## 13. Alternator excitation systems

Alternator excitation systems include the following components:

- Excitation current source system (exciter)
- Wake-up current control system (controller)
- Wake-up system (wake-up device)

Excitation systems are subject to high requirements and must provide for all circumstances that may arise during operation, including faults and transients. These demands are increased with higher unit power and design constraints (lower short circuit power) with respect to the static and dynamic stability of the alternator. The excitation power of the system is between 0.3 and 0.6 % of the rated alternator power (e.g. a 235 MVA unit has an exciter of 1100 kW).

The requirements for excitation systems are as follows:

- High operational reliability (higher than the alternator itself), so it usually contains a reserve exciter. Reliability is mainly influenced by the ring pick-up system and the excitation security of the exciter itself
- Continuous and extensive excitation current and voltage regulation to ensure the entire operating range of the alternator with a ceiling margin for destabilizing transients (for rotary exciters 1.6 to 1.8 $U_{fN}$ , for independent thyristor exciters 1.6 $U_{fN}$ and for dependent exciters up to 2 $U_{fN}$ ).
- Sufficient rate of change of excitation voltage characterized by the so-called exciter idle response - the mean rate of change of the exciter relative voltage in the first 0.5 sec ($v$ = 0.5 to 2)
- Sufficient alternator wake-up speed in case of sudden power relief or failure

Additional requirements for excitation current controllers:

- Maintaining the desired magnitude of the alternator clamp voltage and reactive power supply independent of active load (including emergency and fault conditions) at a minimum for reliable operation of the self-consuming unit
- Maintaining Reactive Load Distribution in Parallel Units
- Monitoring the excitation limit as a limit of static stability of the alternator operation

Types of excitation current sources:

- System with rotary exciter
- Static excitation system with rings on the shaft
- Static ringless excitation system

According to the primary source of excitation voltage we distinguish systems:

- Independent (source of derivative winding or auxiliary exciter, excitation voltage and therefore current are independent of the voltage state of the power supply itself)
- Dependent (source of excitation transformer from own consumption)(when supplied from the terminals of the alternator, it is necessary to first supply a pulse of at least 0.1 $U_N$ for at least $3T_{D0}^{/}$ - approx. 30 sec.)

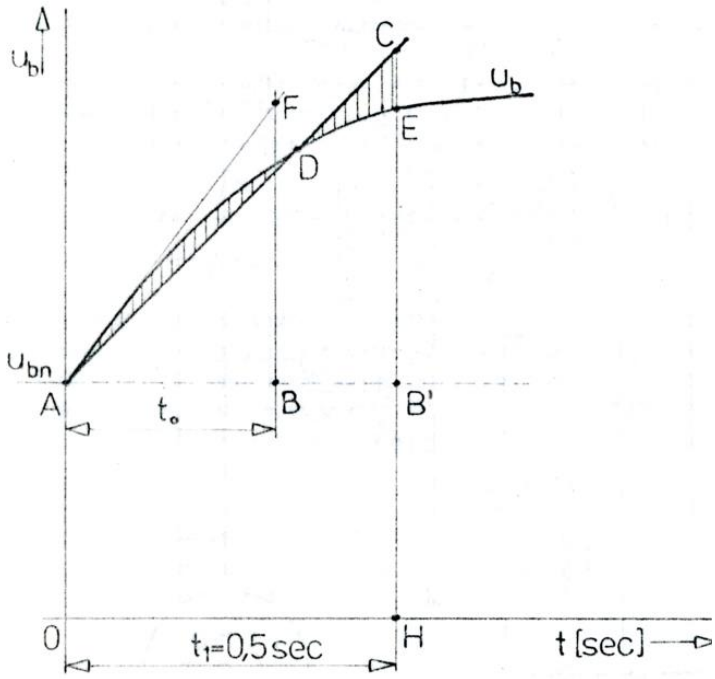
$$\overline{B'C} = \Delta u_B$$
$$\overline{BH} = u_{BN} = 1'$$

$$v_B = \frac{\frac{\Delta u_B}{u_{BN}}}{t_1} = \frac{\Delta u_B}{0.5} = 2\Delta u_B \ [\ ]$$

$$\overline{BF} = \Delta u_{B0}$$

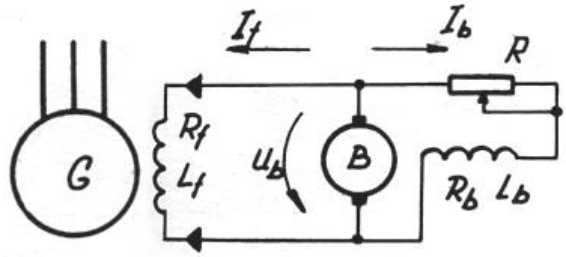
$$v_{B0} = \frac{\frac{\Delta u_{B0}}{u_{BN}}}{t_0} = \frac{\Delta u_{B0}}{t_0} \left[\sec^{-1}\right]$$

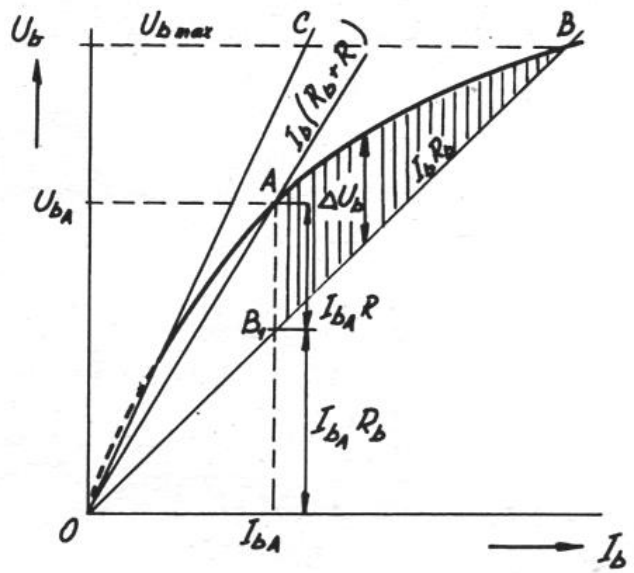
$$v_{B0} > v_B$$




**Excitation systems with rotary exciter**

Use for alternator outputs up to 125 MVA.




The operating point "A" is determined by the external magnetization characteristic 0B and the series resistance characteristic $I_b \cdot (R_b + R)$.

The operating point at $R \to 0$ is "B" determining $U_{bMAX}$. The slope of the linear characteristic increases with load.

The rate of exciter voltage rise during a surge ( $R \to 0$ ) (this is a DC circuit):

$$U_b = i_b \cdot (R_b + R) + \frac{d\Psi_b}{dt} \qquad U_b = i_b \cdot R_b + \frac{d\Psi_b}{dt}$$

$$\Psi_b = L_b \cdot I_b = L_b \frac{U_b}{R_b} = T_b \cdot U_b \qquad T_b = \frac{L_b}{R_b}$$

$T_b$ - time constant of the derivative winding of the exciter

$$U_b = i_b \cdot R_b + T_b \frac{dU_b}{dt} \qquad \frac{dU_b}{dt} = (U_b - i_b \cdot R_b)\frac{1}{T_b} = \frac{\Delta U_b}{T_b}$$

We marked the difference in characteristics $\Delta U_b = U_b - i_b \cdot R_b$

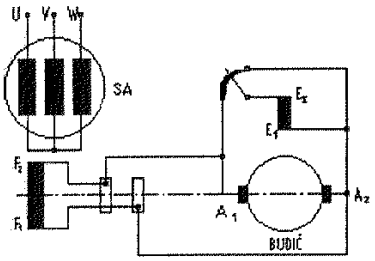
$$t = T_b \int_{U_{bA}}^{U_{bMAX}} \frac{dU_b}{\Delta U_b}$$

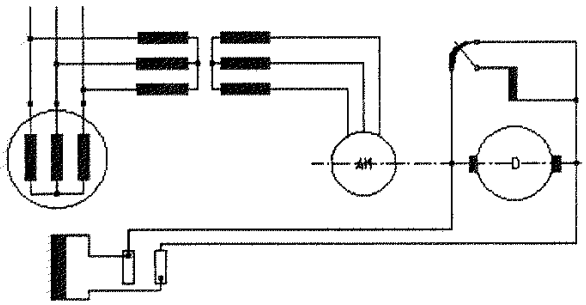
The time is inversely proportional to the difference area of the characteristics.

The change of excitation voltage is better for high-speed machines, therefore in hydroalternators the exciter is driven by an asynchronous drive supplied from its own power supply.

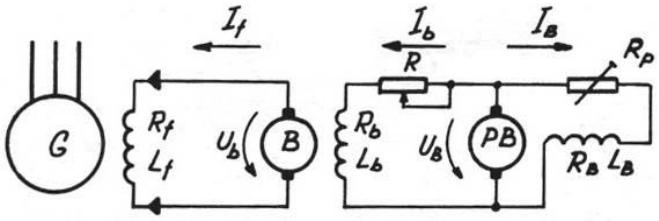
The system does not allow continuous control for small values of excitation current and has reduced reliability mainly due to the commutator.





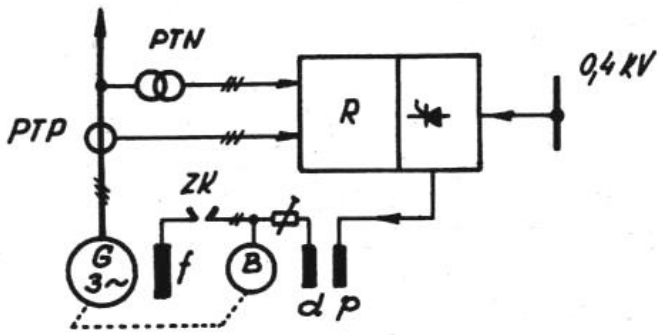



**Excitation systems with rotary exciter and auxiliary exciter**



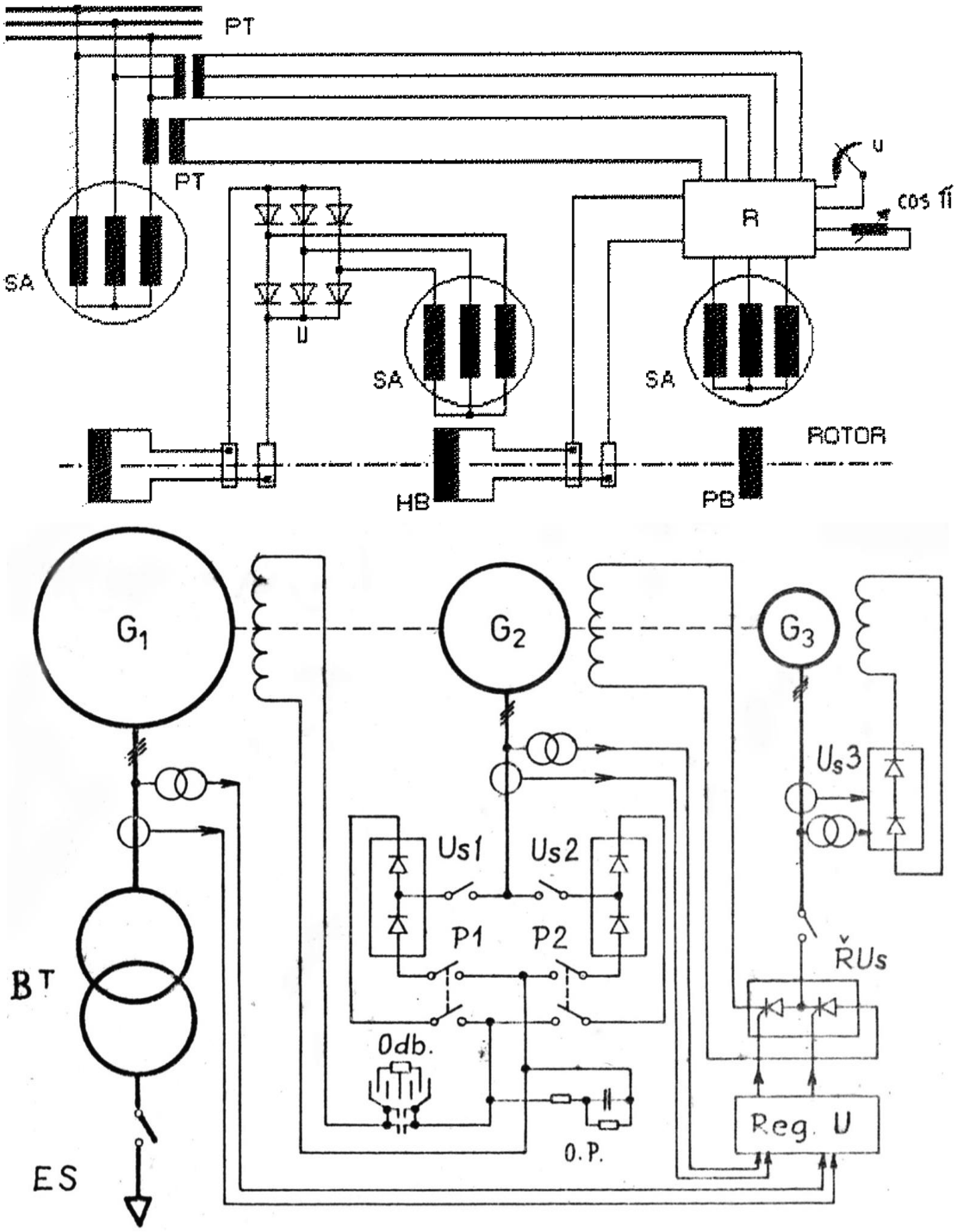

The operational reliability is even worse (this time even two machines with commutator), but the smoothness of voltage regulation is good and the speed of surge boost is higher.

**Excitation systems with rotary exciter and additional excitation winding**



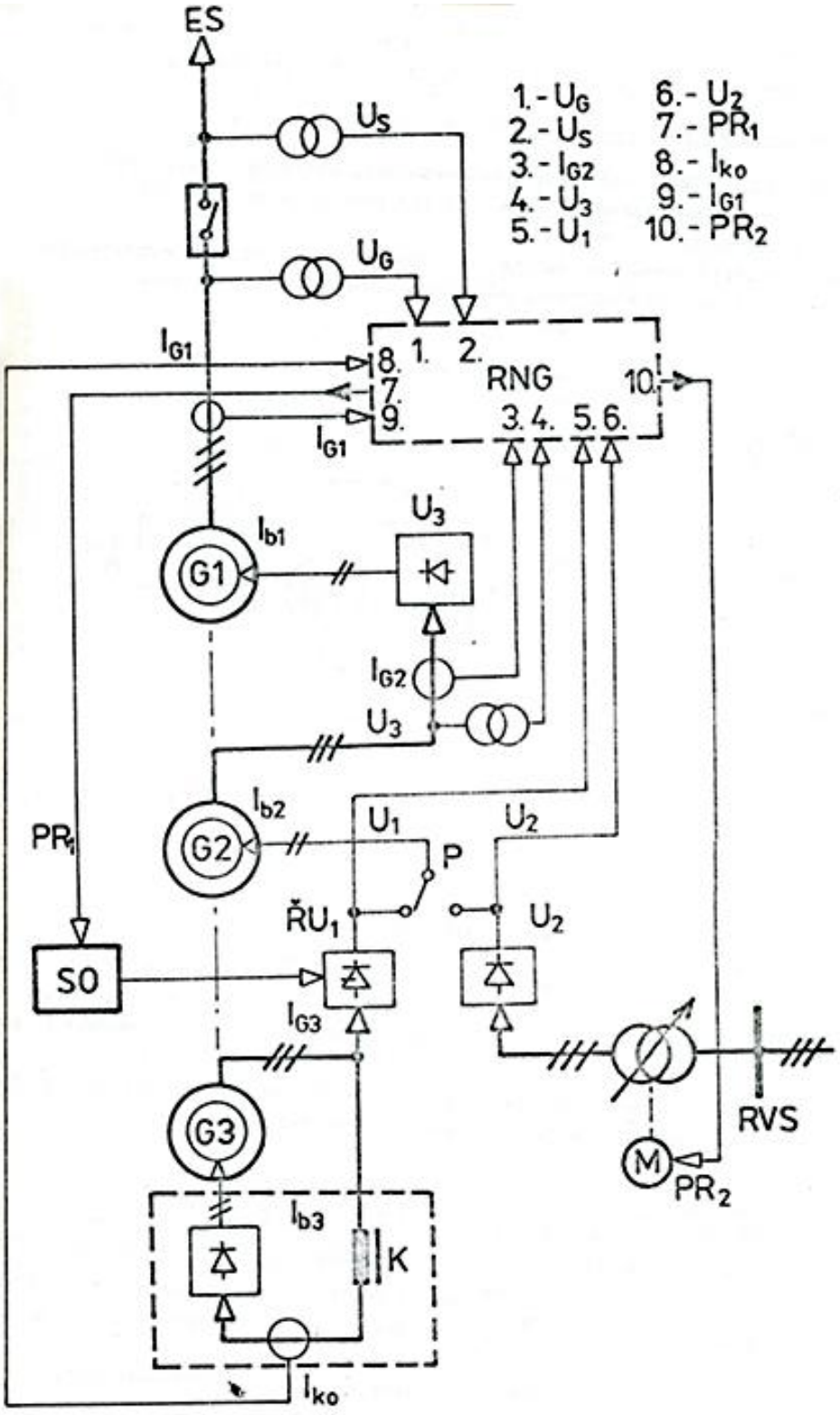

The derivative excitation winding is set approximately to the alternator idle condition. The rectifier of the auxiliary winding controlled by the controller is fed from its own power supply.
The excitation winding of the alternator is equipped with a quenching chamber for de-excitation.

**Excitation systems with rotary AC exciter and uncontrolled rectifier**



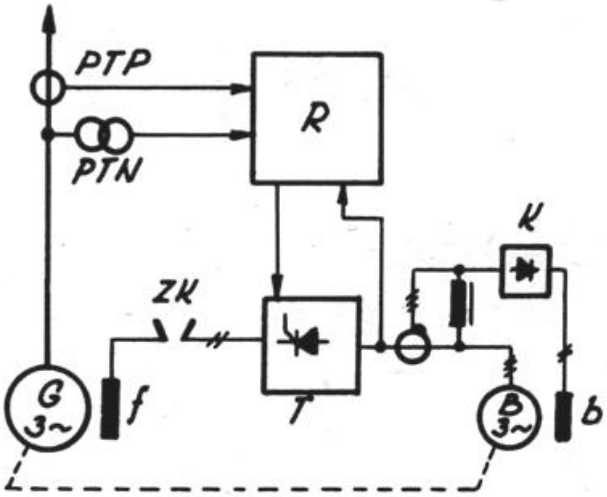

The alternating exciter G2 (alternator) feeds the main excitation winding via the uncontrolled double three-phase bridge rectifier Us1 and Us2. The regulation is performed by the controlled rectifier ŘUs in the excitation circuit G2 fed by the auxiliary AC exciter G3. The excitation winding contains a surge protector in addition to the exciter. The advantage of this design is the higher possible exciter performance, with easier maintenance and a more reliable concept due to the absence of a commutator. It is used for 200 MW units. This circuit does not allow reversal of the exciter voltage.

**Excitation systems with rotary AC exciter and uncontrolled rectifier and reserve excitation**



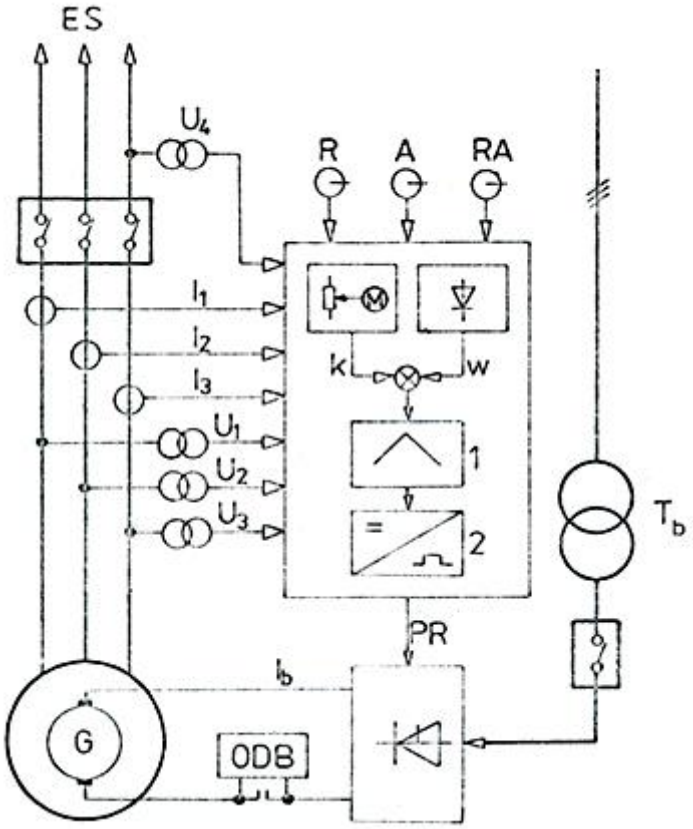

A similar solution of additional excitation of the AC exciter G2 is alternatively possible via an IR transformer from its own power supply. The solution is also used for 200 MW units.

**Excitation systems with rotary AC exciter and controlled rectifier**




The auxiliary AC exciter "K" is independently regulated to a constant voltage (current phase compounding). The thyristor control system increases the control dynamics. It is also possible to operate with a negative excitation voltage and therefore inverter operation in combination with an extinguishing chamber can be carried out.The efficiency of the excitation system is also higher. The disadvantage is the high purchase cost of necessarily oversized thyristor blocks (in case of short circuit in the EC and failure of one of them). This design was used for the 500 MW unit.

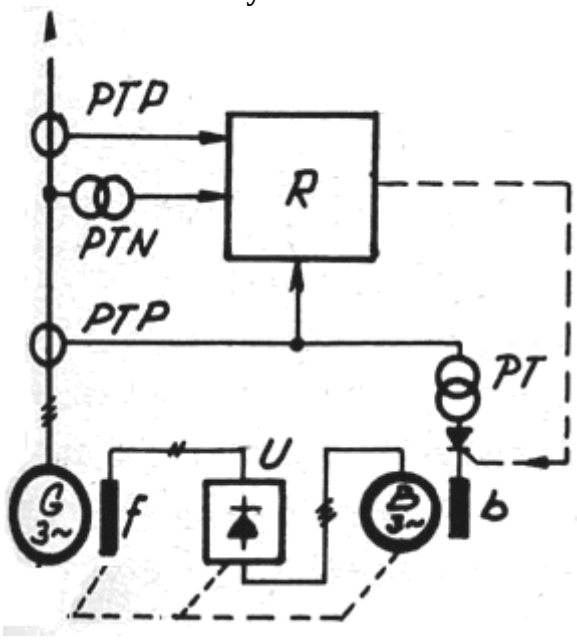
**Excitation systems with excitation transformer and controlled rectifier**




The system has similar characteristics as the previous one, with the disadvantage that in case of a significant drop in the voltage in the network (especially in case of a short circuit), the possibility of intensive wake-up is lost and the alternator is in danger of losing synchronism.

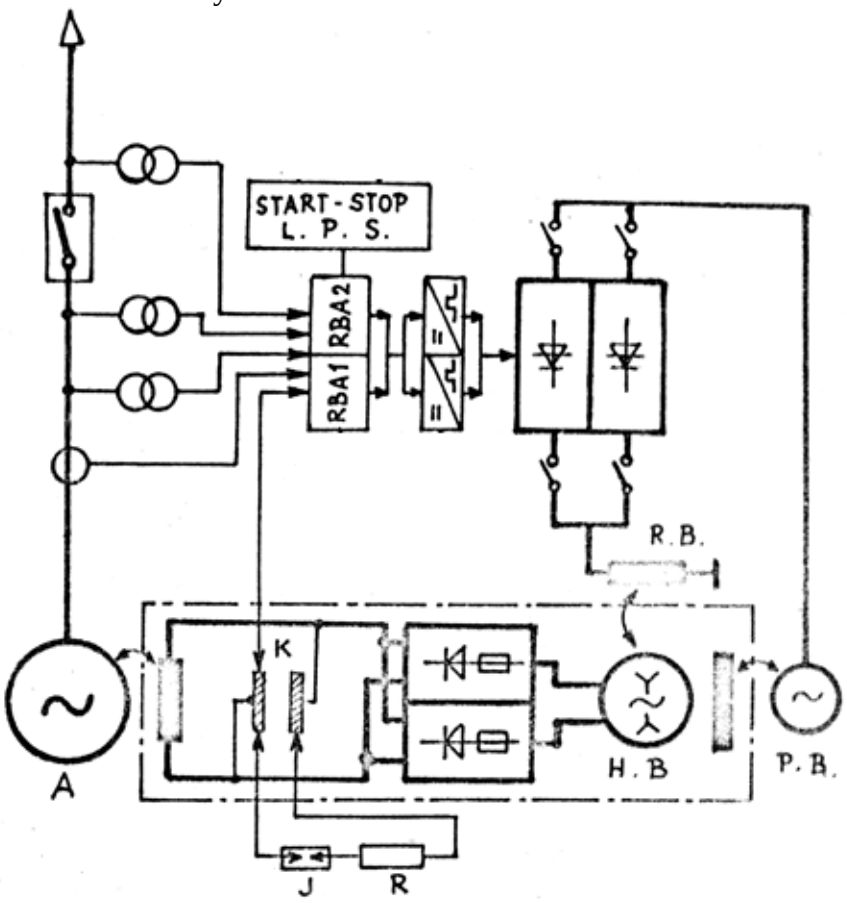
Therefore, this system is supplemented by both current phase-compounding regulation and an attempt to supply the excitation from as independent a grid as possible.

**Brushless excitation systems with uncontrolled rectifier**




The biggest advantage is the elimination of moving contacts from the main excitation circuit (the transmission does not need rings and brushes) because not only the rectifier is located on the rotor, but also the alternator (alternator in inverted design with AC winding on the rotor and excitation on the stator).
The excitation of the excitation machine via the current transformer is advantageous in the case of close short circuits, the voltage is rectified by controlled thyristors.
The advantage is high reliability, the disadvantage is lower dynamics of excitation regulation compared to the controlled rectifier. The wake-up is also slow, therefore it is used only for smaller power outputs.

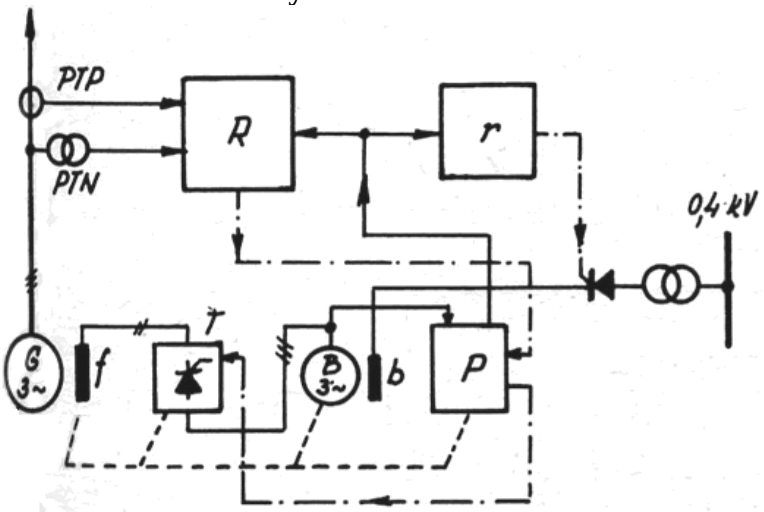
Modified version with auxiliary exciter:



Auxiliary rings must be installed for voltage magnitude measurement and surge protection in the main excitation circuit. The excitation current is measured indirectly through the air coils in the inter-pole space of the main exciter rotor.

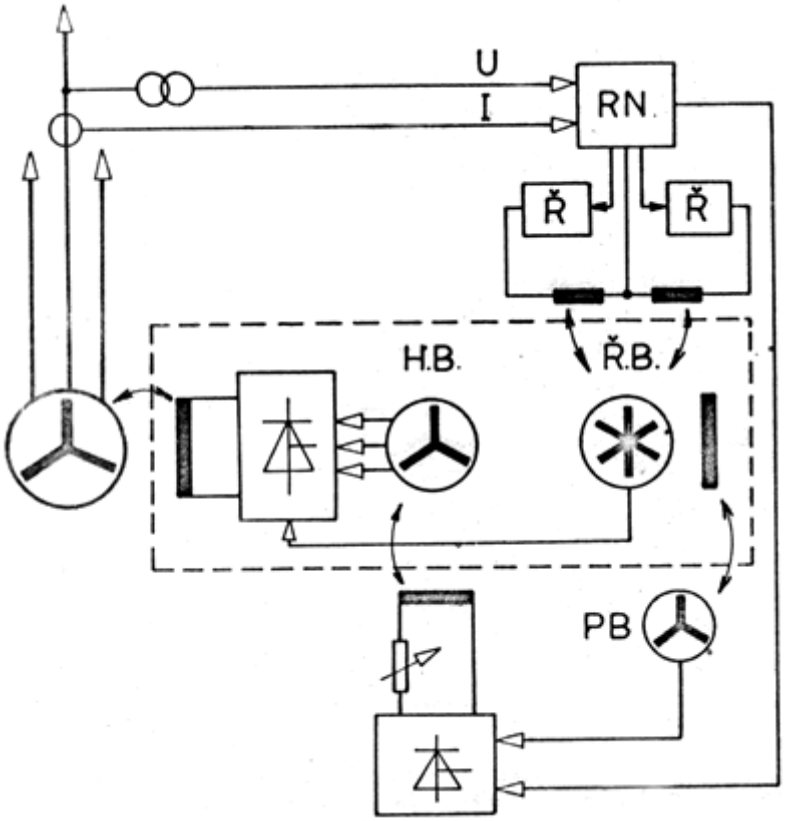
To reduce the excitation time constant, the main exciter is a six-pole design (operating at 150 Hz). The diode design must be sufficiently oversized due to their problematic maintenance.

**Brushless excitation systems with controlled rectifier**

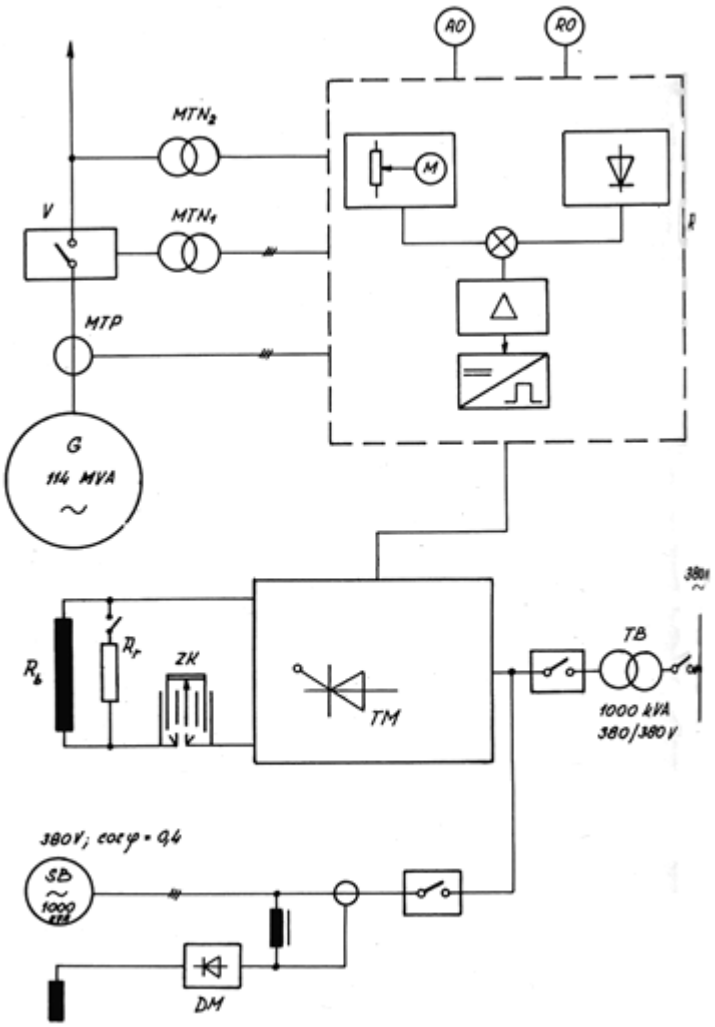



The information from and to the rotor is transmitted via a multichannel converter "P". The advantage is the greater dynamics of the wake-up regulation and the possibility of wake-up by inverter operation. The disadvantage is the high purchase costs due to the mechanical stress on the rotor components.

The converter is designed e.g. as a six-channel control exciter with excitation in the longitudinal and transverse axis.




There are also designs with a rotating transformer (dependent source) with even better dynamics, but this requires transferring all excitation power through the air gap.




In addition, asynchronous operation during motor start-up must be ensured for reverse hydroalternators.

Example of wiring for the hydroelectric power plant Dalešice, where the resistor $R_r$ is connected just at start-up.

**Features of wake-up systems**

Of the many requirements placed on excitation systems, the most important is the maintenance of static and dynamic stability of the alternator, i.e. its synchronous operation with the grid during close short circuits, excitation faults and step load changes. Dynamic behaviour requires the solution of the equation of motion for the load angle:

$$J\frac{d^2\vartheta}{dt^2} + D\frac{d\vartheta}{dt} = \frac{P_T - P_{EL}}{\omega},$$

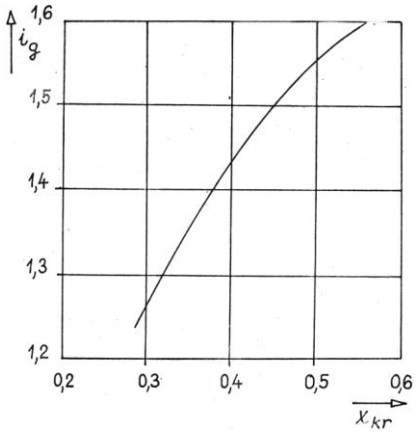
where D is the damping factor determined mainly by the effect of the alternator damper and the active resistances through which the currents are closed. The solution of such an equation necessarily involves an analysis of the behaviour of the turbine and its controller and, in addition, many representative cases have to be solved.

The verification of the static stability of the excitation controller is limited to the determination of the minimum so-called "transfer reactance" $X_{KR}$ (from the alternator to the point of short circuit) at which the system is still stable, i.e. the excitation is able to maintain the required alternator stator current and the load angle has not exceeded the limit when the delivered active power starts to decrease depending on it. This is particularly important for dependent excitation systems where the alternator terminal voltage affects the magnitude of

the excitation voltage and thus a higher margin must be considered (relative excitation voltage ceiling $K_S$ to 2.5). Unfortunately, the dependence of the stator magnitude on the excitation current is non-linear, so the magnitude of $X_{KR}$ depends on the required short-circuit current.

For the required short-circuit current $i_G$ and a specific short-circuit reactance $x_K$ determine the generator clamp voltage: $u_G = i_G \cdot x_K$ . Compare the maximum excitation current value at a given clamp voltage $i_B = K_S \cdot u_G$ with the required excitation current value from the inductive characteristic and denote their difference by $\Delta i_B$ . For values at different "electrically distant" short circuits and thus different $x_K$ at $K_S = 2.5$ we obtain a table:

| $i_G$ | $x_K$ | $u_G$ | Maximum achievable $i_B$ | Needed $i_B$ | Book now $\Delta i_B$ | Sessions $x_K$ and $x_{KR}$ |
|---|---|---|---|---|---|---|
| 1.5 | 0.50 | 0.75 | 1.88 | 1.81 | 0.07 | $x_K > x_{KR}$ |
| 1.5 | 0.45 | 0.68 | 1.68 | 1.68 | 0.00 | $x_K \approx x_{KR}$ |
| 1.5 | 0.33 | 0.5 | 1.25 | 1.35 | -0.10 | $x_K < x_{KR}$ |




As the required alternator current decreases, the value of the critical reactance $x_K$ at which this current is still sustainable decreases, i.e. the short circuit can be electrically closer to the alternator.