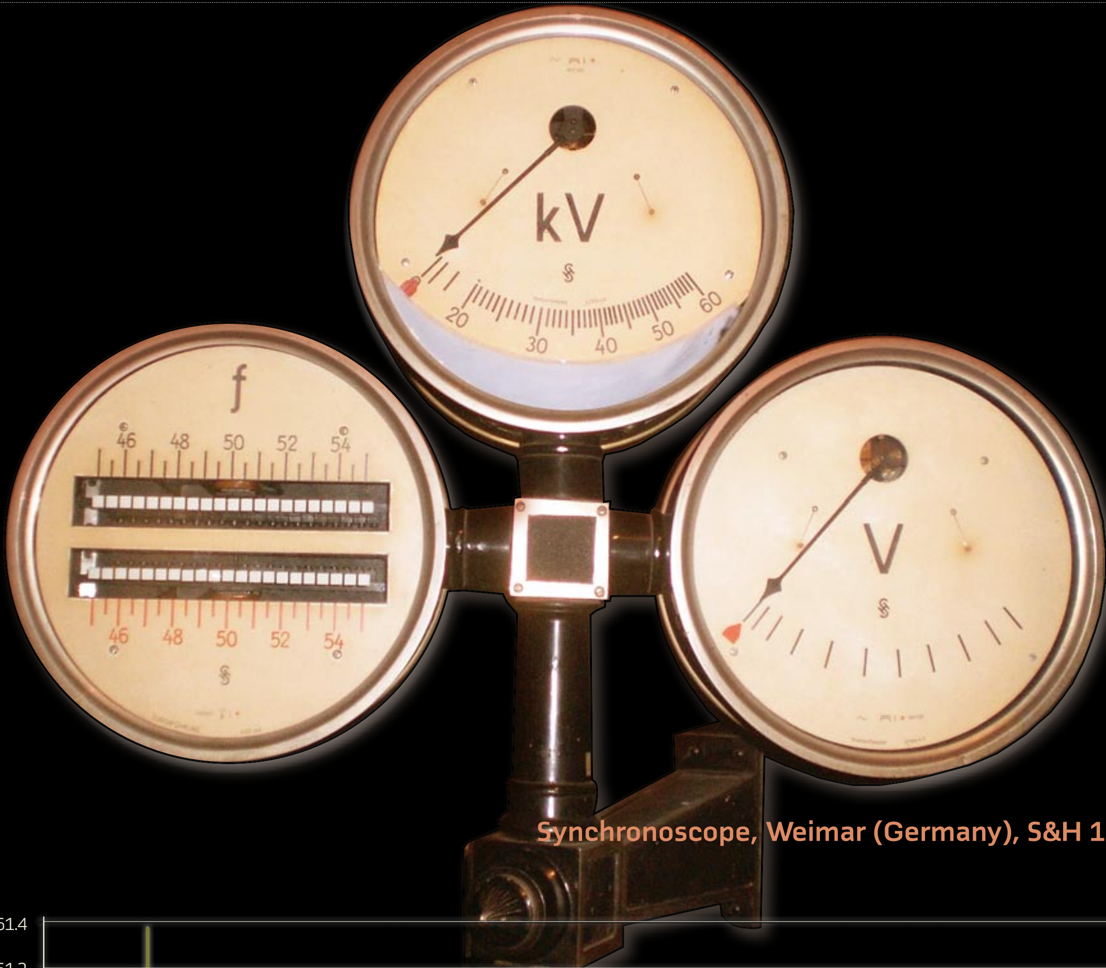
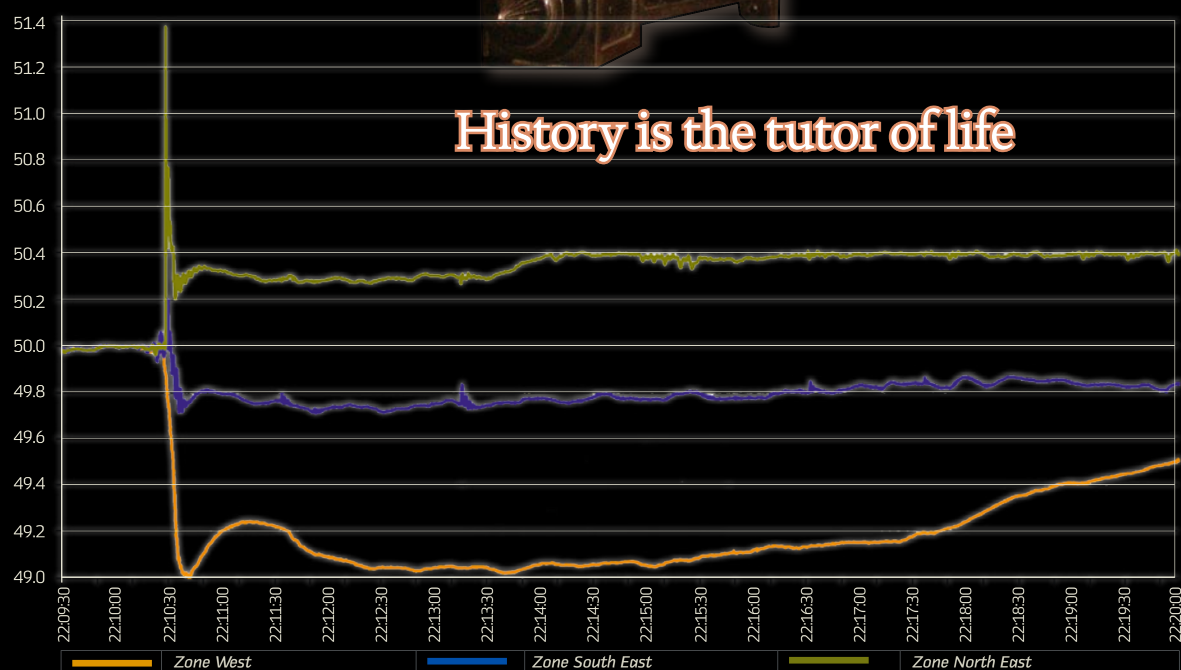


Synchronoscope, Weimar (Germany), S&H 1924

History is the tutor of life



Frequency in the islands of the UCTE-grid due to load-shedding 2006-11-04

by Walter Schossig, Germany

Protection History

Frequency Protection

Operating a generator for a longer time in under-frequency conditions decreases the lifetime of the turbo-alternator. On the other hand generators should be connected to the grid as long as possible to avoid blackouts due to an unbalance of generation and consumption.

If the frequency of the unit is decreasing during operation this indicates a breakdown in the grid in the area where the power station is connected. The reasons for that might be overload due to drop-out of a generator, or decreased steam inlet of the tube. If the unit is no longer connected to the grid, auxiliary devices such as pumps, can be out of step and endangering the supply of the unit. The delivery rate of pumps and blowers decreases with the third exponent of the rotation speed, bearings can become dry due to insufficient amount of lubricant and damages to bearings can occur. This is dangerous for the entire unit and stopping of the machines would be the end result.

Stopping is also required if in case of a disaster the frequency in the grid decreases, and a self-protection of the machine is necessary.

Inventor of the Frequency Relay

The German- American engineer Charles Proteus Steinmetz, originally named Karl August Rudolf Steinmetz (Figure 1) is accepted as the inventor of the frequency relay. The principle was patented in 1900. Steinmetz became a General Electric employee and the president of the American Institute of Electrical Engineers (AIEE, 1901/02).

The small separate networks and even the first interconnected systems have been operated with a fluctuant frequency at this time. Figure 3 shows a record made in 1910.

The fluctuations have not been perceived as annoying by the customers at this time. Nevertheless they are an indicator for the stability of the grid and for the endangerment of the generator. A paper mentioning frequency protection was already published in the magazine *Electrical World* in 1909, but was of minor importance.

A very simple and reliable frequency relay was the induction relay shown in Figure 2. It uses the difference principle. Both cores got the same windings, one was resistive only and the other one was equipped with a big inductance. Connecting the same voltage and depending on the frequency will move the relay into one direction or the other.

The problem of power system stability; the recognition of its importance in power system engineering; and the gradual development of the necessary technology to deal with it effectively, are all as old as the alternating-current generation and transmission of electric power. One of the first technical papers dealing with power system stability was written in

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.

AIEE Transactions by W. L. R. Emmet in 1901 under the title "*Parallel Operation of Engine-Driven Alternators*". Since that time, the phenomenon of power system stability has been under continuous scrutiny by electric power system engineers. The development of the basic theory, verification of that theory by physical tests on full-scale electrical apparatus, and formulation of effective, practical means to deal with the stability problem, have been an integral part of the progress of power system technology.

Many of the early giants of electric power technology contributed their genius to the better understanding of the power system stability problem. Thus, as early as 1920 C. P. Steinmetz wrote a technical paper titled "*Power Control and Stability of Electric Generating Stations*," and C. L. Fortescue in 1925 wrote on "*Transmission Stability. Analytical Discussion of Some Factors Entering Into the Problem*". From the mid-1920's on, the technical literature on power system stability became increasingly extensive, as the surge toward higher voltage transmission raised new technical questions that needed to be studied, resolved, and incorporated into the body of knowledge of power systems engineering.

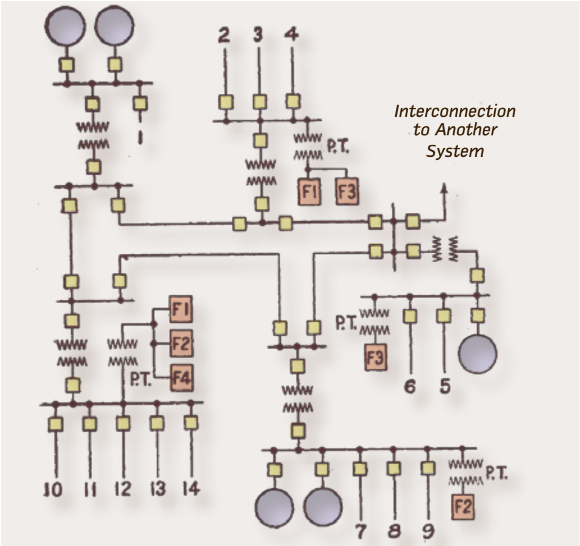
Frequency relays of the slow-speed (induction disk) type were commercially available in 1921, and the high-speed (induction-cup) type was put into use in 1948.

H. J. Carlin and J. L. Blackburn, proposed a new frequency relay for power-system applications in 1944. Figures 4 and 5, and table 1 show the scheme of a frequency relays, the installation in a grid and the setup.

High-speed frequency relays of induction-cup type were put into use in 1948. One of the first relays of this type was a CFF (Figure 6a and 6b) by General Electric.

The setting range General Electric's CFF13A (1948) was between 44 and 61 Hz, and so it could be used in 50 Hz as in 60 Hz systems for over- and under-frequency purposes. Unfortunately the startup value depends from the measuring voltage. Figure 7 shows the error limit for the relay against voltage in the 1950s.

5 **Single-diagram of power system with frequency relays set for selectivity**



F1 to F4 Relays | P.T. Voltage transformers | 1 to 14 Breakers

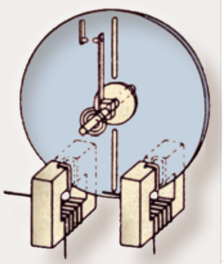
table 1 **Frequency relay setup (USA, 1944)**

Underfrequency Relay (Normal Frequency 60 Cycles)		
Relay	Setting Cycles	Trip Feeders
F1	59.5	4 and 12
F2	59	9 and 14
F3	58	2 and 16
F4	57	10

Several companies produced frequency relays with rotating plate in the years 1950 – 1960. Westinghouse introduced the frequency relays CF-1 (Figure 9 and Figure 10). GE's induction disc type frequency relay IJF is shown in Figure 8. Characteristics for the over-frequency relay IJF51A and the under-frequency relay IJF52B can be seen in Figure 11.

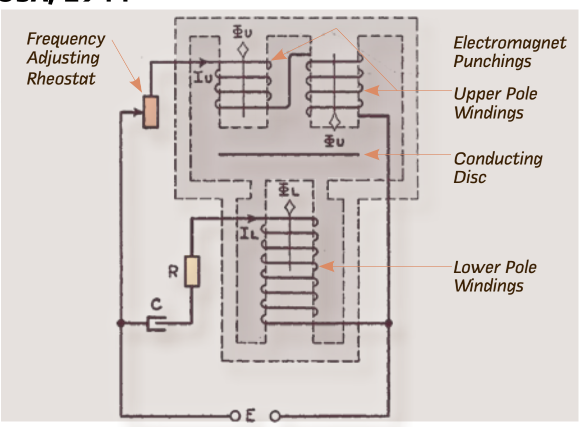
1 **Charles Steinmetz**
(1865-1923)

2 **Induction relay with** difference-principle

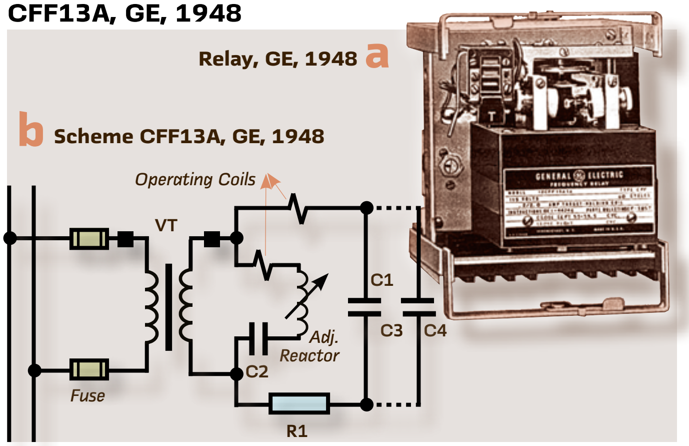


3 **Frequency Recorder**
(1910)

4 **Schematic diagram of frequency relay, USA, 1944**



6 **High-speed induction-cup under-frequency relay, CFF13A, GE, 1948**



New relays introduced in the 1950s were resonance relays that used RLC-circuits.

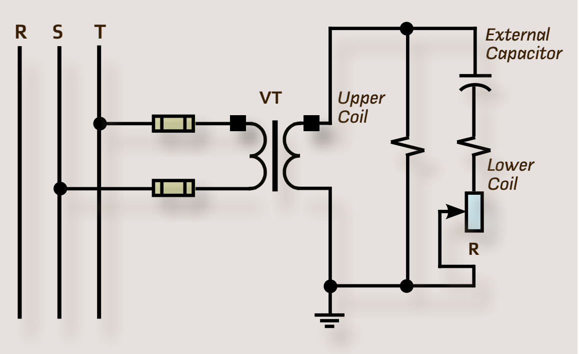
Static Frequency Relays

The new relays, presented in the 1950s, have been resonance relays using RLC-circuits. A typical example is Siemens RVf2 from 1958, later produced as 7RP95 (Figures 12 and 13). The relay was used for supervision of voltage and frequency. It was single-phase voltage relay, a combination of reactor and capacitor was connected ahead the measurement-system. The measurement system was tuned to be in resonance at nominal frequency, a bottom-contact was open now. If the frequency is constant, the relay operates as undervoltage-time relay. If the frequency is decreasing, the reactor-capacitor-system is out of resonance, the current in the system decreases. The relay drops-out.

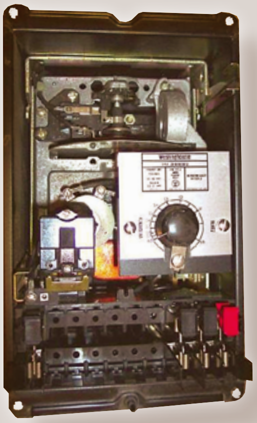
Charles J. Durkin, Jr.; Edwin R. Eberle and Peter Zarakas presented at IEEE the "Con Edison rate-of-change (ROC) relay" in 1959 (Figure 14). The proposed characteristic of the ROC relay was defined by four parameters:

- **Flat-Frequency Setting:** Frequency setting at which the relay would trip when the rate-of-decay of frequency was negligible. This setting would be adjustable between 58 and 60 Hz.
- **Rate-Advance Control:** Automatic compensation of the flat-frequency trip point depending upon the rate-of-decay of frequency
- **Inhibit Control:** Maximum frequency at which tripping would be permitted regardless of the rate-of-frequency decay. This control would be adjustable over the 58-60-Hz tripping range

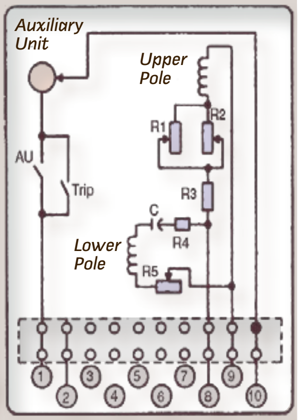
8 Circuit diagram, IJF, GE



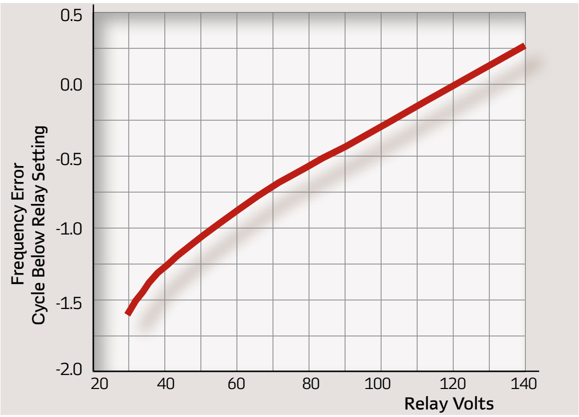
9 Frequency relay CF-1, Westinghouse, 1963



10 Scheme CF-1, Westinghouse, 1963

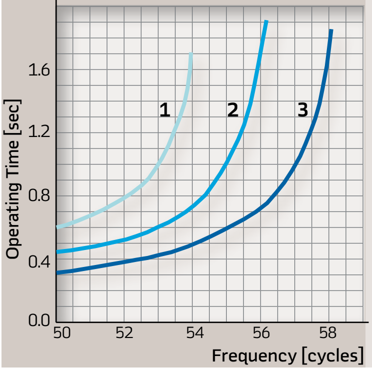


7 Error limit CFF13A, GE, 1959

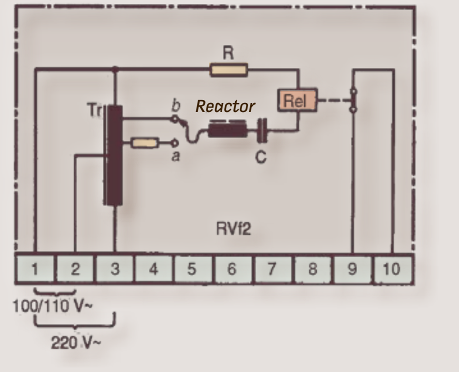


11 Time-frequency characteristics, GE

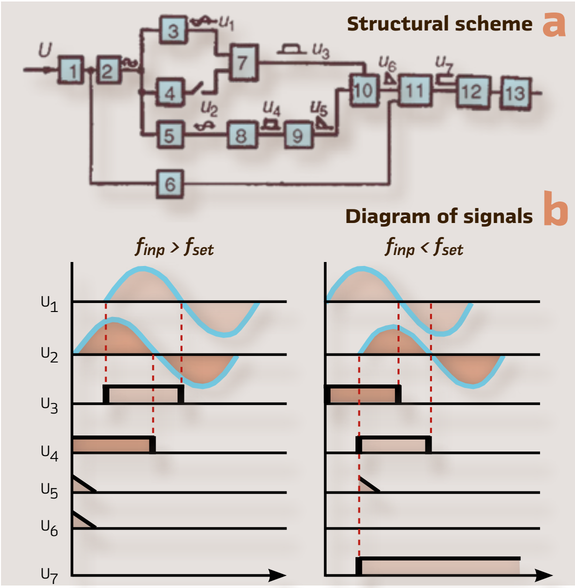
Over-frequency relay IJF51A and under-frequency relay IJF51B



12 Circuit diagram of RVf2, Siemens, 1958



15 Electronic frequency relay, РЧ-1, USSR, 1971



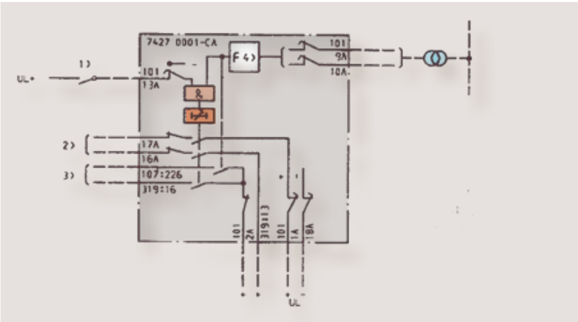
The USSR produced the РЧ - series frequency relays.

13 Frequency relays RVf2, (Siemens, 1958)

■ **Time Delay:** To prevent tripping for apparent low-frequency conditions resulting from phase shift during system disturbances. This delay would be adjustable between 5 and 15 cycles.

The electronic under-frequency relay РЧ -1 and the over-frequency relays РЧ -2 have been produced in the Soviet Union since 1971 (Figure 15). ASEA presented their static frequency relay RXFE-4 in 1990 (Figure 18). The Czech ZPA Trutnov produced a frequency relay F13 with a similar principle as the RVf2 in 1975 (Figure 17). An operating range of 80% of the nominal voltage was sufficient for load-shedding purposes but not for power stations. So BRA developed an auxiliary device for voltage stabilization SPS751 to be used with the F13 (Figure 25).

18 Frequency relay RXFE, ASEA, 1990



1 Main circuit-breaker | 2 Tripping | 3 Alarm | 4 f > or f <

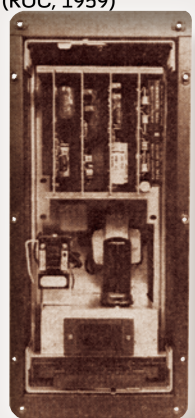
A simpler solution was the usage of a Zener diode (up to 0.6 of the nominal voltage). Introducing electronics allowed more accurate measurement. Two main principles won through in the next years (Figure 19a and 19b). Both convert the connected voltage into a rectangular signal.

■ Comparison of time TN of the rectangular with the duration of a nominal signal (*left*)

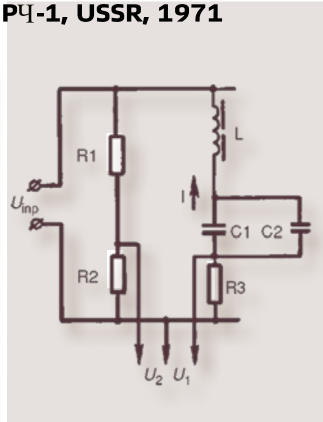
■ Counting the length of the rectangle with pulses of an oscillator (*right*)

Production of frequency relay FCX103 started at BBC in 1973 (Figure 20 and Figure 21). It allowed detecting over- and under-frequency, additionally the estimation of the gradient df/dt was possible. Westighouse's under-frequency relay KF was developed in 1975. Siemens presented the single stage

14 Con Edison rate-of-change relay, (ROC, 1959)

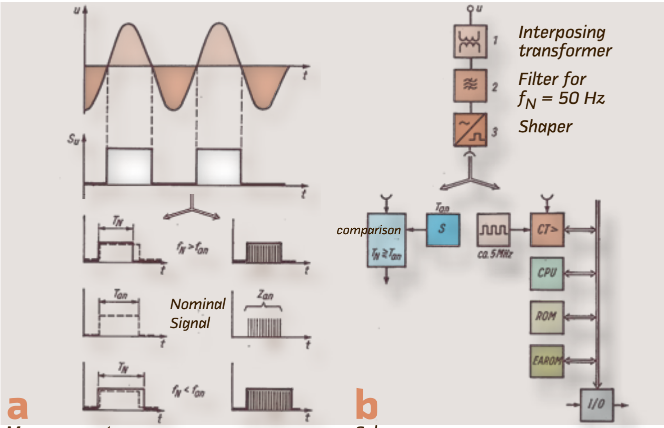


16 Measuring scheme РЧ-1, USSR, 1971



17 Frequency relay F13, ZPA, 1975

19 Principles of static frequency relays



frequency relay 7RP22 and the two-stage 7RP23 in 1980. The voltage range was between 0.6u to 1 U_n. The R&D-department of an east-German utility developed the frequency relay SRF4 in 1984 (Figure 26). The comparable quantity was a 100-kHz-quartz.

Microprocessors

Donald N. Ewart and Francisco P. Demello presented a paper "*A Digital Computer Program for the Automatic Determination of Dynamic Stability Limits*" at IEEE in 1967. An 8-bit-µP operated as load-shedding in 1975. The fine tuning allowed steps of as small as 0.01 Hz with an accuracy of ± 0,005 Hz. This resulted in a reset ratio of > 0.999.

One of the first digital relay at all was BBC's frequency relay FC 95 in 1978 already (Figure 24).

AEG introduced single- and multi-stage frequency relays SFT10, 20 and 40 in 1981 (Figure 23). An 8-bit-µP supervised the cycle duration with minimum time as long as 4 cycles.

Aligarh Muslim University in India proposed an interesting solution in the 1980s (Figure 22). Siemens presented 7RP72 in 1986 (Figure 28). GEC/ALSTOM's digital definite time frequency relay (1999) is shown in Figure 27a and 27b. Finally ABB's generator protection relay SPAF140C (1998, Figure 30) and the SPAF340C developed for load-shedding (Figure 31) should be mentioned.

Under special circumstances the unit can become out of step due to an overload. In that cases load shedding of feeders can be the solution (Figure 29). If the frequency decreases load can be switched off (according to a time-stepping). A special solution for load shedding was proposed by BBC in 1978 - the base version a frequency-dependent, programmable four-stage device for up to 80 feeders. It was used in medium voltage grids and in industrial one (Figure 32). How important load shedding can be showed the huge disturbance in Europe 4th of November 2006. After an operation the European UCPTE-grid was divided into 3 islands. A further drop of frequency in area 1 (West) could be avoided.

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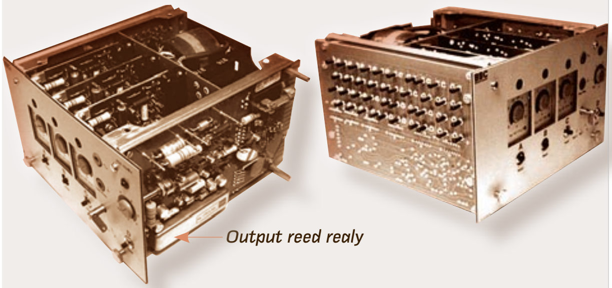
21 Static frequency relay FCX103, BBC, 1973



22 Block diagram of under / over frequency relay, AMU, India 1981

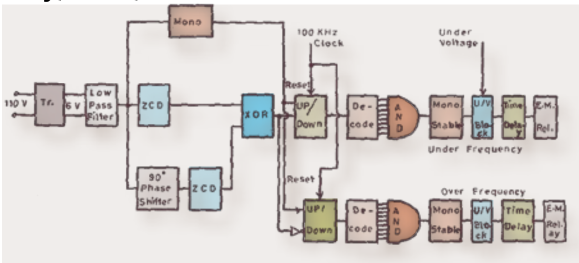


Figure 22: The solution proposed in the 1980s by the Aligarh Muslim University, India

23 Four-stage frequency relay SFT40, AEG, 1981

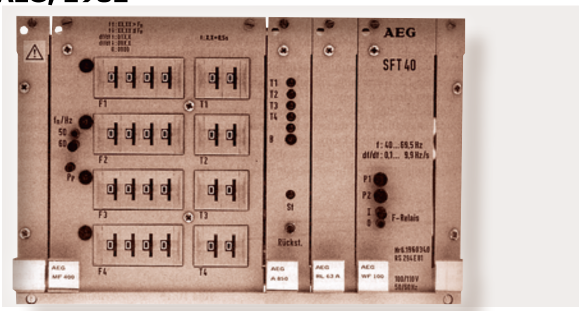
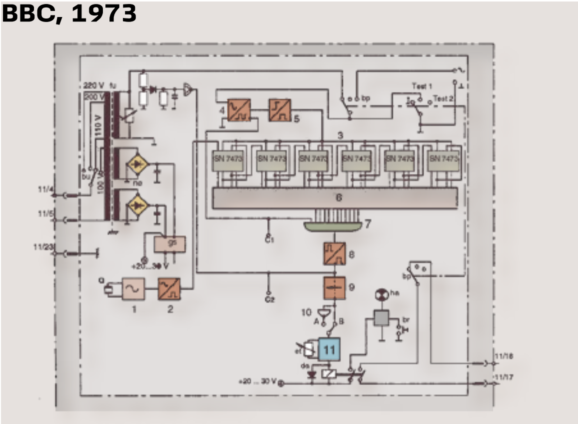
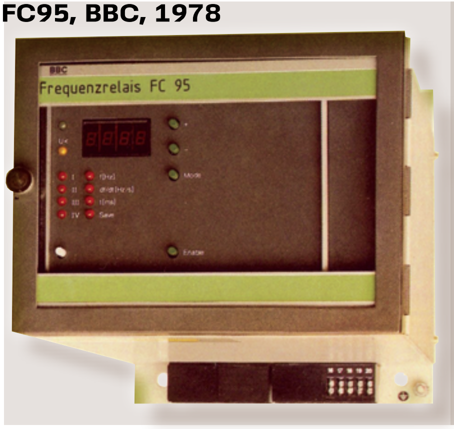


Figure 23: AEG introduced single- and multi-stage frequency relays SFT10, 20 and 40 in 1981.

20 Scheme of frequency relays FCX103b, BBC, 1973

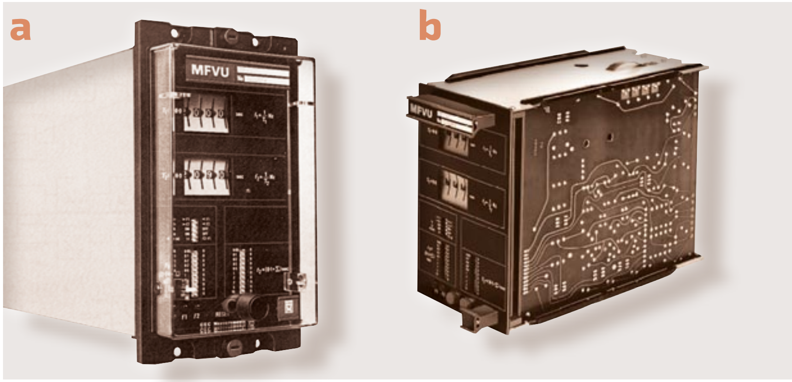


24 Digital frequency relay FC95, BBC, 1978



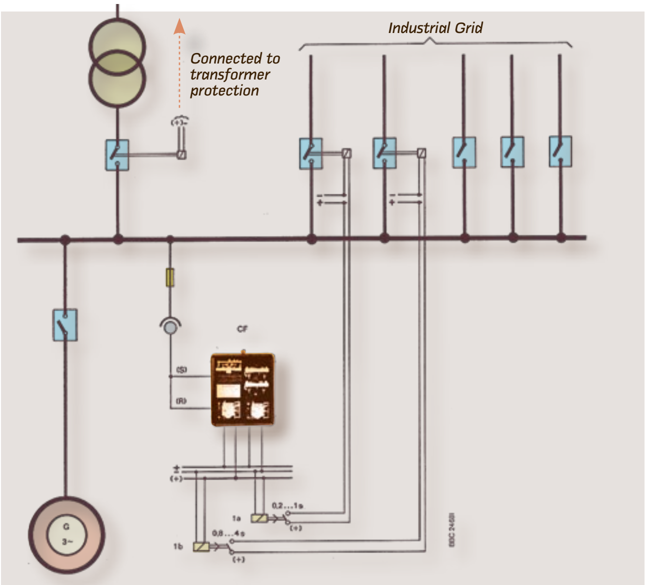
25 Auxillary device for voltage stabilization SPS751, BRA, 1975

27 Frequency Relay, GEC /ALSTOM, 1999



28 Frequency relay 7RP72, Siemens

29 Load shedding with frequency relays CF, BBC, approximatelly 1960



30 Frequency relay SPAF140C, ABB

Frequency relay SPAF140C, ABB, 1998

31 Frequency relay SPAF140C, ABB

26 Frequency relay SRF4,

BRA, 1984

32 Load shedding device KF91, BBC, 1978