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Influence of Load Modes on Voltage Stability of Receiving Network at DC/AC System

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Abstract. This paper analyses influence of load modes on DC/AC system. Because of widespread use of HVDC, DC/AC system become more complex than before and the present modes used in dispatch and planning departments are not fit in simulation anymore. So it is necessary to find load modes accurately reflecting characteristics of the system. For the sake of the voltage stability, commutation failure, etc. the practical example of the receiving network in a large DC/AC system in China is simulated with BPA, and the influence of Classical Load Mode (CLM) and Synthesis load model (SLM) on simulation results is studies. Furthermore, some important parameters of SLM are varied respectively among an interval to analyse how they affect the system. According to this practical examples, the result is closely related to load modes and their parameters, and SLM is more conservative but more reasonable than the present modes. The consequences indicate that at critical states, micro variation in parameters may give rise to change in simulation results radically. Thus, correct mode and parameters are important to enhance simulation accuracy of DC/AC system and researches on how they affect the system make senses.

1 Introduction

Owning to enormous advances in large transmission capacity, low cost and strong regulating ability, HVDC technique is used widely. China Southern Power Grid (CSG) has constructed “Eight AC and Eight DC” west-to-east power transmission channel, whose large capacity and long distance make it become one of the most complex DC/AC system in the world. In the east is its receiving network, where lack of reactive power supply and closed electrical distance among inverter stations bring a severe test to the area. Even a fault from a long distance may give rise to commutation failure, which is a common error causing large impact to the system[1,2]. There are a great deal of studies about load modes, which play an important role in simulation of power system and are the key factors at voltage stability[3]. Incorrect mode gives rise to separation or even opposite conclusions between simulation and reality[4]. For example, difference modes result in difference results on voltage fall during fault period and make opposite judgement in commutation failure. As HVDC is developing quickly and used widely, the DC/AC system becomes complex, so static mode or impedance-motor mode is not able to meet requirement of simulation and evaluating system stability.

This paper analyses the influence of different kinds of load mode and parameters on DC/AC system by BPA, which is introduced by China Electric Power Research Institute (China EPRI) from

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Bonneville Power Administration. After continuous development, it turns out to be Chinese style BPA suitable to Chinese reality and is used widely in various power sectors including CSG.

2 Synthesis Load Modes (SLM)

2.1 Introduction of the Modes

The existing modes are directly connected to the 110kV bus. In fact, it is impossible[5]. Paper [6] calls these kinds of mode Classical Load Mode (CLM). Usually CLM is a parallel combination of impedance and motors. Its defects are following:

(1)The impact of distribution network on static loads is ignored. Impedance of distribution, influenced by non-linear loads, cannot be separated by mean of present mathematical technique.

(2)If motors consume more reactive power than the bus supplies, consumption at constant current and power loads become negative. In other words, they are equivalent to reactive sources. Thus, voltage stability is improved significantly. In fact, there are no such sources in actual network.

China EPRI propose Synthesis Load Mode (SLM)[5,6] taking distribution network into account, who is more comfort to structure of power system and gradually researched in power grid. Its structure is shown at Figure 1. Below equivalent impedance is the virtual bus, which is connected directly to reactive power compensation, static loads, motors and equivalent generators.

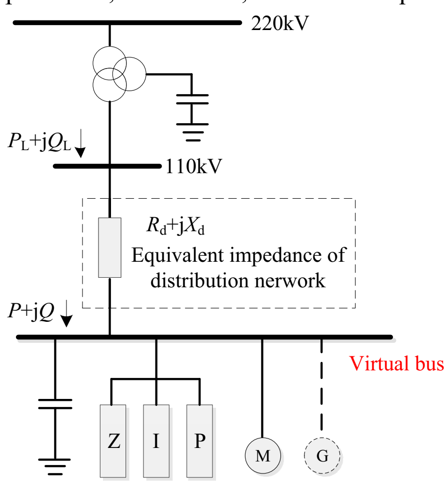

Figure 1. Structure diagram of SLM.

Before simulation, initiation is needed. Voltage (V_{vir0}) and apparent power (P_0+jQ_0) on virtual bus can be worked out through flow calculation. Other running parameters can be easily calculated. Due to limited space, this section only states how to calculate apparent power on static loads (P_{sta0}+jQ_{sta0}) and Capacity of reactive power compensation (Q_{C0}). These are the most different points in algorithm compared with CLM. Subscript '0' means initial value prepared for transient calculating and it is eliminated in the following text for convenience.

Power from the equivalent generator (P_{G0}+jQ_{G0}), active power consumed on motors (P_M) are known.

Power of static loads is shown as below:

$$\begin{cases} P_{sta} = P + P_G - P_M \\ Q_{sta} = P \cdot \tan \alpha_{sta} \end{cases} \tag{1}$$

where tanα_{sta} is power factor of static load; P_M is active power on motors.

Capacity of reactive power compensation is as follow:

$$-Q_{\mathrm{C}} = Q + Q_{\mathrm{G}} - Q_{\mathrm{M}} - Q_{\mathrm{sta}} \tag{2}$$

where Q_{M} is reactive power on motors, and it can be calculated according to its operating parameters.

The front minus sign means capacitive reactive power. Formula (1) guarantees positive value of reactive consumption on static loads so that there are no unreasonable reactive sources occurring in the process of calculation. SLM will be more conservative than CLM in voltage stability.

2.2 Comparisons on Fault Response CLM and SLM

Some short circuit accidents are set up. A fault occurs at 0.2s and the breakers on both sides work at 0.3s. It tempts to make comparison on fault response of eight HVDC systems, so as to study the distinction between SLM and CLM. Parameters of CLM, recommended by EPRI, are show in Table 1, while that of SLM are shown in Table 2.

Table 1. Parameters of CLM.

X_{S}	R_{S}	X_{m}	X_{r}	$\mathrm{R_r}$	A	B	T_{j}	Z_{P}/%
0.02	0.18	3.5	0.12	0.02	0.85	0.15	2.0	100

Table 2. Parameters of SLM.

X_{S}	R_{S}	X_{m}	X_{r}	$\mathrm{R_r}$	A	B	T_{j}	R_{d}	X_{d}	Z_{P}/%	Z_{P}/%	Z_{P}/%
0.03	0.115	3.2	0.15	0.012	0.85	0.15	2.3	0.025	0.05	26	57	17

Results of simulation are shown in Tables 3-5. Two systems of N-C DC share the same AC bus in an inverter station and their fault response are similar, so only one of them is recorded. Numbers on the both side of '/' respectively means results of SLM (left) and CLM (right), and '*' represent fault side of a line. Table 3 shows Instant fault voltage of AC bus of inverter stations, while Table 5 shows transient lowest voltage of them after breakers work in 2s. Table 4 shows instant extinction angle(Unit :°). If γ<8°, it is judged that commutation happens.

Table 3. Instant fault voltage of AC bus of inverter stations.

Fault line	T-G	G-Z	X-A	J-C	Y-G	P-Q	N-C
P-D*	0.94/0.97	0.96/0.98	0.89/0.90	0.72/0.74	0.85/0.87	0.97/0.98	0.85/0.87
Y-X*	0.81/0.87	0.44/0.47	0.93/0.94	0.89/0.92	0.85/0.88	0.52/0.54	0.81/0.85
J*-R	0.99/1.00	0.99/0.99	0.97/0.97	0.85/0.83	0.93/0.93	0.99/1.00	0.92/0.92
S-G*	0.88/0.86	0.90/0.91	0.74/0.77	0.82/0.85	0.55/0.57	0.93/0.94	0.83/0.86

Table 4. Instant fault extinction angle of inverter stations.

Fault line	T-G	G-Z	X-A	J-C	Y-G	P-Q	N-C
P-D*	14.5/15.5	16.3/16.7	14.2/15.0	0.0/0.0	8.7/10.8	16.6/16.9	18.0/18.0
Y-X*	0.0/4.8	0.0/0.0	15.7/16.4	11.0/12.4	3.5/7.9	0.0/0.0	18.0/18.0
J*-R	16.2/16.7	17.1/17.3	17.1/17.4	5.6/7.6	14.2/14.9	17.3/17.5	18.0/18.0
S-G*	6.5/8.9	13.4/14.2	0.0/5.4	0.0/0.0	0.0/0.0	14.3/15.0	18.0/18.0

Table 5. Transient lowest voltage of those buses in 2s after fault line being cut.

Fault line	T-G	G-Z	X-A	J-C	Y-G	P-Q	N-C
P-D*	0.81/0.87	0.88/0.91	0.78/0.82	0.58/0.62	0.71/0.76	0.91/0.93	0.71/0.76
Y-X*	0.41/0.6	0.58/0.81	0.63/0.90	0.55/0.78	0.50/0.87	0.61/0.85	0.51/0.82
J*-R	0.97/0.99	0.97/0.98	0.95/0.96	0.91/0.92	0.92/0.94	0.97/0.98	0.92/0.94
S-G*	0.57/0.97	0.77/0.97	0.73/0.95	0.70/0.91	0.64/0.92	0.83/0.97	0.64/0.92

According to Tables 3-5, commutation failure happens if voltage of a Converter bus is below about 0.85~0.87(p.u.). It is appropriately 1.01(p.u.) when the system is on steady-state operation. Although commutation failure is related to various factors, it still can draw a conclusion that low voltage easily brings out commutation failure. Table 3 and 5 indicate that voltage values of SLM is less than that of CLM as a whole. Stability of CLM system can be kept in four situations. Commutation failure happens inevitably, but voltage is recovered finally owning to regulation of system in HVDC.As for SLM, system is not stable except the fault happens at J-R line (J side), and the system is near a critical state in the first situation (P-D*).

Table 4 indicates that commutation failure happen in T-G, G-Z, Y-G and P-Q DC if a fault occurs at Y-X line (X side), either SLM or CLM is simulated. Their inverter stations are closer than that of the others. Only Y-G DC is discussed here. Figures 2-3 show the curves of extinction angle and voltage of AC bus.

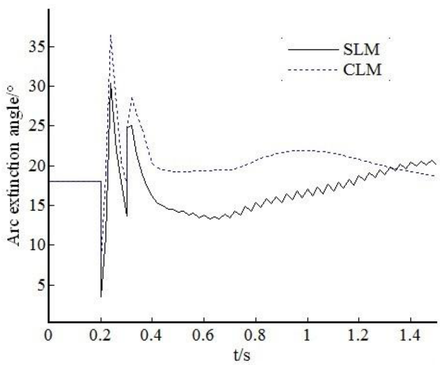

Figure 2. Extinction angle.

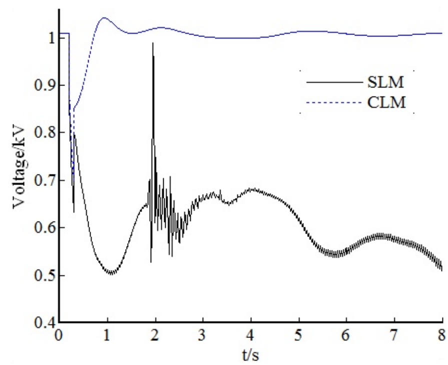

Figure 3. Voltage of Converter bus of Y-G DC.

Figure 2 and Table 4 show that commutation failure happens in either SLM or CLM system as soon as a fault occurs. Advance firing angle β is enlarged forcedly to magnify γ, because their relation can be express as $\gamma = \beta - \mu$ (μ is commutation angle). At 0.2s(+), when a fault occurs, voltage of CLM is 0.88 (p.u.), while that of SLM is 0.85 (p.u.), but the latter drop more quickly before the line is cut (see Figure 3). In 0.3s(-), the former is 0.70 (p.u.), while the latter is 0.63 (p.u.); in 0.3s(+), the former is 0.85(p.u.) and begins to increase, while the latter is 0.795 (p.u.) and begins to decrease. As a result, voltage of CLM system return a stable level and voltage collapse happens to SLM system. Reasons of their discrepancy are following:

(1) Static part of CLM only contains constant impedance loads, while that of SLM consist of three kinds of loads in a certain proportion[7]. Constant impedance and current loads command less reactive power if voltage decreases, so, to some extent, reactive shortage is compensated and voltage drop is avoided, while constant power loads do not. Aside, motors at SLM produce less short circuit current (reactive power) than CLM. Therefore, SLM curve is always below CLM.

(2) Motors demand a great deal of reactive power during recovery period. Algorithm of SLM ensures that constant current and power loads are impossible to become reactive source. So SLM is not as stable as CLM but more proper.

Simulations above indicate that SLM is conservative, but it is not sure that these parameters are the most reasonable. Furthermore, they vary among various regions and change as time goes by. Thus, it is necessary to research how they affect the stability of the system.

3 Impact of Parameters of SLM on Stability

SLM is more appropriate than others modes. But irrelevant parameters lead to large separation and even conflicting conclusion between simulation and reality as well as inappropriate modes[8]. It is necessary to research how they affect the system. Due to limited space, this chapter only discusses the motor ratio (M_P) and ratio of constant load (P_P) in static modes. They are likely to influences the

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stability dramatically. Situation (P-D*) in Chapter 2 is selected to be simulated and curve of voltage and extinction angle in the inverter of Y-G DC is studies. Because the system is actually near a critical state in this situation, contract among difference value of parameters may be very evident. Each simulation only changes one parameter.

3.1 Changes of Motor Ratio

Fault response is analysed when the value of M_P is 0%, 20%, 30%, 40%, 50% or 55%. Particularly, 50% is the initial value. Figures 4-5 show curves of voltage and extinction angle. Interval of time in Figure 5 is 0 to 1.5s, which is the same as below (for extinction angle).

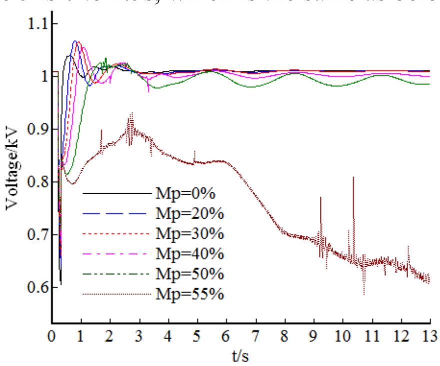

Figure 4. Voltage at different M_P.

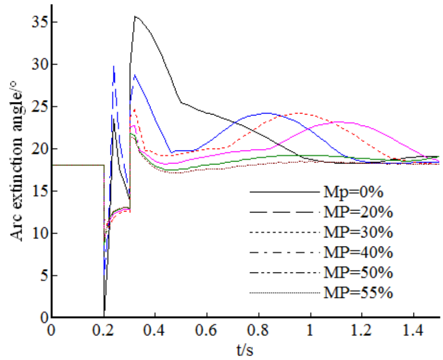

Figure 5. Extinction angle at different M_P.

Figure 5 indicates that the high motor rate reduces the possibility of commutation failure but increases the possibility of voltage collapse. If M_P>30%, γ>8° at 0.2s(+). But figure 4 shows that if M_P >55%, voltage is not able to be recovered because too much reactive power is demanded. To sum up, system is under the most stable condition if M_P is over 30% but less than 50% in this situation.

3.2 Changes of Ratio of Constant Power Load

Ratio of constant power loads in static part of SLM is not as high as common static mode. Initial value of P_P is 17%. The value of P_P is set to be 8%, 12%, 17%, 20% and 23%. Figures 6-7 show curves of voltage and extinction angle.

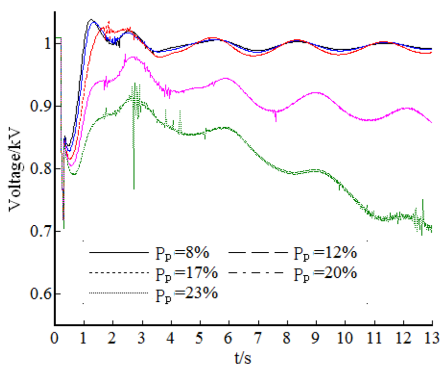

Figure 6. Voltage at different P_P.

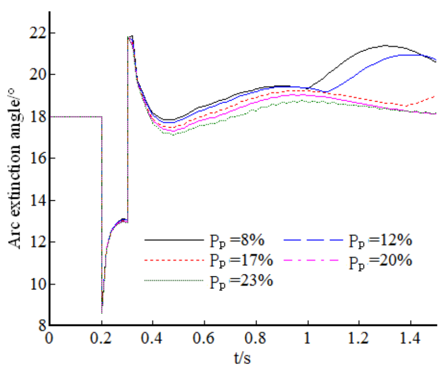

Figure 7. Extinction angle at different P_P.

Increasing P_P or M_P brings out remarkable impact on voltage stability, but the former is more significant. Figures 6-7 show that variety of P_P exerts little influence on voltage fall and commutation fault during fault period but makes a difference in transient voltage stability. Because static load produces no reactive power like motors, voltage fall is not changed as P_P varies. On the other hand, constant power loads demand constant power, so reactive shortage is enlarged if voltage decreases.

therefore, large value of P_P leads to severe power shortage and poor condition on voltage stability. Voltage collapse will happen if P_P is over 20%.

3.3 Analysis of the Simulations

This chapter studies how the two important parameters exert impact on voltage stability of DC/AC system. Only little changes on sensitive parameters may change the system evidently. Furthermore, simulation results may be changed qualitatively if the parameters are near a critical value. Voltage curve changes evidently as P_P vary from 12% to 23%, and it draws totally different conclusions about voltage changes between situation that M_P is 50% and that M_P is 55%. So, Parameters of SLM are important for simulation especially they are near critical states. In actually network, motor ratio is about 30%~60% and ratio of constant power in static loads varied between about 12%~25%.

4 Conclusions

This paper makes comparisons on various load modes and draw following conclusions.

(1) Actual loads are not directly connected to 110 kV or 220 kV buses. SLM takes into account effect from distribution network and the reactive power compensation, and its physics structure is more reasonable. Power factor of static load is defined to eliminate negative constant current and constant power loads. Voltage curves of SLM are below those of CLM as a whole. Thus, SLM is more conservative but rational.

(2) Ratio of motors and ratio of constant power loads play an important part in stability. But increasing the latter is likely to bring out more serious consequence. Parameters vary among various regions and vary as time goes by. Little changes in them may cause huge differences in simulation results if the DC/AC system is running at a critical state. Therefore, accurate parameters are important for simulation of power system and researching how they influence the system makes senses.

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