{ik,t}$	auxiliary variable of CB i
$V_{r,t}$	voltage at root node
$V_{\min}$	minimum adjustment voltage by OLTC
S_t^{OLTC}	tap position of OLTC at time t
β	the voltage change value for each position
κ_t	status variable of switch actions of OLTC
DG_i, ES_i, MG_i, FL_i, SVC_i,CB_i	set of DG, ES, MG, FL, SVC, and CB
$\tau_{p,t}^s$,$\tau_{q,t}^s$	price of active and reactive power at substation
$\tau_{p,t}^{DG}$,$\tau_{p,t}^{ES}$,$\tau_{p,t}^{FL}$	price of active power of DG, ES and FL
$\tau_{q,t}^{DG}$,$\tau_{q,t}^{ES}$,$\tau_{q,t}^{FL}$,$\tau_{q,t}^{SVC}$,$\tau_{q,t}^{CB}$	price of reactive power of DG, ES, FL, SVC and CB
τ_o^{CB},τ_o^{OLTC}	price of per operation of CB and OLTC

dispatch model.

In reality, due to the intermittent power output of renewable DGs and the uncertain consumption of flexible loads, it is a very difficult task to realize the operation optimal of distribution network. Though the introduction of energy storage system may restrain the fluctuation of power to an extent, the stochastic DGs and flexible loads may not be able to complete the dispatching goal, which produce a negative influence on the optimal dispatching. So in this paper, the multi-time scale dispatching method is used to dispatch PV and wind power. Through theshort-term scale optimization, the grid-connected power of the ADN is consistent with the scheduling results of the day ahead value. In addition, the scheduling model is linearized and solved, which improves the solution speed.

In this Section, an introduction is simply discussed, and the remainder of this paper is organized as follows. In Section 2, linearized branch power flow equations and component models are firstly introduced. Then, the day-ahead optimal dispatch model and short-term dispatch model are constructed respectively in Section 3. Section 4 shows the case studies, simulation results and discussions. Finally, the main conclusions are summarized in Section 5.

2. Linearized power flow equations and component models

2.1. Linearized branch power flow equations

In general, the distribution network with DERs is still a radial system, and a schematic diagram of radial distribution network is shown in Fig. 1 [15,16].

In Fig. 1, this paper uses branch “0-n” to illustrate the branch flow and linearization methods. $p_j + iq_j$ is the complex power at node j, which is composed of the complex power ($p_j^c + iq_j^c$) consumed by loads and the complex power ($p_j^g + iq_j^g$) generated by DERs. $P_j + iQ_j$ is the complex power flowing from node j to node $j + 1$. Referring to Fig. 1, the feeder equations based on the branch power flow can be obtained as follows,

$$P_{j+1} = P_j - r_j \frac{P_j^2 + Q_j^2}{V_j^2} - p_{j+1}^c + p_{j+1}^g \tag{1}$$

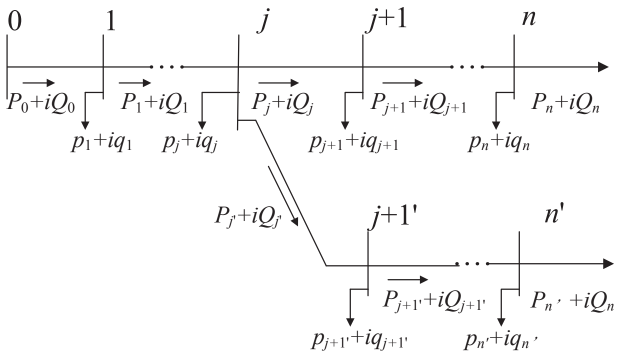

Fig. 1. Schematic diagram of radial distribution network.