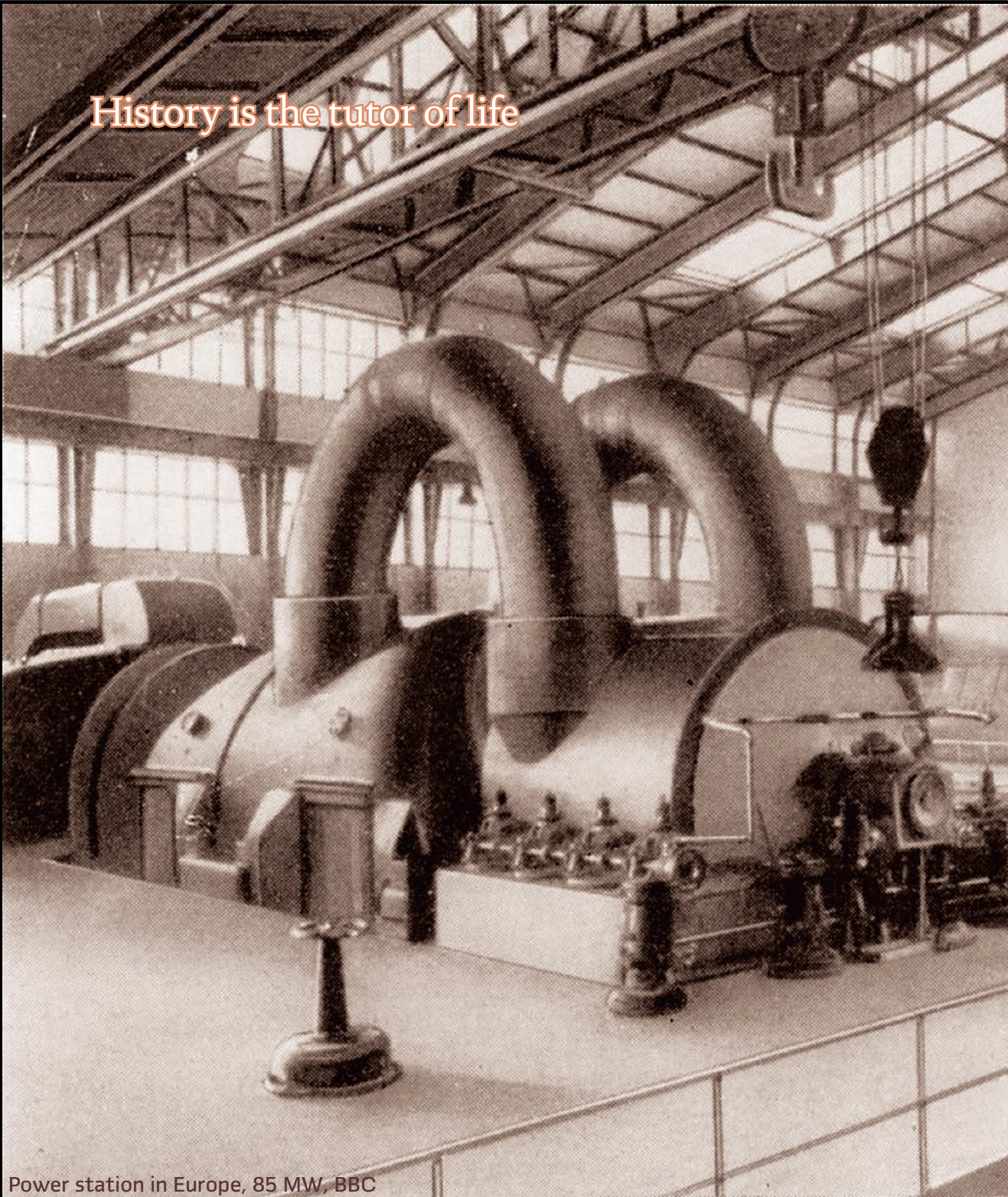


History is the tutor of life



Power station in Europe, 85 MW, BBC



# Protection History

# Generator Protection

## Stator Ground-Fault with unit-Connected Transformer

## 90% Earth Fault Protection

There was a capacitive coupling between transformer and generator. In case of an overvoltage in the high voltage part the resistance is low, it discharges to earth. This means, that the resistance in the lamp is low if the voltage source is not fertile. In case of an earth fault the lamps are getting warm, which increases the resistance and limits earth fault current. This principle could be used in low voltage grids only, where the power was limited. Figure 3 is showing the scheme used. The neutral of generator G is earthed with a voltage transformer S. On secondary side of this transformer the relays R are series connected with lamps. To protect entire winding with star point it was the proposal of Dr. Robert Pohl to move the neutral artificially. His patent (DRP 456761, 1928) showed a current source P series connected with voltage transformer S. Now it was possible to produce a current bigger than the startup value of the relay R even in case of a fault at neutral point directly.

By utilizing electro-magnetic relays it was possible to supervise approximately 80% of the winding, starting from terminal. If moving-coil relays (*magneto-electric*) have been used, the zone of protection could be enlarged up to 90%. The residual voltage needs to be rectified. The extension of the zone was possible because the torsional decreased linear with the voltage in permanent magnetic relays, but with the square at

electro-magnetic relays. This was possible with dynamometric relays as well. In that case one coil was supplied with residual voltage, and the other one with auxiliary voltage.

Special devices with fixed resistances built in 1929, allowed currents of 10 up to 30 A. Dr. Pohl showed, that this is acceptable if the generators are switched off immediately. Bütow showed, that currents below 4 A do not cause a damage, since a carbon channel develops in the mica material. This material was a conducting medium, thus no further warming occurs. It was possible, to operate the damaged machine as long as a substitute could be started.

With frame-leakage-relay RV2 (Figure 1) SIEMENS produced a sensitive and overloadable relay in 1935.

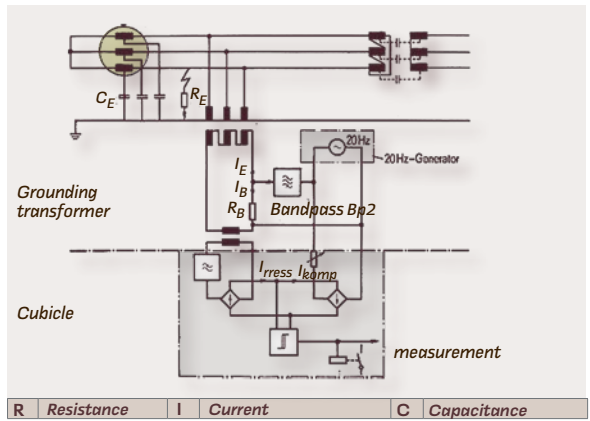
An earth fault supervision as shown in Figure 9 was proposed by Bender, Frankfurt/Oder (Germany) in 1943.  $R_1$  and  $C_2$  are calculated in that manner, that the currents  $i_E$  and  $i_1$  are bigger than the currents through the coupling capacity of the transformer. Now the tripping current could be limited in that manner, that no damages occurred anymore. All earth faults at the neutral winding of the generator could be detected with the current relay 3; the earth faults in the delta-winding could be detected with a voltage-relay 4. Using the scale A allowed to read the information during operation.

To remove the harmonics through the coupling capacity of the unit transformer, Leopold Fersch from SIEMENS, Austria patented (AT876427) a solution as shown in Figure 5. Capacitances (4) at the generator's lead have been in series with coil (5) tuned for the triple of frequency. To achieve, that capacitances became a part of protection zone, the star-point was grounded with the primary winding of transformer (6). The secondary winding was connected to relay (7). Capacitance (8) operated as overvoltage protection.

To avoid the neutral transformer Joachim Hinze from East-Berlin proposed another solution (Figure 6). Between the neutral of voltage transformer (3) and earth was a neutral capacitance (1) with surge arrester (4) in parallel (consisting of reactor (5) and auxiliary relay).

Prof. Atabekow published in the USSR in 1956, that for unit transformer-generators high-resistance neutral-grounding shall be used. The resistance should avoid high voltage

#### 4 Protection with 20 Hz auxiliary voltage, Siemens, 1972



displacement at generator's side in case of short-circuit at the high-voltage-side. The earth fault detection was realized with a current relay. Later investigations showed that in the reality coupling capacities of transformers and generators did not allow big voltage displacements. In case of solid grounding, voltage displacements are short-term only. Due to that the Soviet Union decided to stop generator star point grounding and introduced isolated neutrals. The voltage at the star point was in case of normal operation 2-4 V; an over-voltage relay was sufficient (3 in Figure 10), the setup was in between 10-15 V. A time relay (4) was set up with 0.5s to avoid false alarms in case of transient phenomena. An additional resistance (5) was not necessary. If the earth current at generator's side was more than 5 A (e.g. in case of several generators supplying a single unit transformer) Petersen coils have been used.

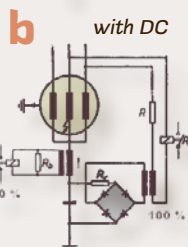
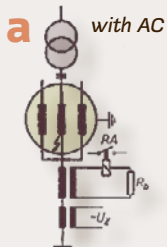
In the US it was common practice, to earth the neutral of generators with a low-resistance. This allowed a detection of earth faults with differential protection. To decrease the effects of big fault currents a high-speed circuit breaker in the neutral was used. This was also very useful if the generator circuit breaker or the de-excitation control failed.

In Eastern Germany false tripping of a stator ground fault

#### 1 Frame-leakage-relay RV2 (Siemens, 1935)

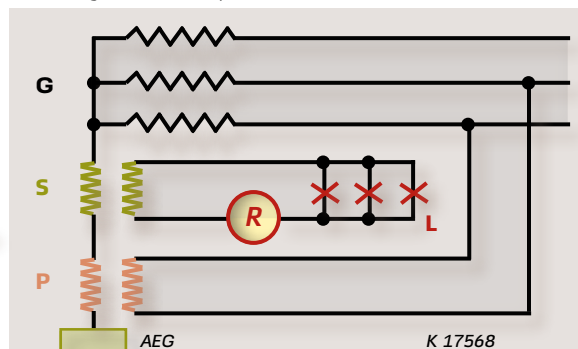


#### 2 100%-Stator ground fault protection

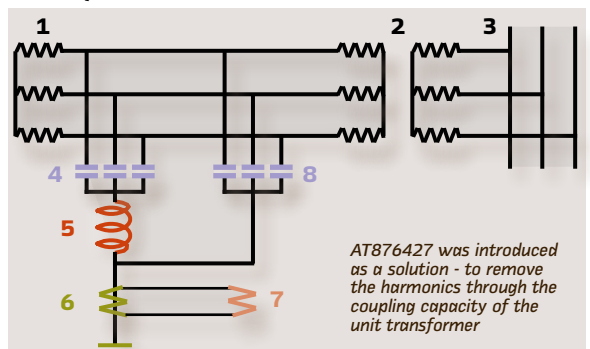


#### 3 Earthing of generator's neutral with lamps

According to Dr. Bütow's patent the neutral was shifted (Dr. Pohl, AEG)



#### 5 Frame leakage protection, Fersch. L., ÖSSW, 1953





## Electromagnetic relays allowed almost 80% supervision of the winding.

protection relays occurred eight times between 1959 and 1961. Analysis of these operations showed that it happened under special circumstances of a certain machine and a special load producing 150Hz voltage. H.J. Hoßfeld developed a blocking circuit (Figure 8 and 11) for this condition.

The limitation of earth fault currents with magnetic amplifier was patented by Reinfried Hauser (Germany) in 1962 - (DE1133808).

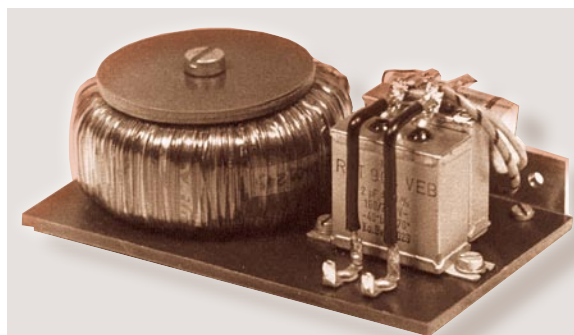
Considering the issue, that the probability of an earth fault near the grounding is low (minor voltage encroachment), a 90%-earth fault protection was estimated as sufficient.

### 100% Earth Fault Protection

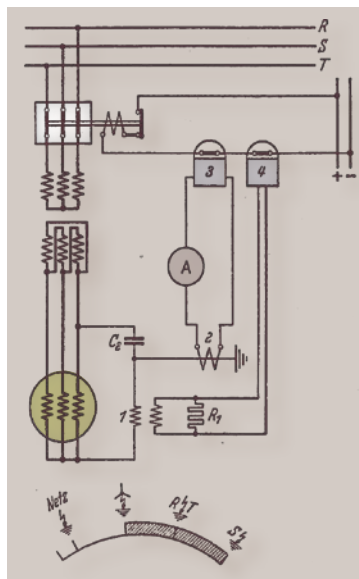
For huge hydrogen-cooled generators the 90%-limitation was not acceptable. Vibrations and elongations due to heat in the stator winding could cause hair-lines cracks, and coolant could penetrate into the stator. This increased the risk of stator ground faults. That's why there was a demand for huge generators (more than 200 MW) to provide an additional protection that can operate near the neutral point - the 100% stator ground. Several approaches have been discussed-additional 50-Hz-voltage in the neutral point, separate source-voltage (frequency < 50 Hz), or an analysis of the 3<sup>rd</sup> harmonic.

SIEMENS introduced a "sensitive protection" to be used as a 100% stator protection in the 1950s. This device used an artificial displacement voltage with AC and DC (Figure 2a/b) In the DC displacement ("Wächter-circuit") the capacitance was connected to DC (rectifier and interposing transformer). The DC is without an effect during normal operation. In case of an earth fault the DC current is supplied by the rectifier. This increases the current consumption in rectifier transformer. A current relay can trip at a certain value. This so called fine-protection RA, realizing a 100%-protection was

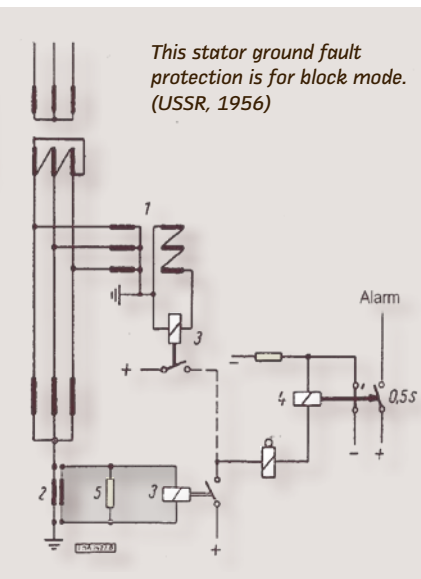
### 8 150-Hz-blocking circuit, Hoßfeld, 1966



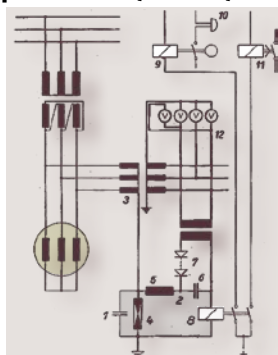
### 9 Earth-fault protection, Bender, 1943



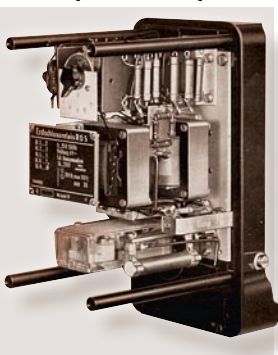
### 10 Stator ground fault protection for block mode



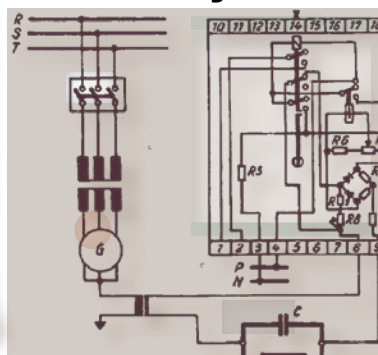
### 6 Stator ground fault protection, Hinze, 1956



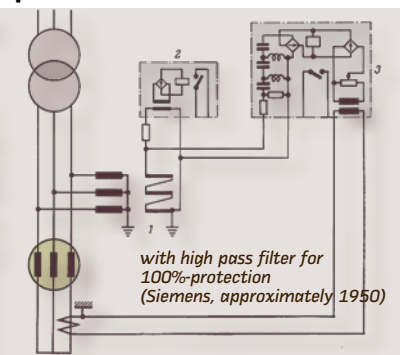
### 7 Earth fault relay RG5, Siemens, 1950



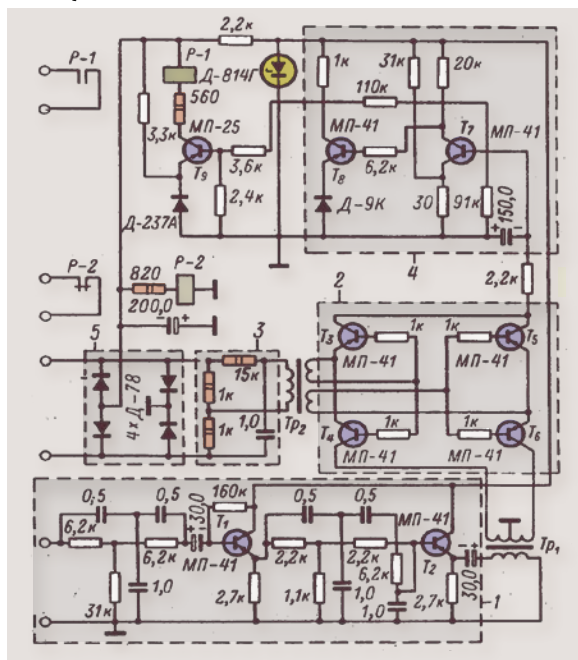
### 11 Relay REG4 with 150-Hz-blocking circuit



### 12 Stator ground fault protection for 70-90%



### 16 Pickup element of 100% - protection, USSR, 1969



delayed, because it was very sensitive against disturbances and inrushes. Since earth fault in the neutral point do not cause displacement voltages, there was no danger of a double-fault. Nevertheless, it made sense to trip fast in case of earth faults at the terminals. This was possible with an additional voltage relay RV set up with 20% - it tripped undelayed. The Swiss company Oerlikon used the same principle in 1965.

Another variance of the 100%-protection worked with 3<sup>rd</sup> harmonic of generator voltage. Figure 12 shows the circuit with separation of 70%- and 100%-relay (2). The high-pass filter in the RG5 (Figure 7) allowed the detection of earth faults in the neutral point and around it.

### Devices with fixed resistances built in 1929, allowed currents of 10 to 30A.

BBC's stator ground fault protection CUH90 was produced in 1966 (Figure 18). The protection system consists of 3 relays in one housing (5 in Figure 15). The device measured the displacement voltage and one phase-to-phase voltage. This allowed a detection of direction and a visualization of the phase with earth fault. The transformer (1) produced the artificial displacement voltage; the auxiliary relay CUG (6) controlled the compensation. For the hydro power station Krasnojarsk (USSR) Vainstein, Smoljlov, Getmabov, Puskov and Cikunov at the Technical University of Tomsk developed a 100%-protection at the end of the 1960s. They superimposed the generator current with a 25-Hz-signal (Figures 16 and 17). The current was produced from the station service, so it was available even at start-up of the generator.

For the 125-MVA-steam-units in Werndorf (Stewag, Austria) and in the two 102-MVA-generator-transformer-units in pump storage power station Kops (VIW Austria, Figure 13), an improved Bütow-protection was used by ELIN. For the connection of resistances and for the production of small displacement voltage for the 100%-protection, only one transformer was used (Figure 19).

All generators with more than 100MVA have been equipped with 100%-protection in Germany, Switzerland, United Kingdom, Yugoslavia and other countries in the 1970s. In other countries it was recommended to do so. The explanation was not the electrical load - this was negligible. It was intended to avoid mechanical damages and issues related to the water cooling of the stators.

SIEMENS presented a protection with an auxiliary voltage with a frequency of 20Hz in 1972 (Figure 4). Horst Gierke (East Germany) proposed another protection for

### 13 HN 8/10, ELIN, 1968

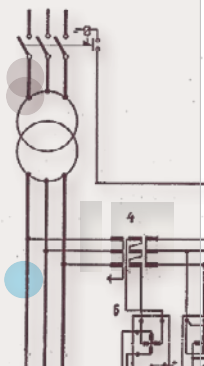
Stator ground fault protection transformer



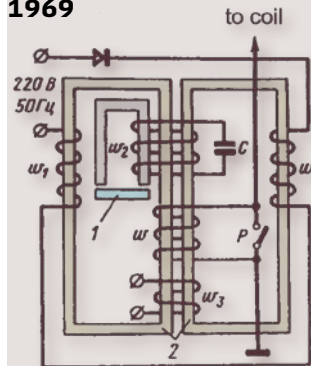
### 14 7UE22, Siemens, 1983



### 15 CUH 90 with CUG, BBC, 1966



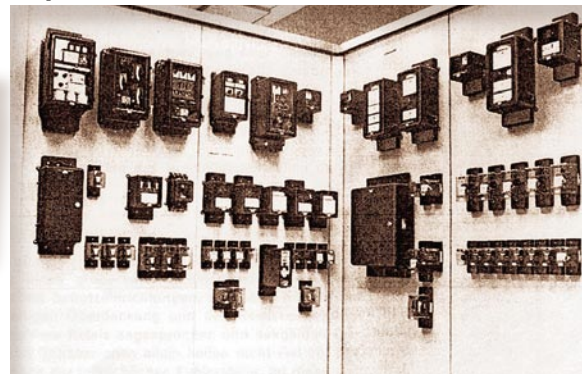
### 17 Principle with 25-Hz-supervision, USSR, 1969



### 18 CUH90c, BBC, 1966



### 19 Protection for the 102 - MVA-units at Kopswerk, VIW, ELIN, 1968



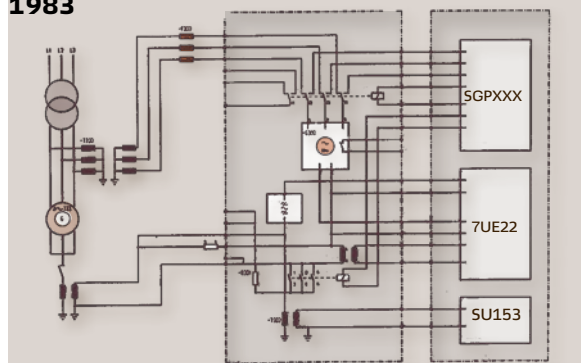


500-MW-units in 1974. This proposal should be used in addition to the existing 90...95%-protection with EAW's REG4. It was mounted between neutral and earth (Figure 25) and injected a DC voltage- without any effect in case of no stator ground faults. All voltage transformers between the generator and the low voltage side have been grounded with a capacitance. A ground fault caused a current flow in the transfer element i and tripped a modified voltage relay RUf5. To realize this function an auxiliary voltage between neutral and earth of 500...600 V was sufficient. ZPA (Czech Republic) produced the static stator ground fault protection G15X2 (Figure 27) in 1975. It allowed 100% detection. To avoid false trippings of the relays during short circuits at the high voltage side of unit transformers Jiri Bermann (ZPA) proposed the blocking in case startup of the short-circuit protection (e.g. of zero residual current relay at bushing's transformer and neutral point) in 1976. Since this should work during short circuits in the near only it was set up to  $I_0 \geq 0.5 I_N$ .

BBC's static relay GIX103 (Figure 26) was produced in the 1970s. It realized common 80%-protection utilizing the 50-Hz-displacement voltage for measurement. Additionally, a coded current (see also Figure 29) was injected. This current got a frequency of 12.5 Hz in case of 50Hz and of 15Hz in case of 60Hz. Now 100% protection was possible.

100%-protection was introduced in the US in 1980 (first time). It was in a 790-MW-Generation with a 25/500-kV-unit transformer in unit No. 2 at Plant Bowen, Georgia Power Company (Figure 22). Clayton H. Griffin and John W. Pope of Georgia Power, presented it at IEEE's PES 1982 Winter Meeting. In the year before R.L.Schlacke of Westinghouse Electric together with G.W.Buckley, Detroit Edison and G.McPherson, University of Missouri-Rolla reported their 100%-relay. It compared the 3<sup>rd</sup> harmonic at the neutral point and the generator's winding. A more robust scheme was proposed by Dr. Laszlo Pazmándi of the Hungarian VEIKI, patent granted, presented at CIGRE 1972 and reported about results of experiments at IEEE in 1975 (Figure 21). The first realization was the relay GTV100 in 1970 (Figure 23). BBC's modular static generator protection

## 20 Combination-100-% stator ground fault protection 7UE22 (Siemens) & SU153, AEG, 1983



## 21 Block diagram of filter and sensing element

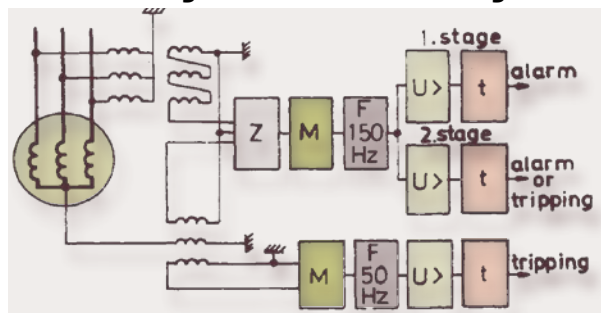


Figure 21:

Z zero-setting voltage divider  
M matching unit  
F active bandfilter  
U voltage detector  
t timing element

## 22 Ground Voltage Relay Protection, Georgia Power, 1980

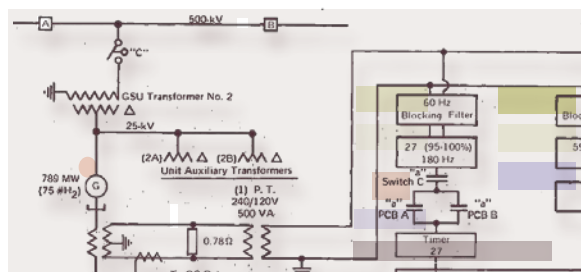
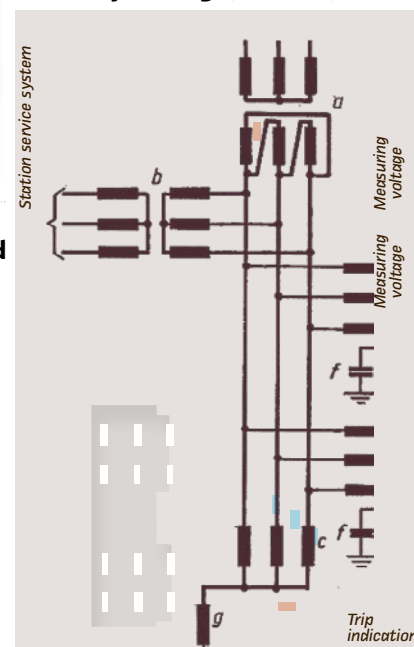


Figure 22: It was introduced in a 790-MW-Generation with a 25/500-kV-unit transformer in unit No. 2 at Plant Bowen, Georgia Power Company, USA.

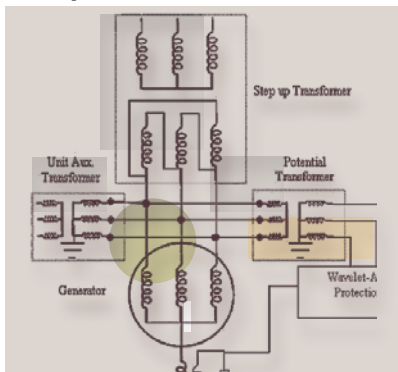
## 23 GTV100, VEIKI (Hungary), 1970



## 25 100%-protection with auxiliary voltage, Gierke, 1974



## 24 New wavelet based ground fault protection scheme, 2007



system GSX4 and GSX5e was presented in 1981 (Figure 31). An interesting combination was a solution proposed in 1983: combining static relays of SIEMENS' 7UE22 with AEG's SU153, realizing a 100%-solution (Figure 20). The earth transformer T300 was designed for,

$$\frac{U_n}{\sqrt{3}} / 500 \text{ V}$$

combined with a load resistance R300 for a short operation of 10s. The resistance depends on the ration of unit transformer and the protection zone of backup protection. SIEMENS 7UE22 uses the principle as shown in Figure 4.

Raimo J. Marttila of Ontario Hydro (Canada) analyzed the 3<sup>rd</sup> harmonic (150 or 180Hz) in phase-ground-voltage of stator's winding and found a 100%-protection. He compared the voltages  $U'_{EM3\Omega}$  and  $U'_{K3\Omega}$  after filtering (Figure 33). The 7UM51 series of SIEMENS was produced in 1992 (Figure 32). The zero-voltage protection was in 7UM512 the 20-Hz-injection for the 100%-protection took place in 7UT515. ABB's generator protection REG216/316 could be equipped with an auxiliary injection unit REX010 and injection transformer block REX011 (Figure 28a and b). The coded rectangular signals ( $U_{is}$ ,  $U_{ir}$ ,  $U_i$ ) with a frequency of  $f_n/4$ , have been injected (stator or rotor winding- Figure 29). The sphere of action was as in Figure 30. ABB, Finland presented the SPAG300 system in 1996. It includes a stator ground fault protection module SPCU1C6 in SPAG331B (Figure 34).

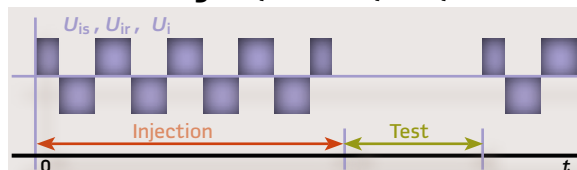
To find a proper solution for the protection of Three-Gorges Power Plant in China, an investigation of Huszhong University of Science and Technology took place in 2000. The required neutral resistance was 8 k $\Omega$ . To achieve 100%- protection a 12.5-Hz-Voltage-Injection was selected.

The last contribution is a proposal by Shaik Abdul Gafoor and P.V. Ramana Rao, Department of Electrical National Institute of Technology, Warangal in India at the ICIIS 2007; and in Sri Lanka - a New Wavelet Based Ground Fault Protection Scheme for Turbo Generators (Figure 24).

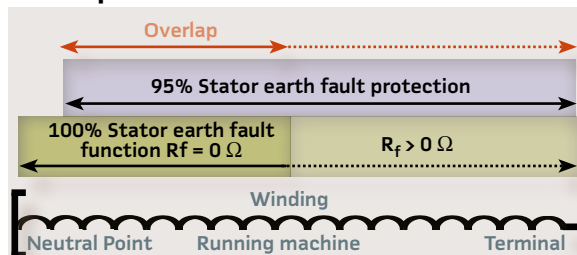
One of the next issues of the series will cover the way to multifunctional relays even for generator protection.

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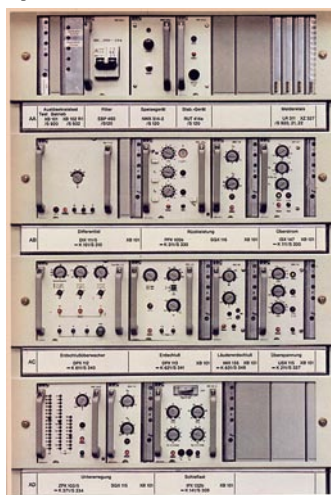
## 29 Coded signals, REX010, ABB, 1994



## 30 Sphere of action



## 31 Static generator protection modular system GSX4, BBC, 1981



## 32 7UM512, SIEMENS, 1992



## 26 GIX103, BBC, 1978



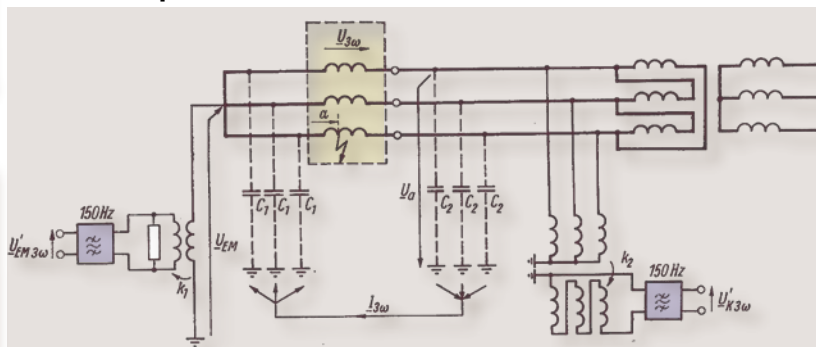
## 27 G15X2, ZPA, 1975



## 28 Auxiliary units, ABB, 1994



## 33 100% protection of Marttila



## 34 SPAG331B contains:

an overvoltage and reverse power relay SPC3B2, an overcurrent relay SPC3C3, and an overvoltage relay SPCU1C6, ABB

