Simulation of Influence of Generator Leading Phase Operation on Voltage and Loss of Gansu Power Grid

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Simulation of Influence of Generator Leading Phase Operation on Voltage and Loss of Gansu Power Grid

ZHANG Yuze, TONG Xinyu, XU Suping, SUN Yuning and CHENG Rui

State Grid Tianjin Electric Power Corporation Chengxi Power Supply Company, Tianjin 300190, China

zyz100rcszyz@sina.com,

Abstract. Generator leading phase operation can not only absorb excess reactive power under small load operation mode, but also smoothly regulate grid voltage to cope with abrupt changes in grid operation. Based on the summer small load typical operation mode of Gansu Power Grid, four calculation conditions are selected to calculate power flow, and the influence of generator leading phase operation on grid voltage and loss is simulated and analyzed. The simulation results show that no matter how the active power output distribution of generators changes in the power grid, the voltage level of the power grid under small load can be significantly improved by generator leading phase operation. However, the grid loss will increase when the generator is in leading phase operation.

1. Introduction

With the continuous development of power system and the extension of high-voltage transmission network, the capacity of high-voltage transmission is getting larger and larger, and the distance is getting longer and longer. When the load of the power grid is in low valley and the line is in light load operation mode, the charging power of the line causes excessive capacitive reactive power in a part of the power grid or network, some nodes are over-voltage or even over the upper limit [1,2]. It not only affects the power quality, but also threatens the operation safety of power grid and power equipment [3,4]. The existing reactive power compensation devices can not fully meet the requirements of excess reactive power compensation, while generator leading phase operation can not only absorb excess capacitive reactive power of power grid, but also smoothly regulate grid voltage to cope with abrupt changes in grid operation [5]. Therefore, generator leading phase operation has become an effective and simple method to adjust the voltage of power grid and improve the power quality. This paper based on the summer small load typical operation mode of Gansu Power Grid, selects four calculation conditions to calculate power flow, simulates and analyzes the influence of generator leading phase operation on grid voltage and loss.

2. Calculation condition

In the summer small load typical operation mode of Gansu Power Grid, the total active power load and reactive power load are 10023MW and 4127Mvar respectively. The operation mode of power plants in Gansu Power Grid is taken as follows to calculate power flow: 1. summer small load typical operation

mode; 2. large thermal power units generate electricity at rated power, while wind farms and photovoltaic power stations generate less electricity; 3. wind farms and photovoltaic power stations generate more electricity, and the active power outputs of large thermal power units are reduced to 60% of the rated capacity; 4. power plants in Gansu Power Grid generally reduce active power output, and the active power difference is supported by other provinces.

Generators with leading phase operation ability in Gansu Power Grid and their leading phase depth are shown in Table 1.

Table 1. Generators with leading phase operation ability and their leading phase depth

Generator	Leading phase depth (Mvar)	Generator	Leading phase depth (Mvar)
BAO PING HE G1	-0.21	JING YUAN G6	-0.7
BAO PING HE G2	-0.23	JING YUAN G7	-1.05
BAO PING HE G3	-0.13	JING YUAN G8	-1
CHONG XIN G1	-1.75	LU BA SI G1	-0.09
CHONG XIN G2	-1.5	LU BA SI G2	-0.089
LI JIE G1	-0.05	LU BA SI G3	-0.086
803 G4	-0.28	SAN DAO WAN G1	-0.2
DA XIA G3	-0.6	SAN DAO WAN G2	-0.2
DUO ER G1	-0.046	SAN DAO WAN G3	-0.14
GAN GU G1	-1.6	WU JIN XIA G1	-0.18
GAN GU G2	-1.6	WU JIN XIA G2	-0.18
FAN JIA PING G1	-0.87	WU JIN XIA G3	-0.18
FAN JIA PING G2	-0.86	WU JIN XIA G4	-0.2
JIU QUAN RE DIAN G1	-0.9	XI RE G1	-0.68
JIU QUAN RE DIAN G2	-0.9	XI RE G2	-0.69
JIN KOU BA G1-2	-0.0378	XI GU G9	-0.6
JING YUAN G1	-0.55	XIAO XIA G1	-0.28
JING YUAN G2	-0.977	XIAO XIA G2	-0.29
JING YUAN G3	-0.7	XIAO XIA G3	-0.25
JING YUAN G4	-0.7	XIAO XIA G4	-0.3
JING YUAN G5	-1.12		

3. Simulation of the influence of generator leading phase operation on grid voltage and loss

3.1. Summer small load typical operation mode

In the case of whether or not the power plants in Gansu Power Grid are operated in leading phase, the power flow calculation is carried out for the the summer small load typical operation mode of Gansu Power Grid. Reactive power outputs of the main generators are compared as shown in Table 2.

Table 2. Comparison of reactive power outputs of the main generators

Generator	Reactive power output without leading phase operation (Mvar)	Reactive power output in leading phase operation (Mvar)
FAN JIA PING G2	4	-1.75
SAN DAO WAN G3	2	-1.83
DUO ER G1-2	4	-2.90
BAO PING HE G3	2	-3.07
BAO PING HE G1	4	-3.26
BAO PING HE G2	4	-3.26
SAN DAO WAN G1	6	-3.43
SAN DAO WAN G2	6	-3.43
GAN GU G1	40	-5.25
GAN GU G2	20	-7.45
JIU QUAN RE DIAN G1	40	-12.68
JIU QUAN RE DIAN G2	20	-15.68
XI GU G9	10	-15.80

The comparison of the above generator voltages is shown in Table 3.

Table 3. Comparison of generator voltages

Generator	Generator voltage without leading phase operation (kV)	Generator voltage in leading phase operation (kV)
FAN JIA PING G2	18.14	18
SAN DAO WAN G3	11.22	10.5
DUO ER G1-2	11.05	10.5
BAO PING HE G3	11.25	10.5
BAO PING HE G1	11.29	10.5
BAO PING HE G2	11.29	10.5
SAN DAO WAN G1	11.24	10.5
SAN DAO WAN G2	11.24	10.5
GAN GU G1	20.79	20
GAN GU G2	20.74	20
JIU QUAN RE DIAN G1	20.81	20
JIU QUAN RE DIAN G2	20.69	20
XI GU G9	18.56	18

Voltages of some important 750kV and 330kV nodes are compared as shown in Table 4.

Table 4. Comparison of voltages of some 750kV and 330kV important nodes

Node	Voltage without leading phase operation (kV)	Voltage in leading phase operation (kV)
750kV DUN HUANG	812.11	803.21
750kV JIU QUAN	809.66	801.64
750kV HE XI	804.53	796.50
750kV WU SHENG	801.13	792.96
330kV YU MEN	376.84	372.59
330kV GUA ZHOU	376.12	372.16
330kV HONG LIU	375.45	371.37
330kV ZHANG YE	371.53	367.48
330kV JIA YU GUAN	368.73	364.49
330kV PING LIANG	366.87	363.43

The loss of Gansu Power Grid is 162MW without generator leading phase operation, while that is 165MW with generator leading phase operation.

As can be seen from Tab.4, when all generators do not take leading phase operation, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU are 812.11kV, 809.66kV, 376.84kV, 376.12kV, 375.45kV respectively. Voltages of 21 110kV and above nodes exceed 1.05 times rated voltage, which do not meet the requirements of voltage qualified range. When the generators with leading phase operation ability is properly operated in leading phase, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU improved significantly. Voltages of 12 of those 21 nodes have fallen to the voltage allowable range.

3.2. Large thermal power units generate electricity at rated power

In the case of whether or not the power plants in Gansu Power Grid are operated in leading phase, the power flow calculation is carried out for the the condition that large thermal power units generate electricity at rated power. Reactive power outputs of the main generators are compared as shown in Table 5.

Table 5. Comparison of reactive power outputs of the main generators

Generator	Reactive power output without leading phase operation (Mvar)	Reactive power output in leading phase operation (Mvar)
SAN DAO WAN G3	4	-1.86
LI JIE G1	8	-2.44
BAO PING HE G3	2	-3.08
BAO PING HE G1	4	-3.26
BAO PING HE G2	4	-3.26
SAN DAO WAN G1	6	-3.44
SAN DAO WAN G2	6	-3.44
JIU QUAN RE DIAN G1	50	-15.99

JIU QUAN RE DIAN G2	50	-15.99

The comparison of the above generator voltages is shown in Table 6.

Table 6. Comparison of generator voltages

Generator	Generator voltage without leading phase operation (kV)	Generator voltage in leading phase operation (kV)
SAN DAO WAN G3	11.32	10.5
LI JIE G1	11.00	10.5
BAO PING HE G3	11.28	10.5
BAO PING HE G1	11.31	10.5
BAO PING HE G2	11.31	10.5
SAN DAO WAN G1	11.27	10.5
SAN DAO WAN G2	11.27	10.5
JIU QUAN RE DIAN G1	21.0	20
JIU QUAN RE DIAN G2	21.0	20

Voltages of some important 750kV and 330kV nodes are compared as shown in Table 7.

Table 7. Comparison of voltages of some 750kV and 330kV important nodes

Node	Voltage without leading phase operation (kV)	Voltage in leading phase operation (kV)
750kV DUN HUANG	828.86	816.53
750kV JIU QUAN	818.14	810.31
750kV HE XI	813.51	798.78
750kV WU SHENG	800.18	792.09
330kV GUA ZHOU	382.74	379.31
330kV HONG LIU	381.65	377.89
330kV YU MEN	378.69	373.54
330kV ZHANG YE	373.75	368.44
330kV JIA YU GUAN	370.81	365.55
330kV PING LIANG	366.87	362.05

The loss of Gansu Power Grid is 228MW without generator leading phase operation, while that is 229MW with generator leading phase operation.

As can be seen from Tab.7, when all generators do not take leading phase operation, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 750kV HE XI, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU are 828.86kV, 818.14kV, 813.51kV, 378.69kV, 382.74kV, 381.65kV respectively. Voltages of 40 110kV and above nodes exceed 1.05 times rated voltage, which do not meet the requirements of voltage qualified range. When the generators with leading phase operation ability is properly operated in leading phase, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 750kV

HE XI, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU improved significantly. Voltages of 25 of those 40 nodes have fallen to the voltage allowable range.

3.3. Active power outputs of large thermal power units reduce to 60% of the rated capacity

In the case of whether or not the power plants in Gansu Power Grid are operated in leading phase, the power flow calculation is carried out for the the condition that active power outputs of large thermal power units reduce to 60% of the rated capacity. Reactive power outputs of the main generators are compared as shown in Table 8.

Table 8. Comparison of reactive power outputs of the main generators

Generator	Reactive power output without leading phase operation (Mvar)	Reactive power output in leading phase operation (Mvar)
SAN DAO WAN G3	2	-1.00
SAN DAO WAN G1	5	-1.69
SAN DAO WAN G2	5	-1.69
BAO PING HE G1	3	-2.1
BAO PING HE G2	3	-2.1
BAO PING HE G3	3	-2.1
DUO ER G1-2	4	-2.22
GAN GU G2	30	-3.21
JIN KOU BA G1-2	3	-3.78
GAN GU G1	30	-4.15
LI JIE G1	4	-4.94
XI GU G9	10	-12.97

The comparison of the above generator voltages is shown in Table 9.

Table 9. Comparison of generator voltages

Generator	Generator voltage without leading phase operation (kV)	Generator voltage in leading phase operation (kV)
SAN DAO WAN G3	10.94	10.5
SAN DAO WAN G1	10.95	10.5
SAN DAO WAN G2	10.95	10.5
BAO PING HE G1	10.99	10.5
BAO PING HE G2	10.99	10.5
BAO PING HE G3	10.99	10.5
DUO ER G1-2	11.05	10.5
GAN GU G2	20.65	20
JIN KOU BA G1-2	10.27	10.26
GAN GU G1	20.68	20
LI JIE G1	11.16	10.5

XI GU G9	18.54	18

Voltages of some important 750kV and 330kV nodes are compared as shown in Table 10.

Table 10. Comparison of voltages of some 750kV and 330kV important nodes

Node	Voltage without leading phase operation (kV)	Voltage in leading phase operation (kV)
750kV HE XI	795.67	787.83
750kV WU SHENG	795.32	787.46
750kV JIU QUAN	794.84	787.36
750kV DUN HUANG	792.85	781.85
330kV YU MEN	371.46	368.94
330kV ZHANG YE	369.138	364.07
330kV PING LIANG	368.64	363.21
330kV JIA YU GUAN	363.63	360.98
330kV GUA ZHOU	363.36	359.94
330kV HONG LIU	362.16	359.15

The loss of Gansu Power Grid is 179MW without generator leading phase operation, while that is 180MW with generator leading phase operation.

As can be seen from Tab.10, when all generators do not take leading phase operation, voltages of 9 110kV and above nodes exceed 1.05 times rated voltage, which do not meet the requirements of voltage qualified range. When the generators with leading phase operation ability is properly operated in leading phase, voltages of 4 of those 9 nodes have fallen to the voltage allowable range.

3.4. Power plants in Gansu Power Grid generally reduce active power output

In the case of whether or not the power plants in Gansu Power Grid are operated in leading phase, the power flow calculation is carried out for the the condition that power plants in Gansu Power Grid generally reduce active power output. Reactive power outputs of the main generators are compared as shown in Table 11.

Table 11. Comparison of reactive power outputs of the main generators

Generator	Reactive power output without leading phase operation (Mvar)	Reactive power output in leading phase operation (Mvar)
803 G4	4	-0.12
FAN JIA PING G1	30	-9.66
FAN JIA PING G2	30	-9.66
JIU RE G2	30	-20.37
JIU RE G1	30	-20.63
JIU QUAN RE DIAN G1	30	-44.09
JIU QUAN RE DIAN G2	30	-44.09

The comparison of the above generator voltages is shown in Table 12.

Table 12. Comparison of generator voltages

Generator	Generator voltage without leading phase operation (kV)	Generator voltage in leading phase operation (kV)
803 G4	11.36	10.5
FAN JIA PING G1	18.44	18
FAN JIA PING G2	18.44	18
JIU RE G2	21.76	20
JIU RE G1	21.76	20
JIU QUAN RE DIAN G1	21.91	20
JIU QUAN RE DIAN G2	21.91	20

Voltages of some important 750kV and 330kV nodes are compared as shown in Table 13.

Table 13. Comparison of voltages of some 750kV and 330kV important nodes

Node	Voltage without leading phase operation (kV)	Voltage in leading phase operation (kV)
750kV DUN HUANG	824.56	816.18
750kV JIU QUAN	822.88	814.88
750kV HE XI	819.15	807.50
750kV WU SHENG	808.31	800.12
330kV YU MEN	379.16	376.98
330kV GUA ZHOU	379.71	376.71
330kV ZHANG YE	377.22	374.30
330kV HONG LIU	377.96	374.28
330kV JIA YU GUAN	371.68	368.64
330kV PING LIANG	367.15	364.96

The loss of Gansu Power Grid is 147MW without generator leading phase operation, while that is 150MW with generator leading phase operation.

As can be seen from Tab.13, when all generators do not take leading phase operation, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 750kV HE XI, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU, 330kV ZHANG YE are 824.56kV, 822.88kV, 819.15kV, 379.16kV, 379.71kV, 377.96kV, 377.22kV respectively. Voltages of 134 110kV and above nodes exceed 1.05 times rated voltage, which do not meet the requirements of voltage qualified range. When the generators with leading phase operation ability is properly operated in leading phase, the voltages of 750kV DUN HUANG, 750kV JIU QUAN, 750kV HE XI, 330kV YU MEN, 330kV GUA ZHOU, 330kV HONG LIU, 330kV ZHANG YE improved significantly. Voltages of 119 of those 134 nodes have fallen to the voltage allowable range.

4. Analyse and summary

From the simulation results under four calculation conditions, the following conclusions can be drawn.

①Under the small load operation mode, the problem of high voltage or even exceeding the upper limit is common in Gansu Power Grid, which is not conducive to the safe operation of power grid and electrical equipment, and affects the service life of various types of electrical equipment.

②The voltage under small load operation mode can be significantly improved if the generators with leading phase operation are operated in leading phase. From the above calculation results, it can be seen that the leading phase reactive power of the leading phase generator is not large, but can greatly improves the voltage quality of each node in the power grid, and reduces the cost of production and maintenance of the power grid. No matter how the distribution of active power output of generators in Gansu Power Grid changes, the leading phase operation mode of generators can achieve the above effect.

③By comparing the grid loss whether the generators operate in leading phase, it can be seen that when the generators operate in leading phase, the grid loss increases by 0.4%-2%.This is because the loss of parallel branch of line and transformer is proportional to the square of operation voltage.When the voltage of power grid decreases, the grid loss will increase.

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