A Study on Capacity of Distributed Generation and its Effect on Short Circuit Current at Micro-grid Operation Mode

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***Abstract*—Now more and more distributed generations will be connected to distributed power system. It's found that different distributed generation has its own operation characteristic such as fluctuation and uncertainty. When micro-grid is to be island the voltage and frequency will change, so different control modes have been used on different distributed generation. Different kinds of distributed generation have different behavior when system operates normally or fault occurs. Classification and equivalence were adopted to deal with all kinds of the distributed generations in system. The distributed generations with same control mode can be combined to an equivalent generation. When system operates on grid-connection mode the short circuit current relies on the capacity of grid so it is rather large for the capacity of distribution grid is much more than that of distributed generations. But when micro-grid operates on island mode the short circuit current may decrease to a relative small value. Over current protection is widely used in distribution system, and the performance of it is dependent on operation mode, so the value estimate of short circuit current is necessary for verification of credibility and selectivity. Two summations of capacity were proposed to estimate the minimum and maximum short-circuit current in island.**

Keywords-capacity of distributed generation；equivalent capacity; short-circuit current；operation mode；over current protection

I. INTRODUCTION

Now the technology of distributed generations interests people to use renewable energy such as gas turbines, micro turbines, photovoltaic battery, fuel cells and wind-power. The advantage of renewable energy is obvious, but such energy is hard to use directly for its fluctuation and uncertainty, so distributed generations are often connected into power system, especially into the terminal of distribution grid.[1-4] Inverter interfaced distributed generator has special fault response, and fault analysis is more complex.[5-7] Programming, course and protection must be influenced unavoidable.[8-10]

The capacity of distributed generations ranges from several KWs to MWs, so the connection modes are different. Large capacity distributed generations such as wind farms and photovoltaic station are often connected to higher voltage network, for example 10KV distribution network. But a lot of small capacity distributed generations are connected to system near consumers separately. So many connection points make the distribution network complex and hard to manage, if a uniform manage system is built to solve the problem, too much communications and data processing will be another difficult problem. According to the complex state, equivalence of distributed generators, fault current estimate and effect on relay protection of distribution network are presented in this paper.

II. CALCULATION AND EQUIVALENCE OF DISTRIBUTED GERERATION CAPACITY

Different distributed generations have different characters, so different control mode may be adopted to give out energy sufficiently. The Maximum-Power-Point Trackers control strategy is studied deeply and used in wind turbines and photovoltaic battery. The inverters of these generators are often controlled with stable power control (PQ control) and the output power may be lower than the setting point. Power control mode has maximum power limit and current limit, and the two limits are useful to us for analysis. The output power can impact system operation mode and short circuit current.

When the system runs at micro-grid mode, another kind of generator must be connected into grid to supply basic voltage and frequency, it is stable voltage/frequency control (VF control) generator usually. Because VF control generator need adjust output power and reactive power according to system state, the energy source must be able to supply enough power, so the energy storage elements are often used for VF source to keep system stable. Some energy storage elements such as battery, flywheel, superconductor coil are often used in the system. Fuel cell and micro-turbine generation are also used to

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adjust power in the system The VF control generator has its power limit and current limit too, when system fault occurs near the generator or power is lost too much, power limit or current limit is liable to get, then system voltage and frequency can not be keep normal at micro-grid mode.

In some area there may be more than one distributed generators in distribution network, and they may be connected into different buses as figure 1 shows. Analysis shows the same control mode distributed generators have the same character, so we can do equivalence to the distributed generators in the system. For analyzing the impact on distribution network by micro-grid, the equivalence is adopted. The total distributed generators in the area can be seen a new larger generator, the capacity of the new generator can be expressed as (1) and (2).

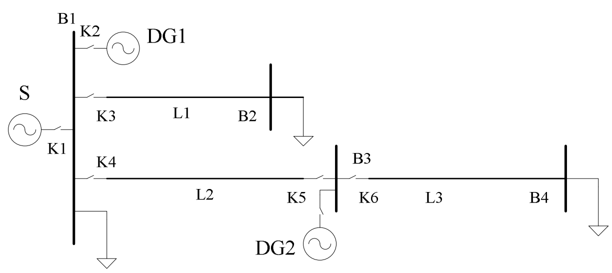

Figure 1. DGs connected to buses in distribution network

$$S_{\min} = \sum S_{Vf} \qquad (1)$$

$$S_{\max} = \sum S_{Vf} + \sum S_{PQ} \qquad (2)$$

Equation (1) shows a special operation state, all the PQ control generators exit for some reason, when fault occurs in distribution network, all the VF control generators supply fault current. The equivalent capacity of micro-grid is least at this operation state and fault current from micro-grid is minimum. The other way round all the PQ control generators get full power output as setting, the equivalent capacity of micro-grid is most. If fault occurs at this time, the equivalent generator may supply maximum short circuit current.

When system operates at grid-connection state normally, distribution network can supply relative stable basic voltage and frequency, so all VF control generators may supply little power output or exit. But when micro-grid operates at island mode, VF control generators must keep the power of island system balanceable, so they often need compensate the power loss. After the island connected to distribution network again, the energy storage units (VF control generators usually) need charge, then the VF control generators change to load as far as the energy storage equipment charge fully.

By the analysis above, for distributed generators' output and load often fluctuate, so when fault occurs in the system, it's hard to calculate the exact short circuit current. Estimate of short circuit current is useful and practical here. Using (1) and (2), the magnitude of short circuit current can be gotten. The equivalent capacity $S_{\min}$ is called minimum capacity, and $S_{\max}$ is called maximum capacity. Ordinarily short circuit current is between the two limits according to $S_{\min}$ and $S_{\max}$.

III. EFFECT ON OVERCURRENT PROTECTION

Now over current protection is adopted in distribution network abroad. The principle of over current protection is simple and easy to carry out, but it has disadvantage that the performance is prone to impact by system state. The analysis is based on the configuration in fig1. S is distribution network which has large capacity, DG1 and DG2 are distributed generators in system. K1 is the main connection point, when K1 is open, micro-grid will form. B1, B2, B3 and B4 are buses, L1, L2 and L3 are transmission lines, loads are not shown definitely.

A. K1 closed

For fault at L1, S and DG1 and DG2 all supply fault current, fault current at K3 increase and relay 3 can trip faster. The fault current mainly lie on the capacity of S, if operation of S changes little, relay 3 can trip credibly. The equivalent capacity to L1 would be shown as (3) and (4).

$$S_{d\min} = S + \sum S_{Vf} \qquad (3)$$

$$S_{d\max} = S + \sum S_{Vf} + \sum S_{PQ} \qquad (4)$$

For fault at L2, the state of K4 is similar to K3, but the current at K5 lie on the capacity of DG2. If DG2 has too small capacity, K5 may be hard to trip.

Connection of distributed generations make system configuration complex, and system equivalent capacity has more meanings, for an electric device connected in series to the system, two sides may have different equivalent system. So a simple conclusion can be presented that the equivalent capacity of system at one side of fault point lies on all generators in it.

When system operates at grid-connection mode, the relays of large equivalent capacity side may be affected little, and the relays of small equivalent capacity side (DG side) may be affected deeply. The ratio k_1 is proposed to estimate the effect of equivalent capacity difference. If k_1 is too little, the protection relay of DG side may reject to trip and can't cut off fault current. At this time, over current protection configuration at some breakers needs checkout and cooperation again to guarantee trip credibly.

$$k_1 = \frac{\sum S_{Vf} + \sum S_{PQ}}{S + \sum S_{Vf} + \sum S_{PQ}} \qquad (5)$$

B. K1 open

All DGs in system from B1 to B4 have to supply power to keep micro-grid running normally. The equivalent capacity of micro-grid can be shown as (1) and (2), it is so small compared with distribution network. For some distributed generator's output fluctuate random, the equivalent capacity may change from $S_{\min}$ and $S_{\max}$, and range of fault current can be fixed on. The ratio k_2 is proposed to estimate the difference of fault current at all operation modes.

$$k_2 = \frac{\sum S_{Vf}}{\sum S_{Vf} + \sum S_{PQ}} \quad (6)$$

The k_2 shows stability of micro-grid too. A large k_2 shows that there is more standby power in system, so if distribution network disconnects, micro-grid has more possibility to operate continuously. It's advantageous to increase fault current for fault detection and tripping.

To set over current protection, system calculations include power flow and short circuit current calculation must be done above all. The over current protection setting value must be more than maximum load current. For various operations, it's hard to set the value. For example, when fault at L3, voltage of B3 drops at once, DG2 will increase the power output if DG2 is VF control generator. The capacity of DG2 can decide fault current at K6, it's advantageous to accelerate K6 trip as DG2 has enough power capacity. But if DG2 is steady power generator with no more power output, the fault current at K6 may be little more than load current, then K6 will be hard to act for fault cutting.

C. Suggestion

It's a difficult question for configuration and setting of over current protection in distribution network with DGs that the capacity of DG is too small to supply enough fault current to make protection relay trip. So some methods are studied to increase fault current. More VF control generators are installed in system, and dynamic voltage restorer (DVR) has the same function, but investment limit make it hard to execute.

Another way to ensure cutting fault is changing over current protection configuration. Traditional definite- time over current protection can't fit at complex states by all appearances, but inverse-time over current protection may be available, for it is adaptive to the fault current and guarantees selectivity. Furthermore directional current protection must be configured at some relays necessarily such as K5.

IV. SIMULATION ANALYSIS

The line-line voltage of AC system in simulation is 400V. As fig 2 shows, L1 to L4 are all cables, the parameters of all cables are showed as follow: x_1=0.206 Ω /km, r_1=0.072 Ω /km. The length of every cable is shown in fig 2. S is distribution network and its capacity is fixed 5MVA. DG1 and DG2 are distributed generators, the capacity and control mode may change in different simulation states. Load at every bus has rated capacity of 0.15MVA and rated power factor of 0.85.

The simulation runs on Digsilent, which is a new electric simulation soft that has powerful simulation ability and many integrated electrical module.

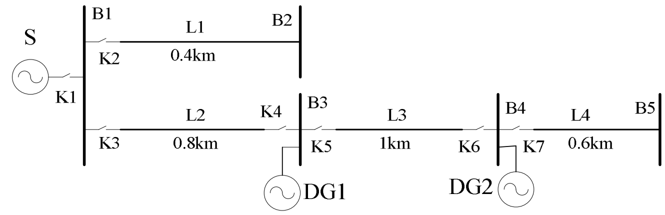

Figure 2. Distribution network with DGs in simulation

A. Operation at grid- connected mode

For keeping the voltage of terminal load bus, DG2 is VF control generator, and DG1 is PQ control generator which can supply power and a little reactive power. Changing the capacity of DGs can change operation mode, then k_1 has different values. Setting fault at middle of transmission line L1 to L4 can get fault current at protective relays list in table 1. In this simulation, K1 is closed.

TABLE 1 Fault Current at Protective Relays at Grid-connected Mode

Capacity of DG1 /MVA	Capacity of DG2 /MVA	relay	Fault Current /KA			
			L1	***L2***	***L3***	***L4***
0.4	0.4	K2	3.461	0.165	0.184	0.211
		K3	0.480	2.062	0.976	0.497
		K5	0.147	0.489	1.536	1.021
		K7	0.206	0.099	0.023	1.209
0.6	0.2	K2	3.557	0.166	0.183	0.194
		K3	0.481	2.068	1.043	0.563
		K5	0.221	0.275	1.587	1.120
		K7	0.214	0.090	0.012	1.191
0	0.4	K2	3.200	0.166	0.190	0.198
		K3	0.539	2.072	1.062	0.930
		K5	0.549	0.447	1.234	0.860
		K7	0.090	0.069	0.023	1.206

Compared between systems with different capacity of DG1 and DG2, it's found that when fault is set at the same location, the fault currents from distribution network have little difference in different DGs' capacity states. Generally distributed generator's capacity is far smaller than the distribution system. So k_1 is small, and the over current protection set at big system side such as K3, K5and K7 can trip reliably. DGs in system must supply more fault current especially when fault occurs near some DG, and the DG may supply the limit current.

When both end of a line include generator, the protective relays at two ends have different setting value to ensure tripping and selectivity, if necessary, power or current directional component must be configured.

B. Operation at micro-grid

When breaker K1 is open, the system operates at micro-grid mode. According to consumers' load, the total power supply of DGs must increase to satisfy the load, or part of the load must be cut off to keep the residual system stable. In simulation the total capacity of DGs were set more than total load. Changing capacity of two kind generators, fault currents at interrelated relays are shown in table 2.

TABLE 2 Fault Current at Protective Relays at micro-grid mode

Capacity of DG1 /MVA	Capacity of DG2 /MVA	relay	Fault Current /KA			
			L1	***L2***	***L3***	***L4***
0.6	0.4	K2	0.711	0	0.046	0.075
		K4	0.737	0.861	0.088	0.183
		K5	0.308	0.268	1.003	0.908
		K6	0.308	0.268	0.369	0.908
		K7	0.143	0.089	0.012	0.971
0.6	1.0	K2	0.955	0	0.047	0.097
		K4	1.000	1.015	0.089	0.198
		K5	0.331	0.976	0.908	0.954
		K6	0.331	0.976	0.974	0.954
		K7	0.229	0.145	0.047	1.065

In table 2, generally fault currents are smaller than that in table 1 at the same fault state. The capacity of VF control generator can affect fault current, especially fault near it. The VF control generators play an important role to increase fault current, the protective relay get the fault current from it and may be easy to trip. But the control system is usually designed to limit output current, so when fault occurs near the buses where distributed generators are connected, the fault current is also smaller than that from distribution network. In despite of control limit, k_2 also can reflect the fault current level at micro-grid operation. For some line fault, the fault current has large difference between k_2 is 0.4 and k_2 is 0.625, then it may bring problems to relay K2.

For technical and economical reason, the VF control generator can't be set too many, so the ratio k_2 is often little. So when over current protection is configured at relays in distribution network, all operation mode must be considered to guarantee the performance of protection device. If DG is connected to distribution network, the original over current protection will need checkout and cooperation again.

V. CONCLUSION

This paper analyzed the relation of the capacity of distributed generator and fault current in system. Two ratio k_1 and k_2 are proposed to estimate the difference from the equivalent capacity of DGs and the impact on traditional over current protection. After analysis and simulation, conclusions were obtained.

(1)The VF control mode distributed generations in microgrid can operates as energy storage unit and its capacity may influence the voltage and short circuit current when fault occurs.

(2)The less different between S_{min} and S_{max} is, the less effect on overcurrent protection in micro grid and the less contrast of short circuit current has.

(3)When microgrid operates at island mode, the overcurrent protection will need checkout and cooperation again.

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