Application of Wide Area Monitoring Protection and Control in an Electricity Distribution Network

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Abstract

The application of a Wide Area Monitoring Protection and Control (WAMPAC) system in a 110 kV local area distribution network (six 110 kV substations) is presented in this paper. The WAMPAC system consists of a central unit, and a local unit at each of the six 110 kV substations. It integrates the functions of monitoring, protection and control in the system. The protection function includes feeder protection, transformer protection, bus bar protection and CB fail protection. The control function includes synch check, auto-reclose, standby supply restoration, load shedding and generations tripping. The local area distribution network has embedded generations in it. If it is islanded, the system can shed the load or trip excess generations to keep the frequency near 50 Hz to meet the synch check criteria, so that the CB of the standby supply can be auto-closed and grid supply can be restored to the islanded area quickly.

1 Introduction

In China Southern Power Grid, a local 110 kV electricity distribution network (five or six 110kV substations) may be supplied from a single 220kV/110kV transformer as shown in Fig.1 below. This is mainly to reduce the fault current level in the 110 kV network due to the limit of CB ratings.

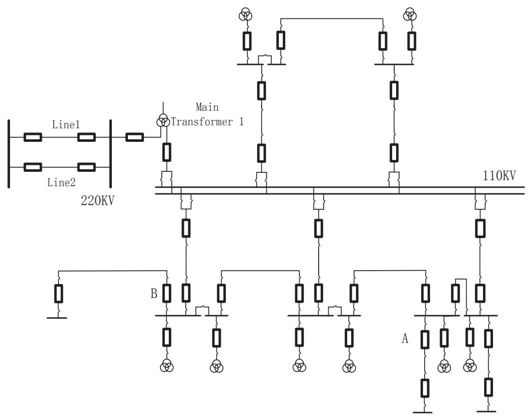

Fig.1: A local 110 kV network with embedded generations

If the two parallel 220kV circuits (line 1 and line 2 shown in Fig.1) or the 220/110 kV transformer is tripped off, the local area network is then islanded. As there are embedded generations in the area (small hydro power plants connected on 10 kV feeders), the voltage of the 110 kV network does not reduce quickly and this will prevent the auto-close of the standby supply from point A or B as shown in Fig.1 above as currently the criteria for the auto-close is dead bus. Since the outputs of the embedded generators often do not match up with the loads in the area and the system frequency will change, eventually all the embedded generations will be tripped off by their own protection. A manual restoration process can then start, but this normally takes a long time (20 or 30 min) to restore all the generations and supplies in the area.

This paper presents a Wide Area Monitoring, Protection and Control (WAMPAC) system developed to reduce the time of restoration of standby supply to the local area network if it is islanded, also to improve the successful rate of auto-close of standby supply. The main control function of the WAMPAC system is to balance the generations and loads in the area network if it is islanded, and to restore grid supply to the islanded area quickly. In addition to the control function, protection functions of bus bar protection, CB fail protection, feeder protection and transformer protection for the 110 kV network are also integrated in the system. This will ensure rapid clearance of fault on bus bars and provide back protection for CB failures. The feeder protection will ensure a fast backup protection to the existing main protection (only one main protection on each 110 kV circuit). If any fault occurs in the 110 kV network, this system can locate and clear fault quickly. If any part of the 110 kV network is split after the fault clearance, the system can take the appropriate measures to keep power balance between the embedded generators and loads. The system uses multi-information exchange in the wide area to provide optimum real time control and protection functions.

2 System Architecture

The WAMPAC system consists of a central unit and a local unit at each substation as shown in Fig.2. The communications between central unit and local units are 2M SDH communication links. The inputs to the local units are plants status, currents, voltages of 110 kV circuits.

The central unit receives the currents, voltages and plant status of 110kV feeder and transformers from all the local units, and the operational data such as power and plant status of 10kV feeders from EMS. It also monitors the power exchanged between the 220kV and 110 kV systems. The local unit is connected to merging units which are connected to CTs, VTs as shown in Fig.3 below. The local units also collect information of CB status, isolators of the primary plants, and send the information to the central unit so the real time topology of the local area network is known by the central unit. If a fault occurs on a 110 kV feeder, the fault can be detected by local units, and tripping commands are then issued by the local units. After the tripping, auto-reclose command is then issued by the local units. If it is a permanent fault, the feeder will be tripped again. If part of the local area network is islanded after the tripping, the central unit can detect the islanding condition, and send the tripping commands to the local units to shed loads or trip excess generations connected at the 10 kV feeders. This is to maintain the frequency near 50 Hz so that the synch check condition can be met. The CB of the standby supply can then be closed so that the islanded area can be connected to the grid quickly. The central unit has the information of the topology of the local area network and the control strategies are determined by the central unit.

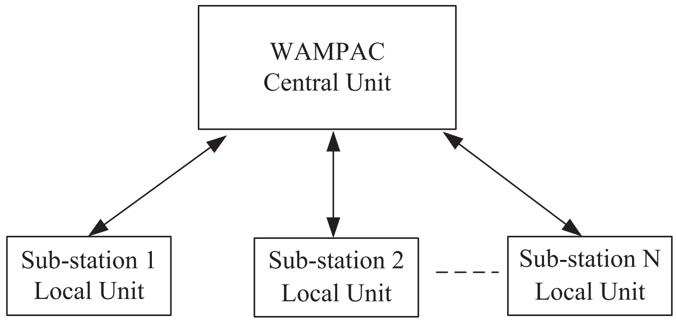

Fig.2 Architecture of the WAMPAC System

At each substation, the local unit is connected to a communicating equipment and merging units as shown in Fig 3 below.

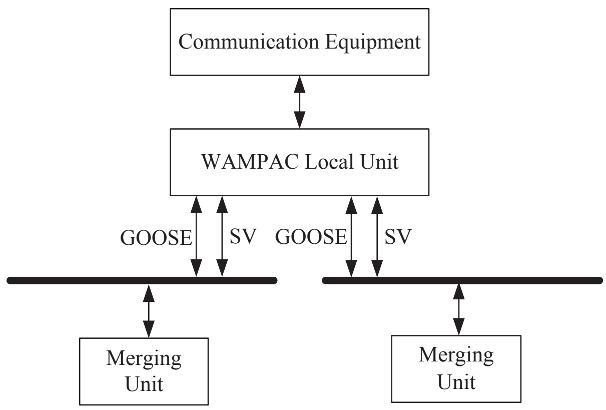

Figure 3 Connecting of WAMPAC Local Unit

3 Multi-information Exchange

If the local 110 kV area network is islanded, the WAMAC system will shed loads or trip generators connected on 10 kV feeders according to a priority order list. To obtain the real time of power of 10 kV feeders, the central unit is connected to EMS to get the information of load, generator output from the EMS. All the information exchanged has a standard format.

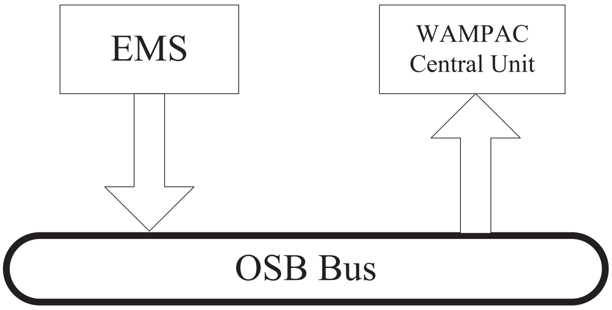

Figure 4 Data acquisition of 10kV feeders

The central unit receives the operational data from local units at each substation, and sends the load shedding or generation tripping command and auto-close command of the standby supply to the local units.

The local units get the sampled values of currents and voltages, and plant status of 110kV feeders and transformers from IEC 61850 process bus as shown in Fig.3. The merging units are connected to traditional CTs and VTs and send the sampled values to the IEC61850 process bus, They also receive the tripping commands from the local unit.

To ensure the reliability of communication between central unit and local unit, the following checks are carried out:
(1) CRC Check;
(2) Address Check;
(3) Signature Check;
(4) Accumulation Sum Check.
The control commands that the central unit sends to the local unit will be checked by consecutive frames command.

4 System Functions

As mentioned above, the WAMPAC system has both protection and control functions. The protection functions include 110 kV feeder protection, 110/10kV transformer protection, 110kV bus bar protection and CB fail protection. It also has the synch check and auto-reclose function.

The main control function of the WAMPAC system is to detect whether after a power system fault , there is any islanded network, such as when both line 1 and line 2 are tripped off, or the transformer 1 is tripped as shown in Fig. 5. When the islanding of an area network is detected, in order to balance the power between embedded generations and loads in the islanded area, the central unit can determine how much load or generation which needs to be tripped off based on the import/export power from/to the 220 kV system which is measured immediately before the islanding. It then makes a quick decision in few hundreds milliseconds to trip generation or shed loads based on a priority order list of 10 kV feeders. The is to enable a successful auto-close of standby supply as the synch check criteria (frequency and voltage) can be met. It is expected that the whole process takes few seconds to connect the standby supply to the islanded area network. This will improve the reliability of supply to the local area network significantly.

4.1 Detection of Islanded Network

As the WAMPAC central unit knows the status of all the CBs of the 110 kV lines, the 220kV lines and the 220/110 kV transformer in the area network, when a 110 kV line or the 220/110 kV transformer is tripped off, the CB changes its status from closed to open position, the central unit can then determine whether there is any islanded area based on the new topology of the area network.

For example, as shown in Figure 5, during normal operation, CB A and C are open. If the parallel circuits of line 1 and 2 are tripped, the 110 kV area network becomes islanded. If line 5 is under maintenance, when line 8 is tripped, substation 2 will become islanded.

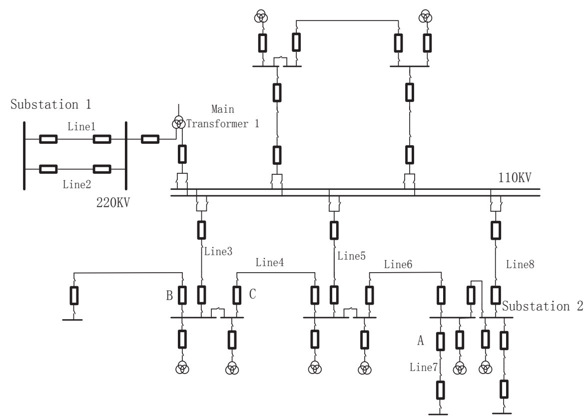

Figure 5 The area network with WAMPAC applied

4.2 Restoration of Standby Supply to the Islanded Network

After a power system fault, if part of the local area network which has embedded generations becomes islanded, the frequency of the islanded network will change and it may not able to meet the criteria of synch check, so the chance of successful auto-closing standby supply is low. This may cause a blackout of the whole islanded network if no control measure is taken.

If the 220kV parallel circuits or the 220/110 kV transformer is tripped off as shown in Fig.5 above, the local distribution network is then islanded. The control measures (load shedding or tripping generations) will be carried out to maintain the frequency to near 50 Hz so that the synch check condition can be met and the CB of standby supply can be closed quickly to restore the grid supply to the islanded network. If a power system fault occurs on a 110 kV circuit, the WAMPAC system will first auto-reclose the circuit. If it is unsuccessful and part of the network is islanded, the load shedding or tripping generations will be carried out to close the CB of standby supply quickly.

4.3 Control Measures for Balancing the Power in Islanded Network

When the area network is islanded, the amount of load shedding or generation tripping will be determined by the central unit according to the amount and direction of the power flow between the 220 kV system and 110 kV network immediately before the islanding. The criteria for the generation tripping or load shedding are as follows:

4.3.1 Tripping Generators

Prior to the islanding, assume that the power flow from the islanded network to the main network is P, then:

If $P < Pmkn$: No tripping generation, where Pmkn is a threshold setting of tripping generation.

If $P \geq Pmkn$: tripping generations, the amount of generation tripping is $dP = P - Psetn$, where Psetn is a setting.

Tripping generation is according to a principle of minimum under tripping. For example, if 100MW generation tripping is required and there are four sets of generators available for tripping, their capacities are 30MW, 40MW, 50MW and 59MW respectively, then the two generators whose capacities are 40MW and 59MW are selected to trip.

After the above action, if the frequency of the islanded network is still above the allowed value, then further tripping of generations will be carried out. The criteria is as follows:

If $f \geq festh1$ and $t \geq tfh1$, then tripping the first set of generations

If $f \geq festh2$ and $t \geq tfh2$, then tripping the second set of generations

……

If $f \geq festhn$ and $t \geq tfhn$, then tripping the nth set of generations.

4.3.2 Load Shedding

Based on the amount of power of the islanded network imported from the main network, there are three strategies for load shedding:

If the imported power is small before the islanding, considering the spinning reserve capacity of the embedded generators, there is no need to take control measures of load shedding.

If the power shortfall of the islanded network is so large that the embedded generators are unable to maintain their stability, all the generators in the islanded network will be tripped off, and then the CB of the standby supply will be closed to the islanded network quickly.

If the power shortage is between the two situations above, control measures of load shedding will be carried out. Assume that P is the amount of power of the islanded network imported, then:

If $P < Pmk1n$, no load shedding , where Pmk1n is a threshold setting of load shedding.

If $Pmk2n > P \geq Pmk1n$, load shedding takes place, the amount of load shedding is $dP = P - Pset1n$, where Pset1n is a setting.

If $P \geq Pmk2n$, trip all the generators in the islanded network, and then close the CB of the standby supply. Where Pmk2n is a setting.

After the above action, if the frequency of the islanded network is still below the allowed value, further load shedding will be carried out as follows:

If $f < festh1$ and $t \geq tfh1$, then shed the first set of loads

If $f < festh2$ and $t \geq tfh2$, then shed the second set of loads

……

If f <festhn and t≥tfhn, then shed the nth set of loads

As the importance of each load is different, the order of the load shedding is carried out according to a priority list of each 10 kV feeder. Specific allocation method is as follows:

First divide all the loads of 10 kV feeders at each substation into m sets, then set their priority of each 10 kV feeder in each set of load. The priority of the 10 kV feeders that are not allowed to trip is set to 0. The WAMPAC central unit then determines which 10 kV feeder to trip at each substation according to the priority list.

4.3.3 T-connection of Generators to 10 kV feeders

In order to save costs, some small hydro generators are connected to 10 kV feeders using a T off connection. These 10 kV feeders have a mixed connection of small hydro generators and loads. In the summer, these feeders will export power to the grid, but in the winter these feeders will import power from the grid. The WAPMAC central unit will simply treat these feeders as a generator or load depending on the direction of the power flow of the 10 kV feeders.

5 Conclusion

A WAMPAC system has been developed for application in an 110kV distribution network in China Southern Power Grid. The system integrates the functions of protection, stability control of islanded network and fast grid supply restoration. The protection functions in the WAMPAC system provide main protection for 110 kV bus bars, CB fail protection, and fast backup protection for 110 kV circuits and transformers. The system uses multi-information exchange between central unit and local units at each substation. This makes the detection of islanding very easy. The control function in the WAMPAC system is mainly to balance the generations and loads in the islanded network to maintain the frequency near 50Hz so that the synch check condition can be met and standby grid supply can be connected to the islanded network quickly. Without the control measures, the islanded network may lose stability and eventually all the embedded generations will be tripped off and lose supplies to all customers. A manual restoration process normally takes a long time (20 or 30 min) to restore power to all customers. It is expected that, with the application of the WAMPAC system, the islanded network can be connected to the grid in less than 10s. This will significantly improve the reliability of supply to the area network. The WAMPAC system has been in service since Dec 2013, so far its performance is satisfactory.

References

[1] Yuan Ji-xiu. Wide-area protection and emergency control technology, China Electric Power Press, 2007

[2] Power system stability and control technology, China Electric Power Press, 2000
