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Test results of modern pilot schemes for coordination of line distance protection relays

***Abstract**. The paper presents example results of modern pilot schemes tests and the testing methods description. Distance protection coordination functions have been tested for GE Multilin UR-series devices. Every type of available pilot schemes has been checked in synthetic test and during the real coordination between D60 and D90Plus devices. For POTT scheme, coordination between two L90 protections has been realized through the different communication link types, for comparison reasons.*

***Streszczenie.** Artykuł przedstawia przykładowe wyniki badań współczesnych układów koordynacji i opis metod ich testowania. Funkcje koordynacji zabezpieczeń odległościowych zostały przetestowane dla urządzeń serii UR firmy GE Multilin. Każdy dostępny rodzaj układu koordynacji został sprawdzony w teście syntetycznym oraz podczas rzeczywistej koordynacji między urządzeniami D60 i D90Plus. Dla układu POTT, koordynacja między dwoma urządzeniami L90 została zrealizowana za pomocą różnych rodzajów łącza komunikacyjnego, dla celów porównawczych. (**Wyniki badań nowoczesnych układów koordynacji działania zabezpieczeń odległościowych linii elektroenergetycznych**).*

Keywords: power system protections, substation protections, testing of power protections.
Słowa kluczowe: automatyka zabezpieczeniowa, zabezpieczenia stacyjne, testowanie zabezpieczeń.

Introduction

Pilot schemes for coordination of distance relays are an integral part of modern transmission line protection systems. The wide range of implemented interoperability functions and advanced programmable logic gives an opportunity to adapt protection devices to nearly all the prevalent conditions. Communication channels for pilot scheme signals transmission may be realized using a number of link types, standards and transmission protocols [1 – 5]. Protection devices are usually equipped with several of them.

The paper presents the some results of tests performed in the Power Protection and Control laboratory, of the Institute of Power Engineering, Warsaw University of Technology. The research was aimed to investigate operation of real pilot schemes implemented in modern line protection devices manufactured by GE Multilin.

Tests have been performed in three main stages:

- the first stage was two-step synthetic test of each pilot scheme, implemented in D60 device:
  - Direct Under-reaching Transfer Trip (DUTT),
  - Permissive Under-reaching Transfer Trip (PUTT),
  - Permissive Over-reaching Transfer Trip (POTT),
  - Hybrid POTT,
  - Directional Comparison Blocking (DCB),
  - Directional Comparison Unblocking (DCUB);
- the second stage was a set of tests of real coordination between D60 and D90Plus relays, considering all above-mentioned pilot schemes, using protection contact inputs/outputs as direct communication links;
- the third stage includes tests of POTT scheme function for coordination between two L90 devices, with usage of different telecommunication link types:
  - no link (lack of coordination),
  - direct Ethernet/IEC61850 connection with cross-over cable,
  - Ethernet/IEC61850 connection through switches,
  - Ethernet/IEC61850 connected to SDH network through the switches,
  - direct fiber connection in C37.94 standard,
  - fiber optic connection (C37.94) through SDH network.

Modern 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).

DUTT scheme uses only under-reaching zone 1. When a fault occurs within the reach of this zone, the local relay 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 receives that signal and generates tripping signal 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.

PUTT scheme 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. However, tripping signal generation in remote substation is conditioned by an additional supervision, which is local forward zone pick up signal. PUTT is generally interference-immune pilot scheme. False remote trip signal is not relevant without local fault notice in forward direction.

POTT scheme uses over-reaching zone 2 (e.g. in General Electric UR-series devices [6]-[8]) or initially extended zone 1 (e.g. in Siemens SIPROTEC devices [9]) to generate trip signal for transmission to remote relay. 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.

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 relay, but (for remote relay) after short time delay dedicated to awaiting a possible blocking signal. In case of an external fault, 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.

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

Besides the above-mentioned types of pilot schemes, some special interoperability solutions may be implemented in certain modern protection devices. One example is Hybrid POTT function, available in many of GE Multilin 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 conditions.

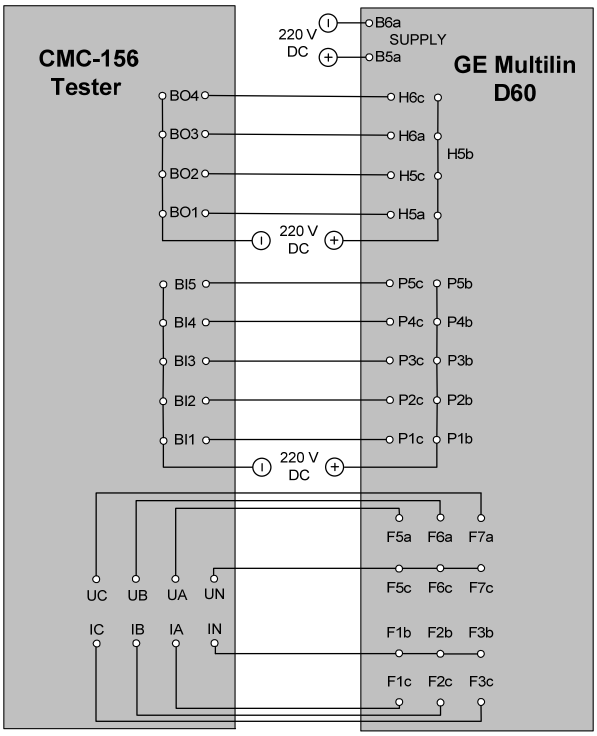

Fig. 1. Connection diagram of D60 and CMC-156 tester during synthetic tests of D60 pilot schemes functions

Synthetic pilot scheme functions tests

Tests of standalone D60 device's pilot scheme functions have been performed using Omicron CMC-156 tester, controlled by dedicated PC software. The simplified electrical connections diagram for this stage f thests is illustrated in Fig. 1.

The configuration of D60 device [6] and its pilot scheme functions has been realized by using dedicated *EnerVista UR Setup* software (Fig. 2) and primary checked using *Omicron Test Universe* software environment and internal functions (Fig. 3).

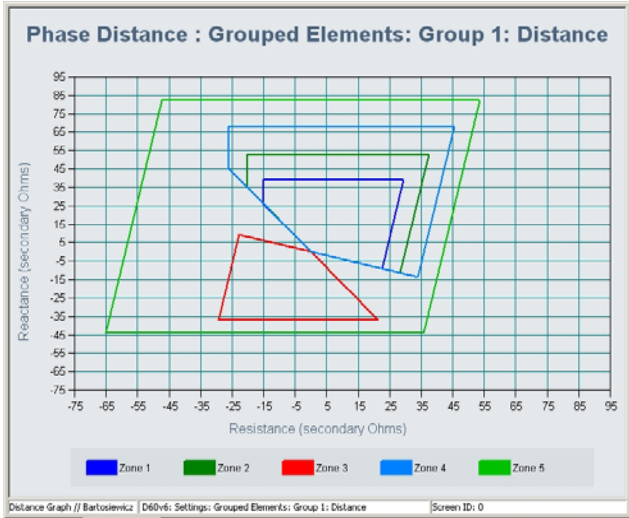

Fig. 2. Distance graph for example D60 phase-distance function settings

The aim of this stage of tests was to validate (using CMC-156 binary inputs and outputs) transmitted signals and D60 relay responses for each pilot schemes, each number of communications bits (1, 2 or 4) and for each type of faults (internal and external, phase-to-ground and phase-to phase faults). Test fault state sequences (for currents and voltages) are every time designed and redirected to the relay by means of *Omicron State Sequencer* software module.

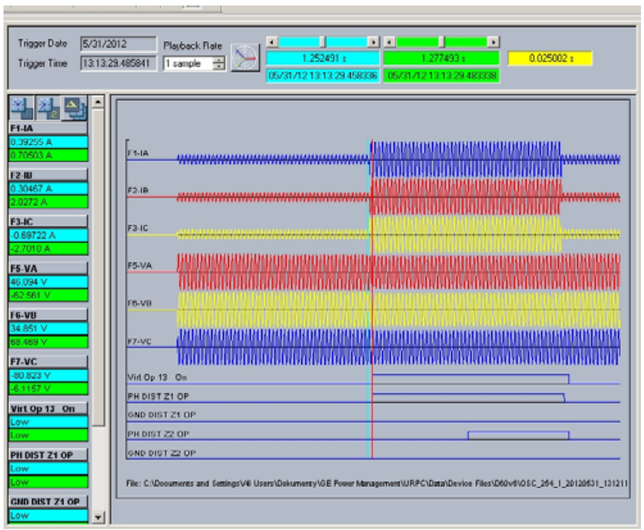

Fig. 3. Internal D60 device oscillography record for symmetrical fault

Test of coordination between two devices

Connection diagram for the second stage of tests is illustrated in Fig. 4. Omicron CMS-156 amplifier has been used to force additional three currents and three voltages for D90Plus device. Configuration of D90Plus device [8] and its pilot scheme functions has been realized by using additional *EnerVista UR Plus Setup* software (Fig. 6).

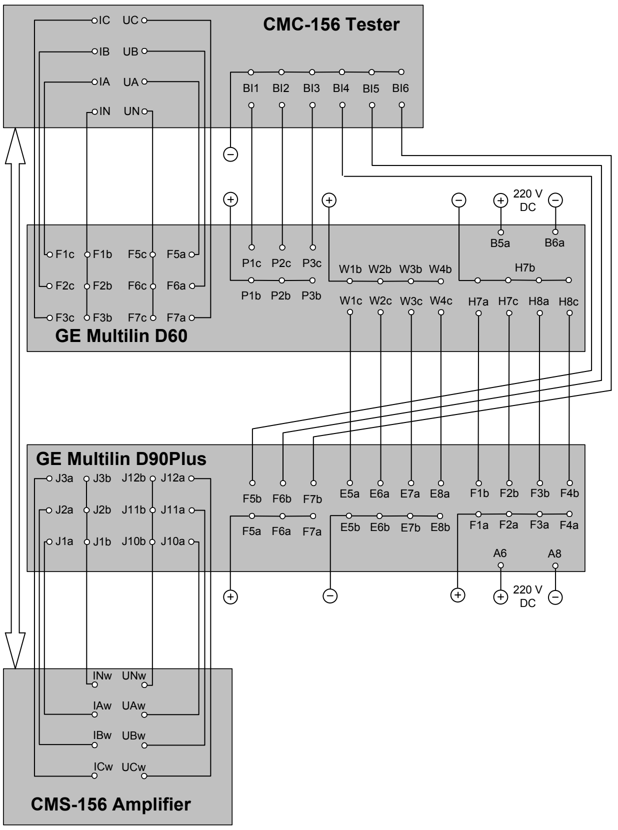

Fig. 4. Connection diagram of D60 and CMC-156 tester during synthetic tests of D60 pilot schemes functions

Second-stage tests have been performed to validate D60 and D90Plus devices interoperability for each type of pilot scheme. D60 has been tested as a local relay (closer to locations of simulated faults), and D90Plus as the remote relay. In addition, time delays have been measured for direct binary signal exchange. All the tested pilot schemes worked properly for each kind of simulated fault, with a significant acceleration of remote device tripping for internal faults (Figure 7).

Test of different communication link types

The last stage of tests has been performed for comparison of different communication link types. POTT has been the only tested pilot scheme. In this case two L90 protection devices [7] have been used.

Simplified and generalized connections diagram for this set of tests are shown in Fig. 5. Only two binary inputs of CMC-156 tester have been used - one for each relay tripping signal.

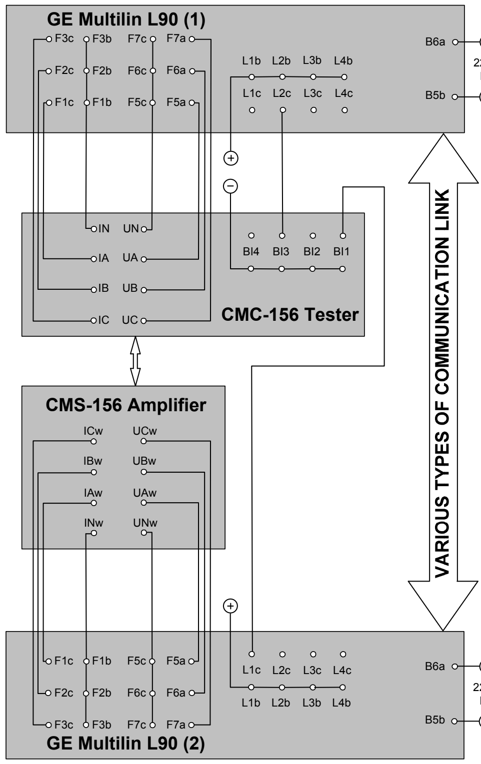

Fig. 5. Connection diagram of D60 and CMC-156 tester during synthetic tests of D60 pilot schemes functions

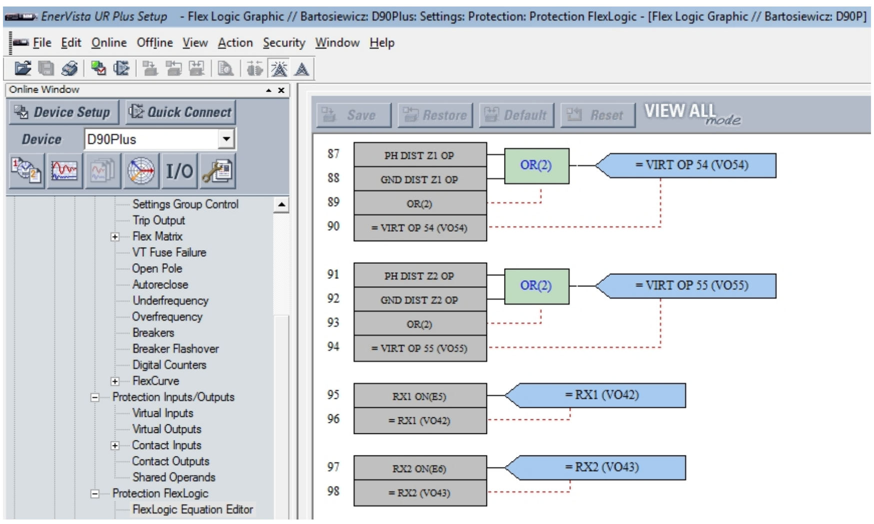

Fig. 6. Screenshot of *EnerVista UR Plus Setup* software window: functions tree on the left; on the right – visualisation of programmable logic (*Flex Logic*) settings

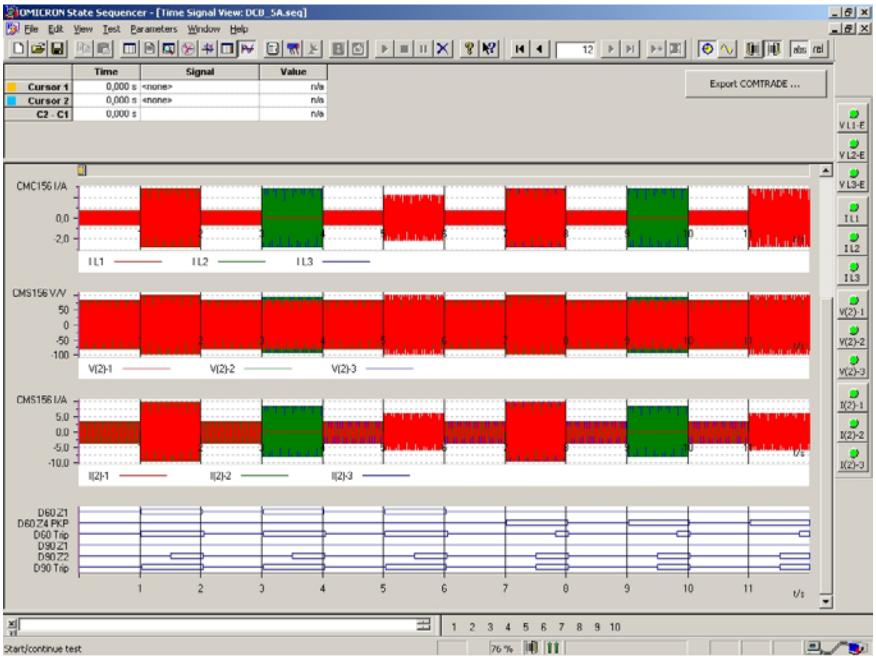

Fig. 7. Test results of DCB pilot scheme (with 4-bit signal coding) for six types of faults (simulated on even seconds): first three internal faults and second three external faults (accordingly symmetrical, phase-to-phase and phase to ground fault for each fault location); Z1, Z2, Z4 – zones 1, 2, 4; PKP – pick-up of relay in given zone; Trip – overall (measured) device trip

The most important results of performed tests are time delays between tripping signals of each relay, for POTT trip signal transmission through several communication links (Table 1), and difference between measured values (Fig. 8).

Table 1. Set of average tripping time delays

Communication link	Average time delay between tripping signals of coordinated relays [ms]
No link (lack of coordination)	504.1
Direct exchange of binary signals through contact inputs/outputs	6.2
Direct Ethernet connection in IEC61850 protocol (GOOSE/GSSE)	3.8
Ethernet/IEC61850 connection through switches	5.1
Ethernet/IEC61850 connected to SDH network through switches	10.4
Direct optic fiber connection in C37.94 standard	6.9
Fiber connection (C37.94) through SDH network	14.1

In case of standalone work (lack of coordination), the average delay of remote L90 device tripping delay exceeds half a second. This is related to second-zone tripping.

POTT function ensures lowering the value of remote device tripping delay to several seconds. The shortest delay has been measured for direct Ethernet connection in IEC61850 protocol, because of the highest bit rate for this link – 100 Mbps. Use of switches gives additional delay of approximately 1 ms, and connection between switches realized through SDH network – another 5 ms.

Direct optical fiber connection in C37.94 protocol (64 kbps) ensures delay of about 7 ms, and realized through digital SDH network – about 14 ms. Short time delay for direct exchange of binary signals (6 ms) results from use of fast (static) contact inputs (*Form-C* type).

Additional latency, caused by using digital SDH network, is also different for Ethernet and optical connection (Table 2). About 2 ms longer delay for C37.94 protocol results from different type of data encapsulation and transmission through SDH network. For optical connection, VC-12 data container is used (2 Mbps) in opposite to VC-3 container (about 50 Mbps) for Ethernet protocol.

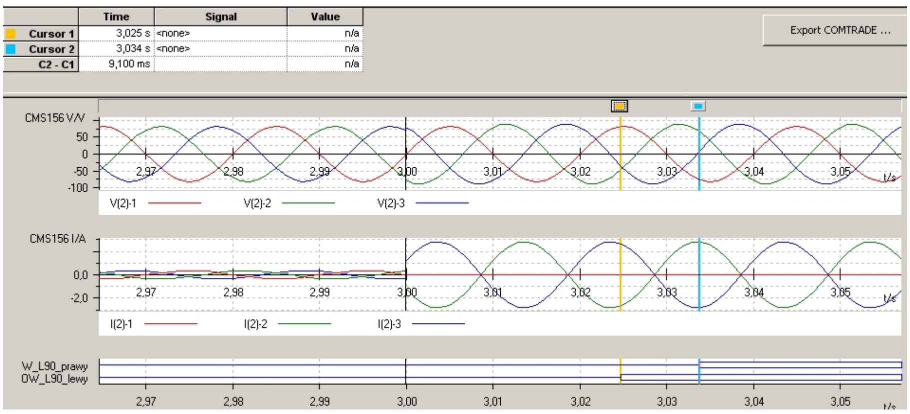

Fig. 8. Example of tripping delay measurement for phase-to-phase fault near L90 (2) device (called “L90_lewy”)

Table 2. Set of SDH network additional latency times

Communication protocol		Ethernet / IEC61850	C37.94
GE Multilin TN1Ue SDH Multiplexer Unit		ETHER-100	DATA-NX64F
Latency added by SDH network [ms]	Fault near L90 (1)	5.2	7.4
	Fault near L90 (2)	5.5	6.9
	Average	5.35	7.15
Directional asymmetry /(1) – (2)/ [ms]		-0.3	0.5

The directional asymmetry of SDH network additional latency is not significant (a few percent of the whole SDH latency) and not clearly directionally determined – for one protocol it has negative value (for accepted method of measuring) and positive for the other one. The directional asymmetry values are increasing for delay measurement of the whole connection (Table 3).

Table 3. Set of tripping time delays with directional distinction

Communication link	Tripping time delay [ms]	
	Fault near L90 (1) /signal to L90 (2)/	Fault near L90 (1) /signal to L90 (2)/
Direct Ethernet/IEC61850	4.5	3
Ethernet/IEC61850 through switches	5.9	4.2
Ethernet/IEC61850 connected to SDH network through switches	11.1	9.7
Direct C37.94 optical fiber	7	6.9
Fiber connection (C37.94) through SDH network	14.3	13.8

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 results of performed tests, both synthetic and real coordination, have demonstrated the ability of General Electric UR-series devices to effectively implement their protection tasks, for each of the simulated power system work cases.

Multibit encoding of transmitted signals (both tripping and blocking type) allows sending information concerning the fault itself (its occurrence) - additional information like type of fault and faulted phases, which may help the remote relay in selective and reliable tripping.

Regardless of the types of used pilot scheme and communication link, tripping acceleration for remote relay is significant – even two orders of magnitude shorter tripping time. Relative to local relay tripping time, measured remote tripping delays have been really short – much shorter than typical fast tripping of tested devices for their instantaneous zones of operating (20 ms to 30 ms).

Coordination of line distance protection relays may be effectively realized in IEC61850 protocol, with GOOSE/GSSE frames transmission through wide area networks (WAN), using SDH or DWDM digital networks. What is more, latency added by modern networks is really short. Therefore, they could successfully replace the previously used direct pilot links, and even increase connection reliability using advanced protection solutions of WAN networks.

Fast communication systems are increasingly being used for the power systems. Even many research centres in the world have been working on development of new control systems based on fast communication platforms [10 – 12]. It is expected that control systems of that kind will be implemented in power systems in a near future.

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