The Characteristics of Voltage Regulation with SVR Considering Load Model

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Abstract. The load model is of great importance for voltage stability in power systems. The model structure and model coefficients of different load models will affect the voltage regulation. This paper analyzes the correlation and the relationship between load model and voltage stability. It is found that, if the different load models under the same voltage regulation control strategy can be analyzed, it can provide an important basis for the simulation modeling of voltage stability and the rationality of the voltage regulation strategy in the power system. Therefore, based on the openDSS software, the IEEE33 node is taken as an example to analyze the voltage stability of different load models during the SVR voltage regulation process.

Introduction

In recent years, the scale of China's power grid has been expanding. The complexity of power system operation is increasing. It is necessary to adopt a mathematical model which is closer to reality, to simulate the operation of the power system effectively. Therefore, various simulation analysis of the power system must select the appropriate mathematical model for each component firstly.

Voltage stability is essentially load-stable, and the characteristics of load are important for voltage stability studies. According to whether the dynamic characteristics of the load are reflected, the load model can be generally divided into two types: static model and dynamic model. The structure of the basic static load model is: power function model; polynomial model. The static load model is primarily used in power flow calculations and steady state analysis based on power flow calculations. In [1], the load modeling is carried out by the measured data of the power system. Finally, the impact characteristic model of load is proposed. In [2], a solution and specific implementation method, which adapted to the requirements of smart grid simulation, are proposed for on-line quasi-real-time correction of integrated load model parameters.

At present, most researches on load modeling are numerous, but the analysis of the load model to the SVR voltage regulation problem is rare. In this paper, four different load models are applied to the voltage regulation problem respectively. By analyzing the influence of different load models on the voltage regulation under the same voltage regulation strategy, the optimal load model is analyzed in the future voltage regulation modeling simulation.

Load Model

Because SVR voltage regulation is the voltage stability problem, it belongs to power flow calculation. Therefore, the static load model is mainly used in this paper, and the static load model of power system can be subdivided into four types, which are constant impedance model (CZ), constant current model (CI), constant power model (CP), and ZIP model.

The ZIP model consists of three basic components of different proportions, as shown in Figure 1, where Z is the constant impedance, I is the constant current, and P is the constant power.
Figure 1. ZIP model.

The ZIP model is usually expressed as follows:

\[
\begin{align*}
    P &= P_N (a_p U^* + b_p U^* + c_p) \\
    Q &= Q_N (a_q U^* + b_q U^* + c_q) \\
    a_p + b_p + c_p &= 1, a_q + b_q + c_q &= 1
\end{align*}
\]  

(1)

Where: \( U^* \) is the standard values, \( P_N \) and \( Q_N \) are the active and reactive powers respectively at the rated voltage; \( a_p, b_p, c_p \) are the percentage coefficients of the above three kinds of active loads; \( a_q, b_q, c_q \) are the above three The composition percentage coefficient of the reactive load.

Specially, when \( a_p = b_p = a_q = b_q = 0, c_p = c_q = 1 \),

\[
\begin{align*}
    P &= P_N \\
    Q &= Q_N
\end{align*}
\]  

(2)

At this time, the load model degenerates into a constant power model.

When \( b_p = c_p = b_q = c_q = 0, a_p = a_q = 1 \),

\[
\begin{align*}
    P &= P_N U^* \\
    Q &= Q_N U^*
\end{align*}
\]  

(3)

At this time, the load model is a constant impedance model.

When \( a_p = c_p = a_q = c_q = 0, b_p = b_q = 1 \),

\[
\begin{align*}
    P &= P_N U^* \\
    Q &= Q_N U^*
\end{align*}
\]  

(4)

At this time, the load model is a constant current model.

The Effect of the Load Model on Voltage

The load model mainly includes the model structure of the distribution network and the corresponding model coefficients. During the steady state process, in view of the less transient change of loads in the distribution network, it can be approximated supposed that the model structure of the load is relatively stable. Therefore it can be described by using a static load model. However, the model parameters of different static load models have differences in the essential sense. To a certain extent, this difference will affect the combination type, dynamic characteristics and voltage sensitivity of the load, which will affect the voltage regulation. Since the voltage stability is essentially load-stable, the voltage change during the intelligent voltage regulation process will cause a change in the load, which will affect the power flow of the system and in turn affect the voltage.

Known method of voltage drop:

\[
\begin{align*}
    \Delta U &= \frac{P' R + Q' X}{U_2}; \quad \delta U = \frac{P' X - Q' R}{U_2}
\end{align*}
\]  

(5)
\[ U_1 = (U_2 + \Delta U) + j\delta U = U_2 + \frac{P' R + Q' X}{U_2} \]  \hspace{1cm} (6)

For the general line, if further simplification is needed, the third item can be omitted, that is, \( \delta U \) is omitted.

At the same time, the voltage drop will further affect the network loss, the network loss affects the power flow, and the power flow in turn further affects the voltage. The network loss expression is simplified as:

\[ P_{\text{loss}} = 3I^2 * R \]  \hspace{1cm} (7)

The above formula are the correlation between load and voltage. When choosing different load models, it will also affect the voltage drop, affect the network loss, affect the power flow, and then affect the voltage distribution. Below we will adjust four different load models to analyze the effect of voltage regulation respectively.

**ZIP Model**

When the selected load model is a ZIP model, the above formula is combined to derive the effect of the available load parameters on the voltage as follows:

\[ \Delta U = \frac{P' R + Q' X}{U_2} = \frac{p_n(a U'^2 + b U' + c)R + Q_n(a U'^2 + b U' + c)X}{U_2} \]

\[ = \frac{U'^2(a_p R + a_q X) + U'(b_p R + b_q X) + c_p R + c_q X}{U_2} \]  \hspace{1cm} (8)

When the ratio of active load to reactive load is different, \( a_p, b_p, c_p, a_q, b_q, \) and \( c_q \) take different values, the effects on voltage are different.

**CZ Model**

When the selected load model is the CZ model, that is, when the load model is a constant impedance model, the above formula is combined to derive the influence of the available load parameters on the voltage:

\[ \Delta U = \frac{P' R + Q' X}{U_2} = \frac{p_n U'^2 R + Q_n U'^2 X}{U_2} \]

\[ = \frac{U'^2(P_n R + Q_n X)}{U_2} \]  \hspace{1cm} (9)

In this model, the network loss is proportional to the node voltage value, which means that the constant impedance model will amplify the effect of the voltage.

**CI Model**

When the selected load model is a CI model, that is, when the load model is a constant current model, the above formula is combined to derive the influence of the available load parameters on the voltage:

\[ \Delta U = \frac{P' R + Q' X}{U_2} = \frac{p_n U' R + Q_n U' X}{U_2} \]

\[ = \frac{U'(P_n R + Q_n X)}{U_2} \]  \hspace{1cm} (10)

Meanwhile, under this model, the network loss is basically not affected by the voltage regulation, and has nothing to do with the change of the node voltage.

**CP Model**

When the selected load model is the CP model, that is, when the load model is a constant power model, the above formula is combined to derive the influence of the available load parameters on the voltage:
\[
\Delta U = \frac{P'_R + Q'_X}{U_2} = \frac{P_R + Q_X}{U_2}
\]

Under this model, there is a negative correlation between the network loss and the node voltage.

SVR Voltage Control Strategy

SVR Optimal Placement

Firstly, for all load models, taking the constant power model as an example, the feasibility of the voltage regulation strategy obtained by the programming is tested. By comparing the voltage regulation effect of the IEEE33 system with and without placing the voltage regulator, it can be seen that the voltage regulation effect is very obvious with SVR from the Figure 2.

In order to test the voltage regulation performance of SVR on different lines, we selected several typical lines from IEEE33, used as the load model. In openDSS, keeping the voltage ratio at 1.025, the regulator voltage position is adjusted. The result is shown in Figure 3 and Table 1:

Table 1. Network loss after placing the voltage regulator on different lines.

| PLoss/line | Line1  | Line4  | Line5  | Line8  | Line19 |
|------------|-------|-------|-------|-------|-------|
| PLoss      | 205.851 | 203.026 | 202.560 | 204.981 | 202.677 |

The simulation results show that the sensitivity of different lines to the voltage regulator is different, that is to say, when the voltage regulator is placed on different lines, the voltage regulation effect is different. When the regulator is placed on the Line 5, the node voltage is between the lower limit of 0.93 pu and the upper limit of 1.07 pu, and the voltage regulation effect is best. At the same time, Table 1 shows the network loss of Line 5 is slightly small.

Analysis of SVR Voltage Regulation Strategy

The SVR voltage regulation control strategy can achieve the best voltage optimization effect. To achieve this goal, we start with the establishment of the sensitivity matrix to improve the voltage quality and reduce the network power loss. Here we choose the network loss to the tap sensitivity and voltage deviation to the tap sensitivity.

The voltage deviation \( \Delta U \) and network loss \( P_L \) are state variables, and the voltage regulator tap \( T_{ij} \) is control variable. Therefore, an analytical expression of the relevant sensitivity can be obtained.

(1) The sensitivity of the network loss to the tap is:

This sensitivity is also called the micro-increasing rate of the active network loss versus ratio, expressed as:

\[
S_{PT} = \begin{bmatrix} \frac{\partial P_L}{\partial T_{ij}} \end{bmatrix}
\]

(12)

(2) The sensitivity of the voltage deviation to the tap is:
\[ S_{VT} = \left[ \frac{\partial \Delta U}{\partial T_{ij}} \right] \]  

(13)

The network loss sensitivity \( S_{PT} \) indicates that the network loss responds with the change of the control variable transformer ratio tap \( T_{ij} \); the voltage deviation sensitivity \( S_{VT} \) represents the response of the voltage deviation with the change of the control variable transformer ratio tap \( T_{ij} \). For a good tuning in terms of pressure strategy, we hope that when the tap changes, the network loss will be as small as possible, that is, the network loss sensitivity \( S_{PT} \) should be small, and the voltage deviation should be changed as much as possible when the tap changes, so that the voltage regulation can be satisfied. That is to say voltage deviation sensitivity \( S_{VT} \) should be large.

Therefore, according to the above analysis, this paper will discuss the influence of four different load models on the voltage regulation. It can be judged according to the above sensitivity matrix, and the load model with small network loss sensitivity and high voltage deviation sensitivity is selected as the optimal voltage regulation model.

**Influence of Different Load Models on Voltage Regulation**

Based on the above theoretical analysis, this study uses IEEE33 nodes as an example to simulate the effects of different load models on voltage regulation. The following figure shows a single-line diagram of a 33-node, 4-side radial distribution system with a voltage of 12.66 kV and a rated voltage of 10 MVA, the upper and lower limits of the voltage are 1.03 pu and 0.97 pu, respectively. For detailed system data, see [6].

![IEEE33 system node map](image)

![Network damage sensitivity of four load models](image)

The following research content is based on the above SVR voltage regulation strategy. By changing the category of the load model in the IEEE33 system in openDSS, namely the ZIP model, the CP model, the CZ model, and the CI model, it is observed that under the same voltage regulation strategy, the four different loads have the different voltage-regulating effect. In order to more intuitively compare the influence of different models on the voltage regulation, here we do some simulation analysis by using the above-mentioned network loss sensitivity and voltage deviation sensitivity of the tap. The simulation results are as follows:

By simulating the voltage regulation effect of four different load models under 32 different taps, the curve of the network loss to the tap is obtained:

The simulation results in the above figure show that the four different load models have a great influence on the sensitivity of the network loss. The following analysis mainly observes the difference of the network loss of the load model during normal voltage regulation, that is, the tap is more than 17.

The network loss curve of the constant power model shows a downward trend with the change of the voltage regulation tap. And the sensitivity of the network loss to the tap is \( S_{PT} < 0 \); The constant current model's network loss basically tends to be constant, with the change of voltage regulation tap. And the sensitivity of the network loss to the tap is \( S_{PT} \approx 0 \); The network loss curve of the constant impedance model shows a linear upward trend with the change of the voltage regulation tap. As the voltage rises, the sensitivity of the net loss to the tap is \( S_{PT} > 0 \); The ZIP model is a combination of a constant power model, a constant impedance model and a constant current model. The voltage
regulation effect is affected by the ratio of the active load to the reactive load percentage $a_p$, $b_p$, $c_p$, $a_q$, $b_q$, $c_q$. Therefore, we don’t analyze the ZIP model.

According to the SVR voltage regulation strategy, the load model with the network loss sensitivity less than zero is generally selected as the optimal voltage regulation model, so the constant power load model is generally selected.

By simulating the voltage regulation effect of four different load models under 32 different taps, the curve of voltage deviation to tap is obtained:

![Voltage deviation sensitivity of four load models.](image)

The simulation results in the above figure show that the transformation of four different load models has little effect on the voltage deviation sensitivity, that is, different load models have less influence on the voltage during the voltage regulation process. However, by carefully observing the above figure, it can be found that the voltage deviation curve of the constant power model is at the top, and the voltage deviation sensitivity $S_{VT}$ is relatively large. That is to say, the same tap is transformed, and the voltage regulation effect of the constant power load model is more obvious.

In summary, during the voltage regulation process, the four different load models have less influence on the voltage and have a greater influence on the network loss. According to the principle of the highest sensitivity of voltage deviation and the minimum sensitivity of network loss, the constant power model is generally selected as the best voltage regulating model in the voltage test.

Summary

This paper starts with four different load models, theoretically analyzing the SVR voltage regulation strategy and the influence of different models on SVR voltage regulation. At the same time, in order to more intuitively display the influence of different load models on voltage regulation, we introduce voltage sensitivity and Network loss sensitivity. Then take the IEEE33 system as an example, and use the openDSS software to analyze the optimal placement position of the SVR applicable to the system. And then starting from the ZIP load model, the CZ load model, the CI load model and the CP load model, we analyze the voltage regulation effect of the different load models for the SVR. According to the test results of the IEEE33 bus test system, the following conclusions are drawn: four different load models have less influence on the voltage and have a greater influence on the network loss.

References

[1] Ye Jing. Research on Some Problems in Power System Load Modeling[D]. North China Electric Power University (Beijing) North China Electric Power University, 2012.

[2] Xu Zhenhua. Research on generalized integrated load modeling method for smart grid[D]. Hunan University, 2012.

[3] Zhou Wen, He Renbiao. Review of Research on Power Load Modeling Problem[J]. Modern Electric Power, 1999, 16(2): 83-89.

[4] Price W W, Taylor C W, Rogers G J. Standard load models for power flow and dynamic performance simulation [J]. IEEE Transactions on power systems, 1995, 10(CONF-940702--).
[5] Wang Chunyi, Yan Hong, Sun Wei. Analysis of load characteristics of typical foreign power grids[J]. Power Demand Side Management, 2013, 15(6): 61-64.

[6] Yin Yonghua, Guo Jianbo, Zhao Jianjun. Preliminary Analysis of the “8•14” Blackouts in the United States and Canada and Lessons to Be Learned[J]. Power System Technology, 2003, 27(10): 8-11.