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Joint Operation Method for Distributed Photovoltaics and Energy Storage System in Distributed Network

Author: Hai Huang[1], Lu Yin[2], Yongshu Zhang[1], Wei Wang[2], Wei Ye[1], Weijun Zhang[1]
Company: 1. State Grid Fujian Electric Power Company, Ltd.
2. Sichuan Energy Internet Research Institute ,Tsinghua University

I. INTRODUCTION

With the photovoltaics(PV) installed capacity increasing, energy storage can be used as an important regulation measure for the grid security. The application of energy storage technology in the distributed network can effectively solve the problem of light abandonment and promote the consumption of renewable energy.

Considering the positive influence of the energy storage system on the consumption of distributed photovoltaic power generation, a joint operation method for the distributed photovoltaics and energy storage system considering the impact of curtailment is proposed in this paper. In this joint operation method, the overall operating cost of the system is taken into the consideration, including the network loss, curtailment cost and energy storage operating cost. Combining the load flow constraints that reflect the influence of voltage rise, as well as the operating conditions of the distributed photovoltaics and energy storage system, a nonlinear optimization model is developed. Then a solution method based on dynamic voltage iteration is proposed. To simplify the solution, the nonlinear constraints are simplified into a sensitivity-based linear model for the inner layer. Then a dynamic voltage iteration process is added for the outer layer to eliminate the error caused by the sensitivity-based linear model.

II. JOINT OPERATION MODEL

The objective function of the joint operation model mainly consists of three parts, the costs of the PV curtailment, network loss and energy storage operating respectively. The curtailment cost directly reflects the objective to improve the PV consumption. The network loss can be equated to a certain extent with the load variance optimization, which plays a role of load peak shaving and valley filling. The energy storage operating cost reflects the guiding effect of the electricity price on the charging and discharging behaviors.

The model operation constraints power balance constraint of the grid, power constraint of the energy storage, capacity constraint of the energy storage system, security constraint of the grid and PV operation constraint.

III. SOLUTION METHOD

The load flow equations make the model a multi-period coupled nonlinear optimization, which is difficult to solve. Usually, the dynamic programming method is used to get the solution for each time period through recursive algorithms or get the solution by a multi-period nonlinear way with the high-dimensional variables. However, curse of dimensionality or convergence problems exist for these two types of methods. In this paper, a dynamic-voltage-iteration based solution method is proposed to translate the nonlinear constraints to the sensitivity equation. Then the voltage is corrected by iterative process to achieve accurate and fast optimal solutions.

The voltage is no longer obtained in the load flow. So the voltage related constraints can be simplified by the sensitivity relationship between the voltage amplitude and the input power.

$$U_i^k(t)=U_i^{k-1}(t)+\mathbf{M}_P\Delta\mathbf{P}+\mathbf{M}_Q\Delta\mathbf{Q}$$

So the network loss in the objective function can be simplified.

$$P_{\text{loss}}(t)=\left[\mathbf{I}_i^a(t)\right]^T\mathbf{R}_l\left[\mathbf{I}_i^a(t)\right]+\left[\mathbf{I}_i^b(t)\right]^T\mathbf{R}_l\left[\mathbf{I}_i^b(t)\right]$$

$$\mathbf{I}_i^a(t)+j\mathbf{I}_i^b(t)=\mathbf{T}\mathbf{I}_i^a(t)+j\mathbf{T}\mathbf{I}_i^b(t)$$

$$I_i^a(t)-jI_i^b(t)=\frac{P_i(t)+jQ_i(t)}{U_i^a(t)+jU_i^b(t)}$$

As the voltage amplitude needs to be used as the parameters for calculating the objective function, and the sensitivity based simplified linear relationship is adopted for the voltage constraints, the method of voltage dynamic iteration is used to reduce the voltage amplitude errors that may be generated from the simplified linear relationship. This method can help to gradually converge to the most optimal solution..

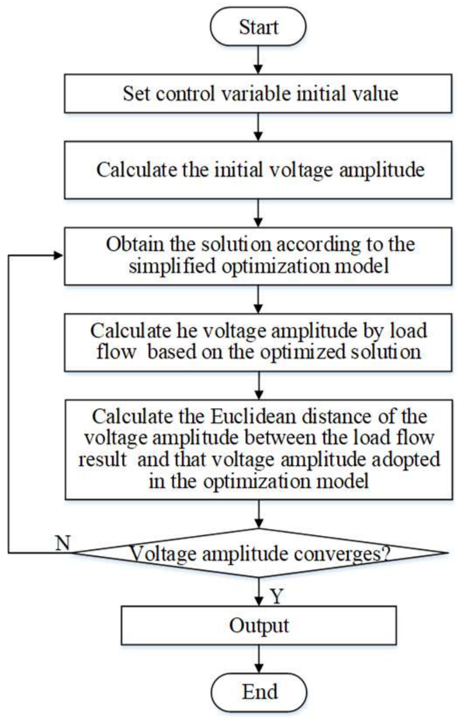

Fig. 1 Flow Diagram of Solution Method Based on Voltage Dynamic Iteration

IV. CONCLUSION

The joint operation model in this paper has been developed with comprehensive considerations to the overall operating cost of the system. Then a solution method based on dynamic voltage iteration is proposed. The nonlinear constraints are simplified into a sensitivity-based linear model. The error caused by the linear model is eliminated by the iteration process.

The case analysis shows that this model can effectively make the energy storage system charging in PV peak output periods and improving the PV consumption. With the solution method, effective convergence can be achieved within 10 iterations. When the PV penetration reaches 48% and the energy storage system is installed, the typical curtailment can be reduced from 0.68% and 1.29% to 0% and 0.48% in spring and summer respectively. If the capacity of the energy storage system is increased or the PV penetration is enhanced, the energy storage system will have a more significant effect on the consumption of the PV system.

Tel: 13581759906
E-Mail: yinlu183@163.com

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