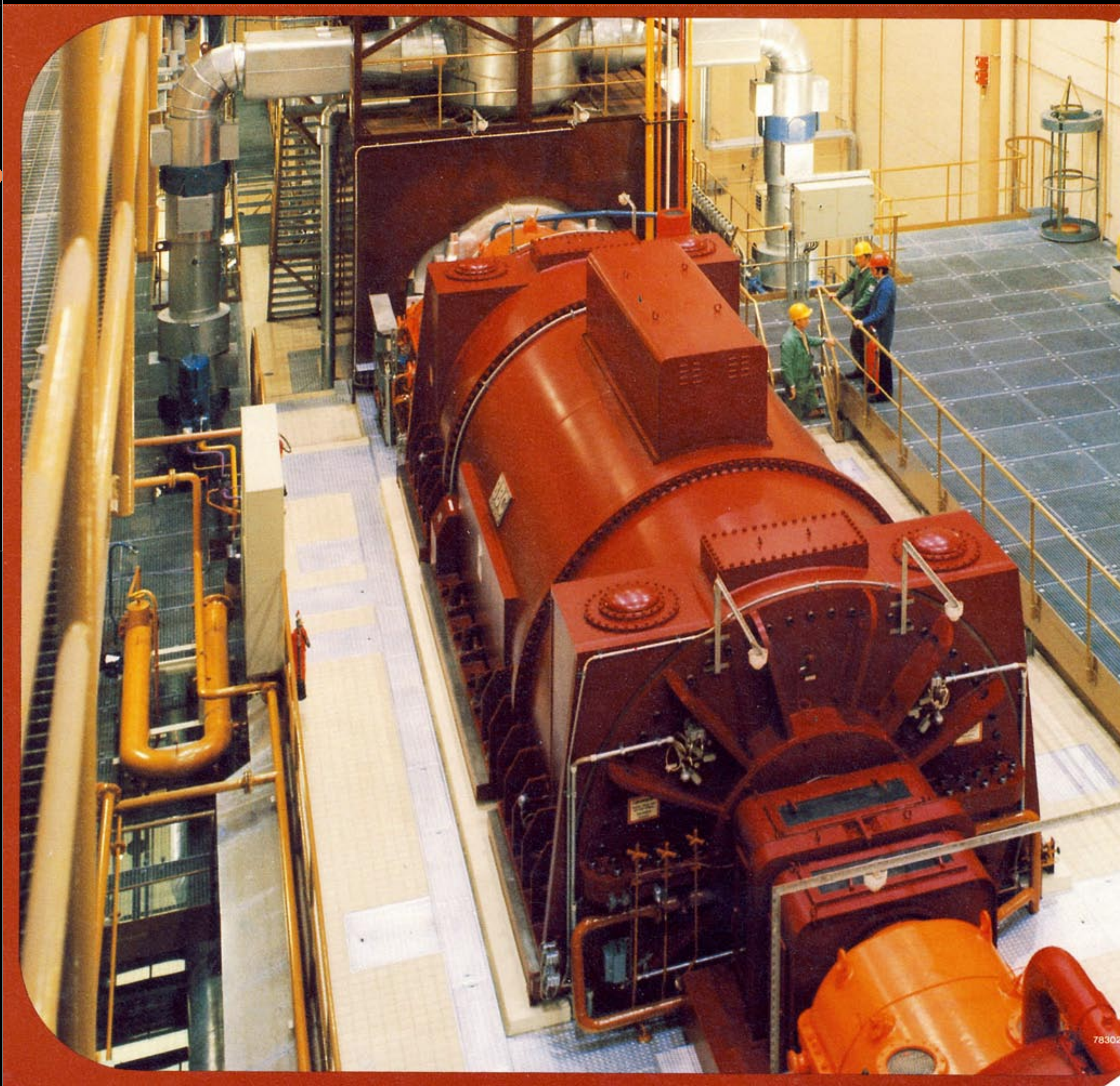


History is the tutor of life

The first gas turbine –
Compressed air power station in
Huntorf - static generator protection GSX6
(BBC, 1978)

by Walter Schossig, Germany

Protection History

Generator Protection

The Way to Multifunctional Generator Protection

The steps in the development of generator protection from single devices up to combination of electromechanical relays have been covered in the last issue of PACWorld.

Static generator protection started in the 1960s, e.g. overvoltage protection, load-unbalance protection and others. It was the goal, to realize all functions electronically.

BBC produced the two-step unbalance protection with linear measuring functionality IPX in the beginning of the 1960s (Figure 2). Rotor fault display IWX worked with faults up to 1200 Ω, winding protection UBX recognizing the displacement voltage of the 50-Hz-wave up to 2 %, and stator ground fault protection IXX protected 100 % of winding.

Differential protection D2 with moving coil technology became stable utilizing electronics (type DIX), and operating times could be decreased. The reverse power relay PPX could detect a minimum reverse power of 0.5 % of nominal power

ELIN produced analog protection in 1968, which have been used in a 125-MVA-steam-unit in KW Werndorf (Stewag) and in two 102-MVA-transformer units in the high pressure storage power station Kops (Vorarlberger Illwerke) - both Austria.

The company ZPA Trutnov (Czechoslovakia) developed static relays, e.g. generator protection GTX in 1970. Later in the 1970s they developed a protection concept for 500-MW-units called G500X1. Most of the protection functions have been realized electronically, and the devices became smaller than the mechanical relays. Typical examples of the system have been:

- The two-step impedance protection D15X2 (*See the image in the PACWorld June 2010 issue*) and
- The stator-ground fault protection G15X2- consisting of two relays (Figure 3).

In this device the main protection is a sensitive voltage relay supervising neutral voltage. This is the common mode with isolated neutral. The voltage element was insensitive against harmonics, the settings have been 5, 10 and 15 % of U_n. The other circuit was a voltage scales considering the 3rd harmonics to detect fault location. The scales could detect faults in the neutral too. The static protection GTX1 (Figure 1) was used for 50 up to 500-MW-units. A 200 MW unit required 5 cubicles.

SIEMENS used electronic relays as the only operating protection first time in the storage power station Wehr, Schluchseewerk AG in 1975.

The first gas turbine – compressed air power station in the world was put into operation at the German Norddeutsche Kraftwerke AG in Huntorf at 1st of December in 1978 (the Figure on page 70). The BBC machine (341 MW) was the

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.

most powerful at all over the world in this time. The unit was equipped with static generator protection "Modulsystem GSX6", BBC. (See Figure 6).

The first commercial usage of microprocessors was at the Austrian Donaukraftwerke AG in 1979. A stability protection for rotors MSTAB was delivered by ELIN (Figure 4).

SIEMENS produced a series with static protection in the early 1980s. As examples over-current 7SJ31, Generator- and Transformer Differential 7UD21/7UT24 and impedance protection 7SL18. For power supply the device 7SV11 was required to convert the battery voltage to the required ± 15 V and ± 24 V. Inputs and outputs have been separated galvanically. The auxiliary voltages have been protected with MCBs. To couple external signals an input unit 7UW20 was used (with capsuled cover gas relays).

Table 1 shows SIEMENS' static relays as it was in 1984. The plug-in boards were mounted in cubicles. To achieve redundancy there was a power supply for protection 1 and another for the 2nd one. To trip circuit breakers the operating units 7UW13 were used. The tripping matrix distributed the trips of the relays (Figure 7).

BBC's microprocessor over-current/over-load relay MC91 was produced in 1984. It contains all relevant protection functions measuring phase values only. Additional features have been unbalance protection, rotation supervision, stator ground protection and thermal overload with an added Pt 100 element (Figure 5).

ELIN's modular protection system DRS-MODULAR was presented in 1991.

A program to introduce "multifunction generator protection system" (MGPS) was started in the US in 1987, and lab-tests were reported in early 1992. After correcting minor problems, the evaluation was completed and a decision was made to install the MGPS at a 238 MW combined-cycle generation site. The MGPS was installed in a monitoring mode only and was set to trip an additional lockout relay which did not trip the unit. This installation was completed in September 1992. A two year field evaluation was required to qualify the MGPS for a tripping application.

table 1 Static Generator Protection Relays of SIEMENS, 1984

SIEMENS' Static Relays as in 1984	
7SJ31	Over current
7RE26	Stator ground 80 %
7UE22	Stator ground 100 % and block mode
7UD21	Generator differential
7UT24	Transformer differential, 2 windings
7UD25	Transformer differential, 3 windings
7UW21	Rotor ground fault
7UR22	Rotor ground fault, 2 step
7VM31	Out of step
7RE21	Rise of voltage
7UU21	Under excitation
7RP22	Frequency
7SL18	Machine impedance
7SW22	Breaker failure
7UW13	Operating device
7UW20	Input device
7UW13	Operating unit
7SV11	Power supply
7TA2	Trip matrix
7VP2	Test set

In April 1993, an additional MGPS was installed on a 693 MW fossil steam generator. This MGPS was also set to trip a lockout relay but not the generator. In late 1993 and early 1994, eight additional MGPSs were installed on hydro generators and connected to monitor and trip a lockout relay, but not to trip the generators.

In December 1993, an MGPS using an alternate design was installed on a 350 MW pumped hydro generator. This MGPS was also connected to trip an additional lockout relay which did not trip the generator. Figure 8 shows the distribution of the protection functions in two MGPS.

Two prototypes have been installed and have been in service since 1993 in a hydro generating station. The utility has approved two different MGPS products for installation on new generation systems. For the larger generators, two different vendor products have been used on each unit to provide appropriate redundancy to prevent common mode failures.

ABB's generator protection relay series SPAG300 –presented in 1992- realized different protection functions

1 Static generator protection GTX1G, (approximately 1970, ZPA)

2 Static unbalance relay IPX132-b, BBC (approximately 1965)

3 Stator ground fault protection G15X2, ZPA (approximately 1970)

A program to introduce "multifunction generator protection system" (MGPS) was started in the US in 1987.

with different modules. E.g. SPAG331B (Figure 11) with unit SPCP3B2, a combined single-stage reverse power and two-stage overvoltage relay module with definite time characteristic, SPCJ3C3, a two-stage overcurrent relay module with a definite time, or an IDMT low-set and an instantaneous or definite time high-set stage and SPCU1C6, a two-stage, definite time neutral displacement voltage , measuring overvoltage relay module with definite time characteristic.

The first numerical generator protection was developed by BBC in 1987 (Figure 9a/b) using Intel's 16-bit-processor 80186 (10 MHz). The scheme of the REG200 series is shown in Figure 12.

At the end of the 1980's BBC/ABB's Modures-Series (REG100, 110, 216 and 316) were produced. REG216 was equipped with more than 36 analogue inputs and utilized the protection functions ANSI (59N) (64) (87G) (87T) (50/51) (49) (64R) (59) (27) (81) (32) (46) (59) (59R) and (51/27).

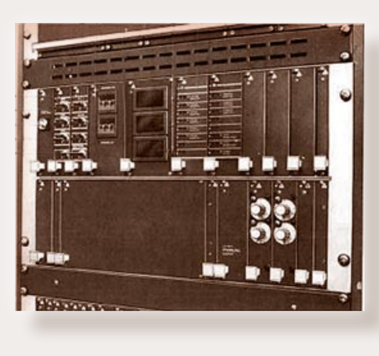
To increase availability and to achieve redundancy two plug-in systems could be combined (REG110 and REG150 as shown in Figure 10. The main protection functions have been identical, short circuit protection was realized as follows:

- REG110 with minimum impedance protection
- REG150 with high impedance differential protection

The COMBIFLEX system, was developed by ABB in 1990, where single devices could be combined into groups. Figure 13 shows a typical apparatus group. An overview of protection functions in COMBIFLEX is shown in table 2.

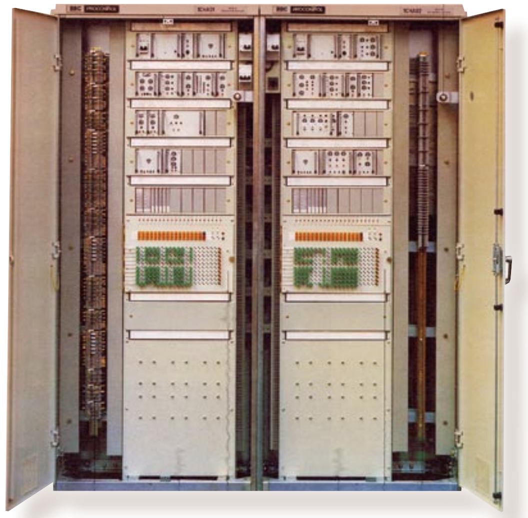
SIEMENS proposed their new concept for generator protection with the digital machine protection 7UM5 in

4 MSTAB, ELIN, 1979
Microprocessor stability relay

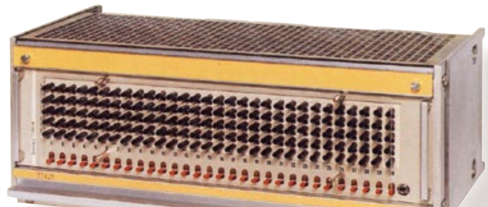


5 MC91, BBC, 1984,
Microprocessor controlled over-current relay

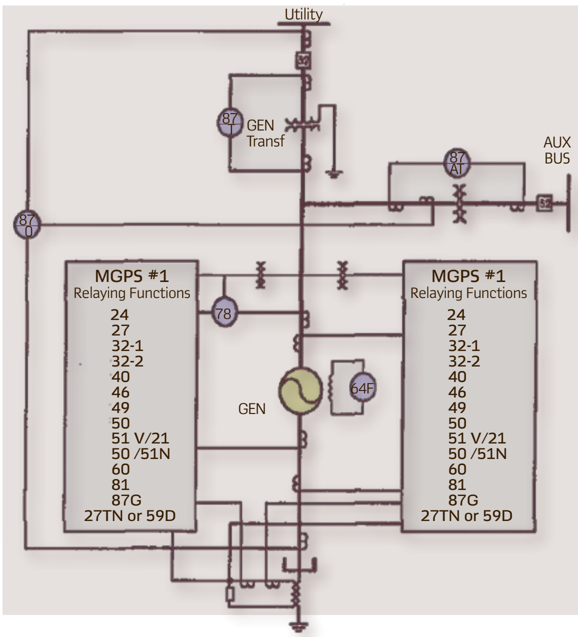
6 Static generator protection GSX6, BBC, 1978



7 Trip matrix 7TA2, Siemens, 1984,



8 Typical Protection for a Large or Important Generator, IEEE, 1998

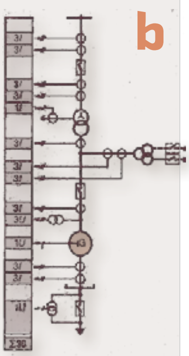


9 Generator protection REG216 (BBC, 1987)

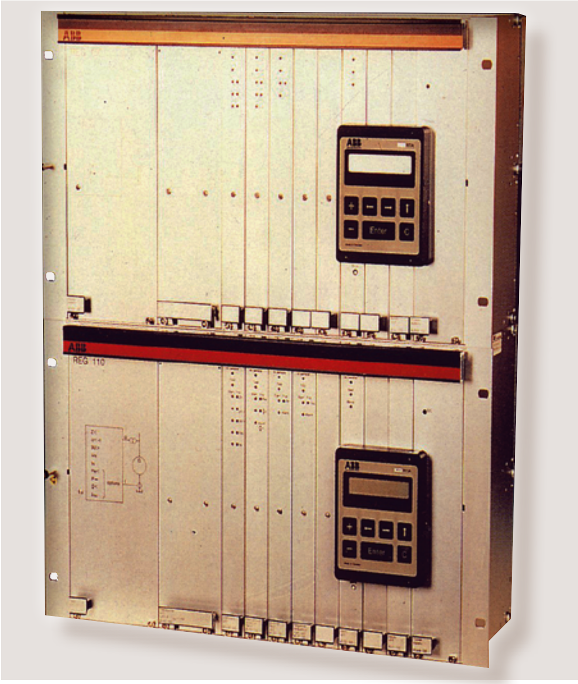
a

REG216 - Scheme

b



10 REG110 & REG150 combined, ABB, 1993



The COMBIFLEX system was developed by ABB in 1990.

table 2 Examples of protection functions in COMBIFLEX, ABB, 2006

Function	Protection	Comment	ANSI
100% stator E/F	RAGEK		59N/27N
Underexcitation I	RAGPK		40
Underexcitation II	RAPDK	RXPDK 21H	40
Rotor E/F	RAHL	+ Injection unit RXTTE 4	
Rotor E/F I	RAPDK	+ Injection unit RXTTE 4	64R-DC side
Negative seq. Overcurrent	RAIIK		46
Diode failure	RAIDK	RXIDK 2H standard	
Dead machine protection	RAGIK		50/27
Reverse power	RAPPK		32
Stator Differential	RADSC		87G
	RADHA		
Block Differential	RADSB		87T & TC
Turn Differential	RAIDK or RAEDK		59N or 50N
Turn Differential	RAIF/RAEG		
Restricted E/F	RADHD	High impedance E/F	87N
	RAPDK	Active E/F current	87N
Selective E/F	RAIG	Sensitive E/F diff.	87N
Bearing current	RARIC	0.4 - 1 A	

1992 (Figure 17). The protection devices required for small machines, unit machines with medium and big power is shown in Figure 15. The relays 7UM511, 7UM512 and 7UM515 provide different functionalities which can replace each other and allows redundant usage.

Beckwith Electric produced its microprocessor-based generator protection relay M-3430 that uses digital signal processing with 15 protective relaying functions since 1993 (Figure 16).

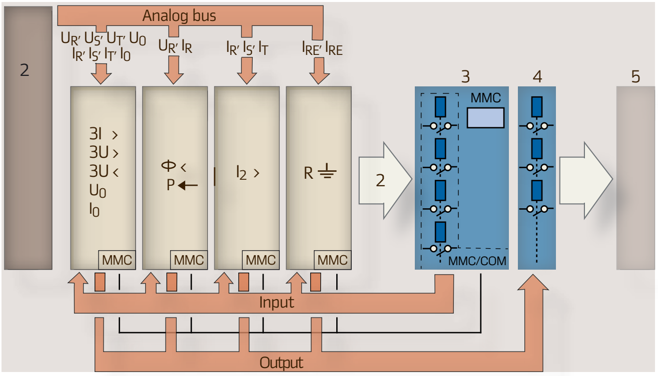
GEC's MIDOS contains protection relays as shown in Figure 14. The fully digital DRS system of ELIN was used at Swiss Rail (SBB) in 1995 for the first time.

This was the same year when AEG came out with digital generator protection PG851 and PG871 (Figure 22). Later, the additional relay PG811 was used (Figure 23). As it was with the other vendors, the protection functions were more or less distributed and redundant. The 90%-stator earth fault protection (67N) was included in PG851; the 100%-function was a part of the PG781 (with 20Hz-measurement). Rotor earth fault was implemented in PG811.

Generators bigger than 100 MVA have been equipped with PG871 as main and with PG851 as backup-protection.

11 Generator protection relays SPAG331B, ABB, 1992

12 Numerical protection REG200-Series, ABB



Smaller generators worked with one or two PG851. One of the first applications was IKW Staßfurt (Germany) with 3 50-MVA-units, 10/110 kV and the power station Cukrownia Lubna in Poland. GE's digital generator protection relay was produced in 1997- the functions are visualized in Figure 18 and Figure 25. Additionally in 1997 GE presented the SR489 generator management relay with additional backup and monitoring functions (Figure 21).

Beckwith Electric's Integrated Protection Systems for generators M-3425 is shown in Figure 26.

SEL's 300-G (Figure 28) came out in 1998, the functions are in Figure 29.

Chinese SIFANG produced digital unit protection CST30A in 1999 (for huge generators).

Since 2001 GE produces Generator Management Relay G60 (Figure 27) and G30 as Combined Generator and Transformer Protection. Developing the EUROPORT-Series (2005) Protecta (Hungary) presented Digital Generator and Generator-Transformer Unit Protection DGBV-EP (Figure 19). SEL's 700-series (2010) contains Intertie and Generator Protection Relay SEL-700G (Figure 20).

A further development of SIEMENS SIPROTEC (in 2000) was a redundant protection concept for bigger generators with unit transformers utilizing 7UM6 and 7UT6 (Figure 24).

ABB's new series 670 (2007) also contain a generator protection IED REG670.

Finally I want to remind you, that for conventional as well as for static protection in the past for instance in 500-MW-units at least 12 cubicles were used. During the transition period it was common, to have 2 times static relays (e.g. system 1 and system 2- Boxberg Germany) or, later, two have a static and a digital system (Schwarze Pumpe Germany).

Testing technology and the generations should be covered in a later article.

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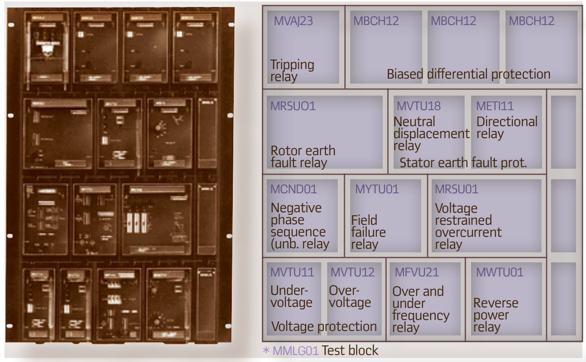
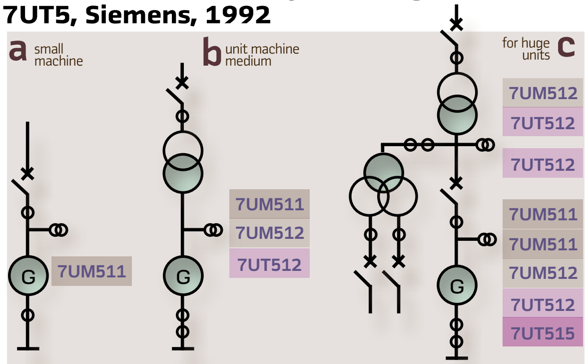
14 Generator protection MIDOS, GEC, 1995



15 Protection concept utilizing 7UM5 and 7UT5, Siemens, 1992



16 Generator protection relay M-3430, Beckwith Electric, 1993

13 COMBIFLEX, a typical apparatus group, ABB, 1990

17 Machine protection relay 7UM515, Siemens, 1994

18 DGP, GE, 1997

19 DGBV-EP, Protecta, 2005

(Generator - trans-former unit relay)

20 SEL-700G, SEL, 2010

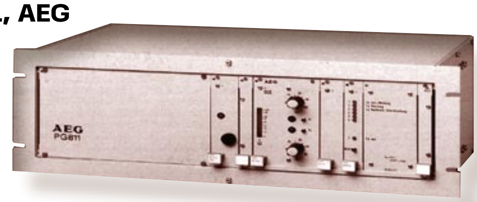
(Intertie and Generator Protection Relay)

21 Generator management relay SR489, GE, 1997

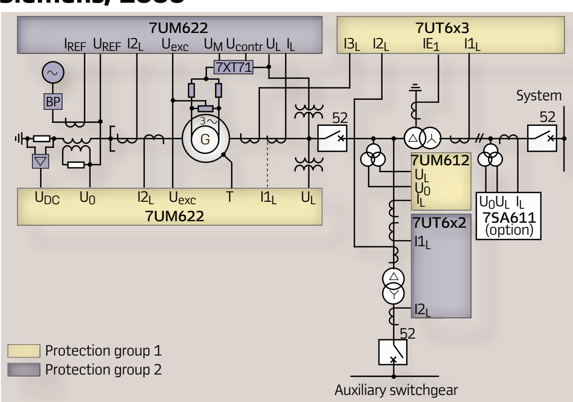
Combined Generator and Transformer management relay SR489.

22 Digital generator protection PG851 and PG871, AEG, 1995

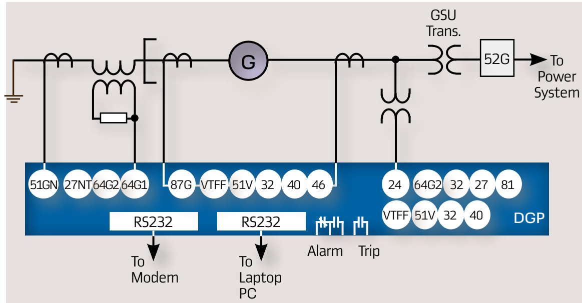
23 Generator protection- additional relay PG811, AEG



24 Redundant concept with SIPROTEC, Siemens, 2000



25 Single line diagram DGP, GE, 1997



26 Front panel M-3425, Beckwith Electric, 1998

27 Generator management relay G60, GE, 2001

28 SEL-300G, SEL, 1998

29 Functions of SEL-300G, SEL, 1998