Simulation of criteria for selection of remote protection settings with remote starting in lines with distributed sources

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Abstract. The article presents the conditions of coordination of adjacent remote protections with remote start-up, considering the peculiarities of parameters, operating modes and operating conditions of partitioned branched distribution lines. The influence of parameters and modes of operation of such lines on the technical characteristics of these protections, in particular, on the range of control settings for resistance and operating time at the end of the range and the requirements for the linearity of time characteristics. It is recommended to use the results of the conducted research for adjustment of remote protections of partitioned lines with sources of distributed generation. In order to ensure the selective action of protection in different modes of operation of the lines and the convenience of choosing the settings of operation, the time characteristic of the protection must be linear. In addition, the linearity of the protection time characteristic allows the operation time value to be used to determine the distance to the short circuit location. Due to the need to debug the protection by the time of operation from the operation of the arresters and from burnout of the fusible insert fuses soldering in the event of a short circuit directly behind the fuse, the initial duration of protection should be 0.25…0.40 s.

1. Introduction
Remote protections, which by their principle of operation selectively disable damage in networks of any configuration [1], are widely used in networks 35…110 kV and above [2]. Such protections use remote instantaneous relays with different characteristics in the complex plane [3] and have separate current [4] and remote starting bodies [5]. Such protections by their technical characteristics and performance do not meet the requirements of protection of 10 kV distribution lines with distributed generation sources [6], because on these lines it is advisable to use remote protection with remote start [7] and dependent on the resistance of the short circuit loop time delay [8]. In addition, remote protections required for branched distribution networks with relatively small capacities of protected lines must be characterized by the necessary technical characteristics [9] and low cost [10], ease of installation and maintenance [11]. In a number of publications, in particular [12], the problems of using relay protection for distribution networks with network redundancy and distributed generation sources are considered. Attention is paid to the peculiarities of protection operation in different modes of operation of such networks, namely: normal [13] and post-emergency [14].

The protection of lines with distributed generation sources must meet the general requirements of ensuring the necessary sensitivity [15], selectivity of action for different types of damage [16]. Difficulties in providing the required sensitivity when using the maximum current protections [17] and...
current cut-offs in such networks [18] are caused by the low level of short-circuit currents from backup sources [19]. The peculiarities of relay protection in partitioned networks when powered by backup sources are given [20].

Dependences of distribution of short-circuit currents on the highway of the sectioned line in the mode of work with the disconnected point of automatic switching on of a reserve [21] and in the power supply mode from a reserve substation at average parameters of lengths and resistances of sections show that the current cut-off established on the main section sectioning point [22], provides protection of approximately 67% of the highway of the first section of the line [23]. The cut-off installed at the sectioning point [24], debugged from the maximum short-circuit current in the adjacent section [25], provides protection of only 20% of the line of the line when powered by the main source [26].

The power supply from the backup short-circuit current in the protected area is much smaller than the current cut-off setpoint at the sectioning point, so in this case, the current cut-off set at the sectional circuit breaker is ineffective [27].

In modern conditions of development of distributed generation sources the problems of improvement of relay protection for distribution networks with distributed generation sources are investigated [28]. Attention is paid to the peculiarities of protection operation in different modes of operation of such networks, namely: normal and post-emergency [29]. The protection of lines with distributed generation sources must meet the general requirements of ensuring the necessary sensitivity, selectivity of action for different types of damage [30]. Difficulties in providing the required sensitivity when using the maximum current protection and current cut-off in such networks are caused by the low level of short-circuit currents from backup sources [31]. Peculiarities of relay protection execution in partitioned networks at their power supply from distributed generation sources are given [32].

2. The aim and objective of research
The aim of the work is the expediency of using remote starters of remote protection to increase the sensitivity of protection of partitioned lines with sources of distributed generation is substantiated.

Research of operating modes, parameters of lines with sources of distributed generation and criteria of definition of settings of remote protections with dependent endurance of time for these lines allow to define the basic technical characteristics of the specified protections: range of adjustment of settings on resistance and time of operation; the nature of the dependence of the time of operation of the protection against resistance on the input terminals of the relay; current of 10% of accuracy of operation of protection; permissible limits of inaccuracy of protection settings; limits of initial time of protection operation; arrangement of protection and its repair taking into account operating conditions.

3. Materials and methods
Distributed lines with distributed generation sources (even in the mode of open point of automatic switching on of the reserve) from the point of view of ensuring selectivity of action have the same requirements for protections as lines with the point of automatic switching on of reserve. Lines with two-way power supply, so to perform sensitive and selective protection of such lines, it is advisable to use remote protections with remote start and dependent on the resistance of the loop short circuit time delay. The increase in their sensitivity compared to current is on average 50% for the protection of the main sections and 60% for the protection installed on the sectioning points, and for the latter the required value of the sensitivity factor of 1.5 is provided in 95% of cases.

Such protections provide selective disconnection of damages on protected sites in all modes of operation of partitioned lines with devices of automatic switching on of reserve and with sources of distributed generation, provide coordination of protections of main sites with protection of power substations with smaller time delay of the last 10/0.4 kV. To do this, when using non-directional remote protections, the time characteristics of adjacent protections must have the same slope (figure 1). To select the most effective ways to perform remote protections and develop recommendations, it
is necessary to determine the technical characteristics of protection. To do this, determine the conditions of coordination and selection of protection settings for resistance and operating time at the end of the range. The conditions for selecting the protection resistance are determined in four steps.

**Figure 1.** Coordination of working remote protections with dependent time delay in different modes of operation of partitioned lines with sources of distributed generation: ______ – power supply from substation 1; __. __. __ – power supply from substation 2; 1, 5 – switches of the main sections of lines; 2, 4 – sectioning switches; 3 – point of automatic inclusion of reserve.

The first step. The need to ensure the required sensitivity at the end of the protection zone:

\[ Z_{\text{ust}} \geq K_{ch} \cdot Z_{zah}, \]  \( (1) \)

where \( Z_{\text{ust}} \) – setting of resistance of operation of remote protection, Ohm; \( K_{ch} \) – protection sensitivity factor; \( Z_{zah} \) – resistance on terminals of the protection relay at short circuit in the most remote settlement point of a protection zone, Ohm;

The second step. The need for debugging from the minimum design resistance on the relay terminals in the normal mode of operation of the line – \( Z_{r.n.} \):

\[ Z_{\text{ust}} < Z_{r.n.} \cdot (K_{n.d.} \cdot K_{p.d.})^{-1}, \]  \( (2) \)

where \( K_{n.d.}, K_{p.d.} \) – coefficients, respectively, reliability and return of remote protection;

The third step. The need for debugging of 0.4 kV busbars transformers of consumer substations:

\[ Z_{\text{ust}} < K_{n1} \cdot Z_{0-TP}, \]  \( (3) \)

where \( Z_{0-TP} \) – resistance from the place of installation of protection to 0.4 kV busbars of the most powerful of the consumer transformer substations located near the place of installation of protection, Ohm; \( K_{n1} \) – reliability coefficient, which takes into account the error of protection operation, measuring transformers;

The fourth step. Coordination with protection of the adjacent site on resistance of operation:

\[ Z_{\text{ust}} \ll (Z_{\text{ust.nast.}} + Z_{m.}) \cdot K_{n2}^{-1}, \]  \( (4) \)

where \( Z_{\text{ust.nast.}} \) – resistance of the next protection, placed closer to the place of damage, Ohm; \( Z_{m.} \) – resistance along the line to the place of installation of the next set of protection, Ohm; \( K_{n2} \) – reliability factor, which takes into account the error in the resistance of the protection and the protection of the adjacent area.

Thus, the condition for selecting the resistance can be written in the form (figure 2):
The resistance of the protection is determined by the largest of the resistances of adjacent areas. To ensure the selective operation of the protections in different power supply modes of the partitioned line, the time characteristics of the protections acting on the disconnection of switches installed on the line of the line must be adjusted with one angle of inclination. For convenience of adjustment of characteristics of protections and possibility of their use for indication of a place of damage it is desirable to provide linear dependence of time of operation of protection against resistance on terminals of the relay. The operation time of the protection at the end of the coverage area is determined by the following conditions:

- The need to ensure the degree of selectivity \( \Delta t_s.z. \) in case of damage near the place of installation of the next switch on the line (sectional or automatic switching point of the reserve) (figure 2);
- The need to debug the protection against the time of burnout of fuse-links of consumer substations in case of damage to transformers when the resistance to the place of damage is in the area of protection.

4. Results and discussion

Fulfillment of this condition when using remote protections with dependent time delay is ensured, because the resistances of consumer transformers with a capacity of 100 to 420 kVxA vary within 60.6...14.4 Ohm, which exceeds the resistance of the partitioned section of the line.

Therefore, for high-power branches located near circuit breakers (protection), a short circuit behind a consumer substation transformer is equivalent to damage at the end of the protection zone or even in an adjacent area, which allows to coordinate remote protections with fuses on taps during operation. To ensure the first condition, the time of operation of the protection at the end of the zone must meet the condition:

\[
t_{s,z} \gg (t_{s,z.0} + \Delta t_{s,z}) \cdot Z_{ust} \cdot Z^{-1}_{m},
\]

**Figure 2.** To determine the operating conditions of the remote protection with remote start and dependent time delay.
where $t_{s,z,0}$ – time of operation of the next set of protection at the beginning of the zone of action, s; $\Delta t_{s,z}$ – degree of protection selectivity, s; $Z_m$ – resistance on the highway to the place of installation of the following protection, Ohm.

At a certain maximum duration of action at the end of the zone, this condition is decisive when choosing $Z_{ust}$ protection since:

$$t_{\max} \cdot (t_{s,z,0} + \Delta t_{s,z})^{-1} \gg Z_{ust} \cdot Z_m^{-1}. \quad (8)$$

Then,

$$Z_{ust} \ll Z_m \cdot t_{\max} \cdot (t_{s,z,0} + \Delta t_{s,z})^{-1}.$$

This interdependence in the choice of settings for resistance and time of operation of the protection is due to the fact that the protection must contain a remote starting body and the body of the dependent endurance time.

Based on the need to ensure the sensitivity and selectivity of operation in different modes of operation of the line, as well as coordination with the operation of fuses installed on consumer transformer substations, the conditions for selecting protection settings can be represented as follows:

$$K_{ch} \cdot Z_{zah} < Z_{ust} < \left\{(K_{n.d} \cdot K_{p.d})^{-1} \cdot (Z_{ust,nast} + Z_{m}) \cdot K_{n,2}^{-1}, \quad (9)\right.$$ 

$$t_{s,z} \cdot (t_{s,z,0} + \Delta t_{s,z}) \cdot Z_{ust} \cdot Z_m^{-1}. \quad (10)$$

The above relations (9), (10) are the main criteria for selecting remote protection settings with remote start and dependent time delay and are necessary to determine their technical characteristics.

The range of adjustment of protection settings on resistance of operation is defined from conditions (9) and parameters of the partitioned lines.

Given that the primary values of the resistance of the sections are within 1…50 Ohm, and the values of the transformation coefficients of current transformers $n_t$ within 5…20 and voltage transformers at the points of partitioning and automatic switching on the reserve $n_m=50$, the limits of resistance settings operation on secondary values should be from 0.1 to 8.0 Ohm.

The range of adjustment of settings by operation time is selected under condition (10).

Then $(t_{s,z} + \Delta t_{s,z}) = 0.6 \ s$ and $Z_{m}/Z_{ust} = 0.1…0.5$ for most lines, the time of operation of the protection at the resistance on the clamps is equal to 0.9 $Z_{ust}$, must be adjusted within 1…6 s.

In order to ensure the selective action of protection in different modes of operation of the lines and the convenience of choosing the settings of operation, the time characteristic of the protection must be linear.

In addition, the linearity of the protection time characteristic allows the operation time value to be used to determine the distance to the short circuit location.

5. Conclusions

1. The values of short-circuit currents in different modes of operation of the lines differ significantly and for the selective operation of the protection at the selected settings for the time of operation it is necessary to ensure unambiguous time characteristics when changing levels of operating protection currents. Therefore, it is necessary to ensure 10% accuracy of the protection of the resistance of operation within the currents of 4…75 A at a setting of 0.4 Ohm per phase.

2. To ensure the selective operation of sets of adjacent sections in the selected range of settings for the operation time 1…6 s taking into account the limits of change $Z_{m}/Z_{ust}$ from 0.1 to 0.5 difference in operating time at resistance $Z=0.9 \cdot Z_{ust}$ should not exceed 20% at the maximum setting time from 2 s to 6 s and no more than ± 0.2 s at the maximum operating time of 1…2 s.

3. Due to the need to debug the protection by the time of operation from the operation of the arresters and from burnout of the fusible insert fuses soldering in the event of a short circuit directly behind the fuse, the initial duration of protection should be 0.25…0.4 s.
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