

The intention of this series of articles is to begin to piece together the true account and timeline associated with PAC developments and to recognize the achievements of the pioneers of early and modern PAC technology.

The farther backwards you look, the farther

Introduction to the History of Selective Protection

forward you are likely to see (Winston Churchill)

THE TECHNOLOGICAL DEVELOPMENTS AND ACCOMPLISHMENTS OF PROTECTION EQUIPMENT are rarely a cause célèbre within the power industry. It is easy to understand why this is so when one considers that the little black box often pales into insignificance when compared with the physical scale, size and cost of generators, transformers and switchgear. Indeed protection topics are often only discussed after a disturbance or blackout.

Nowadays we achieve a high security of supply thanks in part to the secure and reliable performance of protection, automation and control (PAC) equipment. Indeed people take the availability of electricity for granted and pay little attention to the effort required to reach this state.

That is why it is useful to consider the first steps of electrical power supply protection and to note the technological development from the early fuse protection up the current state of the art initiatives. Such consideration may provide an insight into the silent, often obscure work on protection and substation automation systems. This will be the first in a series of articles where we will outline the steps in the development of PAC equipment. We admit that there may be information in the articles which may be subject to debate, particularly with regard to the historical accuracy of certain events and the fact

that we do not have access to all records. Indeed the articles may appear to be biased towards European developers, but this Eurocentric perspective is due to access and availability to data. We warmly welcome contributions from our readers, particularly those who may be familiar with historical developments that may have been going on in parallel in other regions, e.g. United States, Japan, former USSR etc.

Technological developments typically follow certain rules and in general you can observe three stages of development. Initially, there can be quite a gentle or silent start-up however this ripple is often followed by a stormy wave of developments which eventually moves towards a more steady state with ongoing incremental activity. This reflects the fact that new ideas are often treated with skepticism and, in the absence of any real need, are not put into practice unless genuine technical or practical reasons exist for doing so. Necessity breeds invention and those ideas that satisfy needs in the industry are more likely to be successfully pursued. Another driver for inventions is the goal to overtake the competition in the market place. In such cases existing ideas are often recycled and improved. One invention supersedes the other. As the German protection pioneer Hans Titze mentioned in his award winning ("Conrad-Matschoß-Medal") publication in 1962,

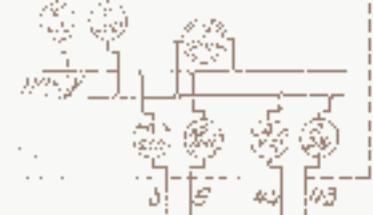
by Walter Schossig



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 reunition 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 "Power System Protection". He works on a chronicle about the history of electricity supply, with emphasis on protection and control.

Station
LNG



Relaisplan
Erläuterung:
Unabhängiges Maximal-Zeit Relais.
Pfeilstromrelais



Einstellung:
Zweite Zahl - Zeit in Sekunden
Untere Zahl - Auslösestrom.

“New ideas sometimes appear like an avalanche: new, up to now unknown approaches appear.” This observation is valid even today as people rush to exploit the possibilities offered by new technological developments.

100 Years Selective Protection

Developments in PAC equipment were not linear or consistent throughout the years. Some ideas and proposals were rejected initially (perhaps the market conditions were not right or there was not a full appreciation for the proposal's capability or there was no apparent need for the solution). Some ideas were discarded only to be rediscovered by others who recycled them, improved them and exploited them to their full potential driven perhaps by different market conditions or technical challenges.

The beginning of relay development goes back into the first half of the 19th century. In a paper for the French Academy of Sciences, the Frenchman Breguet noted the physical appearance of thin conductors near a telegraph station after a lightning strike. He had observed that the thin conductors had disintegrated after the lightning strike leaving only traces of what had existed beforehand.

His paper, dated the 3rd of May 1847, stated that “...to protect the devices and especially to protect the employees in the station I recommend the use of electricity conductors, 3-4mm in diameter, made of iron and to be located 5-6m from the device.” The report continued, “We connect larger diameter wires of equal metallic behavior to the thinner wire conductors. This approach allows only the amount of electricity that can be carried through the thin wire to be conducted to the stations. In the case of a fault discharge the wire fuses and interrupts the current outside the building, not inside.” The Breguet paper is considered the birth of the fusible link.

The Fusible Link

The distribution grids proposed by Edison and his company to supply electric lighting systems used fusible links. In 1880 the fusible links used strips of lead (“Edison Lead Switch”).

Another solution discussed a “lever switch whose lever had a reduced diameter which fused at a certain level of current”.

In the early days of electric power systems the protection requirement was simply to interrupt the flow of fault current. However selectivity emerged as a growing requirement as electric power systems became more complex with interconnection of transmission lines and the parallel operation of generators.

In 1910 the municipal utility in Hannover was one of the first recorded cases to introduce a color code for fuse identification. The utility had specified the use of fuses on every feeder to achieve selectivity on their system. The utility specified the size of fuses required for all lines and, in an effort to make the specifications more memorable, the authorities in Hannover used a fuse identification color code based on the color of stamps issued by the German postal authority.

In 1904 Kortler proposed the idea of time delayed self reclosing fuses. This technology is widely used today in medium and high voltage grids and is referred to as automatic reclosing or autoreclosing.

The Relay

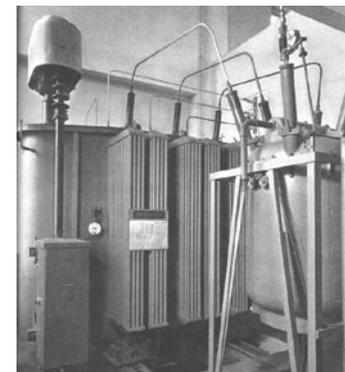
The word “relay” was established in the time when stage coaches were a means of transportation. A “relay” was a station for the change from tired horses to fresh ones. In the military the term “relay chains” refers to a chain of annunciators for passing on messages and commands. The introduction of protection relays was of course only possible after the creation of suitable switching devices that were capable of extinguishing the fault current arc and could also withstand the onerous short circuit currents generated under fault conditions. Brown proposed an oil circuit-breaker in 1892. With the introduction of direct release (directly initiated by the primary current) and secondary relays (supplied by current transformers or voltage transformers) “oil self switching circuit breakers” were developed.

1 Color of the German stamps and the fuse identification color code



Fuse		Stamp	
Rated Current [A]	Color	Value in pfennigs	Color
6	green	5	green
10	red	10	red
20	blue	20	blue
25	yellow	25	yellow+black

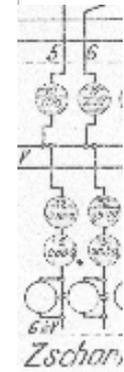
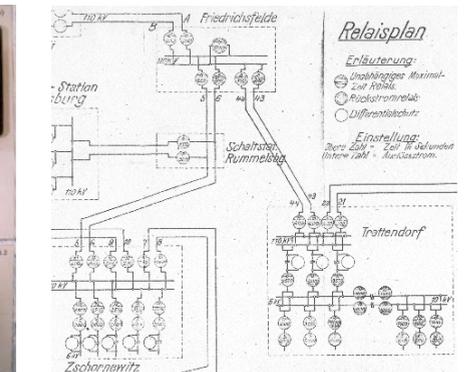
2 Oil Circuit-Breaker with Direct Release (Elektra Birsek, CH)



3 Lewis B. Stillwell (IEEE) 4 First Protection Relays



5 110-kV-Tripping-Schedule 1922 (Elektrowerke AG, Berlin)



The Birth of the Protection Relay

The first relay for protection purposes was proposed by Stillwell at 1900 although its application was limited since there were no reliable switching devices for the interruption of short-circuit currents at that time.

In future articles we will consider the development from simple overcurrent relays through to directional and distance/differential protection devices. We will discuss the different generations of relays as the technology progressed from the initial basic designs towards the current generation of adaptive digital relays.

The aim will be to inform the reader about key aspects of the different technology employed for protection purposes. It is interesting to note at this stage that one of the earliest cases of the application of a line differential relay was in England in 1912 and of a distance protection relay in Germany in 1921. Records show that both types were being used in the United States shortly thereafter.

The physical aspects of relays such as the shape, size, dimensions, casing and color have evolved and it can be noted that the physical appearance of relays have changed dramatically.

In the early years they looked like measuring instruments and changed as shown in figure 4.

One of the earliest connection of two separate grids (19th of November 1887), namely two power stations (Markgrafenstrasse and Mauerstrasse in Berlin, Germany), was synchronized using the synchronizing-bright method /synchronizing-dark method or sometimes referred to as dark-lamp synchronizing. An incandescent lamp is used by engineers to estimate the synchronism of the two grids by using to the brightness or otherwise of the light to estimate the voltage difference (magnitude and angle).

The lamp is switched between the same phases of each generator/system. When the engineer uses the dark method to synchronize the systems the lamp is initially brightly lit and this reflects the fact that there is a voltage from

one generator and no voltage from the other. The excitation of the second generator is adjusted and the voltage changes. Consequently the brightness of the lamp changes as the phase angle or the rotation speed of the generator changes. The lamp is completely dark when both generators/systems are in a fully synchronized state and it is safe to switch in. The bright-method works in the opposite way, i.e. the lamp is bright under synchronous conditions.

This synchronizing method was published by Brown Boveri Company (i.e. BBC but now known as ABB) in October 1928. The paper describing this method was published by Stoecklin but it is not clear whether he was the inventor. The author was unable to obtain any further information concerning the patent for this method.

Nowadays almost half the continents are interconnected and operating in parallel using WAMS and GPS systems. Such interconnection would barely have been imagined a hundred years ago. The 220kV grids of France, Germany and Switzerland (“the star of Laufenburg”) were interconnected in 1958. The Western-European UCPTÉ-grid and the East-European CENTREL/VEAG/BEWAG-grid with parts of the Romanian and Ukrainian grid were inadvertently connected one year before the “electrical reunion” of Germany. Obviously consumers remained unaware of this fact. Such interconnection was made possible by the effective operation of synchronizing devices.

Trip times of early PAC equipment were often dubious and dependent on inaccurate timing mechanisms that could only be set to operate in 2 seconds or in the case of generator protection 10 seconds or even up to 30 seconds. The tripping schedule published in 1922 (see figure 5) shows the settings of an overcurrent protection relay (i.e. 12 seconds). The relay operated on lines 5 and 6 of the Zschornewitz – Lichterfelde substation in Berlin and its operating time upon detection of a fault was set at 10 seconds. Such relay time delay settings are unimaginable by today's standards.

Pioneers of Protection Technology

The upcoming series of articles will mention the devices, techniques and protection philosophies of many pioneers of PAC protection. For example, names synonymous with protection such as Buchholz, Täuber, Pfannkuch, Cleveland, Merz-Price, Bütow, Westinghouse, Kuhlmann, Biermanns and Paul Meyer will be discussed.

We will consider Petersen coil and Bauch's neutral earthing transformer, the paradox of Bauch, Bollinger's switches, Horn's annunciator, Stotz's mini circuit breaker; Scharf's triangle and the Poleck circuit.

There are many other people whose achievements in PAC history and development warrant a mention and indeed those whose achievements should be honored. We look forward to receiving suggestions and contributions from our readers to augment the information that we have collated.

Generations of Protection

Relay technology has evolved from the simple electromechanical or moving-coil relays that were introduced in 1940, to electronic or static relay modules in the 1960s and ultimately towards the more sophisticated microprocessor-based protection devices in the 1980s. Technology was exploited to avoid unwanted tripping and provide more discriminating, stable and reliable performance through the addition of time-delays, fault direction and impedance measurements to the relay's tripping criteria.

It is incredulous to modern protection engineers that at one time the timing elements on protection relays were running bowls as shown in figure 6. Such devices are perhaps the origin of the phrase "relay run times".

Protection sensitivity increased with the use of new measuring technologies in instrument transformers and relays. Relay self supervision also led to increased reliability. The development of voltage memory for three-pole close-up faults helped to avoid unwanted relay operations ("dead zone").

Difficulties in detecting faults that had short-circuit values below the relay pick-up levels, for example when large machines are operating at low load times such as on Sunday and at night, caused researchers to develop protection that would operate under such fault criteria. BBC developed the crossed-coil instruments for protection purposes and patented this in 1928. These electromechanical relays are no longer manufactured but many remain in successful service worldwide demonstrating the effectiveness of the design.

Other developments in technology now mean that engineers no longer have to go to the substations and look for physical indications of faults, e.g. broken pieces of porcelain from power system equipment, fallen lines and towers etc. Modern PAC equipment aids engineers in identifying the nature and location of the fault.

The Wife as an Autorecloser

It may come as a surprise to many to know that in the past many substations contained not only switchyards, transformers and control rooms but also the engineer's

apartment.

One advantage of such an arrangement was that as the switching engineer worked as the substation operator during normal working conditions, his wife was in a position to supervise the substation (although admittedly she did have a limited license for autoreclosing circuit breakers!).

Although Bollinger patented a "Self Running On-Break-Switch for Automatic Reclosing" in 1913 it seems that the first published papers concerning autoreclose, and the operational problems associated with autoreclose, did not appear until 1925 in both the United States and Germany.

Autoreclose technology has obviously developed over the years however. I still remember a station where a circuit breaker operated a three stage autoreclose sequence through the use of weights and levers that moved the breaker.

In the past the switching engineer was able to supervise all feeders in a station through a simple visual check of the ammeter readings against predefined values that were marked on the ammeter faces. With the advent of unmanned stations, faults and irregularities were identified by the transmission of the feeders sum indications. However if it was not possible to transmit information like an earth fault or a Buchholz-warning, an alternative possibility of communicating the occurrence of a fault was when the actual tripping of a line caused the customer suffering the outage to contact the utility to complain about the power cut.

Remote Control

It could be said that the dividing wall was the first "remote control" initiative implemented to protect operators switching potentially explosive oil circuit breakers. Through time mimic boards were introduced to stations – these were the precursors to the modern Human Machine Interface (HMI) now installed with station computers.

The development of protection and substation automation systems had taken place in parallel however with the introduction of digital technology these two technologies began to converge.

The convergence started with the proprietary exchange of information between protection and substation control systems. The journey from "Interface Number 6" (i.e. the forerunner of today's standard IEC 60870-5-103) and IEC 61850 involved many individuals and significant effort on various international working committees. The latest implementation of PAC technology allows the exchange of power system information across political borders and geographical regions and permits the synchronization of electric power systems to form huge power grids.

Measurement of Power System Values

The conversion of primary power system values to secondary ones are an essential aspect of the protection systems. A measurement technique without iron was proposed by Rogowski and Steinhaus in 1912 however the application of those ideas have only recently been seriously considered and implemented by the power industry.

In 1926 Arnold proposed a nominal secondary value of 1A, however many utilities still use the 5A rating.

Today we speak about the Holmgren-circuit but in actual fact it was Nicholson who in 1910 proposed and patented a method of measuring zero current.

The Language of Engineers

As the electric industry expanded it soon became essential to establish a common set of terms, standards, rules and regulations to allow effective communication between engineers.

Engineers communicate with drawings – they have done so in the past, are doing so now, and will continue to do so in the future. The first harmonization of symbols took place in 1928 and ten years later the first International Electrotechnical Vocabulary (IEV) was published by the International Electrotechnical Commission (IEC1).

The American Institute of Electrical Engineers (AIEE) (now IEEE) introduced codes for the description of protection functionalities in 1928. For many years the use of American National Standards Institute (ANSI) / IEEE codes was limited to the Americas however the codes are now being used all over the world. Some of you, dear readers, might remember the block diagrams from the 30's – you know how to value modern drawings, right?

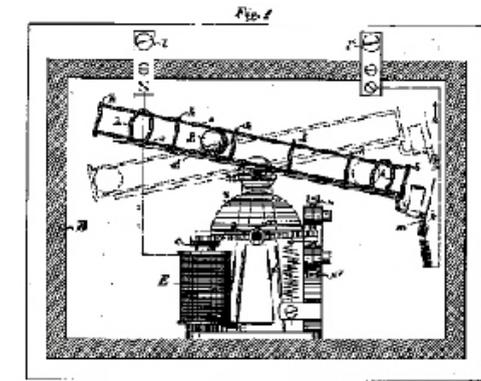
Practical Tests

Often when there were savings in primary equipment, additional funds were made available for more elaborate protection solutions. These solutions were tested using stage faults. There were no grids with isolated or with high resistance grounding on the 30kV grid in Berlin but Kuhlmann obtained the first measurements in 1908 having received special permission to conduct the necessary tests from the director Wilkens.

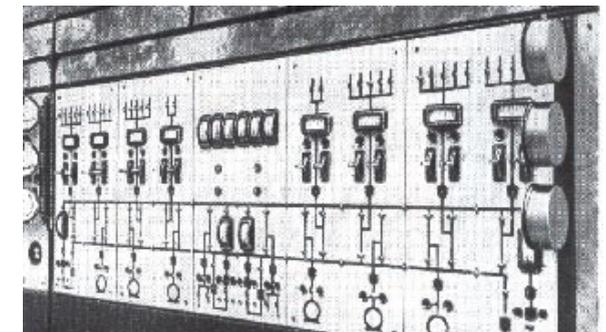
Examples of stage faults include those in 1925 on the 110-kV-grid of the Bavarian utility „Bayernwerke“; in the 1990's on the 380-kV-grid of Switzerland/ Austria; and in the 750kV interconnection between Hungary and Ukraine.

One of the first cases of a stage fault in the United States and Canada was on the high voltage terminal of transformers in 1924. Stage faults were frequently used in the 1950s in the former Soviet Union on the 30-kV, 110-kV and 220-kV systems. Shorting circuits with spring energy storage were manufactured in Poland and had an operating time of 120 ms

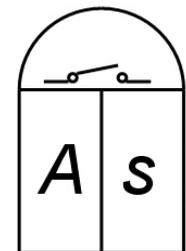
6 Time Relays 1891, DRP 59 192



7 Mimic Diagram Symbols EW Amsterdam, 1908 (AEG)



8 Symbol TOC-Relay 1928



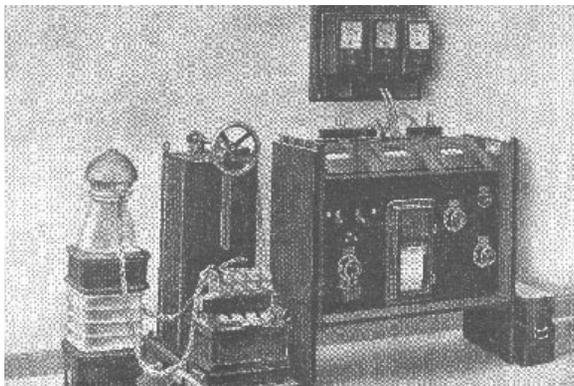
9 The first IEC 1938

05-45-085	Relais : Appareil destiné à produire dans un circuit une modification donnée lorsque certaines conditions se réalisent dans le même circuit ou dans un autre circuit.	Relay : Apparatus intended to produce a given change in a circuit when certain conditions are realised in the same or in another circuit.	Relais, Schütz Relais, relé Relevador, relé Relajso
05-40-095	Contact à la terre : Connexion accidentelle d'un conducteur avec la terre. Lorsque l'impédance en est négligeable, la connexion s'appelle « terre franche ». Par abréviation on emploie le mot « terre ».	Contact to earth, earth : The accidental connection of a conductor to the earth. When the impedance is negligible, the connection is called a "dead earth".	Erdschluss Contatto a terra, terra Contacto a tierra, tierra Terkontaktó

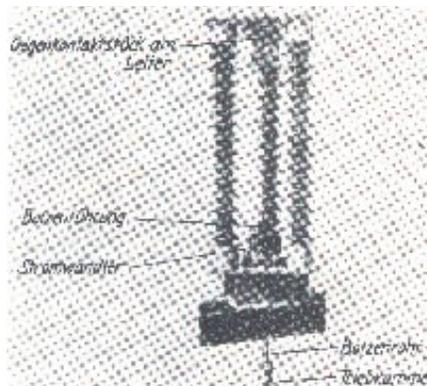
1. The IEC was founded in June 1906, in London, England.

2. The AIEE was a United States based organization of electrical engineers that existed between 1884 and 1963. It merged in 1963 with the Institute of Radio Engineers (IRE) to form the Institute of Electrical and Electronics Engineers (IEEE).

10 Testing Devices Dr. Paul Meyer AG 1925



11 110-kV Short Circuit, DSSR (IfE).



12 Short-Circuit Stage Fault 380 kV Station Pradella



13 Process Computer in the Substation Bad Kissingen (SIEMENS)



on the 110 kV system and 200 ms on the 220 kV system. Shorting circuits with explosive cartridges were manufactured in the former Czechoslovakia and were used in the former German Democratic Republic (GDR) for testing on 110-kV transformers.

The Introduction of Electronics

In 1934 Wiederöe proposed the use of electronics in protection devices. Four years later Maret proposed the use of electronic tubes instead of electromechanical relays for line differential protection. The introduction of analogue measuring techniques began in 1965 and by 1967 Morrison had analyzed the use of computers for grid and network simulation. Two years later Rockefeller published his Masters thesis "Computer Protection" and from hence digital protection technology was to become a reality.

In 1977 the 110-kV/20-kV substation Bad Kissingen substation in Germany became the first substation in Europe that was completely protected by digital protection. This substation had a computer to implement the protection processes and for the real-time logging of events.

Summary

As mentioned earlier, the main focus of these articles is to discuss the historical development of protection and substation automation, including distance and differential protection; generator protection; the evolution of the technology used in protection systems; issues associated with faults and fault location; testing devices; and measurement transformers.

Protection has evolved from a single phase fuse to the protection of a six phase line or an n-phase transformer. We will attempt to outline the important contributions of the pioneers. The value of their contributions can be appreciated if we consider the influence their developments have had on the ability of modern engineers to provide us with a reliable power supply.

We expect there will be gaps in the information provided. This could be caused by missing manuals, lack of technical records and gaps in the author's knowledge. I ask for your understanding. Any comments, suggestions and corrections are most welcome. Please send them to walter.schossig@pacw.org