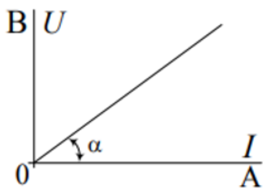
Basic knowledge

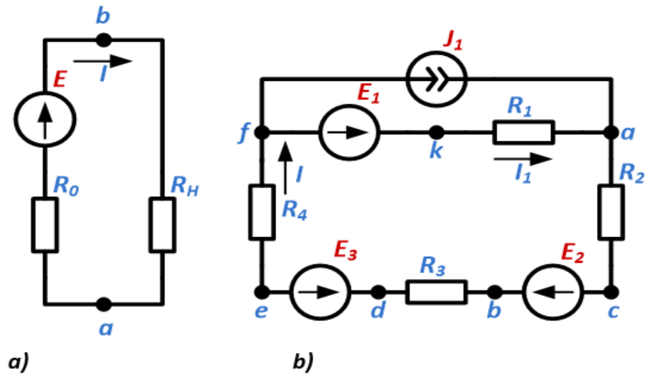
LINEAR DC CIRCUITS WITH ONE AND TWO POWER SOURCES



Linear direct current circuits are characterized by the proportionality between voltage and current (Ohm's Law). In circuits with a single power source, the current is determined by the circuit's resistance. In circuits with two sources (such as batteries), complex connection schemes are possible, such as series and parallel connections of sources, which affect the total voltage and current.

An electrical circuit in which a constant (time-invariant in magnitude and direction) current flows is called a **direct current (DC) circuit**. In DC circuits, the source of electrical energy is characterized by the electromotive force (EMF) E and the inner resistance R_n, while the load (receiver) is characterized by resistance R.

To describe sources and loads of energy in direct current circuits, the relationships between voltage U and current I are used, which are called the volt-ampere characteristics (VAC) of these elements.



Schemes of a simple (a) and a branched (b) direct current circuits

The current in such a circuit is determined by Ohm's law:

$$I = \frac{E}{R_0 + R_n}$$

Where E is the EMF source; R_0 is the internal resistance of the EMF source; R_n is the load resistance.

For the section of the circuit containing the EMF (the segment acb in diagram b), Ohm's law in a generalized form is:

$$I_{ab} = \frac{U_{ab} \pm E_2}{R_{ab}}$$

Where $U_{ab} = \varphi_a - \varphi_b$

The «+» sign is used if the direction of the EMF coincides with the chosen positive direction of the current. If a section of the circuit or its branch contains, in addition to the EMF source, an ideal current source, then the total current in the considered section:

$$I_{ab} = \frac{U_{ab} \pm E_2}{R_{ab}} \pm J_1$$

Where J_1 - current of the current source.

The principle of independence of EMF action is formulated as follows: in a linear electrical circuit, the effect exerted by each EMF individually can be considered independently of the effects of the other EMFs in the circuit. This property forms the basis of the superposition principle: the current in any branch of an electrical circuit can be viewed as the algebraic sum of the currents in that branch due to the action of each EMF separately.

Basic knowledge

LINEAR DC CIRCUITS WITH ONE AND TWO POWER SOURCES

According to the **superposition principle**, the expression for the currents can be presented as:

$$I_k = E_1 \cdot g_{k1} + E_1 \cdot g_{k1} + \cdots + E_k \cdot g_{kk} + \cdots + E_n \cdot g_{kn}$$

The mutual resistance of two branches is the reciprocal of their mutual conductance. The mutual conductances are related to each other as follows:

$$g_{kn} = g_{nk} = \frac{1}{R_{nk}}$$

Procedure for calculating using **the superposition method:**

- The original circuit is divided into separate analysis circuits, each with only one EMF or one current source active. All other EMF or current sources are considered absent, but their internal resistances are retained in the circuit.
- The currents in the branches of each auxiliary analysis circuit are determined.
- To find the currents in the original circuit, the currents from each of the analysis circuits are algebraically summed for each branch.

The superposition principle cannot be used when calculating power because power is a quadratic function of current or voltage.

The reciprocity principle is as follows: if a certain EMF, located in one branch of an arbitrarily complex linear electric circuit, causes a current in another branch of the same circuit, then in the absence of other EMFs, the same EMF, when transferred to the second branch, will induce a current of the same magnitude and phase in the first branch.

Nonlinear direct current circuits

In such circuits, elements with nonlinear characteristics are present (for example, diodes, transistors), where Ohm's law does not apply. The current and voltage are related by a nonlinear function, which leads to complex operating modes and requires specialized analysis methods.

Elements whose parameters depend on the magnitude and/or the direction of variables (such as voltage, current, magnetic flux, charge, temperature, light flux, etc.) associated with these elements are called nonlinear elements. Nonlinear elements are described by nonlinear characteristics, which do not have a strict analytical expression, are determined experimentally, and are specified graphically or in tabular form.

Nonlinear elements can be divided into two-pole (bilateral) and multi-pole (multilateral) types. The latter include three (various semiconductor and electronic triodes) or more (magnetic amplifiers, multi-winding transformers, tetrodes, pentodes, etc.) poles, through which they connect to the electrical circuit. A characteristic feature of multi-pole elements is that, in general, their properties are described by a family of characteristics representing the dependencies of output parameters on input variables and vice versa: input characteristics are plotted for a series of fixed values of one of the output parameters, while output characteristics are plotted for a series of fixed values of one of the input variables. According to another classification criterion, nonlinear elements can be divided into inertial and non-inertial types. Inertial elements are those whose characteristics depend on the rate of change of variables. For such elements, the static characteristics, which define the relationship between the actual values of variables, differ from the dynamic characteristics, which establish the relationship between the instantaneous values of variables. Non-inertial elements are those whose characteristics do not depend on the rate of change of variables. For such elements, the static and dynamic characteristics coincide.

Basic knowledge

NONLINEAR DIRECT CURRENT CIRCUITS

Depending on the type of characteristics, nonlinear elements are classified as having symmetric or asymmetric characteristics. A symmetric characteristic is one that does not depend on the direction of the defining quantities, i.e., it has symmetry about the origin of the coordinate system: f(x) = -f(-x). For an asymmetric characteristic, this condition does not hold, i.e., f(x) ≠-f(-x). The presence of a symmetric characteristic in a nonlinear element can, in many cases, simplify the analysis of the circuit by allowing it to be performed within a single quadrant.

By the type of characteristic, all nonlinear elements can also be divided into elements with unambiguous and ambiguous characteristics. An unambiguous characteristic is one where each value of x corresponds to a single value of y, and vice versa, i.e., y = f(x) is a one-to-one relation. In the case of an ambiguous characteristic, some values of x may correspond to two or more values of y, or vice versa. In nonlinear resistors, ambiguity in the characteristic typically relates to the presence of a falling segment where du/di < 0, while for nonlinear inductive and capacitive elements, it is associated with hysteresis.

All nonlinear elements can be categorized as controlled and uncontrolled. Unlike uncontrolled elements, controlled nonlinear elements (usually three- or multi-pole elements) contain control channels through which they vary their main characteristics—voltage-current, Weber-ampere, or Coulomb-volt relations—by changing quantities such as voltage, current, light flux, etc.

The nonlinear properties of nonlinear DC electrical circuits are determined by the presence of nonlinear resistors. Due to the lack of a direct proportionality between voltage and current in nonlinear resistors, they cannot be characterized by a single parameter (one value of R). In general, the relation between these quantities depends not only on their instantaneous values but also on their derivatives and integrals over time.

Parameters of nonlinear resistors

Depending on the operating conditions and the specific problem, nonlinear resistors are characterized by static, differential, and dynamic resistances:

- **Static resistance** is defined as the ratio of voltage across the resistive element to the current flowing through it.

- **Differential resistance** is the ratio of an infinitesimal increase in voltage to the corresponding increase in current.

It should be noted that for an uncontrolled nonlinear resistor, $R_{st}>0$ always, while R_d (differential resistance) can take on negative values.

In the case of an inertial nonlinear resistor, the concept of **dynamic resistance** is introduced, determined from the dynamic voltage-current characteristic (VAC). Depending on the rate of change of a variable, for example, current, not only the magnitude but also the sign of R_{din} can change.

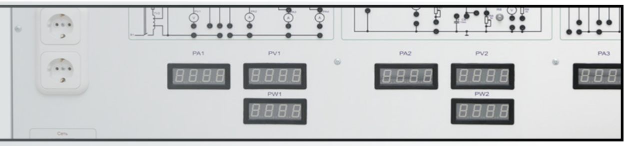
Methods for analyzing nonlinear DC electrical circuits

The electrical state of nonlinear circuits is described based on Kirchhoff's laws, which are generally applicable. However, it should be remembered that the principle of superposition is not valid for nonlinear circuits. Consequently, calculation methods developed for linear circuits, based on Kirchhoff's laws and the superposition principle, generally do not apply to nonlinear circuits.

There are no universal methods for analyzing nonlinear circuits. The known techniques and approaches have various capabilities and areas of application. In general, when analyzing a nonlinear circuit, the resulting system of nonlinear equations can be solved using the following methods:

Basic knowledge

NONLINEAR DIRECT CURRENT CIRCUITS



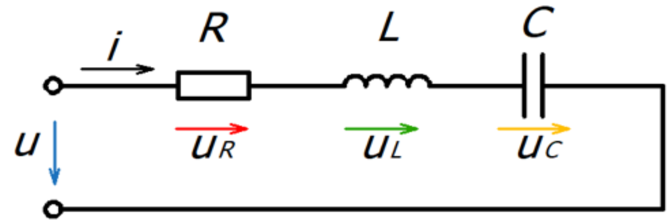
- Graphical;
- Analytical;
- Graph-analytical;
- Iterative.

AC circuits with series connection of an inductor, resistor, and capacitor

These circuits are called RLC circuits (resistor, inductor, capacitor). They involve complex impedances, and analysis is conducted using the method of complex amplitudes. The interaction of reactive elements causes phase shifts between current and voltage.

A coil with active resistance R, inductance L, and capacitor with capacitance C are connected in series. The voltage across the active resistance is in phase with the current; the voltage across the inductor leads the current by 90°, and the voltage across the capacitor lags the current by 90°. The circuit carries a sinusoidal current:

$$i = I_m \cdot \sin \omega t$$

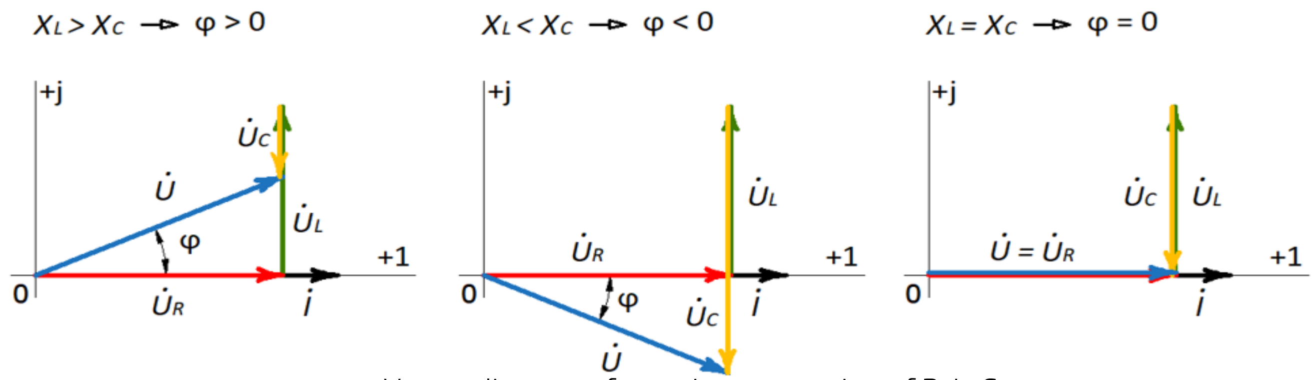


When constructing vector diagrams of the circuit, consider three cases:

$X_L>X_C$, the circuit exhibits inductive behavior. The voltage vectors across the inductor and capacitor point in opposite directions, partially cancel each other out. The voltage vector at the input of the circuit leads the current vector.

$X_L<X_C$, the circuit exhibits capacitive behavior. The voltage vector at the input laggs behind the current vector.

$X_C=X_L$, the inductive and capacitive reactances are equal. The voltages across the inductor and capacitor fully cancel each other. The current in the circuit is in phase with the input voltage. In the electrical circuit, a resonance mode of voltages occurs.



Vector diagrams for series connection of R, L, C

The current in resonance mode reaches its maximum because the total impedance z of the circuit has the minimum value.

$$I = \frac{U}{z} = \frac{U}{\sqrt{R^2 + (X_L - X_C)^2}}$$

Basic knowledge
AC CIRCUITS WITH SERIES CONNECTION OF AN INDUCTOR, RESISTOR, AND CAPACITOR

Condition for resonance:

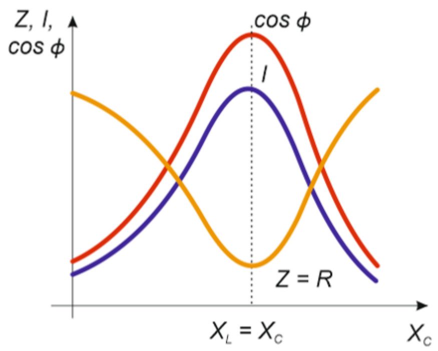
$$\omega_0 \cdot L = \frac{1}{\omega_0 \cdot C},$$

from here, the resonance frequency is equal to:

$$\omega_0 = \frac{1}{\sqrt{L \cdot C}}$$

From the formula, it follows that resonance mode can be achieved by the following methods:

1. Changing the network frequency;
2. Changing the inductance;
3. Changing the capacitance.



Resonance curves in the voltage resonance mode

At the resonance frequency, $U_L = U_C$ and they mutually cancel each other out; the circuit current is maximum, and the source voltage is applied across the active resistance. Voltages across the inductor and capacitor in the circuit can reach values many times greater than the input voltage. This is because each voltage is equal to the product of the maximum current I_0 (which is the largest) and the corresponding inductive or capacitive reactance (which can be large).

$$U = R \cdot I_0 \ll X_L \cdot I_0 = X_C \cdot I_0$$

AC transmission lines

Transmission lines with a voltage of 500–750 kV are designed both for transmitting large amounts of electrical energy from major thermal and hydraulic power plants, located far from industrial centers, to consumption areas, and for mutual power exchange between power systems. Depending on the transmitted power and purpose, 500–750 kV transmission lines are built as single-circuit, double-circuit, or with a larger number of circuits. These voltage transmission lines are predominantly erected on single-pole supports. Double-circuit supports for 500 kV lines are less commonly used due to limited space and high land acquisition costs. Inter-system connections are generally made as single-circuit; the second circuit is included if there are prospects for transmitting large capacities through them.

Double-circuit (and three-circuit) power lines are constructed only using a tied scheme, with a series of intermediate substations or switching points, spaced 250–350 km apart.

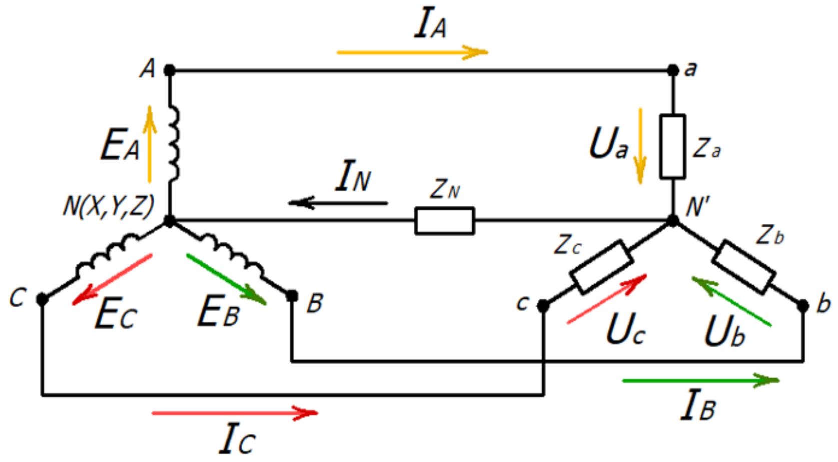
Three-phase circuits with star (wye) and delta (triangle) connections

Three-phase systems can be connected in a «star» (Y) or «delta» (Δ) configuration. In the «star» scheme, one end of each phase is connected to a common node, while in the «delta» scheme, the phases are connected in a loop. These configurations affect the system parameters and operating modes.

Basic knowledge
AC CIRCUITS WITH SERIES CONNECTION OF AN INDUCTOR, RESISTOR, AND CAPACITOR

Connecting loads in a star (Y) configuration

If the ends of all generator phases are connected to a common node, and the starts of the phases are connected to a load forming a three-arm star of resistances, a three-phase star-connected circuit is created. In this case, the three return wires merge into one, called the neutral or zero wire.



A three-phase circuit connected in a star (Y) configuration

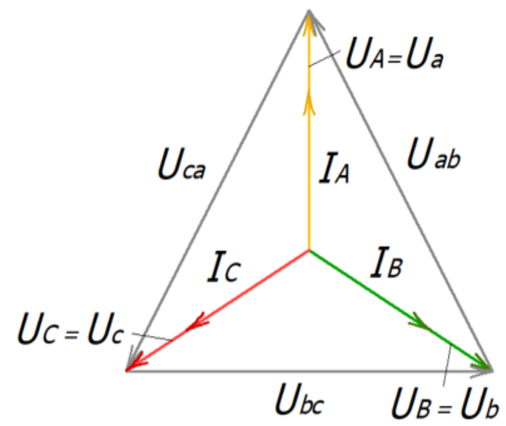
Wires going from the source to the load are called line conductors. The wire connecting the neutral points of the source N and the receiver N' is called the neutral (zero) conductor (ZN — resistance of the neutral wire).

Voltages between the beginnings of the phases or between the line conductors are called line voltages. Voltages between the beginning and end of a phase or between a line and the neutral wire are called phase voltages.

Currents in the phases of the receiver or source are called phase currents, while currents in the line conductors are called line currents. Since line conductors are connected in series with the source and receiver phases, the line currents in a star connection are also simultaneously phase currents.

Special cases:

1. Symmetrical load. The phase resistances of the load are identical and equal to a certain active resistance $Z_a = Z_b = Z_c = R$.



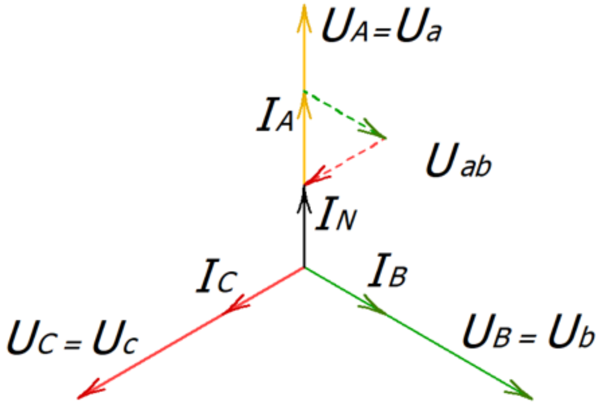
Vector diagram of a three-phase circuit for a symmetrical load

2. The load is unbalanced, with, $R_a < R_b = R_c$, but the neutral conductor resistance is zero: $Z_N = 0$ (neutral conductor is present).

Basic knowledge

THREE-PHASE CIRCUITS WITH STAR (Y) AND DELTA (Δ) CONNECTIONS

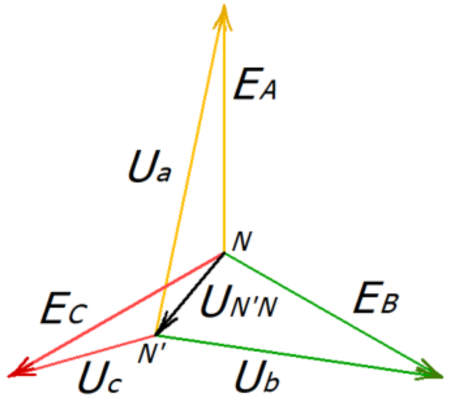
Condition for the occurrence of resonance:



Vector diagram of a three-phase circuit connected in a star configuration with a neutral wire of zero resistance and an unbalanced load

3. Unbalanced load Ra=Rb=Rc, with no neutral wire.

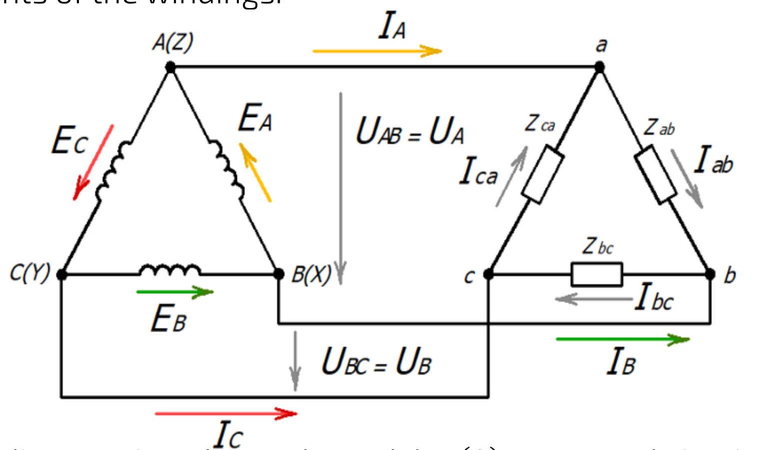
The phase current vectors align in the same direction as the corresponding load phase voltage vectors. The zero-resistance neutral wire in a scheme with an unbalanced load compensates for the unbalance in the load phase voltages, meaning that with the inclusion of this neutral wire, the load phase voltages become equal.



Vector diagram of a three-phase star-connected circuit with an unbalanced load and a broken neutral wire

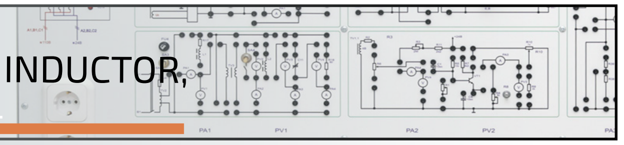
Connecting loads in a delta (Δ) configuration

If the end of each generator winding phase is connected to the beginning of the next phase, a delta (Δ) connection is formed. Three line conductors leading to the load are connected to the connection points of the windings.



Three-phase circuit connected in a delta (Δ) configuration

As shown in the diagram, in a three-phase delta (Δ) connected circuit, the phase voltages and line voltages are the same.

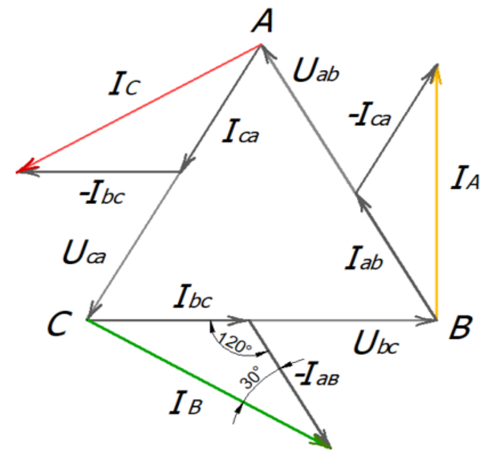


Basic knowledge

AC CIRCUITS WITH SERIES CONNECTION OF AN INDUCTOR, RESISTOR, AND CAPACITOR

Connecting loads in a star (Y) configuration

The load is considered symmetrical if the phase resistances are identical. The vectors of the phase currents align in the same direction as the vectors of the corresponding phase voltages, since the load consists of active resistances.



Vector diagram of phase and line currents for a symmetrical source

Three-phase circuits connected in a star (Y) configuration are more widely used than those connected in a delta (Δ) configuration. This is because, first, a star-connected circuit allows obtaining two types of voltages: line and phase voltages. Second, if the phases of the winding of an electrical machine connected in delta are in different conditions, additional currents appear in the winding, which load it. Such currents are absent in the phases of an electrical machine connected using the star scheme. Therefore, in practice, it is avoided to connect the windings of three-phase electrical machines in delta.

Line circuits with nonsinusoidal periodic currents that include an inductance coil and a capacitor

Analysis of such circuits requires the use of harmonic components and spectral analysis methods, as the resulting currents and voltages contain multiple harmonics.

RMS (effective) values of nonsinusoidal voltages and currents are determined by:

$$U = \sqrt{U_0^2 + U_1^2 + U_2^2 + \cdots}; \; I = \sqrt{I_0^2 + I_1^2 + I_2^2 + \cdots};$$

where U_0 and I_0 are the direct (constant) components of the nonsinusoidal voltage and current, decomposed into Fourier series; U_1, U_2,..., I_1, I_2... are the RMS values of the individual harmonic components of voltage and current, respectively.

$$U_1 = \frac{U_{1m}}{\sqrt{2}}; \; U_2 = \frac{U_{2m}}{\sqrt{2}}; \ldots; \; I_1 = \frac{I_{1m}}{\sqrt{2}}; \; I_2 = \frac{I_{2m}}{\sqrt{2}}; \ldots;$$

where U_{1m}, U_{2m}, ..., I_{1m}, I_{2m}, ... are the respective amplitude values of the individual voltage and current components.

The harmonic composition of the voltage of a controlled rectifier is described by a Fourier series:

$$U = U_0 + U_{1m} \cdot sin(2\omega t + \varphi_1) + U_{2m} \cdot sin(4\omega t + \varphi_2) + U_{3m} \cdot sin(6\omega t + \varphi_3)$$

The RMS (effective) value of the harmonic component currents can be determined from an expression of the form:

$$I_K = \frac{U_{K-1}}{\sqrt{(R15 + R_{L1})^2 + (k\omega L1)^2}}$$

where k = 2; 4; 6;...; ω = 2 π f; f = 50Hz – supply frequency; R_{15} = 510 Ohm; R_{L1} – taken from the calculations in laboratory work num.8 (or measured with a multimeter).

Phase shift between the current and voltage of the corresponding harmonic components:

Basic knowledge
Line circuits with nonsinusoidal periodic currents that include an inductance coil and a capacitor

$$\varphi_{ki} = arctg\frac{K\omega L1}{R15 + R_{L1}}$$

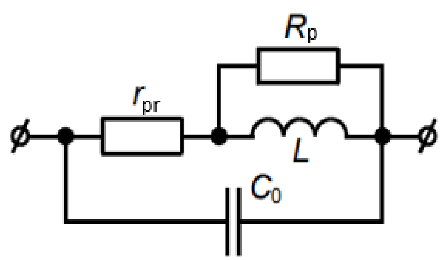
RMS (effective) value of nonsinusoidal current:

$$I = \sqrt{I_0^2 + I_1^2 + I_2^2 + \ldots + I_K^2 + \ldots}$$

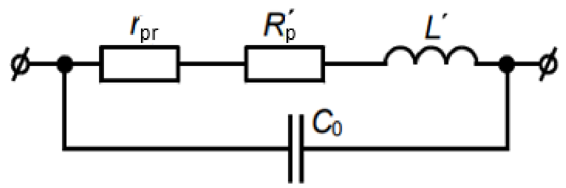
Based on the measurement results, the source voltage is recorded in the form of a Fourier series.

Equivalent circuit of an inductance coil with a closed magnetic core

This is a model that replaces the inductance with an equivalent resistance or resistance with inductive reactance, accounting for the magnetic properties of the magnetic core material. When performing electrical calculations, one of the equivalent circuits is used.



$L \neq L'$;
$R_p \neq R'_p$



r_{pr} – wire resistance; R_p – losses in the magnetic core; C_0 – intrinsic (parasitic) capacitance:

- inter-turn capacitance;
- terminal capacitance of the coil;
- capacitance of individual turns relative to the core.

It is evident that the equivalent circuit of a real inductor coil represents a resonant circuit, which distorts the properties of the inductor itself. Therefore, coils are used at frequencies where the capacitance C_0 does not have a significant effect.

An important parameter of the inductor coil is its quality factor (Q). When the intrinsic capacitance C_0 is sufficiently small:

$Q = \frac{X_L}{R}$ R – total losses in the wire and magnetic core. The higher the quality factor (Q), the better!

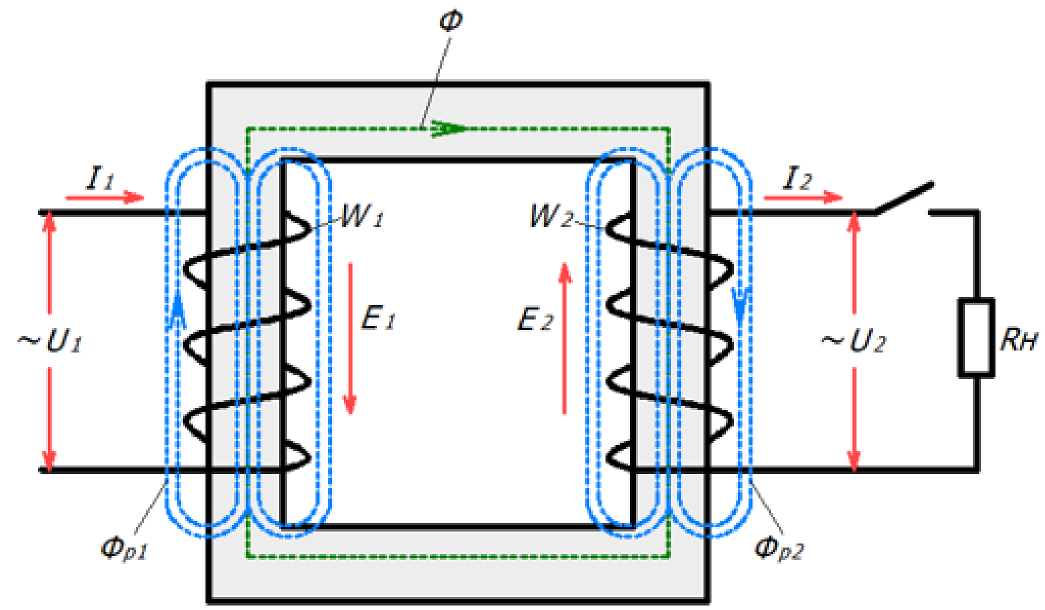
Single-phase transformer

Device for transmitting electrical energy between circuits through magnetic coupling, consisting of primary and secondary windings, weakly coupled by the magnetic field. The main part is the core, which improves the efficiency of transformation.

A transformer is a static electromechanical device used to convert alternating current of one voltage into alternating current of another voltage without changing the frequency.

Transformers have become widespread as devices that allow the transmission of electrical energy over long distances with minimal energy losses in power lines. They are also used to connect electrical energy sources of different voltage levels into a unified power system.

Basic knowledge
Single-phase transformer

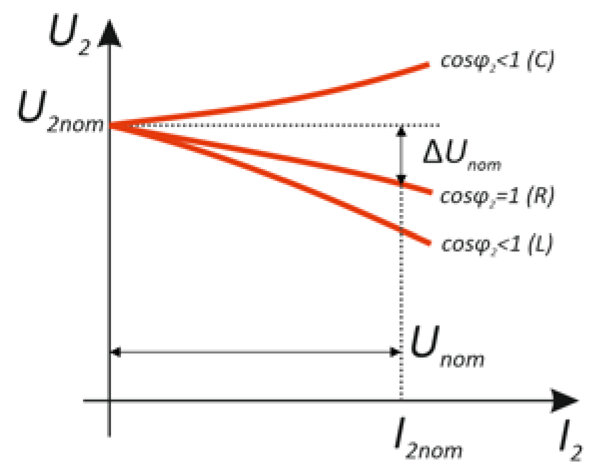


Transformer device

Transformer operating modes:

- Idle (no-load) mode.
- Load mode of the transformer.

In load mode, the external characteristics of the transformer are determined: $U_2 = f(I_2)$, at U_1 = constant, with $\cos\varphi_2$ = const.



External characteristics of a transformer

Short-Circuit Mode

The transformer short-circuit test is conducted during transformer research to determine the electrical power losses in the winding conductors and the parameters of a simplified equivalent circuit of the transformer.

The short-circuit test should not be confused with the short-circuit mode, which occurs at the rated voltage of the primary winding. Short-circuit mode is an emergency operating mode for a transformer. In contrast, the short-circuit test is performed at a very low voltage U_{1sc}, which is selected so that the currents in the primary and secondary windings correspond to the rated currents of the windings (in the range of 3 ... 10% of U_{1rated}). ("sc" can stand for "short circuit," and "rated" means the nominal value).

Basic knowledge
SINGLE-PHASE TRANSFORMER

The test is carried out with the secondary winding short-circuited – the one closed through an ammeter with very low resistance. All the power consumed by the transformer is practically used to compensate for the electrical losses when heating the windings.

Based on the no-load and short-circuit tests, the transformer efficiency η is determined:

$$\eta = \frac{P_2}{P_1} = \frac{P_2}{P_2 + P_{EL} + P_{MAG}}$$

where P_{EL} and P_{MAG} are the electrical and magnetic losses, respectively.

Three-phase asynchronous motor with a short-circuit (squirrel-cage) rotor

The type of motor with a rotating magnetic field of the stator and a short-circuit (squirrel-cage) rotor, which uses induction to transfer energy, is widely used in industry.

A three-phase asynchronous motor consists of two main parts: the stator and the rotor. The stator is the stationary part of the motor that creates a rotating magnetic field. The connection scheme of the three-phase stator winding can be a star or delta. The magnetic field of the stator intersects the conductors of the rotor winding, inducing a alternating emf in them. Since the rotor winding is closed, this emf causes a current in the rotor with the same direction as the emf.

As a result of the interaction between the rotor current and the rotating magnetic field, an electromagnetic force is generated, acting on the rotor conductors. This force creates a rotational torque, which acts in the same direction as the force.

Under the influence of this torque, the rotor starts moving and, after startup, rotates in the same direction as the magnetic field, but with a slightly lower rotational frequency than the field.

The synchronous rotational frequency is determined by the frequency f_1 of the power supply source and the number of pole pairs p of the stator:

$$n_1 = \frac{60 f_1}{p}$$

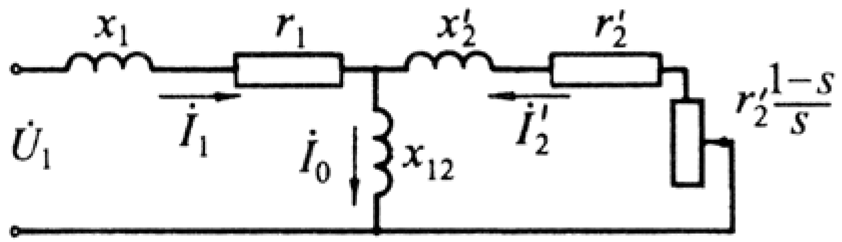
The rotor's rotational frequency is determined by the slip:

$$n_2 = n_1 (1 - s),$$

where s is the slip — the quantity that indicates how much the rotor speed lags behind the speed of the stator's magnetic field.

$$s = \frac{n_1 - n_2}{n_1},$$

To derive the equation of the mechanical characteristic, it is necessary to use the equivalent circuit of the asynchronous motor.



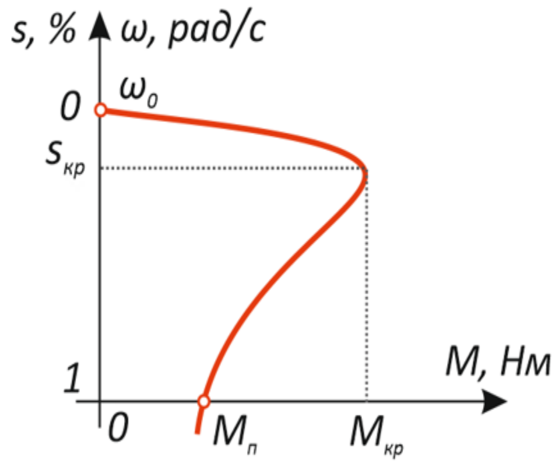
Equivalent circuit of the asynchronous motor

The simplified expression of the mechanical characteristic has the form:

$$M = \frac{2M_k}{\frac{s}{s_k} + \frac{s_k}{s}},$$

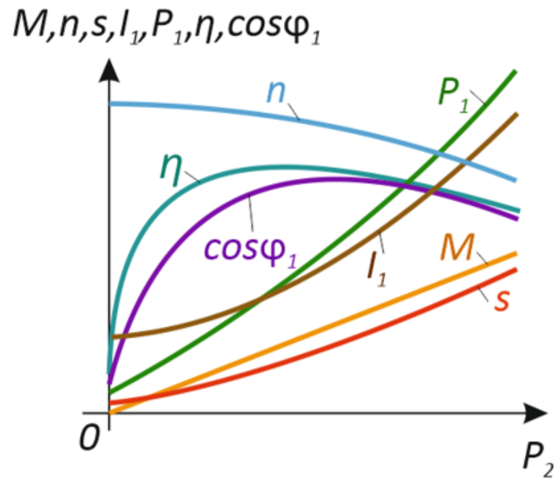
where s_k - is the critical slip;
M_k - is the critical torque.

$$s_k \approx \pm \frac{r_2'}{x_k}, \qquad x_k = x_1 + x_2', \qquad M_k = \pm \frac{m_1 U_1^2 p}{4\pi f_1 x_k}$$



Mechanical characteristic of the asynchronous motor

The operating characteristics of the motor are obtained at constant supply voltage and frequency of the power supply network.



Operating characteristics of the asynchronous motor

Direct current (DC) motor with independent excitation

A motor where the excitation winding is powered by a separate source. It provides stable characteristics and controllability, and is widely used in automation.

A direct current (DC) motor consists of:

- a stationary part – the stator;
- a rotating part – the armature.

Construction of a DC motor

Stator – a hollow steel cylinder, on the inner surface of which an even number of main poles equipped with DC excitation windings are mounted. If the excitation windings are powered from an external source of constant voltage, the motor is called an independently excited motor.

Armature – a cylinder mounted on the shaft of the machine, made from a pack of thin sheets of electrical steel with slots filled with winding, which is connected to collector plates. The system of brushes is applied to these plates.

To ensure as quick as possible startup with limited armature current, the excitation current at startup is made maximum by fully adjusting the variable resistor in the excitation circuit.

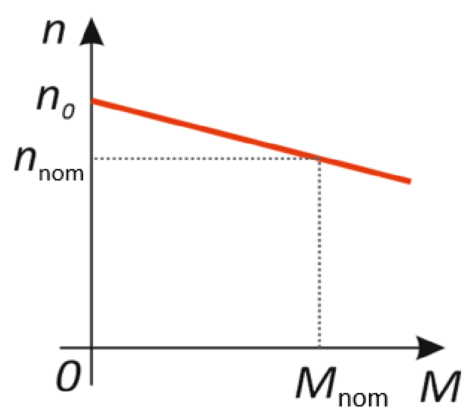
From the expression for the electromagnetic torque, it follows that there are two ways to change the rotation direction:

- Change the direction of the armature current without changing the excitation current direction;
- Change the direction of the excitation current without changing the armature current direction.

Main characteristics of the motor are: mechanical, regulation, and operational characteristics.

Equation of the **mechanical characteristic:**

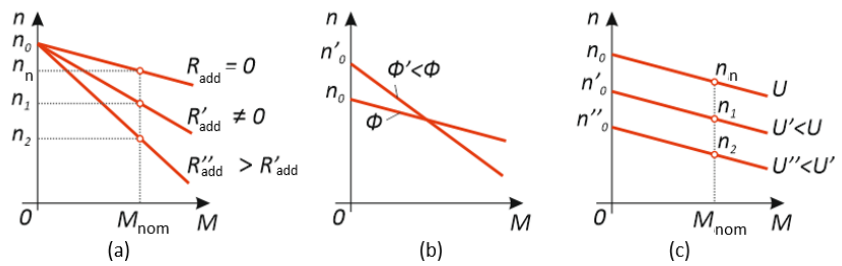
$$\omega = \frac{U}{k\Phi} - M\frac{R_j + R_d}{(k\Phi)^2},$$



Mechanical characteristic of the DC motor

From the equation of the mechanical characteristic, it follows that the rotational speed of the DC motor can be regulated by the following methods:

- by changing the additional resistance in the armature circuit (a);
- by changing the excitation current (b);
- by changing the applied voltage (c).



Mechanical characteristics of the DPT during frequency regulation

The regulating properties of the motor are usually characterized by the regulation characteristic $n_0 = f(I_f)$ or $I_a = f(I_f)$ at $U = U_{nom}$ and a constant load on the motor shaft, particularly in the no-load (idle) mode.

Direct current generator with independent excitation

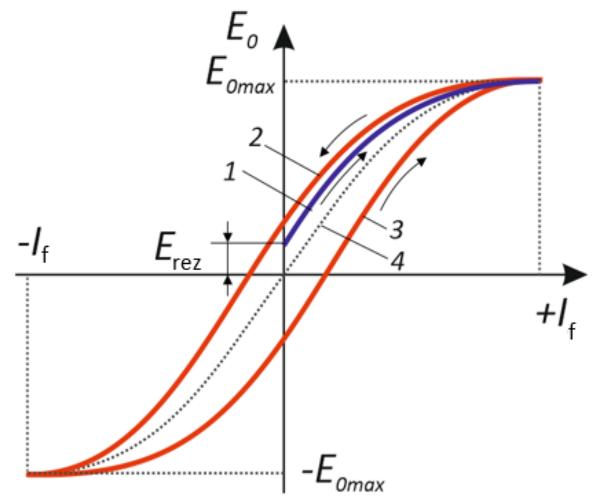
Generator where the excitation is created by a separate coil or source, ensuring stable output voltage under load variations.

The DC generator, like a DC motor, consists of a stator with excitation windings, an armature, and a brush-commutator assembly.

The DC voltage is collected from the load via the brushes.

The electromotive force (EMF) induced in the armature winding, which is rotated at a constant rotational speed, depends solely on the magnetic flux of the main poles or the excitation current.

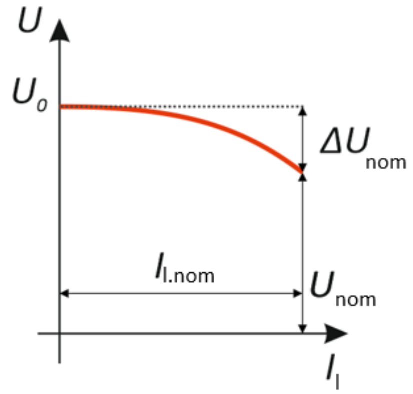
The dependence $E_{a0} = f(I_f)$ when $I_{nom} = 0$ is called the no-load (free-running) characteristic. This characteristic is measured by gradually increasing the excitation current, then gradually decreasing it at a constant speed $n = n_{nom}$.



No-load (free-running) characteristic of the high-voltage DC generator

The dependence of the generator voltage U on the load current I_l, at a constant excitation circuit resistance and a constant armature rotational speed, is called the external characteristic of the generator $U = f(I_l)$.

To obtain data for constructing the external characteristic, the generator is driven at its rated speed and loaded up to the rated current at the rated voltage. Then, gradually reducing the load down to zero load ($I_l = 0$), the readings of the instruments are taken.



External characteristic of the high-voltage DC generator

Basic knowledge

The process of charging a capacitor from a DC voltage source with current limiting using a resistor

When a capacitor is connected to a voltage source through a resistor, charge accumulates gradually, controlled by the resistance, with a characteristic exponential charging dependence.

The charging principle is as follows: when the relay contact is open, the current is limited by a low-resistance resistor. Once the voltage across the capacitor reaches a preset threshold value, the relay contact closes, bypassing the resistor.

Advantages of this charging method include:

- Simplicity of the circuit and ease of implementation;
- High reliability — if the resistor's power rating is properly calculated, the circuit will not fail even in case of a short circuit in the load;
- Ability to operate in both DC and AC circuits.

This method is used for gentle startup in circuits where the goal is to quickly charge large-capacity capacitors.

The drawback of this charging method is that the resistor must be selected according to specific parameters of active and capacitive loads. If the load is unstable, and without additional protection circuits, the scheme may fail.

Starting circuit of an asynchronous motor with a squirrel-cage rotor

For starting an asynchronous motor, relay-contactor control schemes are most commonly used. They allow for automatic asynchronous starting, speed variation, stopping, reversing, braking, and motor protection. Typically, the power circuit is switched using a magnetic starter, while the control circuit is built on various relays (voltage, current, time, thermal, speed monitoring, etc.), whose contacts are low-power.

An important issue when starting an asynchronous motor is limiting the starting current. Due to the high inrush current during direct starting, which can be about 5.5 to 7 times the nominal current, practical methods are employed to reduce this starting current. One such method is temporarily connecting the motor windings in a star configuration.

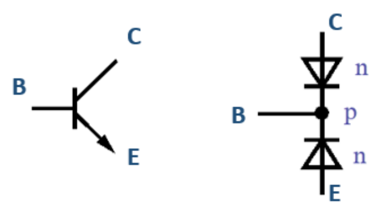
Switching from delta to star and back is done using a special switch. This switching is not performed if the motor windings are connected in a star configuration, as their nominal line voltage is 380V. The starting torque of the asynchronous motor is not very high, so starting is usually carried out without a load.

Single-stage transistor amplifier

An amplifier implemented with a single transistor, providing signal amplification at low levels and simple design.

A transistor is a semiconductor device with three terminals, used for amplifying or switching signals.

A transistor can be thought of as two back-to-back connected diodes that share a common n- or p-layer. The terminal connected to this layer is called the base (B). The other two terminals are called the emitter (E) and the collector (C).



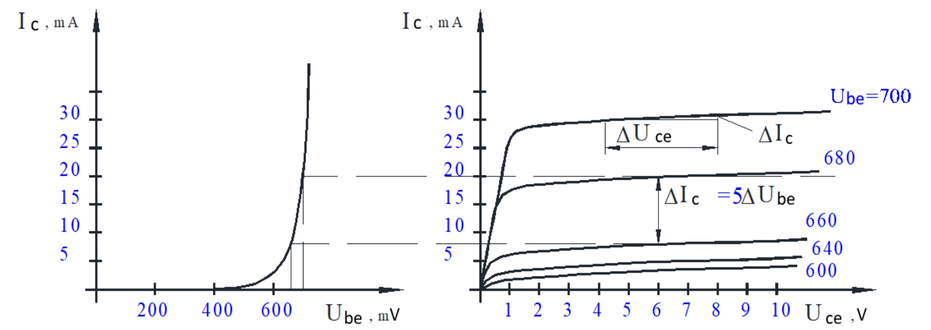
Structure of a transistor

Basic knowledge

The process of charging a capacitor from a DC voltage source with current limiting using a resistor

The modes of a transistor are described in detail using its family of characteristics.

The main feature of a transistor is that the collector current I_c is a multiple of the base current I_B. The ratio of their changes is called the current gain coefficient.



Families of input and output characteristics

The second feature is that the collector current changes little after reaching a certain value of U_{ce}.

The third feature of a transistor is that a small change in the input voltage is sufficient to cause a relatively large change in the collector current. The change in collector current I_c depending on U_{be} is characterized by the slope s.

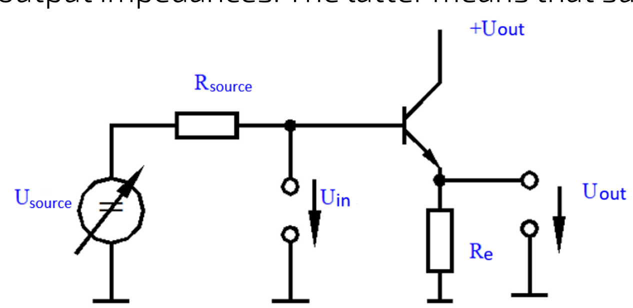
In addition to the parameters mentioned above, the transistor is characterized by the maximum collector current I_{cmax}, the maximum collector-emitter voltage U_{cemax}, the maximum base-emitter voltage U_{bemax}, the maximum collector-base voltage U_{cbmax}, and the cutoff frequency f_{cut}.

There are three main circuit configurations for connecting a transistor in amplifier circuits. Depending on whether the emitter, collector, or base is connected to the common point, the configurations are called with a common emitter, common collector, or common base, respectively.

Two-stage amplifier with direct coupling

A circuit in which two amplifier stages are connected directly without intermediate elements, providing higher gain and stability.

When designing multi-stage transistor circuits, one of the main tasks is the need to match the stages. The circuits must be matched in terms of input and output signal levels and input and output impedances. The latter means that subsequent stages should not shunt the previous ones.



Often, the role of a matching stage with a high source impedance and a low load impedance is performed by a circuit with a common collector or emitter follower.

Emitter follower circuit

Transistor relay with a timing RC circuit

An electronic timer relay is a relay-type device with a set operating or releasing time after the input control signal is applied or removed. In an electronic timer relay based on N-P-N bipolar transistors, the specified delay time for the electromagnetic relay to operate after the control signal is applied is created by a transient process that occurs during the charging of a previously discharged capacitor through a variable resistor.

By changing this resistance, the duration of the transient process can be adjusted, and consequently, the timing of the relay's operation can be varied.

Basic knowledge

SINUSOIDAL OSCILLATION GENERATOR

An electronic generator is a device that converts the electrical energy of a direct current source into energy of undamped oscillations of a specified shape and frequency. It is widely used in radio engineering and communications.

By excitation method, generators are divided into those with independent excitation and those with self-excitation (auto-generators). Generators with independent excitation are oscillation amplifiers that produce external sources. Auto-generators generate undamped oscillations on their own by utilizing positive feedback.

Among auto-generators, there are sinusoidal oscillation generators and pulse generators. Sinusoidal oscillation generators are divided into LC-type auto-generators and RC-type auto-generators. Undamped oscillations in auto-generators are established when two conditions, called self-oscillation conditions, are met. These are the phase balance condition, ensured by positive feedback, and the amplitude balance condition, which depends on the feedback coefficient K_{fb}.

To obtain sinusoidal oscillations at low frequencies, RC-type generators are used. Since an inverting amplifier shifts the signal by an angle of π, then $\alpha = \pi$. This means that the total phase shift of the feedback must also be π, and each RC section contributes π/3.

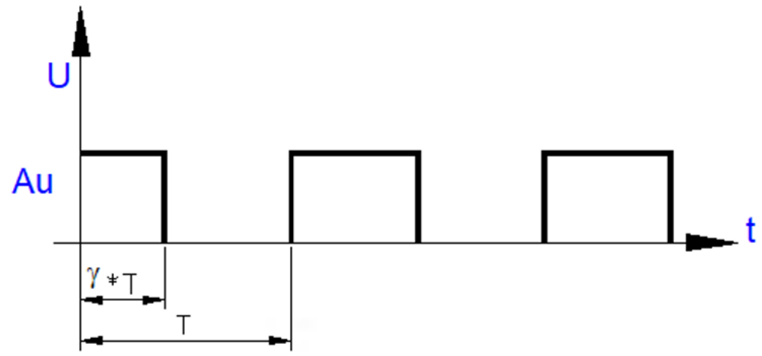
To satisfy the amplitude balance condition, the amplifier's gain must be greater than the attenuation introduced by the phase-shifting network.

Broadband pulse voltage converter

A device that converts voltage using pulse width modulation is used in high-frequency converters and drives. Transmission and signal conversion form the basis of communication, control, regulation, and automation systems.

Depending on the method of forming the control signal or the method of transmitting information, systems can be classified as continuous or discrete.

Pulse width modulation systems are a type of discrete systems. In this modulation method, the period T and the amplitude Au remain constant, while the pulse duration γ·T varies according to some law. The value γ is called the pulse duty cycle.



PWM diagram

Schmidt trigger and digital counters in integral design

Components of digital technology:

- Schmidt trigger — a device for generating a clean signal at threshold levels.
- Digital counters — devices for counting pulses and processing digital data.

Basic knowledge

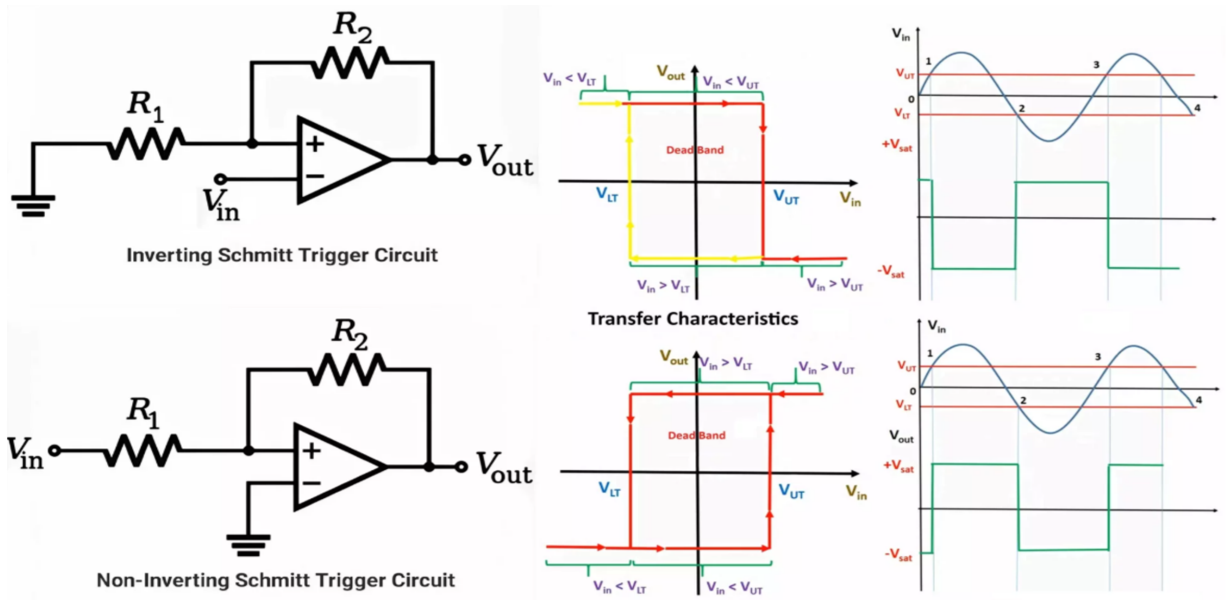
SCHMIDT TRIGGER AND DIGITAL COUNTRES IN INTEGRAL DESIGN

Schmidt Trigger

When an input pulse signal with gentle fronts and edges is applied, the output of the shaping logic element will not be rectangular, because for some time the key circuit remains in an amplifying mode. Additionally, amplified noise from the power supply wires can appear on the front and edge of the output pulse. A noisy, unshaped pulse is unsuitable for triggering clock inputs of flip-flops, registers, and counters.

In such cases, the so-called Schmidt trigger circuit is used, consisting of a two-threshold amplifier with weak positive feedback.

Logic elements with Schmidt trigger properties have internal positive feedback, designed so that the transfer characteristic exhibits significant hysteresis. The transfer characteristic of the studied Schmidt element (b) is bistable and has the form shown in diagram a.



Trigger circuit diagram and current diagram

Pulse Counters

Counting the number of pulses is the most common operation in digital information processing systems. The heightened interest in such devices stems from their high accuracy, the ability to use recording instruments with direct digital readout of results, and their compatibility with computers.

Through digital signal processing, the measured parameter (angle of rotation, displacement, velocity, frequency, time, temperature, etc.) is converted into a sequence of voltage pulses, the number of which—scaled appropriately—represents the value of that parameter. These pulses are counted by pulse counters and displayed as digital digits.

Based on their intended function, counters are classified as simple or reversible. Simple counters are further divided into up-counters and down-counters.

An up-counter performs counting in the forward direction, i.e., addition: upon receipt of a clock pulse at its input, its displayed value increases by one.

A down-counter performs counting in the reverse direction, i.e., subtraction: each pulse causes the displayed value to decrease by one.

Reversible counters can perform counting in both directions, meaning they operate in either addition or subtraction mode, depending on a control signal.

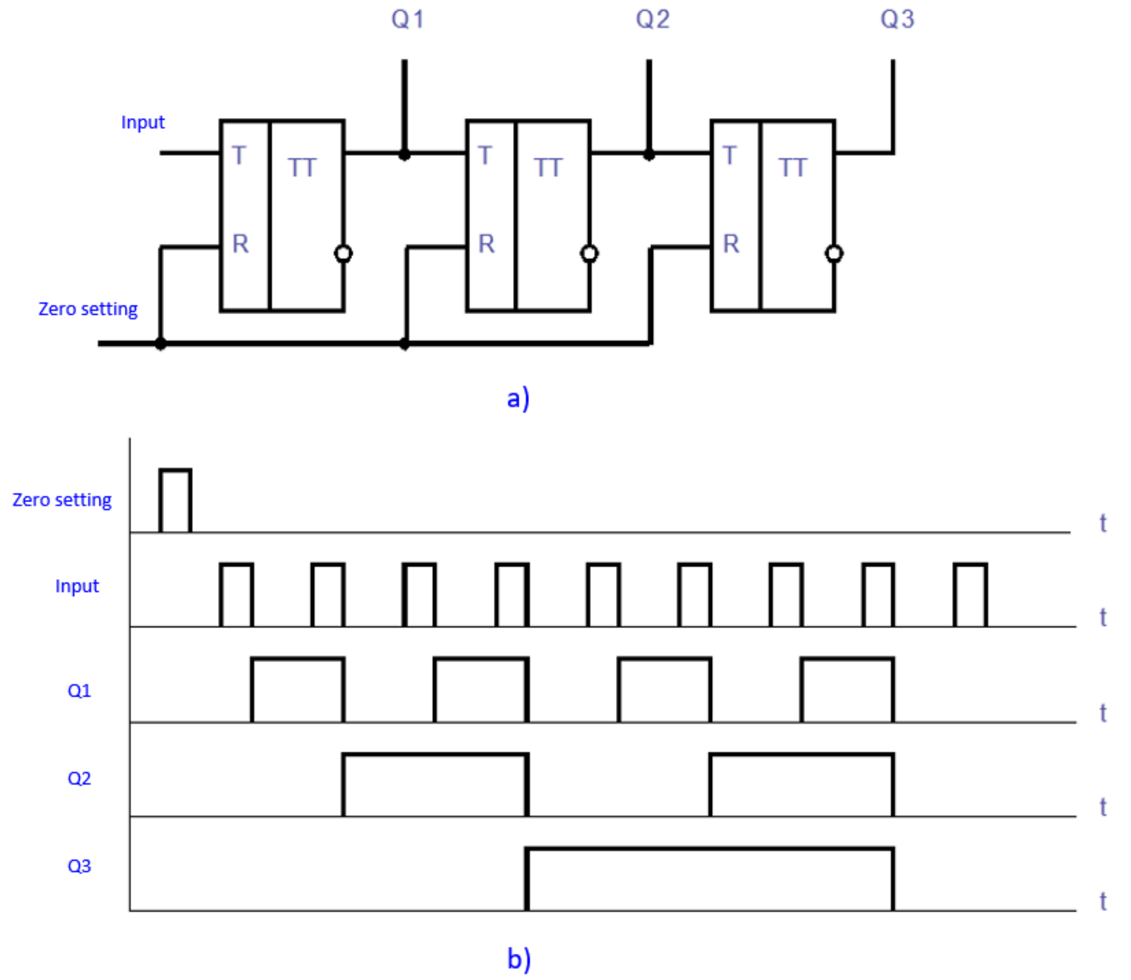
Basic knowledge

SCHMIDT TRIGGER AND DIGITAL COUNTRES IN INTEGRAL DESIGN

The key performance parameters of counters are the count modulus (counting coefficient K) and speed. The speed of a counter is characterized by the maximum clock frequency f_{count} of incoming pulses and the associated settling time t_{set} required for the counter to stabilize. Pulse counters are built using flip-flops, and pulse counting is performed using the binary number system.

The fundamental building block of a binary counter—serving also as its individual digit—is a clocked flip-flop that counts pulses modulo 2.

Multistage binary up-counters with direct coupling are constructed by cascading clocked flip-flops. The input clock pulses are applied to the clock input of the first flip-flop. The clock inputs of subsequent flip-flops are directly connected to the Q (non-inverting) outputs of the preceding flip-flops: the clock input of the second flip-flop is connected to the output of the first, the clock input of the third to the output of the second, and so on.



Timing Diagrams of a Flip-Flop

Counters with a modulus of 10 are called decimal or decade counters. They are widely used for counting pulses and displaying the result visually.