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Schemes Set for Protecting Parallel Generators with Different Capacity in the Integrated Power System

***Abstract**. The output of power stations varies widely with the diverse operating modes in which the vessels integrated power system (IPS) works. Taking two parallel generators with different capacity for example, there are four possible protection schemes set for both the bus breaker and the main breakers of generators. The results show that the setting value used in each of four cases cannot offer appropriate protection for the normal operation of the system. For this reason, a solution is proposed, that is, the time-current principle in combination with the detection of voltage sag.*

***Streszczenie.** Przy dwóch połączonych równolegle generatorach o różnej pojemności trzeba używać cztery układy zabezpieczające dla dwóch łączników szynowych i głównych łączników generatorów. W artykule zaproponowano nowe rozwiązanie układu zabezpieczającego bazujące na analizie czas-prąd i detekcji zapadów napięcia. (**Układy zabezpieczenia generatorów równoległych o różnej pojemności dołączonych do zintegrowanego systemu energetycznego**)*

Keywords: Integrated Power System, parallel generators with different capacity, voltage sag, voltage closedown-overcurrent protection
Słowa kluczowe: zintegrowany system zasilania, generator równolewgłe.

Introduction

For a traditional naval vessel, its propulsion system and power system are two separate energy systems. The capacity of the power system is relatively small, and the output of power stations is almost constant when there is a change in the operating state. To optimize the overall design of a naval ship, simplify its architecture, improve its stealthiness, adapt to new combat patterns and ensure the application of future ship-borne high-energy weapons, the navies in the world are researching and developing the technology of integrated power system (IPS). The IPS is a new-type system used for electric power generation, daily service loads, electric propulsion, high-energy weapons and high power detection devices [1, 2]. Compared with the traditional ship power system, the IPS is much great in power capacity. And meanwhile, it needs more operating modes to fulfill the unified dispatch and centralized control of power generation, power distribution, propulsion power, and power supply for daily service loads. The power supplied to the system varies a lot in different operating modes. For example, the input power in fighting conditions is nearly 7 times as large as that in anchoring conditions. With its security, efficiency and economy taken into account, the IPS may employ parallel-connection generators with different capacity. In this case, there are many options available for the setting values of bus breakers and generator breakers (Taking two parallel generators with different capacity for example, there are four setting schemes). However, which scheme is an optional choice has not been authoritatively determined as yet, while the selection of setting values for breakers are crucial to security, flexibility and stability of the power network as well as continuity of power supply. Therefore, it is necessary to carry out thorough and detailed simulation analyses of the selection of setting values for bus breakers and generator breakers.

Aiming at four possible setting schemes for the bus breaker and generator breakers and based on simulations, this paper has detailedly dealt with the operating characteristics of the bus breaker and generator breakers with four different operating currents at a time when a short circuit occurs in the busbar. The results further prove that the traditional time-current protection method [3] has its limitations, that is, all the four setting schemes of setting values cannot ensure the normal operation of the protection system. For this purpose, the paper has analyzed different characteristics of voltage of the busbar which is in short-circuit conditions and in normal operating conditions and proposed a scheme of time-current protection with the addition of voltage lockout.

System simulation model of two parallel generator with different capacity based on pscad/emtdc

The problem mentioned above is to be discussed with a single power station as an example. The power station is composed of a 10MW diesel generator set (G1), a 50MW gas turbine generator set (G2), a 45MW equivalent propulsion load and some daily service loads. The propulsion motor is supplied through a driver. When a short circuit occurs at the terminal of the motor, its short- circuit current will not flow back to the short-circuit point because of the unilateral conduction of diodes in the rectifying module of the driver. As the propulsion motor does not influence the total short-circuit current at the short-circuit point, it can be simplified as a resistance load with the same power. Short-circuit points F1 and F2 are set on busbars — the BUS1 and BUS2 — respectively. BG1 and BG2 are the generator breakers, and BB1 is busbar breaker. The single-line diagram of the unit of the single power station is shown in Fig.1. The corresponding parameters of main devices are shown in Table 1.

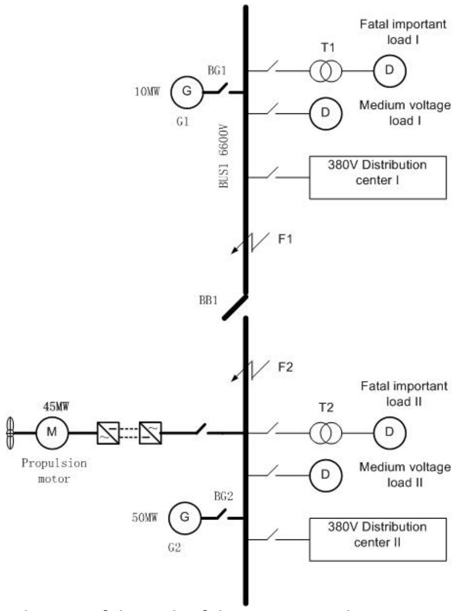

Fig.1. Sketch map of the unit of the power station

Table 1. Parameters of main elements

Element	Type of parameter	Value
Generator Set(G1)	Rated Power	10MW
	Rated L-L Voltage	6.6kV
Generator Set（G2）	Rated Power	50MW
	Rated L-L Voltage	6.6kV
Transformer (T1、T2)	Rated Capacity	8MVA
	Leakage Reactance	0.1p.u.
	Ratio	6600V/380V
Crucial Load I	Power	1MW
Crucial Load II	Power	0.5MW
Medium Voltage Load I	Power	2MW
Medium Voltage Load II	Power	1MW
380V Distribution Center I	Power	2.5MW
380V Distribution Center II	Power	1.5MW
45MW Propulsion Motor	Equivalent Resistance	0.968Ω

Selection of setting values for breakers [4]

The selection of setting values for the breakers is mainly dependent on the equation below:

(1) $$I_{gmax} < I_{qd} < I_{dlmin}$$

Where: I_{gmax} –maximal working current, I_{qd} – overcurrent setting value, I_{dlmin} – minimal short-circuit current.

It is easy to determine the setting value when there is great difference between I_{gmax} and I_{dlmin}. As for vessel power system, the criterion of selecting the setting values for the short-delay protection of breakers is shown in Table 2.

Table 2. Criterion of selecting the setting values for ship breakers (I_e is the rated current of the generator)

Breaker	Action value	
	Current	Time（s）
BB1	3~5 I_e	0.2~0.7
BG1、BG2	2.5~3.5 I_e	0.4~1.2

In this paper, the generator breakers have a short delay protection (the military standard prescribes that an instantaneous protection need not be set for the generator breaker when only two generators are in parallel as a power system), and the busbar breaker has an instantaneous and short delay protection [5, 6]. Generally the overload faults can last a relatively long period of time, so that overload protection is neglected here. The rated current value of G1 is 1093.4A, with its breaker's operating current of short delay protection set as 2730A and the delay time set as 0.6s. The rated current value of G2 is 5467A, with its breaker's operating current of short delay protection set as 13680A and the delay time set as 0.6s. Based on the rated current of G1 or G2, the operating current of instantaneous protection of the busbar breaker can be set as 12000A or 60000A, with its short delay operating current set as 2730A or 13680A and the delay time set as 0.4s.

Simulation and analysis of four setting schemes

Based on the traditional time-current protection principle, there are four setting schemes concerning the setting values of the generator breakers and the busbar breaker because of the different rated current values of two generators in parallel [7]. The four setting schemes are shown in Table 3. The corresponding currents and states of the breakers with three-phase short-circuit faults F1 and F2 are shown in Table 4.

Table 3. Four schemes of the setting values of breakers

Break	Scheme I		Scheme II		Scheme III		Scheme IV	
	Ins.	Short delay	Ins.	Short delay	Ins.	Short delay	Ins.	Short delay
BG1	—	2730A、0.6s	—	2730A、0.6s	—	13680A、0.6s	—	2730A、0.6s
BG2	—	13680A、0.6s	—	13680A、0.6s	—	13680A、0.6s	—	2730A、0.6s
BB1	60kA	13680A、0.4s	12kA	2730A、0.4s	60kA	13680A、0.4s	12kA	2730A、0.4s

Table 4. Short-circuit currents and states of breakers at F1 and F2

Break	Scheme	Scheme I		Scheme II		Scheme III		Scheme IV	
	Short-circuit point	F1	F2	F1	F2	F1	F2	F1	F2
BG1	I_{RMS} at 0.6s	2816A	2817A	2816A	876A	2816A	2816A	—	—
	State of breaker	OFF	OFF	OFF	ON	ON	ON	—	—
BG2	I_{RMS} at 0.6s	4034A	14083A	4242A	14083A	4034A	14083A	—	—
	State of breaker	ON	OFF	ON	OFF	ON	OFF	—	—
BB1	I_{Peak}	63455A	12093A	63476A	15077A	63468A	15066A	—	—
	State of breaker	OFF	ON	OFF	OFF	OFF	ON	—	—
	I_{RMS} at 0.4s	—	3078A	—	—	—	3078A	—	—
	State of breaker	OFF	ON	OFF	OFF	OFF	ON	—	—

A. Determining the setting values of the generator Breakers by their respective rated currents and setting the bus breaker according to the rated current of the larger generator

The setting values of the three breakers are shown in Table 3, Scheme I. Its short-circuit currents and states of short-circuit faults F1 and F2 are shown in table 4, Scheme I.

From Table 4, it can be seen that the bus breaker switches off instantaneously when a short-circuit fault happens at F1 and G2 keeps on working after that. because the short circuit fault has not been eliminated, BG1 (the breaker of G1) switches off after a delay of 0.6s. The system protection functions well.

The waveform of short-circuit current of BG1 at fault F2 is shown in Fig. 2. As the bus breaker cannot switch off in time, G1 stops improperly after a delay of 0.6s. The system protection functions badly. It is obvious that this setting scheme will lead to the rejection of protection.

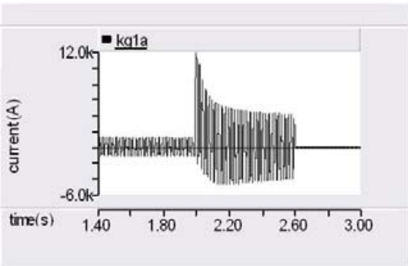

Fig.2. BG1 short-circuit current with F2 fault

B. Determining the Setting Values of the Generator Breakers by Their Respective Rated Current and Setting the Bus Breaker According to the Rated Current of the Smaller Generator

The setting values of the three breakers are shown in Table 3, Scheme II. Its short-circuit currents and states of short circuit faults F1 and F2 are shown in Table 4, Scheme II.

According to the results in Table 4, the bus breaker switches off instantaneously when fault F1 occurs. G2 goes through the short circuit fault and keeps on working. BG1, the breaker of G1, switches off after a delay of 0.6s because the fault has not been removed. The system protection functions well.

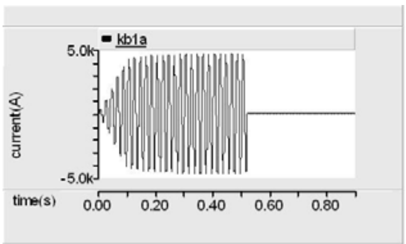

Fig.3. Current waveform of BB1 misaction

The bus breaker switches off in time to isolate the fault when fault F2 happens. G1 goes through the fault and keeps on working. BG2, the breaker of G2 switches off to protect G2. Hence, the system works well. It seems that this scheme can ensure the proper protection. However, considering the working conditions in which G1 stops working and G2 supplies all loads, the bus breaker will be caused to misoperate by the normal working current exceeding the current setting value if the G1 bus supplies excessive power, as shown in Fig.3. (It is possible that such an operating mode appears—the switchover behavior, i.e., a large amount of the load is shifted from another power station to G1 bus). Obviously, this scheme may lead to malfunction of the corresponding breakers.

C. Settings Generator Breakers and Bus Breaker According to the Rated Current of Large-Capacity Generator

The setting values of the three breakers are shown in Table 3, Scheme III. Their short-circuit currents and states in the period of short-circuit faults F1 and F2 are shown in Table 4, Scheme III. The short-circuit current waveform of BG1 at fault F1 is shown in Fig.4.

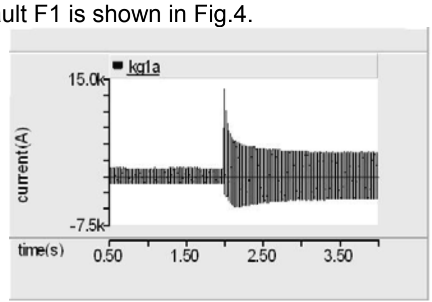

Fig.4. BG1 short-circuit current with F1 fault

According to the results shown in Table 4 and the waveform in Fig.4, the bus breaker switches off instantaneously when fault F1 occurs. G2 goes through the short-circuit fault and keeps on working. BG1 cannot switch off and G1 will continue working in the short-circuit mode because the fault has not been removed and the short circuit current is smaller than the setting value. Thus the generator may be damaged and the protection cannot functions normally.

When a short-circuit fault occurs at F2, G1 will continue working because the short-circuit current is smaller than the setting value. Neither BG1 nor BB1 can switch off. Only after a delay of 0.6s does BG1 switch off because the fault current is larger than the setting value. However, the fault still exists and will damage G1. The protection cannot functions normally.

Obviously, this scheme will lead to incorrect operation.

D. Setting Generator Breakers and Bus Breaker According to the Rated Current of Small-Capacity Generator

The setting values of the three breakers are shown in Table 3, Scheme IV. It is apparent that this scheme cannot ensure the normal operation of the system because the normal working current of G2 is greater than the setting value of its breaker, BG2. This scheme will result in incorrect operation of the breakers at a time when the system normally operates.

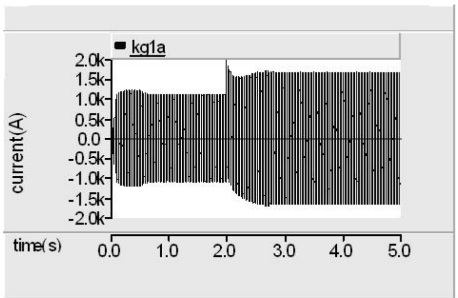

Fig.5. BG1 short circuit current with BB1 closed

In addition, the operating current setting of generator breakers used as a backup protection for far-end short circuit is difficult to fulfill. The simulation analysis is focused on the backup-protection setting of the generator breaker when the secondary winding of the 6600/380V transformer (in the 380V distribution center) is short-circuited and the secondary winding breaker refuses to work. The setting values of generator breakers are shown in Table 3, Scheme I. When BB1 turns on, the short-circuit current waveform of BG1 is shown in Fig.5. When BB1 turns off, the short circuit current waveform of BG1 is shown in Fig.6.

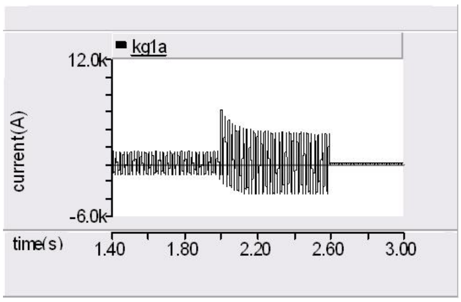

Fig.6. BG1 short circuit current with BB1 open

It can be seen from the Figures that G2 will share above 85% short-circuit current when BB1 turns on. Therefore, the short-circuit current through BG1 is too small to make BG1 start its short delay protection and so the fault remains, which will have an unfavourable influence on the fault loads.(it is likely that the long- delay protection will start but its switch-off will start in tens of seconds.) With BB1 on, BG1 is good for the back-up protection for far-end short circuit.

To sum up, all the four setting schemes mentioned above cannot ensure the normal operation and protection of the system, as well as the back-up protection of far-end short circuit. Therefore, it is necessary to adopt the compound protection to which some other protection means are added or to modify the operating mode of the system.

Protection method combined with voltage judgement

In view of what is described above, the protection scheme may fulfill effective protection on condition that the differences in properties between short-circuit and normal operation can be made correctly. As a matter of fact, the busbar voltage has a remarkable difference between the short-circuit mode and the normal operating mode. In other words, the voltage is almost equal to zero in the short-circuit state while it almost remains constant in the normal operating mode. Hence, not only should the sudden current rise be taken into account, but also the voltage sag should be considered so as to perform reasonable short-circuit protection. The setting sketch is shown in Fig.7.

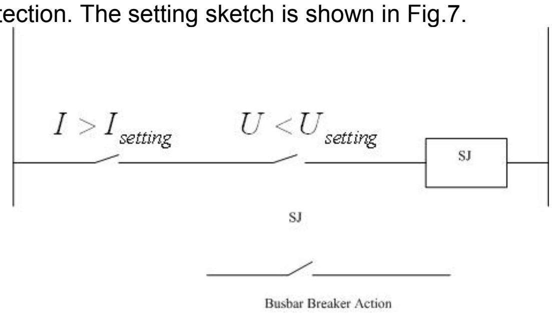

Fig.7. Sketch of current compounding voltage protection

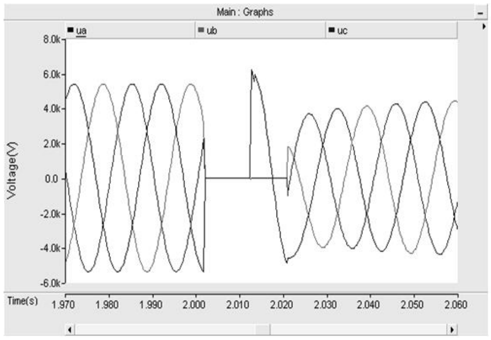

Fig.8. Busbar voltage waveform with F2 fault

Fig.8 illustrates the busbar voltage waveform in short-circuit fault F2.It indicates that an obvious sag appearing in busbar voltage when F2 is short circuited can be used to cooperate with a sudden rise in current to form an effective protection.

Conclusions

A detailed simulation analysis has been made of several protection schemes set for the generator breakers and bus breaker in times of parallel collection of the generators with different capacity. The simulation results demonstrate that the traditional time-current protection principle cannot ensure the normal operation of the system. Therefore, a scheme has been proposed of combing voltage sag judgment and the time-current protection with the addition of voltage lockout. the scheme can provide an effective protection for the power system consisting of different-capacity generator in parallel.

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