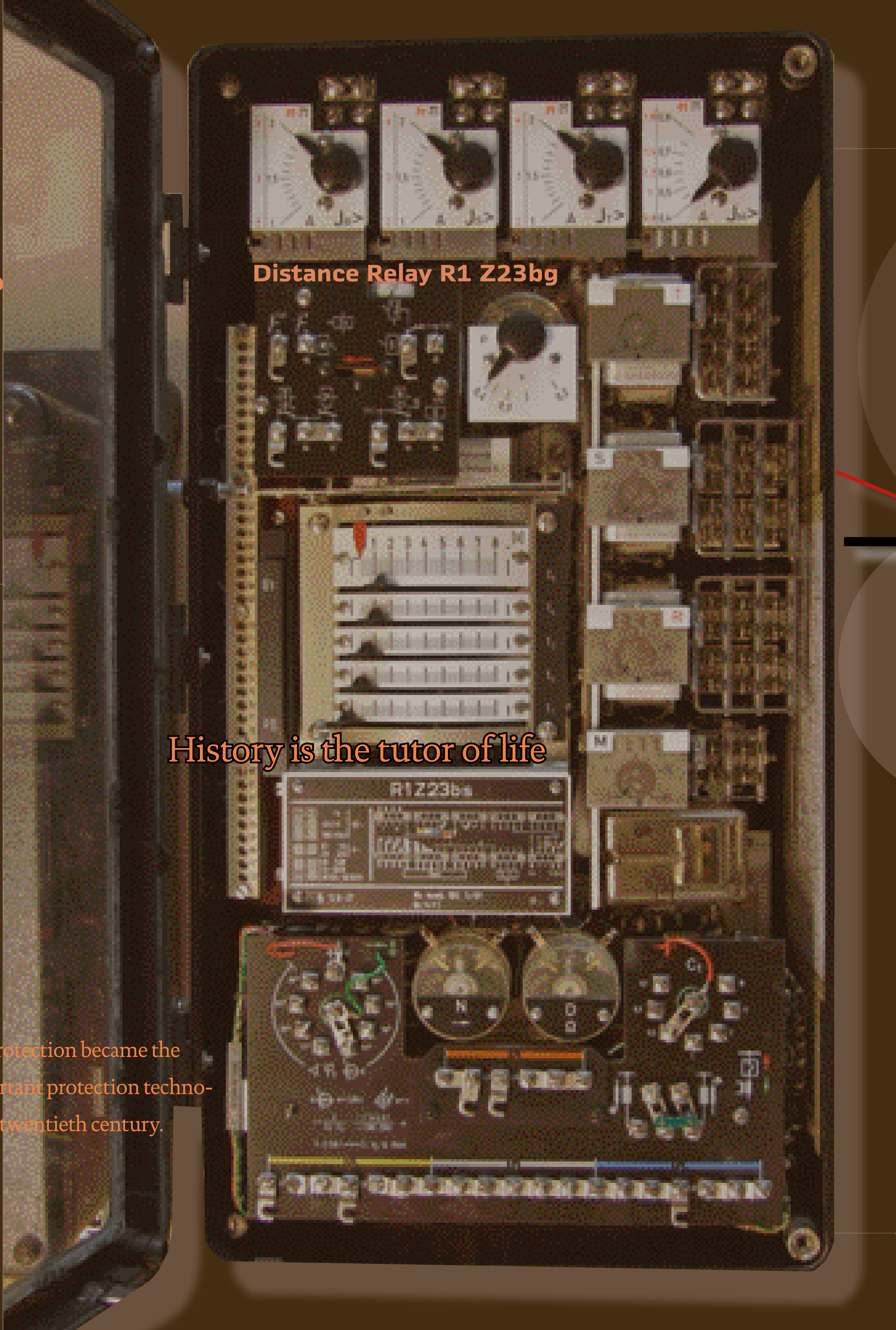
Distance Relay R1 Z23bg

History is the tutor of life



Distance protection became the most important protection technology in the twentieth century.

by Walter Schossig

Protection History

This article discussees the next phase in distance protection development

Distance Protection

From Protection Relays to Multifunctional

From continuous to multi-zone characteristics

First publications and first relays for distance protection were covered in the last issue. The requirement of the utilities was a decrease of the tripping time to a value less than 2 s. To achieve this they skipped the distance-to-fault depending continuous tripping characteristic and changed to cascaded (multi-step) or mixed characteristics. The distance relays provided by BBC and Siemens in 1928 still used the continuous characteristic. Stoecklin J. proposed and BBC developed a Relay that used the crossed-coil-ohmmeter (*known from measuring devices*). It was patented for selective protection. The base time of this relay was 0.5 to 1 second, which increases with the distance to the fault up to five second. The device consisted of three mechanically united main parts. The impedance startup started a timing mechanism, while an ohmmeter limited the relay's time. The timing element -clockwork with manual winding - measured the time and operated exactly. It disburdens the current system; the result was a well working device with small power consumption, even with low currents. The clockwork stored approximately 100 seconds operating time - equal to 50 operations of the device. Only after this, a manual raise was necessary - an issue that was welcomed by operating staff at this time because it requires a systematic check of the relays. The Ohmmeter functioned as the directional element as well, eliminating the need for special reverse-power relays. A flag showed an operation of the relay and a slave pointer the distance of the fault. For resetting, a winding up of the clock up to a stop position was necessary- pointer and clock came back into normal position.

Impedance protection of Siemens was put into operation with the 50-kV-ring Bleicherode-Huepstedt-Muehlhausen-Langensalza (Germany) in 1929 . (Figure 6). In the same year distance protection was used for the first time in the 28-kV-grid of Vienna (Austria). To prevent out-of-step of generators and motors, a change from continuous to multi-step time characteristics was observed in the next 10 years. A fast tripping time of less than 0,3 s was achieved with balance beam electromechanical elements. Therefore, these relays had their own name - "fast distance protection".

At the same time "express impedance relays" for use in medium voltage grids were developed. Their advantage was

Biography

Walter Schossig (VDE) was born in Arnsdorf (now Czech Republic) in 1941. He studied electrical engineering in Zittau (Germany), and joined a utility in the former Eastern Germany. After the German reunion the utility was renamed as TEAG, now E.ON Thueringer Energie AG in Erfurt. There he received his Masters degree and worked as a protection engineer until his retirement. He was a member of many study groups and associations. He is an active member of the working group "Medium Voltage Relaying" at the German VDE. He is the author of several papers, guidelines and the book "Netzschutztechnik (Power System Protection)"He works on a chronicle about the history of electricity supply, with emphasis on protection and control.

the use of a step time characteristics (Figure 3). They were able to protect 70% of the length of line with an operating time of 0,3 s . Neugebauer,H. and Geise,Fr., Siemens, proposed an express impedance relay in 1932. It was the first distance relay in an economical single plate housing per end of line. Fast distance relays were used to achieve short tripping times in the EHV-grid (solid earthed star point). Usually they had three measuring elements (in the English-speaking countries up to six). Single-pole autorecloser with definite 3-phase trip was possible now.

In the medium voltage, the grids had an isolated star point. Petersen,W. invented the earth-fault neutralization in 1917. Since then, especially in the German-speaking countries, compensated grids are quite common. The capacitive earth fault current is compensated by the inductive current and continuing operation of the grid is possible. Fast distance relays with only one measuring element were sufficient to detect 2- and 3-phase short circuit faults.

The distance protection in Europe was the most often used protection technology on mashed or parallel-operated high voltage grids. When the short-circuit power in the grid became higher, the requirement for fast tripping on the whole line length became important. Ackermann already showed a proposal for a step protection in 1920/21. This was used in Siemens reactance relays in 1930, in the Oerlikon-Minimum-Impedance-Protection and the newer distance relays of Westinghouse Co. and General Electric Co.

AEG developed their first fast distance relay in 1934 (SD1). It uses pure three-step characteristics; fast tripping times of 0.3 up to 0.4 s were achieved. As an under-impedance protection it uses two balanced beams, which were set up to different lengths of the line. Additionally it consists of a 3-step timing element and an iron-cored dynamometer as a directional element. Startup was realized with built-in overcurrent elements or - in a separate housing - with under-impedance elements. The right housing consists of measuring elements and the directional element with a tapped voltage-matching transformer (for impedance setup). The other two devices contained the startup, the choice of measuring values and the three-step timing relay. For the detection of two-phase to earth fault the SD1 used for the first time the sum current and a change to the phase-earth voltage for the measurement of the impedance. The one-system protection relay required the right choice of measured values. Special auxiliary relays, with strong contacts were necessary. The SD1 was already equipped with HF-channel to realize a directional comparison protection. For the medium voltage, the less complex SD2 was provided.

The Arrival of Rectifier Technology

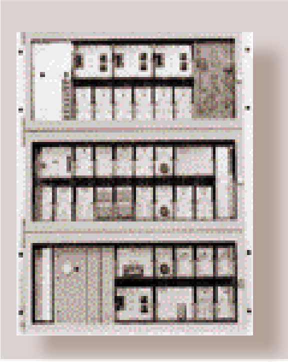
In 1937 AEG presented as a first big vendor the use of metal rectifiers in a distance relay with their SD4. Since then, it was possible to reduce the measurement of the short-circuit loop to a DC-measurement. Influenced by voltage and current, a rectifier operates sensitive plunger coil relays. The power consumption in the voltage circuit could be decreased ten times - in the medium voltage it was possible now to supply several distance relays with one busbar-voltage-transformer.

After the good experiences with rectifier technology in Germany, a bridge connected rectifier was common at the end of World War II. Two or three sets of rectifiers supply relays with one moving coil (Figure 7). Voltages and currents were provided with interposing transformers to the Graetz-Circuit. A polarized moving coil relay was in the shunt arm of the anti-parallel switched rectifiers. It closed the contacts at a certain ratio of voltage and current.

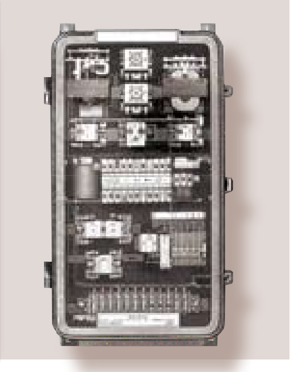
Due to the very low power consumption of the rectifier measuring systems it was not necessary to rectify the whole transformer current - only a current proportional voltage over a diverter resistor was necessary. In the first AEG SD4 relays (1934) this resistor was connected via a phase selection contact to the affected current circuit.

The selection transfer, developed in the last two years of World War II the resistance was realized as a 3-pole one. in relays with doubled earth fault detection as 4-pole. The secondary circuits of the current transformer in that case did not need to be switched. The selection of current was realized with normal contacts. In that case in the current as in the voltage a correct selection of the measuring values was realized.

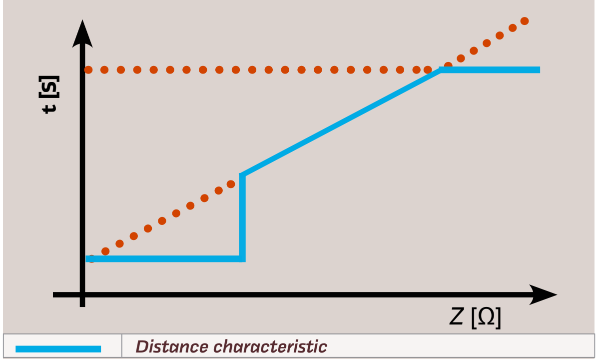
1 Distance relay RAZOG, ASEA, 1970



2 Distance relay LG1, BBC



3 Distance protection characteristic with express contact & maximum operating time



The impact of the electric arc resistance on the distance measurement was a main issue for a long time.

When the corresponding phase selection contacts of voltage and current were from the same auxiliary relays it was simple to justify the contacts to open and close at the same time or to open the current circuit a short time before the voltage circuit and close one a short time after another.

A new measuring principle based on comparison of the peak values with rectified values, was introduced with the distance relays SD4. A bridged-connector rectifier allowed a comparison of any combination of voltages and currents for the estimation of a difference and the estimation of impedance and power (direction). Mixed impedance characteristics (blocking of the circle characteristic along the R-axis) were available to eliminate the resistance of electric arc from the estimation of the distance.

The Impact of Arc Resistance and Power Swing

The impact of the electric arc resistance on the distance measurement was a main issue for a long time. Very early the utilities performed extensive and systematic short circuit tests (e.g. Bayernwerk AG in their 110-kV-transmission-line-grid (1926/27) and Preussenelektra (1929) - both in cooperation with the vendors - AEG, BBC and Siemens. Under impedance-startup in off-peak periods was tested for suitability during these tests and new requirements for further improvements were found. At first, they tried to eliminate arc resistance with real reactance relays. BBC and Siemens provided the first solutions in 1928. Maloperation of relays was observed when power swing occurred between power plants (seen as short circuits by the relays). This was frustrating for the engineers. Power swing blocking and power swing relays were developed. Gutmann,H., AEG patented the modified impedance measurement in 1944. The measuring value of the modified impedance element was:

$$Z = \frac{U \hat{+} k \cdot I}{I}$$

An arcing reserve of 60% was possible with consideration of line angle at the relay's trigger point.

100 % of Line Length with no time delay

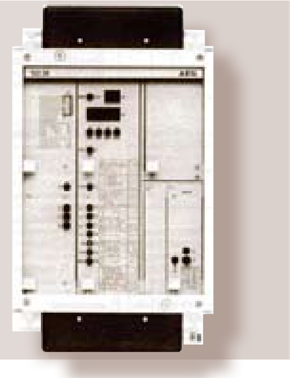
Starting in the 50's of the last century, fast distance relays in connection with automatic reclosers were widely used for the detection of lightning strike faults over the whole length of the line with no time delay - the "overreach".

An auxiliary device was used to enlarge the zone of the first stage up to 115% of the length of the protected line . After the first trip, the value was decreased to the common 85…90% - after an unsuccessful reclosing there was guaranteed selectivity for the second trip. Use of a power line carrier (PLC) channel for accelerating the trips on both sides of the line allowed instantaneous protection of the whole length of the line with the 15%-overreach. This approach was used where PCL connections were available (remote control, phone, remote measurement etc.). The first installation was realized in Germany in the 220 kV grid of Preussenelektra in 1955.

At the end of the 60's distance protection was extended with "distance dependent directional comparison protection

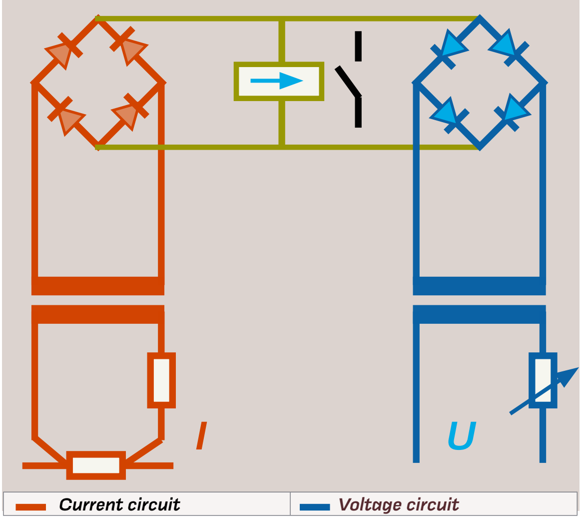
4 Distance relay RD7, 1958

5 Fast distance relay SD36, AEG 1986



6 Observing the Siemens impedance protection when energizing a 50 kV line

7 Circuit for measurememt of the impedance



systems". In these devices the directional information and the measured distance are evaluated. The comparison of distances is performed in the first stage of distance protection only. Several methods are used for tripping. In the United States it was quite common to use "blocking" - the tripping command of the own protection is blocked by the PLC-signal of the other station. Another possibility is "permissive intertripping". If a fault occurs and the device should trip, a permissive signal is provided to the other end. Last, but not least, "inter-tripping " should be mentioned. In that case the distance protection trips its own circuit breaker without a signal from the opposite station. This is also communicated to the other end –it "inter-trips". This scheme realizes a backup protection - at the opposite site neither a distance estimation nor an estimation of direction is necessary.

In the relay SD14, developed by AEG in 1954, the directional element was realized with a small moving coil relay instead of a plunger coil system. The mode of operation is comparison of absolute values of V + I and V – I (*as in the N-Relays with balanced-beam element 30 years before*). Now a higher sensitivity was reached - 1 % of nominal voltage at nominal current. A special series element allowed an angle of up to 30° (inductive) required when used in medium voltage cable systems. Increasing the pressure of contacts for high-sensitive distance relays allowed a further improvement of reliability. A big advantage was the direct-CT-powered operation - it was useable in stations without batteries. The switch to the next stage was realized with " synchronous time relays" (with synchronous motor).

In the USA in almost all cases three balanced-beam-relays were used - permanently connected with voltage and current. They were set up according to three stages with different time settings. Thus, a stepped characteristics was available. German Railways used a similar system.

Self-supervision plays an important role in improving the performance of distance relays.

„Self-Supervision"

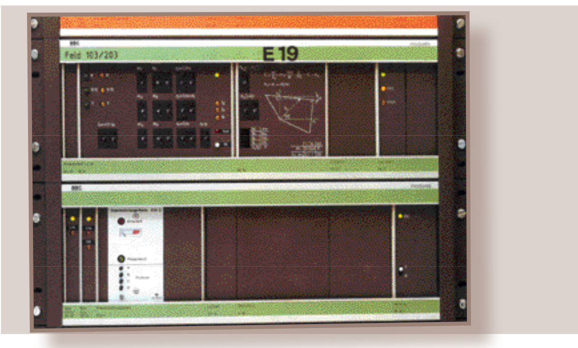
Some of the first distance relays were equipped with voltage transformer supervision. The N-relays (*PAC World, Winter 08 issue, Figure 4*) had a built-in voltmeter. Another possibility was the use of external or internal glow-lamps. Aigner developed a rotating -field discriminator for supervision of interruptions of one or two phases and of the existence of a right rotating field. A fault in the current circuit could be only detected with the startup of sensitive zero-sequence relays. The loss of auxiliary voltage could be visualized with a flag relay. Development of microprocessor-based relays allowed a further self-supervision (*measuring values, CPU-failures, trip-curcuit, circuit breaker supervision…*).

Guidelines for Distance Protection - Further Steps

Lessons learned in the time before World War II show, that a joined operation of adjasent protection systems was

Withdrawable boards allow quick fix of problems in solid state distance relays.

8 Transmission line protection distance relay LZ91 (BBC)



9 Distance relay 7SA500, Siemens, 1986

10 Distance relay DD2, EAW

not successful in any case and that the vendors did not allow that. The same problem occurred when different vendors were used in the same grid. That is why the utilities defined their requirements to allow the usage of relays of different vendors in one grid. The pre-condition to do that was to harmonize the operation behavior of relays. The German VDEW proposed an "Agreement of Utilities for Harmonization of Distance Protection" in 1951. The paper describes relays of the following vendors - AEG - SD4, BBC (L3, LG1- and LG2-Relays, Figure 2) and Siemens RZ24-/ RK4-Relays.

The BBC relays were reactance protection, while AEG and Siemens provided impedance relays (elimination of arc resistance with a mixed-impedance add-on). The guideline defines startup (2-and 3-pole, range of overcurrent or under -impedance-startup); voltage; dead zone; first-zone-time; smallest measuring impedance; maximum operating time, detection of doubled earth faults; power consumption.

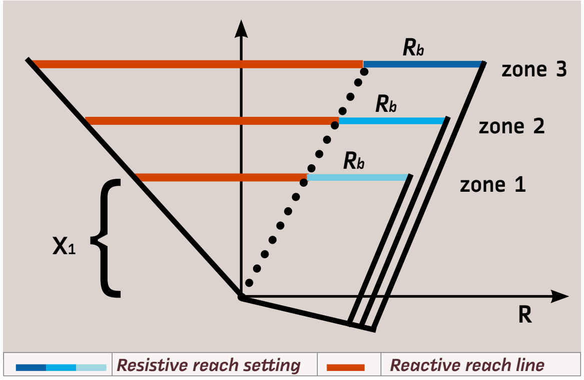
Other recommendations were regarding the mounting and the usage of the DC measurement (shunt instead of interposing transformers). The recommendation for timing elements was motor drive instead of clockworks (higher moment of force and improved resistance against contamination). Ulbricht,R. und Kadner,G. publish a bulky guideline for time grading coordination with distance protection in the GDR (Eastern Germany) in 1958. The document considers the special circumstances in the GDR after World War II - 13 different types of relays with different characteristics were available. Therefore, the document describes selective time interval and impedance, single and parallel lines, impact of measuring failures at transformers, arc resistance, detection of doubled earth faults; maximum operating time and calculation of short-circuit currents.

ASEA (Sweden) produces the distance RYZKC relays since 1950. To decrease tripping time distance protection was used as busbar protection in transformer infeeds. EAW (GDR) introduced RD7 in 1952. Pushing the button (Figure 4) performed a functional test of the relays (*only if the tripping circuit was interrupted*). Austrian Rail (ÖBB) used an auxiliary distance relay in their 16 2/3 Hz grid since 1957. It was developed by Gutmann,H, AEG, and was named SD4/ WZD0. It was a joint initiative with German Rail and AEG and could be used for non-fading earth-faults as well (*the other phase was earthed in another station, and then a doubled earth fault occurs and the faulty line could be tripped*).

Backup Protection

Lively discussions regarding the use of backup protection started in 1960. Norway, Russia and England preferred doubling protection in the EHV grid. They used two similar or equal relays. An expert from the United States reported the „ breaker-and-a-half approach" - the reserve was the circuit breaker, because failures of breakers and tripping circuits are more likely than with relays and measuring transformers. The EHV grid in Germany uses a backup relay per feeder *("main" and "backup" or "system 1" and "system 2"*). Both systems are separated; up to today, it is quite common to merge different type relays (e.g. distance and differential protection) of

11 Distance relay RAZOG, ASEA, 1970



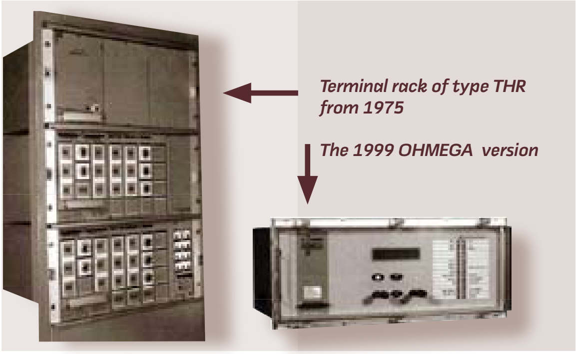
The first distance relay with polygonal characteristic was produced by ASEA in 1970

12 Distance relay PD531, AEG, 1991

This is one of the examples for the usage of microprocessors in distance relays

13 Distance relay 316LZ (ABB,1990)

14 Distance relays THR and OHMEGA



different vendors. To avoid malfunction a "2 out of 3 circuit" was discussed often but did not became established.

Introduction of Electronics

The first electronic distance protection was used in 1959. The French EdF reported the commissioning of a transistor based distance protection in the 200 kV grid. In its first year it worked properly in 38 cases (of 40 faults). According to vendor's publications the relay needed only 2 VA (in current and voltage) and the stepped characteristic should be nearly perfect, not depending on the short-circuit current. Other documents describe an English distance relay with Mho-circle, based on transistors. It was developed for the South African EHV grid and was proved of value. It should be mentioned that the vendor at this time warned against big enthusiasm for "transistor relays".

The sophisticated electromechanical relays in bridge-connected rectifier circuit were better and more economic at this time. The first distance relay with polygonal characteristic (Figure 11) was produced by ASEA in 1970 - the three-phase static relay RAZOG (Figure 1) with a shortest operating time of 21 ms.

Mann and Morrison, UNSW (Australia) developed algorithms for the calculation of line impedances in the same year. Rockefeller,G.D., Westinghouse; published an IEEE paper one year before and patented a digital distance protection in 1972. Before that he did together with Gilchrist,G.D., (PG&E) a field test with digital line protection PRODAR and a computer in a 230 kV substation in 1971.

It is worth to mention the EHV directional comparison protection RALDA (ASEA) from 1976. It is based on superimposed components principle and achieved a time for estimation of a fault of 2.4 ms. Cubicles for each feeder with swing frame and plugs, introduced at this time, allowed an easy change and combination of withdrawable boards (Figure 9). Beginning in 1985, distance protection with digital measurement was used in the medium voltage as well - AEG introduced the fast distance relay SD36 (Figure 5).

Examples for the usage of microprocessors in distance relays are: 7SA500 (Siemens, 1986 - Fig.9); 316LZ, (ABB, 1990 - Fig 13); PD531, (AEG, 1991 - Fig.12); DD2, (EAW, 1996 - Fig. 10) and OHMEGA, (Reyrolle, 1999 - Fig. 14).

These solutions were the quantum leap - from impedance depending short circuit protection to multifunctional feeder-relays. The development of the different generations of numerical protection and their advantages will be covered in a special article later.

Despite of comprehensive tests, type tests according to international standards by the vendors, certifications and commissioning tests with sophisticated test sets, staged short circuit faults are still valuable. In these tests vendors, utilities and universities contribute. A good example was the international line 750 kV Zapadno-Ukrainskaja (Western Ukraine)- Albertirscha (Hungary) with the distance relays PD551 (AEG) and 7SA502/511 (Siemens) Figure 15.

A special challenge for protection engineers was the commissioning of a six-phase transmission line 93-kV-Goudey Station - Oakdale, NYSEG (US) in 1992. Sambasivan, S and Apostolov,A.P. solved the protection problem with digital differential relays LFCB, directional comparison relays LFDC, distance relays LFZP and a high-speed programmable logic device LFAA (all from GEC ALSTHOM) (Figure 16).

Any comments or questions please send to:

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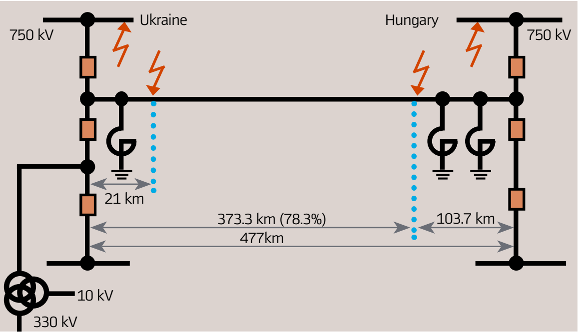
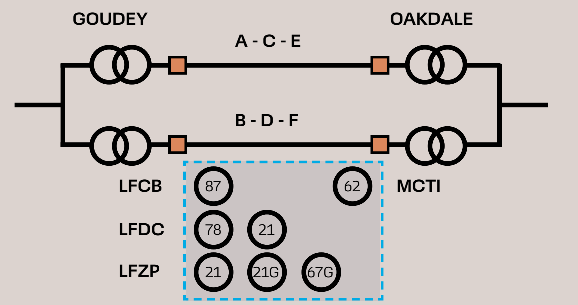
15 Test distance relays PD551, AEG and 7SA5, Siemens in a 750 kV grid



16 Protection of a six-phase line or distance relays OPTIMHO LFZP, GEC ALSTHOM



Six-phase line protection, one end, three-phase group A-C-E or B-D-F