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Research on Optimal Operation of AC/DC Active Distribution Network Based on SOP

Zhanjun LI[a], Zhikai WU[a], Li JIANG[a], Heyan ZHU[a],Ming MENG[b],Yi WEI[b], Guolin ZHU[b]

a State Grid Liaoning Electric Power Company Limited Economic Research Institute, Shenyang 110015,China
[b] North China Electric Power University, Baoding 071003, China

Email: mmwxp@126.com

Abstract. The development of AC/DC active distribution network promotes the improvement of distribution network power supply mode. As a new-type power electronic device,Soft Open Point(SOP) has many benefits for the grid operation. In this paper, the AC/DC active distribution grid was constructed firstly and the control strategy of the back-to-back voltage source of SOP was analyzed in detail. Secondly, a mathematical model was established to reduce the system loss and to improve the node voltage over-limit condition. Considering these problems can be taken as multi-objective and nonlinear optimize problems, this paper put forward the improved genetic algorithm to solve it. Finally, the results of the simulation indicates the effectiveness of the proposed algorithm.

1. Introduction

The development of new energy technologies and the access of a large number of distributed power sources have led to a decrease in the operating efficiency of traditional distribution networks, an increase of system costs, and the reduction operational reliability[1]. The AC/DC active distribution network can autonomously adjust the system voltage and power flow according to the actual operating state of the power system, and realize the coordinated control and optimal operation of the source-network-load level to meet the operational metrics of the power system economy and safety. It is one of the most important forms of active distribution networks in the future [2].

The rapid development of new energy technologies makes AC distribution networks increasingly being unable to meet the needs of the current society. Photovoltaic power generation and storage battery access to AC distribution networks require DC/DC converters. Wind power generation access to AC distribution networks also requires AC/DC/AC converters [3]. The AC line containing several new energy devices will be converted into a DC line, and an AC/DC active distribution network will be constructed in order to meet the safe operation of the distribution network under the premise of reducing converter device, reducing the system cost and thus is the feasible scheme of power distribution network frame optimization[4]. SOP can replace the contact switch in the traditional AC line, flexibly control the connected lines, and can improve the current control status of the "Closed-loop Design, Open-loop Operation" of the traditional distribution network..

Under this circumstance, this paper proposes an active power distribution network frame structure based on SOP in order to reduce power loss of network and to improve the voltage over-limit

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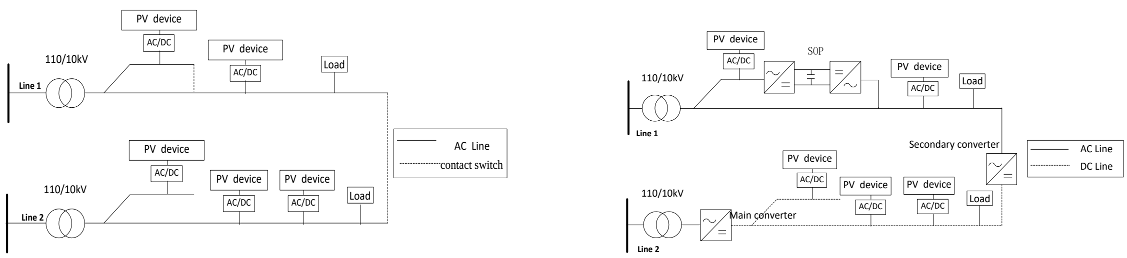
condition firstly. On this basis, a mathematical model was set up for the purpose of optimization. It is necessary to consider multiple output variables in the operation optimization of AC/DC active distribution network with SOP which belongs to the optimization problem of mixed-integer nonlinear function[5]. In this paper, an improved genetic algorithm is used to solve the mathematical model. The improved genetic algorithm is faster than the traditional genetic algorithm, and it is not easy to be trapped in the local solution. Finally, a simulation model was built in Matlab/Simulink to verify the correctness of the AC/DC active distribution network structure and the effectiveness of the proposed algorithm.

2. AC / DC active grid structure with SOP

The structure of the traditional AC distribution network system is presented, as shown in Fig.1(a). The power distribution system consists of two 10kV medium-voltage feeders stepped down by a transformer. The connection switch connects them. Each AC line is connected to a photovoltaic device and load. The contact switch in Line 1 can realize the optimal operation of the traditional distribution network. This paper selects the SOP for power electronics as a substitute for some contact switches, transforms AC line with multiple distributed power sources into DC line, and uses inverter VSC connected DC line with AC line to build a hybrid AC/DC distribution network. The transformed AC/DC active distribution network system structure is proposed, as shown in Fig.1(b). The line 2 contains several photovoltaic devices which is converted into a DC line. The VSC is placed at the connection of the first end of the line 2 and the two lines. The SOP in place of the contact switch in line 1.Based on the AC/DC active distribution network composed of power electronic devices, the coordination between SOP and VSC is adopted to realize the power flow control between feeders and the optimal operation of the system.



(a) (b)

Figure 1. AC/DC active distribution network system structure:(a) Before remodeling (b)After remodeling

3. Optimal modeling and solution of AC/DC active distribution network with SOP

3.1. Control system of SOP

Currently, there are three general structures of SOP: back-to-back voltage source converter (B2B VSC), static synchronous series compensator (SSSC), and unified power flow controller (UPFC) [6]. This paper takes back-to-back voltage source converter as an example to introduce the control strategy of SOP in AC/DC active distribution network.

B2B VSC system consists of two parts of four-quadrant VSC1 and VSC2, DC filter capacitor C, VSC converter grid-side equivalent connection resistance R1, R2 and inductance L1, L2. The filter capacitor C is used to provide DC voltage support and reduce the ripple of the DC bus voltage. L1 and L2 are used to filter out the harmonics of the converter output current. R1 and R2 represent the equivalent resistance of losses between the converter and the AC system.

The goal of this paper is to achieve coordinated control of SOP and VSC in order to reduce system network losses and to improve voltage over-limitation. The AC side voltage of the main converter station is determined by the 10kV bus voltage and the DC side voltage level is 15kV. The control method is Vdc-Q. AC and DC lines are connected from the secondary converter station to accurately adjust the active power and reactive power. The control method is P-Q[7]. SOP outer ring needs to output the AC side voltage, active power, and reactive power in real time according to the current operating state of the system so as to achieve effective control of the system. At this time, the VSC on both sides need to coordinate with each other. In summary, this paper selects the SOP control strategy as PQ-VdcQ control, which is one converter controls the DC side voltage, and the other converter controls the transmission power.

3.2. Mathematical model

Considering that a large number of distributed power sources complicate the operation behavior of distribution networks, traditional static power flow cannot satisfy the optimization requirements. Thus a dynamic power flow optimization method was adopted to reduce power loss of network and to improve voltage over-limit conditions as an objective function. To optimize the problem, this paper establish a mathematical model using the weight coefficient transformation method, so as to converts the multiple objectives into a single goal. Ignoring the power loss of the SOP, the optimized objective function can be expressed as:

$$\min F = C_1(P_{loss}^{AC} + P_{loss}^{DC} + P_{loss}^{VSC}) + C_2(\sum_{i=1}^{n}|V_i - V_N|) \quad (1)$$

In the formula, C_1 and C_2 represent the weight coefficient, and assumed C_1=C_2=0.5. P_{loss}^{AC} indicates loss of AC line, P_{loss}^{DC} indicates loss of DC line, P_{loss}^{VSC} indicates loss of inverter, V_i indicates voltage value of node *i*, and V_n indicates the rated voltage.

The operational constraints of the distribution network include active and reactive power system flow constraints, converter VSC constraints, SOP operating constraints, node voltage upper and lower limit constraints.

$$P_{\mathrm{i}} = U_i \sum_{j=1}^{N} U_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \quad (2)$$

$$Q_{\mathrm{i}} = U_i \sum_{j=1}^{N} U_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \quad (3)$$

$$U_{i\min} \le U_i \le U_{i\max} \quad (4)$$

$$\sqrt{P_{VSC}^2 + Q_{VSC}^2} \le S_{\max}^{VSC} \quad (5)$$

$$\sqrt{P_{SOP1}^2 + Q_{SOP1}^2} \le S_1^{SOP} \quad (6)$$

$$\sqrt{P_{SOP2}^2 + Q_{SOP2}^2} \le S_2^{SOP} \quad (7)$$

$$P_{SOP1} + P_{SOP2} = 0 \quad (8)$$

In the formula, P_i and Q_i represent the active power and reactive power respectively injected into node *i*. G_{ij} and B_{ij} are the real part and the imaginary part of the admittance matrix of the system. θ_{ij} is the phase angle difference between nodes *i* and *j*. U_{imin} and U_{imax} indicate the upper and lower limits of the node voltage *i*. P_{vsc} and Q_{vsc} indicate the active power and reactive power flowing through the converter. S_{max}^{VSC} indicates the upper limit of the converter capacity. *Psop1*、P_{sop2} indicate the active power flowing through the SOP; Q_{sop1}、Q_{sop2} indicate the reactive power flowing through the SOP; S^{sop} indicates the operating capacity of the SOP.

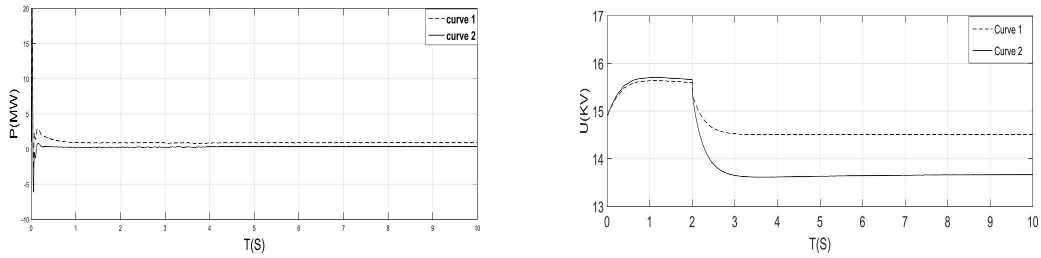
3.3. Solving algorithm

For the optimization model proposed in the previous section, this paper uses an improved genetic algorithm to solve it. When solving the optimization problem of AC/DC active distribution network based on SOP proposed in this paper, the genetic algorithm first encodes and initializes the control variables in the AC/DC system, then brings individuals into the power flow calculation equation and calculates their adaptive value functions; The convergence solution obtained through selection, crossover, and mutation is the optimal power flow for each individual, and then it is taken into the power flow calculation equation to calculate its fitness; The individual objective function values are sorted, and the bad individuals are replaced by excellent individuals, the next round of optimization is performed until an optimal solution is obtained or the upper limit of the number of iterations is reached. This method can effectively avoid falling into a local optimum when solving optimization problems.

3.4. .Analysis of examples

Using Matlab/Simulink to build the AC/DC active distribution network model to verify the correctness of the optimization algorithm. The AC bus voltage is 10kV;The DC bus voltage is 15kV; the rated capacity of the photovoltaic power station is 2MW, and the transmission efficiency is 0.95; the rated capacity of the VSC converter station is 5MW, and the transmission efficiency is 0.98; the rated capacity of the SOP is 5MW, and the transmission efficiency is 1; AC power factor reference is 1.

Fig2(a) shows the power loss generated by the AC/DC active distribution network with and without using the optimization algorithm.The system loss without optimization algorithm is shown as curve 1. The system loss mainly includes the line loss caused by AC line and DC line, VSC converter station loss, etc. The total loss is about 0.5 MW; when the system adopts the optimization algorithm proposed in this paper , the loss of the system is significantly reduced by coordinating the SOP, VSC converter station and photovoltaic power generation unit. After optimization, the loss is about 0.2 MW, as shown in curve 2 of the figure a.



(a) (b)

Figure 2. With and without using the optimization algorithm system comparison chart: (a) system losses (b) the node voltage

Fig2(b) shows the results of using of an optimization algorithm to optimize the voltage at a certain point on the DC side of the AC/DC active distribution network. In actual operation, the unstable output of the distributed power device and the sudden change of the load value will generate voltage fluctuations in the grid voltage and cause the node voltage to exceed the limit. Curve 2 indicates that the load on the DC side increases at 2 seconds. It can be seen that the voltage suddenly drops to about 13.75 kV when the node voltage has crossed the line. After the optimization algorithm was adopted, the lower limit of the voltage was significantly increased, which was about 14.5kV. The voltage of the node did not cross the line, as shown in curve 2 of the Fig2(b).Figure2 shows that the optimized control algorithm proposed in this paper can effectively reduce the system losses and improve the voltage over-limit conditions caused by the unstable output of the distributed power supply by coordinating and controlling the converter station and SOP.At the same time, it also proves that the correctness of the grid.

4. Conclusion

The rapid development of DC-type distributed power supplies, energy storage devices, and electric vehicles has made DC power distribution more and more became a hot topic of research. SOP is a power electronic device that can be used to replace contact switch in traditional power grids and has a significant potential in application, and may even create a new distribution network power supply model.From the perspective of economic operation, this paper established a distribution network optimization operation model, adopted an improved genetic algorithm to solve the mathematical model, and the simulation results verified the rationality of the AC/DC active distribution network structure and the correctness of the proposed optimization algorithm. This method is effective to reduce energy consumption, to improve the voltage over-limit condition, and meets the requirements of the economical operation and green development of the active distribution network.

References

[1] Romero-Ramos E, Marano-Marcolini A. Assessing the loadability of active distribution networks in the presence of DC controllable links. IET generation, Transmission&Distribution,2011;5(11):1105.

[2] S K Chaudhary, Guerrero J M. Enhancing the capacity of the AC distribution system using DC interlinks-a step toward future DC grid.IEEE Transactions on Smart Grid,2015;6(4):1722-1729.

[3] S.K.Chaudhary, E.Demirok, R.Teodorescu. Distribution system augmented by DC links for increasing the hosting capacity of PV generation.In:Proc.Power.Electron.Drives.Energy Syst.(PEDES),2012:1-5.

[4] L.Xiong, W.Peng, P.Loh. A hybrid AC/DC microgrid and its coordination control.IEEE Trans.Smart Grid,2011;2(2):278-286.

[5] C.Chen, C.Tsai,C.Lin,etal.Loading balance of distribution feeders with loop power controllers considering photovoltaic generation.IEEE Trans.Power Syst.2011;8(26):1762-1768.

[6] Wangyu Cao, Nick Jenkins, Jianzhou Wu. Feeder Load Balancing in MV Distribution Networks Using Soft Normally-Open Points. In:2014 5th IEEE PES Innovative Smart Grid Technologies Europe(ISGT Europe),2014:1-6.

[7] Alcala J, Cardenas V, Ramirez-Lopez A R,et al.Study of the bidirectional power flow in back-to-back converters by using linear and nonlinear control strategies.Presented at:2011 IEEE ECCE.