

A protection device with the basic functionality of a distance relay was proposed in 1904 based on simultaneous detection of increase in current and voltage drop.



Dr. Rolf Wideröe

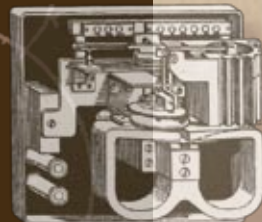


Biermanns J.

### Distanzrelais nach Biermanns Pl. 109223, AEG, 1924



History is the tutor of life.



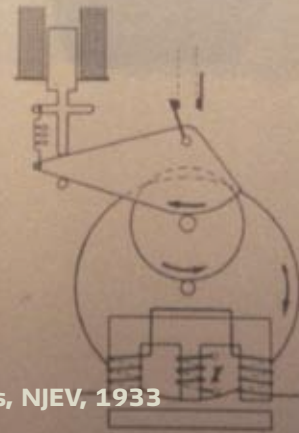
Westinghouse-Distance Protection



Wideröe-Relays, NJEV, 1933



Wideröe-Relays, NJEV, 1933



One Relay Impedance Protection, S&H

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

### Biermanns Distance Relay - Pl. 109223, AEG 1924



# Protection

This article discussed only the industry's initial approach to protection and selectivity

# History

## Distance Protection

### The Early Developments

#### 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 reunification the utility was renamed as TEAG, now E.ON Thüringer 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 Zoned Voltage Drop Protection

At the beginning of the 20th century, effective protection coordination using overcurrent or directional overcurrent relays was no longer sufficient due to high clearing times and operation with spur lines and rings circuits. Distance protection became the most important protection technology. Krämer, Chr., F&G proposed a protection device with the basic structure of a distance relay in 1904. The patent claim definition in DRP 174 218 by Felten & Guillaume-Lahmeyer-Werke AG (F&G) was: "A relay for automatically switching off an alternating current if the current is higher than a nominal value. A series connected coil and a coil connected in parallel exert a force on a rotatable disk. The intention is that the closing time of the auxiliary contact is determined by the current exceeding the nominal value and the associated voltage drop." See Figure 1.

AEG (Allgemeine Elektrizitäts-Gesellschaft) and the company Dr. Paul Meyer AG made great contributions to distance protection. Both were the first German companies to put distance protection into operation around the same time

in 1923/1924 and contributed several patents prior to that. A patent (by inventor Kuhlmann, K.) was granted to AEG on the 23th April 1908. The inventor proposed a Ferraris disk, driven by current. A special voltage magnet worked as a brake and the operating time was dependent on distance.

Another Kuhlmann patent was for a distance protection device that worked as a balance-beam relay dependent on undervoltage and overcurrent with a Ferraris anchor and rotating armature (Patent: DRP 214 164). The balance-beam is a mechanical device so the phase angle between the current and voltage had no impact. Thus the impedance circle, typical for electromechanical relays, was born.

The next invention was by Wecken, W. (Patent: DRP 248 466) and was the basis for selective voltage drop protection.

The relays that existed at that time were used for spur lines with single infeeds. Wecken, W. proposed the ring operation in 1912 and suggested using voltage drop relays to protect the ring. A directional element to determine the direction of the power during short circuits was not available. Meyer, G., J. developed a current and voltage dependent relay for ring

operation one year later. Although this relay worked without a directional element just as other similar devices at that time, Meyer's patent (DRP 269 759) discussed the fact that the direction of power should be the value being controlled.

The directional elements were not taken into consideration for ring operation or with parallel lines because only one oil circuit breaker was used in the substations at the time and therefore it was not necessary to use a directional element. Today, of course, we use circuit breakers in both directions to maintain supply. (Fig. 2, 3, 6)

The operating principle of such a voltage drop device is described as follows. Four driving cores beat against a drum exerting a force. The coils of the cores are connected with a resistance to the voltage. If the voltage is the nominal value, the arbor is lifted by a silk cord. Under fault conditions, the voltage decreases, the arbor will be "coiled up" with an associated speed creating a distance dependent operating time.

A metal-filament lamp connected in series and adjustable resistances allow a change of the characteristics (straight or warped). (Fig. 7)

#### Biermanns-Relays

In February 1916, Westinghouse El. & Mfg. Co. (inventor Crichton, L.N., Patent: DRP 334 760) developed a relay whose operating time was dependent on the ratio  $R/X = Z$ . The device was equipped with a directional element. The corresponding American patent 1 292 584 was issued on January 28th in 1919 having been submitted for consideration December 1912

In 1918 Meyer, G.J. developed an "N-Relay" (N=Netzschutz, the German word for protection systems).

The 4kV network in Karlsruhe (Germany) was equipped with distance relays in March/April 1913. The first "Biermanns Relays" (Fig. 4) were installed on the ELG's (Gotha, Thuringia, Germany) 30kV network in 1924 and it was there that the first in-service tests for this relay took place (Fig. 5). See Figures 8, 13. The red dot on the Biermanns-relay is the color of phase-3. Three relays were necessary per feeder (Fig.

4). The operating times (Fig. 8) appear very high from today's perspective but we should note that they correlate with the practical characteristics of the oil circuit breakers that existed at that time.

Due to the limitations of the breakers (decay of maximum asymmetric short circuit current), the basic operating times were in a range of 0.5 to 1s depending on the selected time delay setting. However steady-state short-circuit current was not dangerous in the substations in this time ("soft" machines and current controllers). The setting characteristic was in a fixed range calculated as  $110 \text{ V}/5 \text{ A} = 22 \Omega$ . If necessary, the operating time could be decreased such that the two parts of the current input windings were connected in series instead of in parallel (See Figure 8).

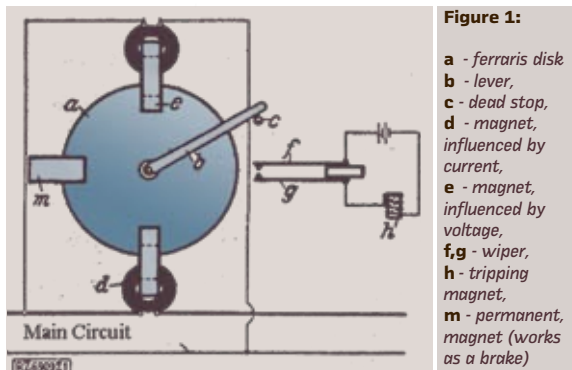
In 1915 Meyer, G.J. introduced a method of switching the voltage from phase-phase to phase-earth. This switching became useful to improve the detection of double-line-to-ground faults. Biermanns (AEG) used it with either phase or zero sequence current in 1925.

Canadian Ackermann, P. proposed a combined voltage and current relay using the resistance principle in 1920 (Fig. 11). Cansfield Electrical Works, Toronto began to use it from 1921. This was the first time that a step characteristic was used and it continues to be used today. See Figures 12. The same technique was used with the reactance protection developed by Siemens, the Oerlikon Minimal Impedance Protection and the new distance relays produced by Westinghouse Co. and General Electric Co.

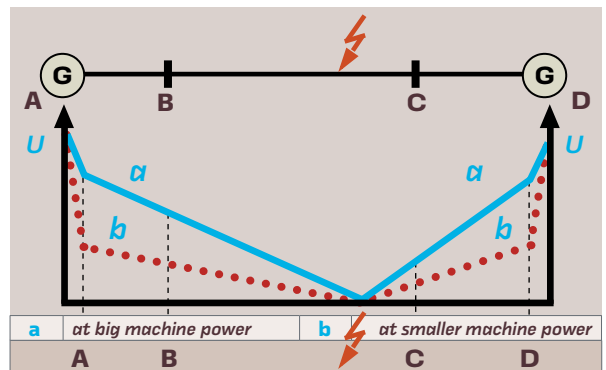
The Westinghouse Distance Relay was released in April 1923 and it is probable that the first substation in the US was equipped with Westinghouse distance relays that same year.

Nevertheless, the use of the Westinghouse relay was not as widespread as the German distance relays. One possible reason might be, that in the US double-circuit lines were generally used and these were protected with differential protection or difference protection (balance relays). Meshed networks were avoided with radial network as the preferred choice in the US.

## 1 Basic Scheme of a Distance Protection (acc. to Chr. Krämer, F&G, 1904)



## 2 Potential Grading during a Short-Circuit



## The operating time is determined by the current, exceeding the nominal value and the voltage drop.

The first substation in Europe that used Westinghouse relays was the double-circuit line from power station “Hedwigschacht” (Seestadt) to Prague in 1925. The utilities “Thuringenwerk” and “Kraftwerk Thuringen AG” decided to use Siemens-Westinghouse Relays for their 50kV network in 1927 (Fig. 9). Note that Phase “R” (phase “a”) is not covered. The first proposal for an AEG distance relay (type 1923) was made by Biermann, J. Several papers and patents clarified the main distance protection topics. They explained the impedance startup; reactive step logic element and the logic used to detect double earth faults.

The name “impedance protection” (or “resistance dependent relay”) arose from the fact that the operating time changed with the voltage/current (=impedance) ratio. Nevertheless Biermanns used the name “distance protection” since the operating time was dependent on the length of the line (German: “Distanzschutz”, French: “Protection des Distance”).

In 1928 Brown, Boveri & Cie (BBC) and Siemens & Halske (S&H) produced their distance relays according to the European practice with consistent time characteristics. High voltage lines used reactance relays since they had the advantage that the arc resistance (ohmic) had no impact. Medium voltage impedance relays with adapted phase shift were developed by BBC. (Fig 10) An interesting “Bergmann-Elektrizitätswerke” patent (DRP 403 934 and DRP 404 867 1923) was developed by Schade, P. The distance relay proposed in the patent was a device where the operation of one side was dependent on

the apparent power, reactive power and resistance values. The other side was operated by a clockwork device moving at constant speed. The operating time decreased depending on the line resistance between the fault location and the relay, i.e. with the distance to the fault (on the spread).

### Startup

Overcurrent startup is sufficient in normal situations on medium voltage (4 up to 60kV) network because the short circuit currents are larger than the nominal currents of the assets being protected.

In meshed 110kV networks that have low power consumption at night and on the weekends, the short circuit current might be as little as the nominal values so under impedance startup is necessary.

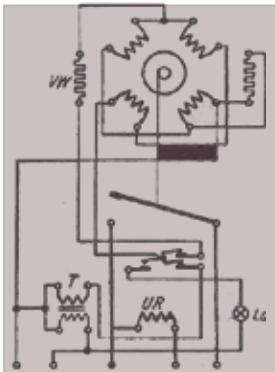
In solidly grounded networks, under impedance startup is required to achieve phase selective startup. This avoids incorrect startups on healthy phases caused by equalizing (circulating) current (paradox of Bauch). Reactance relays were the preferred choice in the 110kV transmission line grid to eliminate the impact of arcs. Values up to 100Ω occurred in off-peak periods prior to the electric arc being cut.

The first distance relay like the aforementioned N-relays, Dr.-Paul-Meyer-AG; Biermanns, AEG and BBC relays were

## 5 Short-Circuit Test-Thuringia, Germany



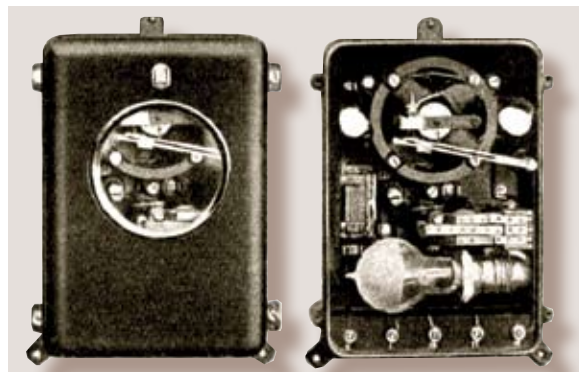
### 3 Scheme of a Voltage Drop Relay



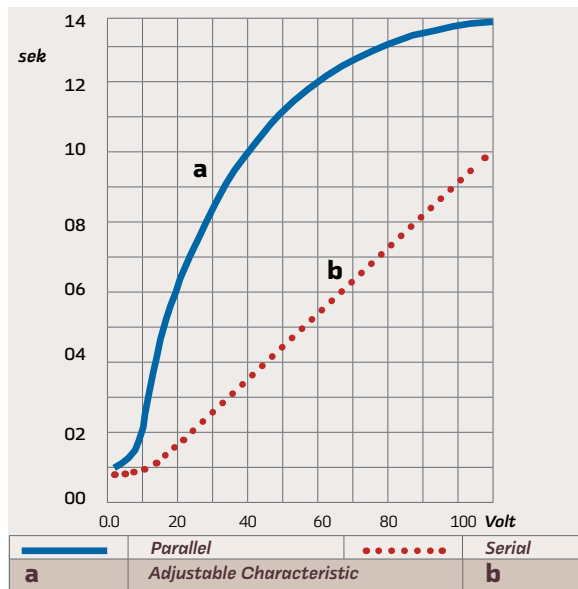
### 4 First Impedance Relays, both 1924



### 6 Voltage Drop Relay (V & H)



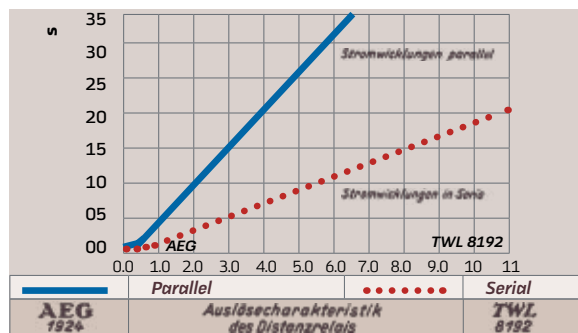
### 7 Characteristics Voltage Drop Relay (V&H)



single pole devices with one startup, one time and one directional element. Typically, 3 relays were installed on each feeder.

Double earth faults were not normally expected in cable circuits and it was expected that every fault would end in a three-phase fault due the long control time in belted cables. Distance relays provided by BBC and impedance relays of Siemens in 1928 had similar designs. The first distance relays that used the reactance principle were developed by BBC and S&H in 1928. Unlike impedance relays, they were used for supergrid applications due to the possibility of high arc resistances in such applications. The first AEG distance relays (with impedance startup element) were named "double distance relays" in 1925/26. Biermanns made substantial earnings from their successful distance protection relay.

### 8 Characteristic Biermanns-Relays, AEG, 1924 (parallel / serial)



## Distance protection was met with criticism in magazines and at conferences at that time.

However, distance relay manufacturing difficulties might explain the reason why S&H preferred other protection systems at that time.

In addition, distance protection was met with criticism in magazines and at conferences at that time. The idea was new for utilities although the distrust and skepticism decreased with increasing numbers of successful short-circuit and double earth-fault operational trials.

#### First Improvements

Many patents were granted in the first years of distance protection technology development. Examples of patents from 1908 up to the 1920's include those of Kuhlmann,K.; Wecken,W.; Chrichton,L.N.; Meyer,G.J., Ackermann,P. and Biermanns,J. Kesselring,Fr. combined the protection and directional relays in one box, the "N-relay". Cohn,,A. proposed to use bimetal strips, saturation transformers and other elements. Kesselring,Fr. further developed the N-relay, the voltage and directional elements from 1924 up to 1927. The Norwegian Wideröe,R. was granted 41 German and 2 American patents in the years 1928-1932 when he worked with AEG; during this time N. Jacobsens Elektriske Verksted (NJEV) was granted 10 patents in Norway. See Figures14,16.

#### Short-Circuit Tests for Relay Usage in Grids

Ackermann,P conducted short circuit tests on Shawinig Water and Power Co's 50kV transmission network in 1920. He observed that time relays with overcurrent tripping devices did not trip due to the low short circuit currents in small machine applications. The impact of arc resistance was not considered at this time. He observed the reduction of the current levels during the short circuit but explained it as a

### 9 Siemens-Westighouse 10 Distance Relays, Impedance Protection BBC, 1928



The operating times appear very high from today's perspective but we should note that they correlate with the practical characteristics of the oil circuit breakers that existed at that time

decrease of the initial short-circuit current up to the level of sustained short-circuit current.

The Preuß. Kraftwerke Oberweser A.G. Cassel 60kV network was fully equipped with V&H voltage drop relays after short circuit tests were carried out. See Figure 5. Other utilities also performed short circuit tests to collect information about the performance of relays and the network under fault conditions. One observation was that short circuit currents could be smaller than the nominal currents. In 1924 Dr. M. Schleicher described the impact of arc resistance on impedance relays. Arc resistance in their 110kV network was investigated by the German utility "Bayernwerke" in 1926/27. The proposal to use the reactance to estimate the distance to the fault was subsequently discarded.

Following significant investigations and network tests with 30 relays, a Norwegian interconnection company "Samkjöringen" (translation in English is 'Cooperation') decided in 1936 to use distance relays to protect their main lines in Eastern Norway. They used Dr. Wideröe, NJEV protection scheme. The Viennese ELIN AG relays subsequently acquired the commercial rights to this protection scheme. The application of an AEG distance relay in a network model was shown at a fair in 1924.

The advantages of distance protection relays were demonstrated by statistics from Elektrowerke AG. They had 43 disturbances on their 100kV network in 1924. Most of them originated in the medium voltage network. The relays in the medium voltage (overcurrent and directional relays) did not work properly 32 times and the number of trips was 3 times higher than they should have been. Replacement of the relays with distance protection resulted in only 2 relay misoperations during the 27 disturbances in 1927.

#### Six-, Three-, Two- and One-Relay-Schemes

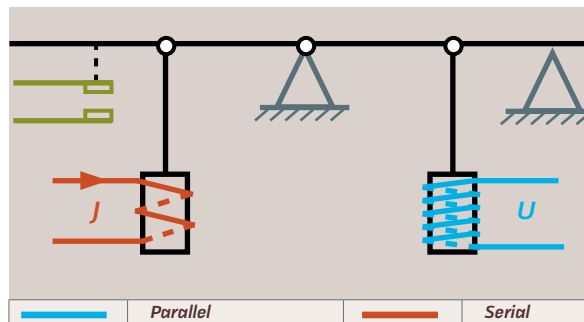
When distance protection was introduced it became obvious that in a case of a double earth fault (base point of fault in different phases of different systems) different measuring values had to be used. Biermanns proposed a scheme in 1924.

The voltage coils were on the phase to phase voltage for short circuit faults and were on the phase to earth voltage for earth faults. He introduced the changeover of measuring circuits with zero-sequence current in the summation current circuit as is used today. The name "zero sequence startup" is used incorrectly - in this application it refers to a changeover of measuring values. O. Mayr proposed a similar scheme in 1924. The commonly used schemes for resistance-dependent protection are described briefly. The following assumptions were made:

- there is no changeover in the current circuit
- in isolated or compensated circuits there are opportunities to reduce the number of CTs required, thereby reducing the number of relays required
- it uses startup overcurrent

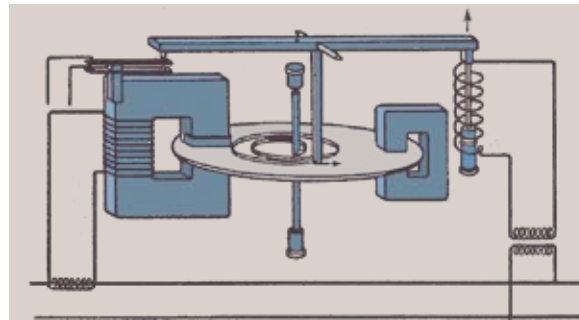
The six relay circuit detects each and every phase-phase fault and phase-earth fault with separate measurement elements. In the case of a double earth fault (where a zero sequence voltage or current occurs) the three relay circuit

## 11 Balance-Relays by Ackermann, 1920



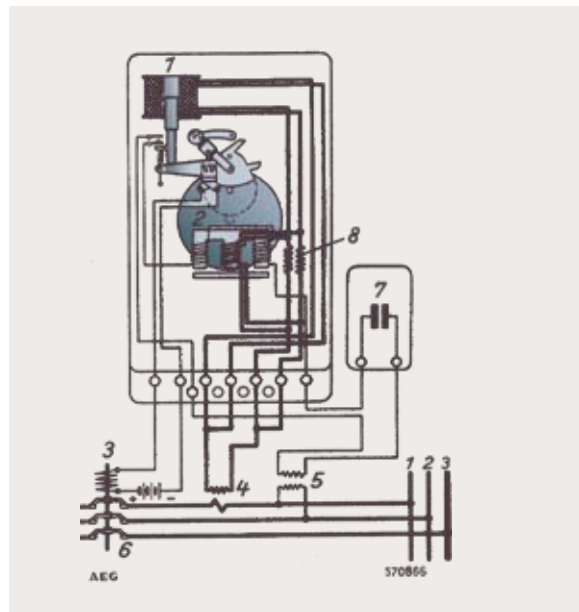
11. The combined voltage and current relay using the resistance principle, was proposed by Canadian Ackermann, P. in 1920

## 12 Induction or Immersion Anchor, Westinghouse-Relays

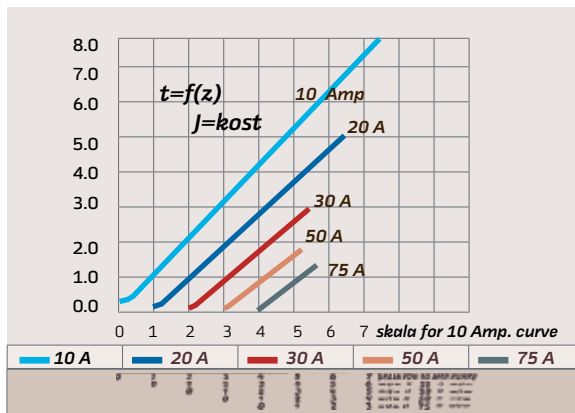


12. Medium voltage impedance relays with adapted phase shift were developed by BBC

## 13 Circuit Biermanns-Relays, AEG, 1923 / 4



## 14 Tripping Characteristic Wideröe-Relays, NJEV



(Fig. 15) uses the voltage change between phases rather than the phase-earth voltage. The two relay circuit uses two measurement elements only with two current transformers. A changeover is possible with the zero-sequence voltage only. A further simplification is possible with one relay circuit, also known as one relay impedance protection. Only one measuring element is necessary and the changeover is dependent on the zero-sequence voltage. The one relay circuit (using 3 current transformers with measuring value changeover in the case of a zero sequence current) is the default solution in the medium and high voltage applications. Subject to phase or zero sequence current startup, the measuring element is connected via interposing relays to the currents and voltages (in accordance with directional elements).

To avoid a changeover of the currents, current proportional values are obtained from interposing transformers or shunts.

Due to the reduced control time and redundancy, six relays circuits are only used in the EHV grid applications.

Practical experience has shown that easy changeout of the scheme is appreciated since it would allow a change of transformer or line lengths settings on site. The Biermanns

relays allowed on site changes of rate of rise with a ratio 1:2 of winding groups connected in series or in parallel. To change the characteristic of an N-relay; the cam disc, the bi-metal strip or the saturation transformer had to be changed. Every new characteristic curve had to be calibrated with a number of measuring points.

Due to the aforementioned results of the short circuit tests, new characteristics were developed, e.g. characteristics that during nominal voltages required double the nominal current value to initiate a trip but in the case of very low voltage (short-circuit!) a current level of 30% of the nominal value was sufficient to trip the relay.

Between 1925-1927 the German utility Bayernwerk in collaboration with vendors S&H, AEG and BBC carried out 70 short circuit tests to study the behavior of the distance protection schemes.

### Requirement for Fast Impedance Protection

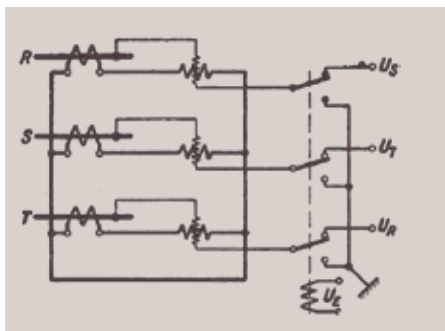
At the end of the 1920s calls for shorter tripping times (less than 2s) grew. This was necessary to prevent the network getting out of step with generators, dynamotors and motors. The breaking power of the oil circuit breakers increased allowing shorter tripping times. The operating time of resistance relays grew proportionally with the distance from the fault location to the relay. The rate of rise of the characteristic had to be considered carefully to avoid protection overlaps along the length of line. The fault locator was born out of the fact that consideration of the operating time of the definite characteristic of the protection relay allowed the fault location to be identified.

The goal for the 60 and 110kV networks was to achieve the shortest tripping time over the entire length of line. For this reason, the more commonly used continuous time characteristics were abandoned in favour of the new step or mixed characteristics.

*Further steps in the development of distance protection will be covered in the next magazine issue.*

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## 15 Three Relay Circuit



## 16 Scheme of a Wideröe-Relay, NJEV

