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Modern pilot schemes for coordination of line distance protection relays

***Abstract**. The paper presents a short review of common pilot schemes which are available in modern line distance protection relays. Some differences in implementations of selected pilot schemes have been shown for comparison reasons. The paper raises the issue of two-relay transmission line protection system and desirability of pilot schemes usage for solving certain problems.*

***Streszczenie.** Artykuł przedstawia krótki przegląd typowych układów koordynacji, dostępnych w nowoczesnych zabezpieczeniach odległościowych linii elektroenergetycznych. Dla porównania zostały ukazane pewne różnice w implementacjach wybranych układów koordynacji. Artykuł porusza kwestię dwu-przekaźnikowych systemów zabezpieczeń linii przesyłowych oraz celowości zastosowania układów koordynacji dla rozwiązania niektórych problemów. (**Przegląd nowoczesnych układów koordynacji działania zabezpieczeń odległościowych linii elektroenergetycznych**).*

Keywords: power system protections, substation protections, transmission lines.
Słowa kluczowe: automatyka zabezpieczeniowa, zabezpieczenia stacyjne, linie przesyłowe.

Introduction

High-voltage power transmission lines are not dead ended in general. Fast tripping at each end of such a line is necessary to safely clear the occurring internal faults. It is essential because of the risk of equipment damage. However, fast fault clearance in transmission lines is also important for power system stability.

The ability to distinguish internal from external faults for every zone and for both directions seems to be the main advantage of time-stepped distance protection. Nevertheless the limitation of instantaneous zones reach causes inability of fast two-ended tripping for some internal fault locations, in case of autonomous work of distance relays at each end of transmission line.

The problem of two-relay transmission line protection has been illustrated in Fig. 1. None of the relays can be set to cover the whole of protected line within the instantaneous zone 1 (Z1). The zone 1 reach is usually set to 80%-90% of the protected feeder length, for each of relays. So the resultant two-sided immediate-tripping reach covers 60%-80% of the total feeder length. Moreover, both end sections of the protected line (each comprising 10%-20% of its length) are one-sided covered by zone 2 (Z2), which results in some delay (typically 0.2 to 0.4 seconds) of tripping for the faults that occurs at this section.

One solution to the problem of partial fast-tripping line protection is the use of pilot schemes for coordination of distance relays operations, using the communication channel and predefined or customized relay functions.

Wide range of implemented interoperability functions and advanced programmable logic gives an opportunity to adapt protection devices to almost all prevalent conditions. Communication channels for pilot scheme signals transmission might be realized using a number of link types, standards and transmission protocols [1 - 4]. More and more modern protection devices have such protocols in their built-in transmission system.

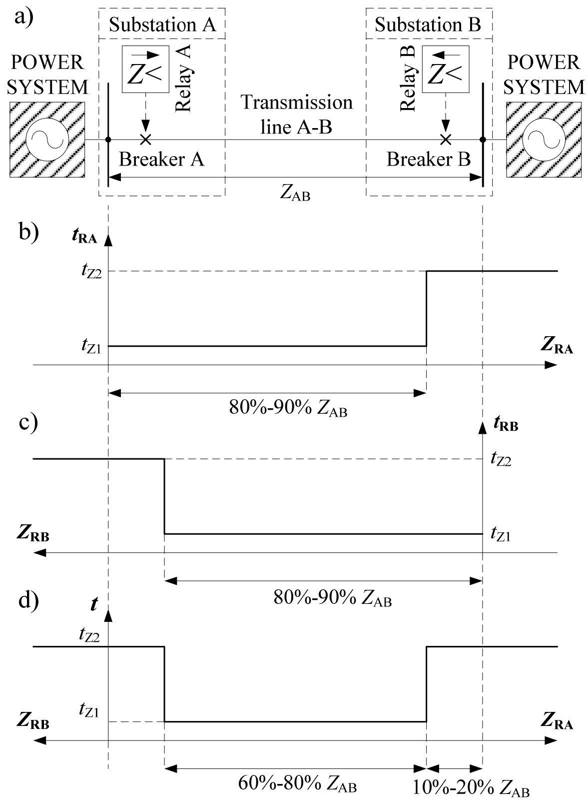

Fig. 1. The idea of transmission line protection using two distance relays working autonomously: a) protected transmission line A-B, b) time-stepped characteristic for relay A (RA), c) time-stepped characteristic for relay B (RB), d) resultant time-stepped characteristic for the entire line protection

Common pilot schemes

Pilot-aided schemes, used for coordination of line distance protection relays, may be split into two groups:

- Tripping schemes, which can be divided into:
  - direct,
  - permissive;
- Blocking schemes, which can be classified into two types:
  - blocking.
  - unblocking.

In general, five common pilot schemes can be distinguished:

- Direct Under-reaching Transfer Trip (DUTT),
- Permissive Under-reaching Transfer Trip (PUTT),
- Permissive Over-reaching Transfer Trip (POTT),
- Directional Comparison Blocking (DCB),
- Directional Comparison Unblocking (DCUB).

Besides the above-mentioned types of pilot schemes, some special interoperability solutions may be implemented in certain modern protection devices.

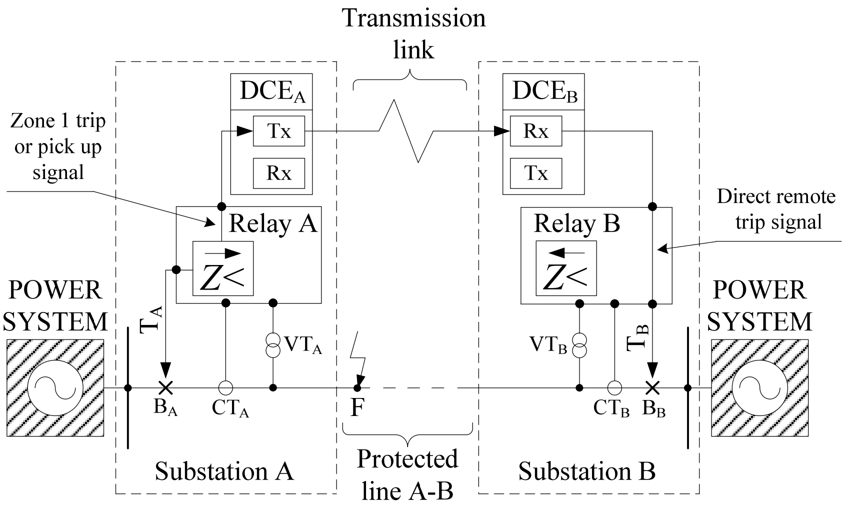

Fig.2. Simplified diagram of DUTT scheme (B – breakers, CT – current transformers, VT – voltage transformers, T – tripping signals, DCE – Data Communication Equipment, Tx – transmitters, Rx – receivers, F – fault location) for an internal fault

Direct Under-reaching Transfer Trip (DUTT)

DUTT scheme uses only under-reaching zone 1 (Fig. 2). When a fault (F) occurs within the reach of this zone, the local relay (A) generates trip or pick up signal (depending on the DUTT function implementation) which is then sent to the remote end through the communication channel. The remote relay (B) receives that signal and generates tripping signal (T_B) without any local permission.

DUTT is not the most commonly used pilot scheme for transmission line protections due to its credibility level and the risk of power system stability loss - from non-power fault tripping.

Permissive Under-reaching Transfer Trip (PUTT)

PUTT scheme (Fig. 3) is one of the permissive pilot schemes. Zone 1 trip or pick up signal (after the fault occurrence) is used for forwarding transfer trip signal to remote relay (B). However, tripping signal generation in remote substation (B) is conditioned by an additional supervision, which is local pick up signal for one of forward zones.

PUTT is generally interference-immune pilot scheme. False remote trip signal is not relevant without local fault notice in forward direction.

Permissive Over-reaching Transfer Trip (POTT)

POTT scheme uses over-reaching zone 2 (e.g. in General Electric UR-series devices [5]) or initially extended zone 1 (e.g. in Siemens SIPROTEC devices [6]) to generate trip signal for transmission to remote relay. POTT scheme simplified principle of operation has been illustrated in Figure 4.

Tripping signal is generated by each of relays after the fulfillment of two conditions:

- Local picking up in over-reaching zone 2 or initially extended zone 1.
- Receiving remote trip signal from the other substation.

Some implementations of POTT scheme (e. g. in GE UR-series) might use additional conditions, such as pick up of ground directional overcurrent protection function (in forward or reverse direction). These solutions help to increase the credibility and reliability of the protection system operations in unfavourable system conditions (e. g. high-resistance faults).

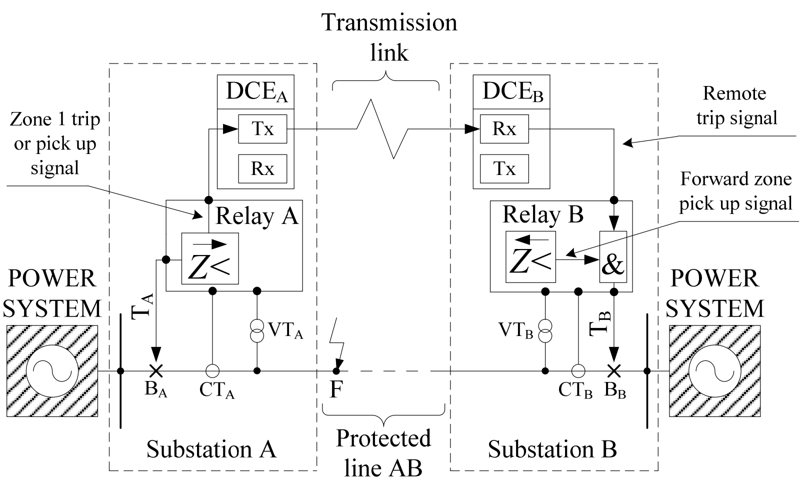

Fig. 3. Simplified diagram of PUTT scheme (B – breakers, CT – current transformers, VT – voltage transformers, T – tripping signals, DCE – Data Communication Equipment, Tx – transmitters, Rx – receivers, F – fault location) for an internal fault

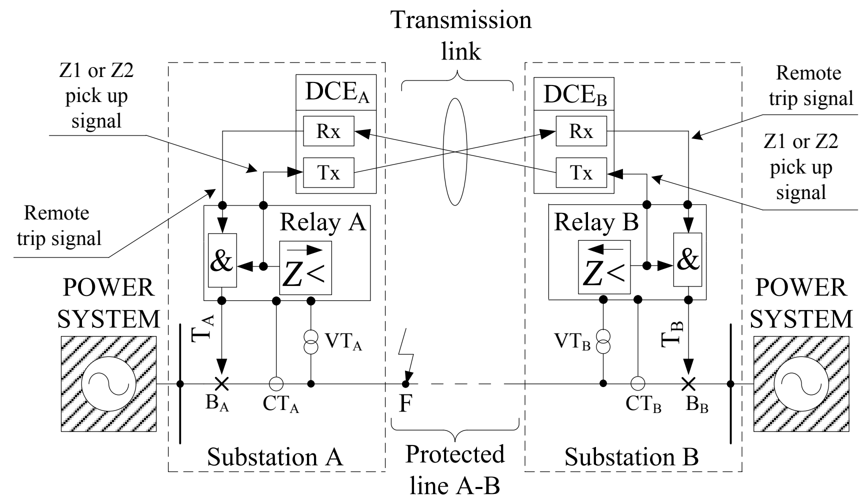

Fig. 4. Simplified diagram of POTT scheme (B – breakers, CT – current transformers, VT – voltage transformers, T – tripping signals, DCE – Data Communication Equipment, Tx – transmitters, Rx – receivers, F – fault location) for an internal fault

Directional Comparison Blocking (DCB)

DCB is the first blocking scheme to be presented. Two common implementations of this scheme can be distinguished:

- A scheme, which uses zone 2 of each relay to compare the direction of the fault notice (e.g. GE UE-series solution).
- Another scheme, which uses extended zone 1 of each relay for direction comparison (e.g. Siemens SIPROTEC solution).

When an internal fault occurs (which is seen in forward direction by both relays) no signals are transmitted, so fast tripping signals are generated autonomously by each relays, but (for remote relay) after short time delay (*td*) dedicated to awaiting a possible blocking signal.

In case of an external fault (Fig. 5), blocking signal is generated by relay which sees this fault in reverse direction. It is transmitted to remote line end, where the other relay blocks local tripping signal.

Directional Comparison Unblocking (DCUB)

DCUB scheme may be applied using two analogous implementations, as for DCB scheme. Nonetheless, this time remote signal is an unblocking signal (Fig. 6).

An occurrence of internal fault will lead to the generation of unblocking signal, which is considered by the remote relay as a kind of permission for instantaneous tripping.

In case of external fault, no signal is transmitted, so remote relay is unable to unblock the fast tripping.

Special pilot schemes

Some protection devices are equipped with unique interoperability functions. One example is Hybrid POTT function, available in many of GE UR-series devices. In has been designed for tree-terminal lines and uses a few additional advanced functions (such as ECHO function or reverse-looking distance and/or overcurrent protection functions) for the improvement of line protection reliability in special cases, such as weak infeed condition.

Furthermore, the pilot scheme functions do not have to be predefined. Modern protection devices includes advanced programmable logic functions, which give the opportunities to use chosen internal signals to ensure an own-designed way of interoperability (for example a solution tested in [7]), with own-designed tripping conditions. A wide variety of communication standards and protocols, available in modern protection devices, additionally increases the number of possible coordination solutions.

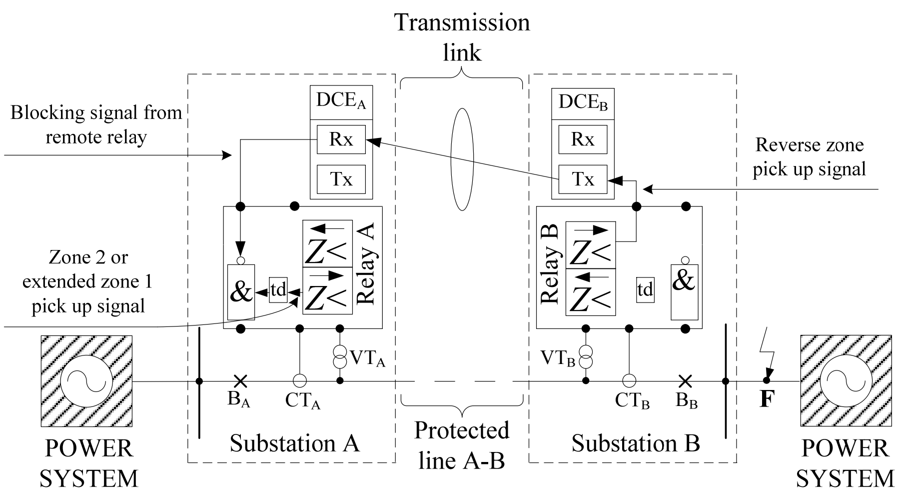

Fig. 5. Simplified diagram of DCB scheme (B – breakers, CT – current transformers, VT – voltage transformers, DCE – Data Communication Equipment, Tx – transmitters, Rx – receivers, F – fault location, td - time delay) for an external fault

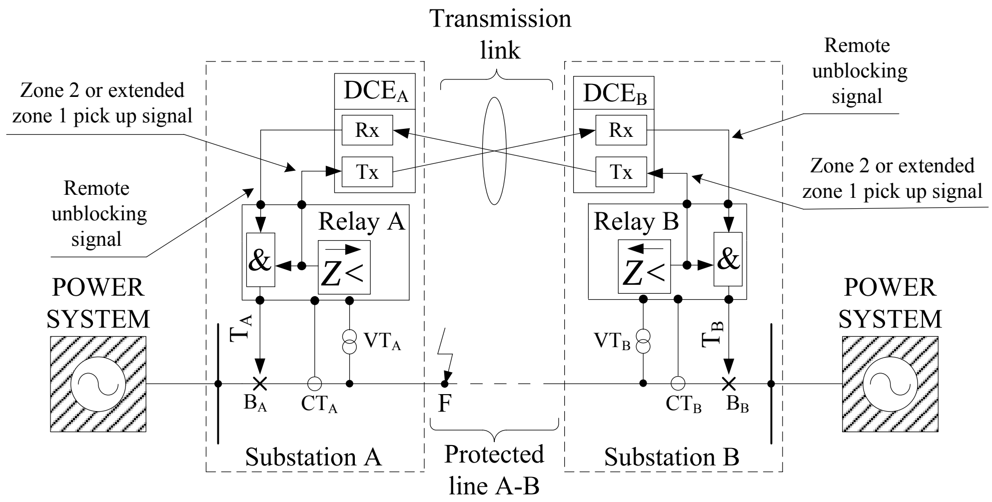

Fig. 6. Simplified diagram of DCUB scheme (B – breakers, CT – current transformers, VT – voltage transformers, T – tripping signals, DCE – Data Communication Equipment, Tx – transmitters, Rx – receivers, F – fault location) for an internal fault

Conclusions

A wide variety of available pilot schemes and possible communications links allows establishing an optimal adaptation of protection system for different technical conditions and operating configurations.

The choice of the one of pilot schemes depends on the level of integration between communication link and main transmission line equipment.

Blocking schemes are used in case of signal transmission through phase conductors, such as Power Line Carrier (PLC). This is justified by the exposure to many kinds of interferences, which may disturb the signal transmission, make it impossible, or even cause false tripping.

Tripping schemes are in turn preferred when communication channels are implemented by using standalone link, such as fiber-optic link, microwave links or using telecommunication technologies, like SDH or PDH digital networks.

Regardless of the types of used pilot scheme and communication link, tripping acceleration for remote relay is going to be significant. It gives an opportunity fast and both-sided clearance of all the internal faults.

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