Research on the Control Strategy of the Inter-provincial Electromagnetic Loop Network in Hubei Power Grid

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***Abstract*—Hubei-Henan transmission section is the first 1000kV/500kV/220kV three-level electromagnetic loop network in China and the most complex loop network in Hubei. According to the present situation of Hubei-Henan transmission section and Hubei-Hunan transmission section electromagnetic loop, the characteristics of the electromagnetic loop network between provinces and the problems that it brings to the security and stability of Hubei grid are analyzed. With the network structure characteristic of Hubei Grid considered, the exiting problems are studied and the corresponding control strategies are proposed. This work can provide certain practical value for the operation of the inter-provincial transmission sections in Hubei grid.**

Keywords-inter-provincial transmission section;electromagnetic loop network; load flow characteristics; security and stability

I. INTRODUCTION

Electromagnetic loop network refers to the power grid in which the transmission lines of different voltage-levels are parallel operated through the transformers' electromagnetic circuit. When the high voltage-level transmission lines of the electromagnetic loop break down, its flow runs through to the low voltage level lines, causing that the transformers and transmission lines overload. The inter-provincial sections undertake the task of power balance and exchange between provinces with heavier load flow, and so the inter-provincial electromagnetic loop is more harmful.

The electric generating feature of Hubei grid is "more hydropower generator capacity, less thermal generator capacity", which causes that the flow direction of the inter-provincial section in wet season is different from that of the dry season. Hubei-Henan transmission section is the first 1000kV/500kV/220kV three-level electromagnetic loop network, resulting in the complexity of the inter-provincial electromagnetic loop in Hubei.

According to the present situation of Hubei-Henan transmission section and Hubei-Hunan transmission section electromagnetic loop, the formation of inter-provincial electromagnetic network and the problems that it brings to the stability and security of Hubei grid are analyzed. The control strategies are proposed to solve the problems in existence when there are not enough conditions to unlock the inter-provincial electromagnetic loop, and its effect is verified.

II. FORMATION OF THE ELECTROMAGNETIC LOOPS

Without 220kV transmission line between Hubei power grid and its neighboring provinces, the electromagnetic loops between provinces are formed as 500kV substation access into inter-provincial section in π-mode. The schematic diagram of the electromagnetic loop between Hubei and Henan is as Figure I.

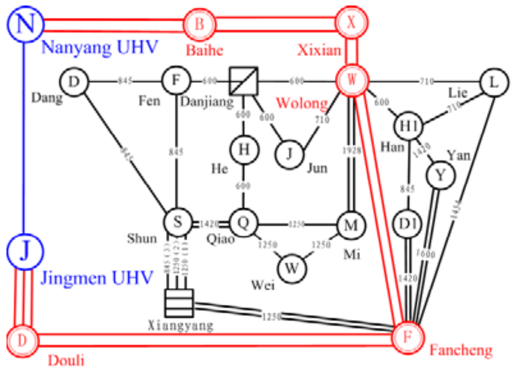

FIGURE I. THE STRUCTURE OF HUBEI-HENAN LECTROMAGNETIC LOOP

Before 500kV Wolong substation access into Hubei grid, Hubei-Henan transmission section is composed by 500kV line Fan-Xi I/II, line Xiao-Shi I/II and 1000kV UHV line Nan-Jing I, forming inter-provincial 1000kV/500kV electromagnetic loop. Wolong substation is planned to go into operation between 2015 and 2016 by accessing into Fan-Xi I/II in π-mode with Fan-Xi I/II replaced by Fan-Wo I/II and Wo-Xi I/II, and the 1000kV/500kV/220kV electromagnetic loop between Hubei and Henan is formed. When 1000kV or 500kV transmission line break down, part of its load flow transfer to 220kV grid, causing that the transmission lines neighboring 500kV Fancheng and Wolong substations take the risk of overload.

Similar to Hubei-Henan transmission section loop, the electromagnetic loop between Hubei and Hunan was formed after Chanling substation accessed into 500kV line Jiang-Fu I/II in π-mode in 2014, as Figure II.

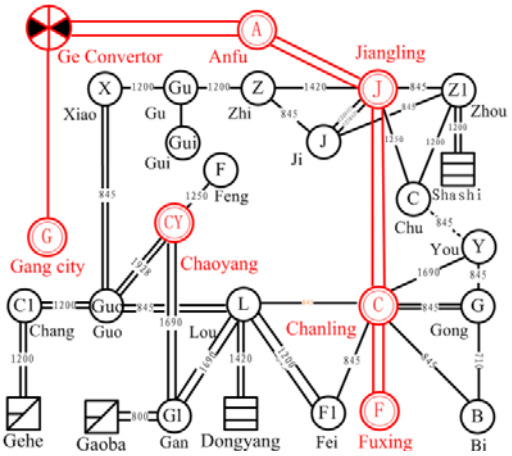

FIGURE II. THE STRUCTURE OF HUBEI-HUNAN ELECTROMAGNETIC LOOP

There was no transfer flow to 220kV grid when Jiang-Fu I/II break down before Chanling accessed into the network, and all the power flow of the section poured into 500kV line Ge-Gang. After 500kV Chanling substation accessed into Hubei grid, Hubei-Hunan transmission channel changes from Jiang-Fu I/II + line Ge-Gang to Jiang-Chan I/II and Chan-Fu I/II + Ge-Gang, forming the inter-provincial 500kV/220kV electromagnetic loop. Compared to the network without Chanling, the conclusion keeps unchanged when Chan-Fu I/II break down, but the power flow transfer to 220kV network via Yichang grid when Jiang-Chan I/II is cut off.

III. THE PROBLEMS OF ELECTROMAGNETIC LOOPS

A. Hubei-Henan Section Electromagnetic Loop

When 500kV Fan-Wo I/II is disconnected due to line failure, 18%, 39% of its flow transfer to Xiao-Shi I/II and Nan-Jing I. The line-style of Nan-Jing I is LGJ-8×500 of which the power limit is 8000MW, and the load flow of Xiao-Shi I/II is very light, so there is no risk of overload for 500kV and 1000kV network during the post-fault of Fan-Wo I/II.

43% of the flow pours into 220kV network, causing Fancheng substation and lines connected risk overload during the wet season; Wolong substation and lines connected risk overload during the dry season similarly. The transfer ratios of important 500kV substations are shown in Table I.

TABLE I. TRANSFER RATIO OF FAN-WO I/II POST-FAULT

Component	Transfer ratio/%	Component	Transfer ratio/%
Wolong	-43.1	Qiao-Shun I	11.9
Fancheng	38.9	WO-Mi I	-12.8
Shiyan	7.3	Line Wo-Dan	-3.3
Xiaogan	-1.4	Line Wo-Han	-9.2
Xiang-Shun I	7.9	Line Wo-Lie	-3.7
Xiang-Shun III	6.3	Line Fen-Dang	5.3

In the initial power flow of the wet season, all the hydropower and thermal units start up and Fan-Wo I/II transmit 2000MW to Henan. The power flow of the important 220kV components during the pre-fault and post-fault is shown in Table II.

TABLE II. FLOW COMPARISON OF PRE AND POST FAULT IN WET SEASON

Component	Pre-fault/MW	Post-fault/MW	Power limit/MW
Wolong #1	83	-348	935
Fancheng #2	332	784	935
Xiang-Shun III	193	319	280
Qiao-Shun I	263	502	460
Line Fen-Dang	145	251	280

In the case of Fan-Wo I/II failure, 38.9% of the power flow transfer to the coupling transformers in Fancheng, leading to that the load flow of Fancheng #2 transformer reaches 784MW. It risk overload when Xiangyang power plant and Danjiang power plant start up less units. E.g. only two units of Xiangyang and four units of Danjiang start up and the load flow of Fancheng #2 transformer reaches overload 941MW in the post-fault duration of Fan-Wo I/II.

In the 220kV network, both Xiangyang plant and Fancheng substation supply power for Qiaoying, Mizhuang and Weizhuang in the load center of Xiangfan grid through 220kV line Xiang-Shun I/II/III. 22.1% of the pre-fault flow transfer to Xiang-Shun I/II/III when Fan-Wo I/II break down, causing that Xiang-Shun III and Qiao-Shun I/II overload.

Besides, part of the flow transfer to the 220kV transmission lines between 500kV Shiyan substation and 500kV Wolong substation. Among them, the transfer ratio of line Fen-Dang is up to 5.3%, leading to that its power flow reaches 251MW approaching the limit. If two units of Danjiang are turned off on the basis of the initial power flow, the flow of line Fen-Dang reaches 291MW overload when Fan-Wo I/II break down.

In the initial power flow of the dry season, Danjiang's net load is 250MW (power generated: 300MW, load: 550MW), and three units of Xiangyang start up, and the pre-fault flow of Fan-Wo I/II is 1000MW transmitted to Hubei. The power flow of the important 220kV components during the pre-fault and post-fault is shown in Table III.

TABLE III. FLOW COMPARISON OF PRE AND POST FAULT IN DRY SEASON

Component	Pre-fault/MW	Post-fault/MW	Power limit/MW
Wolong #1	548	771	935
Fancheng #2	587	362	935
Line Wo-Dan	156	190	200
Line Wo-Han	100	196	220
Line Wo-Lie	108	146	220

There is no risk of overload for the coupling transformers of Wolong while the unit commitment changes in spite of that 43% of the pre-fault flow transfer to Wolong transformers.

According to Table III, line Wo-Dan and line Fan-Wo have been closed to their own limit when Fan-Wo I/II break down. Line Wo-Dan can easily get overload while Danjiang and Xiangyang plant start up less units. For example, the load flow of line Wo-Dan reaches 205MW overload if Danjiang plant's net load is 300MW and only two units of Xiangyang start up. Similarly, Line Wo-Han can easily get overload while Danjiang start up more units and Xiangyang start up less units, for example, the load flow of line Wo-Han reaches 224MW if Danjiang's net load is 0 and only two units of Xiangyang start up.

B. Hubei-Hunan Section Electromagnetic Loop

The power flow of Jiang-Chan I/II is transmitted from Hubei to Hunan both in wet season and dry season. Take the wet season as the initial power flow and the Hubei-Hunan section transmit 2600MW to Hunan. The post-fault transfer ratio of important 500kV substations and 220kV lines neighboring Chanling is shown in Table IV.

TABLE IV. TRANSFER RATIO OF JIANG-CHAN I/II POST-FAULT

Component	**Transfer ratio/%**	**Component**	**Transfer ratio/%**
Jiangling	12.6	Line Chan-Lou	13.1
Chanling	-32.5	Line Chan-Fei	19.4
Chaoyang	16.9	Lou-Fei I	11.1
Line Ge-Gang	67.5	Lou-Fei II	8.3

67.5% of the pre-fault flow pours into 500kV line Ge-Gang, causing that its flow reaches 2162MW overload. 32.5% of the pre-fault flow transmitted from Jiangling and Chaoyang substations to Chanling substation via 220kV network, but there is no risk of overload for 500kV transformers in wet season. The 220kV network neighboring Chanling substation is weak affected by the transferred flow, and the load flow of Chan-Fei, Chan-Lou and Lou-Fei I/II is 518MW, 390MW, 405MW, 304MW during the post-fault of Jiang-Chan I/II, all of these lines overload.

IV. RESEARCH OF THE CONTROL STRATEGIES

A. Restricting the Flow of the Section in Pre-fault

If the transmission capacity of the inter-provincial section is adequate, adopting the strategy of restricting the flow of the section is the most direct and effective. Although the transfer ratio keeps unchanged with the decrease of the section flow, the amount of the transferred flow reduces.

Take the electromagnetic loop between Hubei and Henan as an example, and it can be ensured that Fan-Wo I/II won't get overload during the post-fault of Nan-Jing I while the power flow of the Hubei-Hunan section is limited between 4300MW northward and 5000MW southward.

To ensure that the flow of Hubei-Hunan section can satisfy the demand of Hunan's load, the transmitted power of the section can be limited to 2600MW at most. So other measures must be taken to restrict the power flow of Ge-Gang when Jiang-Chan I/II or Chan-Fu I/II break down.

B. Load Shedding of the Receiving End in Post-fault

If the flow of the section can't be restricted to a secure limit due to the demand of inter-provincial power exchange, the strategy of shedding load of the receiving end in post-fault can be adopted. Its essence is reducing the section flow during the post-fault under the premise of unchanging the section flow of pre-fault.

Keeping the power flow of Hubei-Hunan section 2600MW unchanged, 500kV line Ge-Gang get overload whether it is Chan-Fu I/II or Jiang/Fu I/II that break down. With the strategy of shedding load of Hunan 950MW in case of breakdown, the flow of line Ge-Gang can be controlled beneath its limit 1650MW

If 220kV transmission line get overload, the sequence of load shedding depends on the load sensitivity. To prevent 220kV line Wo-Han, Wo-Lie and Han-Lie from overload while Fan-Wo I/II break down in dry season, load shedding device is equipped in 220kV substation Hangang, Dongjin, Lieshan and Zengdu, the sensitivity of shedding 50MW load is shown in Table V.

TABLE V. LOAD SHEDDING SENSITIVITY OF XIANGFAN

	Hangang	**Dongjin**	**Lieshan**	**Zengdu**
Line Wo-Han	-14	-5	-3	-3
Line Han-Lie	9	3	-7	-7
Line Wo-Lie	-1	-1	-9	-6

For example, when Danjiang's net load is 0MW and two unit of Xiangyang plant start up in dry season, the flow of line Wo-Han reaches 224MW after Fan-Wo I/II's failure, shedding load of Hangang for 50MW can reduce the flow of Wo-Han to 210MW.

C. Cutting off 500kV Transformers of the Receiving End in Post-fault

Different from the strategies proposed above, cutting off the 500kV transformers of the receiving end changes the transfer ratio instead of the inter-provincial section flow (neither the pre-fault nor post-fault flow). More of the pre-fault flow transfer to 500kV and 1000kV network while the transfer ratio of 220kV network reduces. So this strategy is used to solve the problem of 220kV component's overload if the remaining 500kV and 1000kV transmission lines controllable. Two components of the network, the 500kV line that break down and the 500kV transformer of the receiving end, are lost if transformer is cut off as a strategy. The related flow transfer formula is as follow:

$$P_{C2}=P_{C1}+a\%P_{A1}+b\%P_{B1} \tag{1}$$

P_{A1}, P_{B1}, P_{C1} represent the initial power flow of A, B, C; a% represents the transfer ratio of A to C in the case that B is unavailable; b% represents the transfer ratio of B to C in the case that A is unavailable; P_{C2} represents the flow of C in the case that A and B break down or cut off simultaneously.

In wet season, Wolong substation transmits 700MW to 500kV network from 220kV network when Fan-Wo I/II break down. If the coupling transformers of Wolong are cut off in post-fault, the flow of Wo-Xi is 0 and all the 700MW flow transfer to Nan-Jing I and Xiao-Shi I/II. Hubei-Henan section won't get overload in every operation mode while the strategy of cutting off transformers is adopted, so it's feasible for the electromagnetic loop between Hubei and Henan.

According to the definition of the transfer ratio in formula 1, the transfer ratio of Fan-Wo I/II (component A) and Wolong transformers (component B) to the components in 220kV network (component C) is shown in Table VI and VII.

TABLE VI. TRANSFER RATIO OF FAN-WO I/II POST-FAULT (WOLONG TRANSFORMERS UNAVAILABLE)

Component	Transfer ratio/%	Component	Transfer ratio/%
Fancheng	17.8	Xiang-Shun I	1.2
Shiyan	2.5	Xiang-Shun III	1.0
Xiaogan	-6.9	Line Fen-Dang	1.5
Qiao-Shun I	1.1		

Compared to Table I, cutting off the transformers of Wolong can disconnect the 220kV electromagnetic loop, so the transfer ratio of Xiang-Shun I/II/III, Qiao-Shun and Fen-Dang reduces to only about 1% when Fan-Wo I/II break down. The transfer ratio of Fancheng is 17.8%, but 6.5% of it transfer to 500kV Shuanghe substation through Jingmen grid and finally transfer to Xiao-Shi I/II through 500kV network without passing through Xiangfan grid.

TABLE VII. TRANSFER RATIO OF WOLONG TRANSFORMERS POST-FAULT (FAN-WO I/II UNAVAILABLE)

Component	Transfer ratio/%	Component	Transfer ratio/%
Fancheng	45.5	Xiang-Shun I	12.3
Shiyan	11.0	Xiang-Shun III	9.8
Xiaogan	14.7	Line Fen-Dang	8.7
Qiao-Shun I	23.4		

The side-effect of cutting off Wolong transformers is that the initial flow (before Fan-Wo I/II break down) of the transformer transfer to the other 500kV transformers and 220kV connecting lines. In case that the initial power flow is as in Table II, if Wolong transformers are cut off in post-fault, the power flow of Xiang-Shun III, Qiao-Shun I and line Fen-Dang is 232MW, 324MW and 190MW, no overload.

V. CONCLUSION AND PROSPECT

According to the present situation of the existing electromagnetic loops, the problems they cause are researched and the control strategy is proposed.

1) In case that the transmission capacity of the inter-provincial section is adequate, restricting the power flow of the section is effective. There is no risk of overload for 1000kV/500kV electromagnetic loop while the power flow of the Hubei-Hunan section is limited between 4300MW northward and 5000MW southward.

2) The strategy of shedding load of the receiving end won't affect the transmission capacity of the inter-provincial section. The strategy of shedding load of Hunan 950MW can ensure that line Ge-Gang won't risk overload. The strategy of shedding load of Hangang, Dongjin, Lieshan, Zengdu 50MW each could solve the problem that Wo-Han, Wo-Lie, Han-Lie overload slightly when Fan-Wo I/II break down in dry season.

3) The strategy of cutting off transformers of receiving end is used to solve the problem of 220kV component's overload. Cutting off the coupling transformers of Wolong could solve the problem that Xiang-Fan III, Qiao-Shun I, line Fen-Dang get overload when Fan-Wo I/II break down in wet season. Cutting off Chanling transformer could solve the problem that Chan-Fei, Chan-Lou, Lou-Fei I/II get overload when Jiang-Chan I/II break down.

When there are not enough conditions to unlock the electromagnetic loop network, the structure of the 220kV network can be optimized through planning. For example, when 220kV substation Zinan is put into operation in 2016, the problem of 220kV line overload can be solved without cutting off Chanling transformer.

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