Influence of Negative Phase Sequence of Distribution Line to Feeder Terminal Unit Operation

ZENG Xianfeng, HOU Wei, WANG Jie, WANG Xiaoxiang, LI Yuqi
(NR Electric Co.,Ltd.Nanjing 211102,China)

Abstract:
Performing line commutation at an appropriate distribution switch can better balance the inductive reactance between three-phase lines and reduce transmission line losses. However, due to the large number of distribution lines and the complex operating environment, the management of distribution line is very difficult, and after the commutation some distribution lines may be in negative sequence operation because of failing to plan reasonably and no checking phase sequence in time, that affect the normal operation of the feeder terminal unit(FTU). This paper first analyzes the FTU's working principle of the dual power supply, then studies the FTU's protection function configuration, and then obtains the influence of negative sequence operation of the line on the power supply and protection of the FTU. And then, according to the negative sequence operation characteristics of the line, this paper puts forward some suggestions, such as adding phase sequence alarm function, phase sequence adjusted by software, etc. Finally, combined with a negative sequence operation case in Shandong Province, it is verified that the negative sequence operation of the line can affect the operation of the FTU and the proposed method can effectively improve the distribution line management efficiency and the reliability of the FTU.

Keywords:
distribution line, line commutation, negative sequence , feeder terminal unit(FTU), protection configuration

1 Introduction

With the improvement of the automation level and the increase of people's demand for power supply, the quality and reliability of the power supply are getting more and more attention. As important components of the power distribution system, distribution line and feeder terminal unit's operating states have a direct impact on the operating efficiency and reliability of the power distribution system[1].

In the distribution line, conducting the line commutation operation at the appropriate distribution switch can better balance the inductive reactance between the three-phase lines and reduce the transmission line loss, improve the power supply quality. Since the commutation operation is simple and easy, commutation operation is very common in the distribution network[2-3]. However, the development of distribution networks has attached importance to the main network and neglected the distribution network, so that the distribution network protection management has not received attention for many years.

On the one hand, there are many distribution lines and the operating environment is complex. The number of distribution network terminals is numerous and the installation locations are scattered. There are many difficulties in technical management and on-site construction because of the complex environment. Usually, some lines are in the negative sequence operation state after installation or commutation because they are not reasonably re-planned and nuclear phase in time, which would affect the normal operation of the feeder terminal uint (FTU). On the other hand, there are many suppliers and types of power distribution equipment, but the manufacturing standards are not uniform, and the interfaces are complicated. During the process of updating and replacing power distribution equipment, there is a risk the line will be in negative sequence operation due to different manufacturing standards or interface definitions, and no timely verification after replacement.

If the line is installed or commutated and the non-nuclear phase enters the negative sequence, there are two major impacts on the FTU. On the one hand, because the feeder terminal line takes power from the potential transformer (abbreviated as PT), the voltage and phase sequence of the primary line will directly affect the FTU's power supply. On the other hand, the negative phase sequence has an effect on the protection logic of the FTU, which may cause protection mis-operation [4]. It can be seen that in order to improve the reliability of the distribution network, it is necessary to study the operation of the FTU, especially the power supply and protection configuration, when the distribution line is operating in the negative phase sequence.

This paper starts from improving the efficiency of distribution network management and the reliability of FTU. Firstly, the FTU's power supply's working principle is analyzed. Secondly, the FTU protection configuration is studied. Then the influence of the line negative sequence operation on the FTU power supply and protection function is obtained. Finally, combined with the line negative sequence operation characteristics, some improvement suggestions are put forward.

2 Analysis of FTU's power and protection configuration

The power supply of the FTU is generally taken from the PT. Figure 1 is a schematic diagram of the wiring of the FTU device.

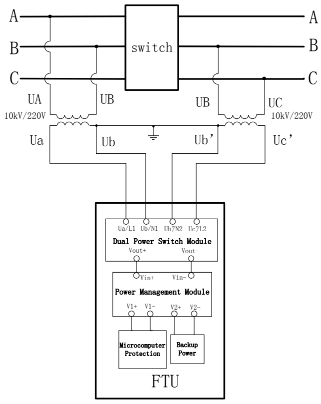

Figure 1 Schematic diagram of FTU wiring

In Figure 1, each side of the primary switch is equipped with a single-phase PT which the ratio is 10kV/220V. One PT takes the AB line voltage, and the other PT takes the BC line voltage. The two PTs secondary side voltages are connected to the feeder terminal, on the one hand as the PT secondary voltage, and on the other hand as the device power supply. In order to continue the operation of the FTU after the line is powered off, FTU has its own dual power switching module and backup power supply. The two power supplies output a power supply to the power management module through the dual power supply switching module in the FTU device, and then the power management module converts the power supply into two DC voltage (DC24V) outputs to power the microcomputer protection device and charge the backup power supply in the FTU[5].

When the line is in operation, the B phases of two PTs' secondary side are shorted and directly grounded. The output U_{ab} and U_{bc} of the two PTs are directly connected to the dual power switching module. Normally, the input L1 of the dual power switching module corresponds to U_a , N1 corresponds to U_b, L2 corresponds to $U_{c'}$, and N2 corresponds to $U_{b'}$, where the voltages between L1 and N1, between L2 and N2, and between L1 and L2 are AC220V.

2.1 Analysis of FTU dual power supply operation

There are two main principles for dual power switching, that one is the dual power switching of the relay principle, and the other is the dual power switching of the rectifier bridge principle[6].

The relay principle is generally composed of one or more relays,that each has multiple normally open or normally closed contacts. The switching time which is often within 50ms between the two power supplies is related to the performance and number of relays[7-8]. Figure 2 is a schematic diagram of single relay dual power supply switching. Ua/L1 and Ub/N1 are the input of the first power supply, Uc/L2 and Ub/N2 are the input of the second power supply, and RLY1 represents the relay. RLY1-1 and RLY1-2 represent the two normally open contacts of relay RLY, and RLY1-3 and RLY1-4 represent the two normally closed contacts of relay RLY1.

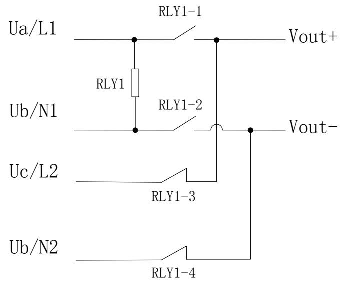

Figure 2 Schematic diagram of single relay dual power supply switching

When the first power supply has a voltage, the relay RLY1 will operate regardless of whether the second power supply has voltage. At this time, the RLY1-1 and RLY1-2 contacts will be closed, and the RLY1-3 and RLY1-4 contacts will be disconnected, the output power is the first power supply. When the first power supply has no voltage, the relay RLY1 does not operate, the RLY1-1 and RLY1-2 contacts are disconnected, and the RLY1-3 and RLY1-4 contacts are closed. At this time, the output power is the second power supply. The dual power supply is switched by controlling the normally open and closed contacts through the relay.

The principle of the rectifier bridge is realized by AC/DC. Because it converts the AC voltage into DC voltage, it can realize seamless switching of dual power supplies, and is generally used in some occasions where the system reliability is high. The following is a brief analysis of the typical bridge rectifier dual power switching principle. In Fig. 3, VD1～VD8 are rectifier diodes, and C1～C3 are capacitors.

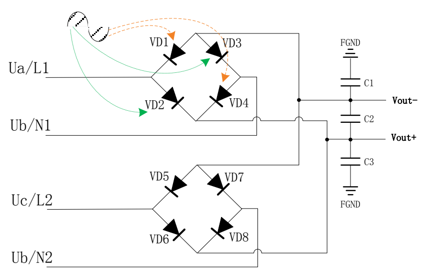

Figure 3 Rectifier bridge dual power supply switching principle

When the AC voltage between L1 and N1 is in the positive half cycle, VD1 is turned off due to the reverse bias voltage, and VD2 is turned on due to the forward bias voltage. At the same time, the negative half cycle voltage at the lower end is simultaneously applied to the negative electrode of VD3 and the positive electrode of VD4, so that VD4 is turned off and VD3 is turned on. That is, when the AC voltage is in the positive half cycle, VD2 and VD3 are simultaneously turned on; when the AC voltage is in the negative half cycle, VD1 and VD4 are simultaneously turned on. The working principle between L2 and N2 is the same as that of L1 and N1, thus achieving the input and seamless switching of the dual power supply through the turn-on and turn-off of the diode.

2.2 Analysis of FTU's protection configuration

There are many types of feeder terminal units, which are usually divided into three remote feeder unit and two remote feeder unit. The main configuration protections of FTU include overcurrent protection, ground protection, reclosing, and so on. Some lines that require high speed and reliability are also equipped with line differential protection[9-10].

In order to improve the sensitivity of overcurrent protection, overcurrent protection is generally selected to be controlled by multi-voltage. In order to improve the selectivity of overcurrent protection, overcurrent protection generally chooses whether to lock by direction.

Since the negative phase sequence operation of the line mainly affects the multi-voltage and directional components, the following mainly analyzes the action logic of the multi-voltage and directional components. Figure 4 is a logic diagram of the overcurrent protection by the direction and multi-voltage blocking. In the figure, VCE indicates that the multi-voltage condition is satisfied, and DIR indicates that the directional condition is satisfied.

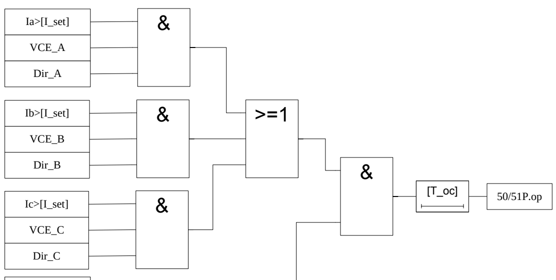

Figure 4 Overcurrent protection logic diagram

The detailed logic diagram for the multi-voltage control element of phase A for overcurrent protection is shown in Figure5. The logic diagrams for voltage control elements of phase B and phase C can be gotten on the analogy of this.

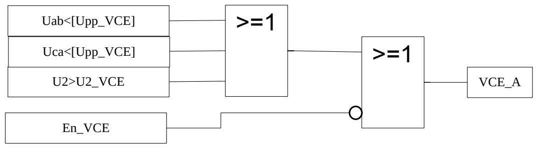

Figure5 Logic diagram of the multi-voltage control element of phase A

Where:

[Upp_VCE] is the voltage setting of the undervoltage control element;

[U2_VCE] is the voltage setting of the negative sequence voltage control element;

[En_VCE] is the logic setting of the voltage control element for the OC protection.

For directional overcurrent protection, phase fault components are internally polarized by the quadrature phase-to-phase voltages. Under system fault conditions, the fault current vector will lag its nominal phase voltage by an angle dependent upon the system X/R ratio. In order to ensure that the relay has the maximum sensitivity for currents lying in this region, it is generally achieved by the relay characteristic angle (RCA) setting[11]. Fig. 6 is a characteristic diagram of a directional element.

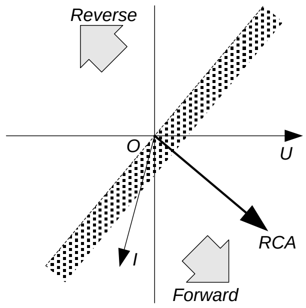

Figure6 Characteristic of the directional element

In order to eliminate the dead zone of the directional component, the directional component generally would store the pre-fault positive sequence voltage information and then apply it to the directional overcurrent elements. If there is a close up three-phase fault happen which cause the polarization voltage very low, it will also ensure the directional overcurrent components work correctly.

3 Influence of negative sequence operation of the line on FTU

3.1 Impact on the power supply of FTU

It is assumed that the B-phase and C-phase commutation operations are performed on the primary side without corresponding adjustment on the secondary side, which will result in the negative sequence operation state. The power supply schematic diagram after commutation is shown in Fig. 7.

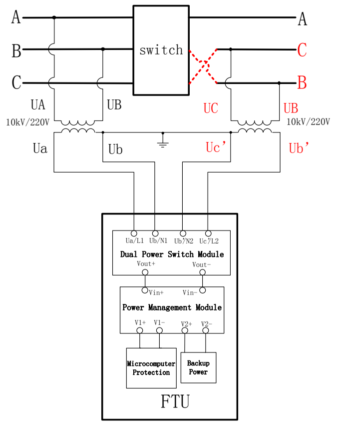

Figure7 Schematic diagram of FTU's power supply after commutation at switch

As can be seen from Figure 7, the voltage phase sequence of the access FTU is no longer consistent with the definition. In the case where the primary line voltage is 10kV rated voltage, the voltage between L1 and N1 is AC220V, and the voltage between between L2 and N2 is also AC220V, but the voltage between L1 and L2 is no longer AC220V. The voltage between L1 and L2 (ie, the voltage between the PT secondary sides U_a and $U_{b'}$ in Figure 3) is analyzed.

If the primary side three-phase voltage is symmetrical, the line voltage amplitude is the rated value of 10kV, assuming the primary side line voltage $\dot{U}_{AB} = 10\angle 0^o kV$, $\dot{U}_{BC} = 10\angle 240^o kV$, $\dot{U}_{CA} = 10\angle 120^o kV$. Then the primary side voltages of the PTs on both sides of the switch are:

$$\begin{cases} \dot{U}_{AB} = \dot{U}_B - \dot{U}_A = 10\angle 0^o kV \\ \dot{U}_{BC} = \dot{U}_C - \dot{U}_B = 10\angle 240^o kV \end{cases} \quad (1)$$

Where: $\dot{U}_A, \dot{U}_B, \dot{U}_C$ represent the phase voltage on the primary side of the line; $\dot{U}_{AB}, \dot{U}_{BC}, \dot{U}_{CA}$ represent the line voltage on the primary side of the line.

Since the two sides of the switch are two separate single-phase voltage transformers with a ratio of 10kV/220V, the PT secondary voltages on both sides of the switch are:

$$\begin{cases} \dot{U}_{ab} = \dot{U}_b - \dot{U}_a = 220\angle 0^o V \\ \dot{U}_{b'c'} = \dot{U}_{c'} - \dot{U}_{b'} = 220\angle 240^o V \end{cases} \quad (2)$$

Where: $\dot{U}_{ab}$ and $\dot{U}_{b'c'}$ represent the secondary voltage of the left PT and the right PT of the switch; $\dot{U}_a, \dot{U}_b, \dot{U}_{b'}, \dot{U}_{c'}$ are the phase voltages of the secondary side.

Since the PT secondary B phase on the left side of the switch and the secondary C phase on the right side of the switch are directly grounded after the commutation, the voltage of $\dot{U}_{ab'}$ between the L1 and L2 connected to the dual power supply switching module is:

$$\dot{U}_{ab'} = \dot{U}_{ab} + \dot{U}_{c'b'} = \dot{U}_{ab} - \dot{U}_{b'c'} \quad (3)$$

Substituting the formula (2) into the formula (3), we can find $\dot{U}_{ab'} = 380\angle 30^o V$. That is, the voltage between L1 and L2 is 380V, which is 1.732 times before the commutation.

If the relay dual power supply switching principle is used, the contact withstand voltage of the relay is required to increase by 1.732 times, which the long-term operation will accelerate the aging of the relay and increase the failure rate of the dual power supply switching module.

If the dual power supply switching using the rectifier bridge principle, a sinusoidal voltage waveform between L1 and L2 is shown in Fig. 8.

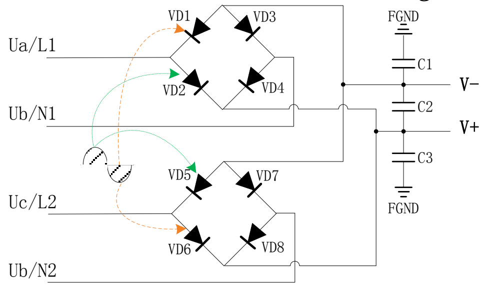

Figure 8: Conduction diagram when input between L1 and L2

When the AC voltage between L1 and L2 is in the positive half cycle, VD2 and VD5 are simultaneously turned on; When in the negative half cycle, VD1 and VD6 are simultaneously turned on. That is, the voltages of the output voltages V_out+ and V_out- are the voltages between L1 and L2, which is 1.732 times the normal voltage, and the overvoltage may cause damage to the internal components of the FTU.

It can be seen that in order to prevent the influence of the negative sequence operation of the line on the FTU power supply, it is necessary to increase the withstand voltage level of the FTU power supply. If 1.2 times the margin is considered, the long-term withstand voltage level of the FTU's power supply should be greater than 2 times the rated value. At this time, it is guaranteed that the power supply of the FTU will not be damaged when the phase sequence is wrong.

3.2 Impact on the protection configuration of FTU

There is no influence on the phase voltage and current amplitude after the negative sequence operation of the line, but it will affect the phase sequence and phase angle between the phases of the feeder terminal.

For the overcurrent protection without the direction, the protection action logic is generally only related to the amplitude and the duration of the fault current, and has nothing to do with the phase sequence. Therefore, the line operating in the negative sequence does not affect the protection of the pure overcurrent principle.

For multi-voltage overcurrent protection, because the multi-voltage component is composed of phase-to-phase low voltage and negative sequence overvoltage in OR logic, the negative sequence overvoltage condition will be satisfied when the line is in the negative sequence operation state. Therefore, the multi-voltage component will always act, which causes multi-voltage overcurrent protection become to pure overcurrent protection and the protection be easily mis-operated due to the lack of a lockout condition.

For directional overcurrent protection, the phase fault elements of this relay are internally polarized by the quadrature phase-to-phase voltages, as shown in the table below:

Table 1 Relationship between operate current and polarizing voltage

Phase of Protection	Operate Current	Polarizing Voltage
A Phase	Ia	Ubc
B Phase	Ib	Uca
C Phase	Ic	Uab

When the phase sequence of the line is wrong, the direction of the operate current and the polarizing voltage does not correspond to the normal situation, which causes the directional component cannot be truly reflect the fault in or outside the zone. The protection is likely to be rejected when the fault occurs in the zone, and it may be mis-operated when the fault occurs outside the zone.

For the reclosing protection, since the distribution network line basically does not operate in a loop, generally it does not require the synchronization function, so the negative sequence operation of the line usually does not affect the reclosing protection. For the line fiber differential protection, there will be a difference current if the phase sequence of the line's two ends is not completely consistent, and then the differential protection may be mis-operated easily[12].

It can be seen that the negative phase sequence operation of the line has a great influence on the protection logic judgment with phase and direction. In order to instantly discover that the line is in negative sequence operation, FTU can add phase sequence alarm function. When the negative sequence or disconnection of the line is detected, the line alarm signal is automatically issued, and when the line voltage returns to normal, the alarm signal is returned automatically. The alarm signal is sent to the master station, and the personnel accurately locate the problem circuit according to the alarm signal, thereby improving the distribution network management efficiency.

In addition, there is a wide range of suppliers and types of equipment for primary distribution equipment. In order to improve the efficiency of secondary rerouting, FTU can increase the function that the phase sequence definition can self-adjusted through software. For example, the B-phase voltage is wrongly connected to the voltage channel of FTU's A phase, and the voltage of the A phase is wrongly connected to the voltage channel of FTU's B phase. If the A-phase and B-phase voltage channels can be redefined only by modifying the FTU's setting value without changing the wiring, it would greatly improve the compatibility of the FTU device with the primary device, and greatly reduce the workload of the staff.

4 Case Studies

In early 2017, a power supply company in Shandong Province carried out a side commutation operation on a certain 10kV power distribution contact line during the reconstruction of distribution network line. Power transmission was resumed after the reconstruction. After several weeks of operation, the communication between FTU at the power distribution switch and the primary station interrupted, as a result of internal power module damage of feeder terminal unit .

The FTU device on the line had been in normal operation state for several months before reconstruction. After the reconstruction, only the primary circuit at the switch was commutated, and there was no change to the PT, CT and secondary circuits. The line entered negative sequence operation because of the lacking of checking phase and planning. Thereafter, the input power of the FTU passed through the dual power module in principle of rectifier bridge, thus the output voltage became 1.732 times of the rated voltage. Overvoltage operation for a long time eventually caused the damage to the device.

The area checked the phase sequence of the distribution line after the problem occurred. However, due to the large number of distribution lines, and the wide range and dispersed locations of terminal installation, the workload of line management and verification workload was very heavy. Even though the problem was discovered, it would often take a long time to perform power interruption and reconstruction, and face so many obstacles regarding to its implementation, as a result of the wide variety of power distribution equipment and their numerous suppliers as well as non-uniform manufacturing standards and interfaces.

In order to prevent similar accidents in the future, the area had improved power distribution terminal in subsequent renovation or new equipment as follows :

Added phase sequence alarm function. When an abnormal negative sequence voltage was detected, the FTU automatically would give an alarm signal, which could be displayed locally or sent to the main station, so as to promptly remind the operation and maintenance personnel of the problem line.

In order to further improve the reliability of power supply and the management efficiency of distribution lines, several measures had been taken. A unified interface standard was proposed on new equipment. The voltage endurance capability of power management module in power distribution terminal were required to raise to more than 2 times of the rated value. The phase sequence of access device should be adjustable by software.

According to above measures, there was no case of damage or mis-operation of FTU caused by negative sequence operation after line reconstruction. It generally avoided the troubles that caused by negative sequence operation of the line, and greatly improved the management efficiency of the distribution network line and the reliability of FTU.

5 Conclusion

There is a wide range of suppliers and types of distribution equipment, which the number is numerous and the installation location is scattered. In the process of line commutation or equipment change, there is a risk that the line will be in negative sequence operation if the commutation or change not been inspected in time, which would affect the normal operation of FTU. In this paper, the FTU's protection configuration and power supply's principle are studied. Combined with the characteristics of line negative sequence operation, the following suggestions are proposed to improve the efficiency of distribution network management and the reliability of FTU.

(1) FTU should add phase sequence alarm function. When an abnormal negative sequence voltage was detected, the FTU would automatically give an alarm signal, which could be displayed locally or sent to the main station, so as to promptly remind the operation and maintenance personnel of the problem line.

(2) In order to improve the reliability of the FTU power supply and the management efficiency of distribution lines, the voltage endurance capability of power management module in FTU should raise to more than 2 times of the rated value.

(3) In order to reduce the workload of field staff rework and improve the efficiency of line management, the phase sequence of access FTU should be adjustable by software.

References

[1] Wu zhili,Wang Xuyang. Reflections on Implementation of the 13th Five-Year Distribution Network Planning[J].Electric Power, 2017, 50(1):25-29.

[2] Fu Jundong, YU Yong, HUANG Laifu .A more economical compensation method for unbalanced load[J]. Power System Protection and Control, 2015(2):126-132.

[3] Lu Huibin,Xu Yong,Wu Yuxiang, et al.Study on Three Phase Unbalance Control Device Based on Commutation Technology[J] Power Capacitor & Reactive Power Compensation ,2016, 37(6):64-69.

[4] Li Zhenguo, XING Xiaohua, CHENG Yanxia. The Effect of Substation Primary System Negative Sequence on the Protection Device and Its Improvement Method[J].Shanxi Electric Power, 2013(1):31-33.

[5] Zhou N C, Jia Y H, Yuan Z. Feeder Terminal Unit Based on System Protection to Distribution Network[J]. Automation of Electric Power Systems, 2006, 30(8):94-97.

[6] Mao G, Xue C, Wang B. Self-test and Auto-switching Dual Adjustable Power Supply Module[J]. Electronic Science & Technology, 2013.

[7] Ahmed S, Flett F, Patwardhan A V, et al. Dual power module power system architecture: US, US6987670[P]. 2006.

[8] Hu H M, Shi Y J, Zhang Y H, et al. Study on Power Supply of the Feeder Terminal Equipment[J]. Applied Mechanics & Materials, 2014, 672-674:914-919.

[9] Sun K, Chen Q, Zhao P. Automatic Faulted Feeder Section Location and Isolation Method for Power Distribution Systems Considering the Change of Topology[J]. Energies, 2017, 10(8):1081.

[10]Liu S. Design and Realization of Feeder Terminal Unit Based on DSP[J]. Journal of East China Jiaotong University, 2009, 1:101-104.

[11] Chen shi, Tai Nengling, Fan Chunju, et al. An Adaptive Current Protection for Weak-Infeed Distribution Lines with Wind Generation[J]. Transactions of China Electrotechnical Society, 2017, 32(3):65-73.

[12] Guo Runsheng, He Caihong. The Influence of Negative Phase Sequence System to Differential Protection fo Main transformer[J] Power System Protection and Control, 2008, 36(24):113-117.

Author's brief introduction:

Zeng Xianfeng (1987-), Male, Xiaogan City, Hubei Province, China, Master, Engineer, mainly engaged in power system relay protection and control research.