ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

Faculty of Electrical Engineering
Power Engineering Department

Induction motor protection systems

Bachelor's Thesis

Study program: Electrical Engineering, Power Engineering and Management
Branch of study: Applied Electrical Engineering
Supervisor: Assoc. prof. Pavel Mindl.

Ibatullayev Aibek

Prague 2017

ČESKÉ
VYSOKÉ
UČENÍ
TECHNICKÉ
V PRAZE

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Ibatullayev** Jméno: **Aibek** Osobní číslo: **437916**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra elektrických pohonů a trakce**

Studijní program: **Elektrotechnika, energetika a management**

Studijní obor: **Aplikovaná elektrotechnika**

II. ÚDAJE K BAKALÁŘSKÉ PRÁCI

Název bakalářské práce:

Induction Motor Protection Systems

Název bakalářské práce anglicky:

Induction Motor Protection Systems

Pokyny pro vypracování:

1) Study up to date possibilities of induction motors protection.
2) Specify protection methods for low and high power motors.
3) On laboratory stand verify protecting characteristics of typical protection relays
4) Discuss obtained results..

Seznam doporučené literatury:

[1] Basic Types of Three-Phase Motor Protection Systems and Operations, https://www.elprocus.com/three-phase-induction-motor-protection-systems-and-its-applications/
[2] Wester, C.: Motor Protection Principles, https://www.l-3.com/private/ieee/Motor%20Protection%20Principles.pdf
[3] Zambre B.M. et all: Microcontroller Based Protection and Control of Three -Phase Induction Motor, in: Iternational Journal on Recent and Innovation Trends in Computing and Communication, ISSN: 2321-8169, Volume:3, Issue: 11, 6287-6292
http://www.ijritcc.org/download/browse/Volume_3_Issues/November_15_Volume_3_Issue_11/1448955350_01-12-2015.pdf

Jméno a pracoviště vedoucí(ho) bakalářské práce:

doc. Ing. Pavel Mindl CSc., katedra elektrických pohonů a trakce FEL

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) bakalářské práce:

Datum zadání bakalářské práce: **09.02.2017** Termín odevzdání bakalářské práce: **26.05.2017**

Platnost zadání bakalářské práce: **30.06.2018**

Podpis vedoucí(ho) práce

Podpis vedoucí(ho) ústavu/katedry

Podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Student bere na vědomí, že je povinen vypracovat bakalářskou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v bakalářské práci.

Datum převzetí zadání

Podpis studenta

Declaration

I hereby declare that this thesis is the result of my own work and all the sources I used are in the list of references, in accordance with the Methodological Instructions of Ethical Principle in the Preparation of University Thesis.

In Prague, 26.05.2017 Signature ....

Acknowledgement

I would like to thank to my supervisor Assoc. prof. Pavel Mindl and Ing. Jan Kyncl, Ph.D for helping and supporting during the thesis. Also my parents for their moral support and the possibilities in they have given me in life, the teachers in school for the knowledge which they have given me.

Abstract

This Bachelor thesis is focused on induction motor protection problems. Basic information concerning of induction machines, its protection and diagnostic methods are included. In the end of work practical laboratory measurements of induction motor overcurrent protection relay characteristics are presented.

Abstrakt

Bakalářská práce je zaměřena na problematiku ochrany asynchronních strojů. Obsahuje základní informace o asynchronních strojích, metodách ochrany a diagnostiky jejich poruch. V závěru práce jsou uvedeny praktické experimentální výsledky z měření vypínacích charakteristik nadproudového relé, určeného k ochraně asynchronních motorů.

Key words

Induction motor, protection relays, diagnostic methods.

Klíčová slova

Asynchronní motor, ochranné relé, diagnostické metody.

Contents:

1. Introduction…………………………………………………………………… 1

2. History of induction motor…………………………………………………. 1

  2.1. Types of induction motor……………………………………………… 2

    2.1.1. Single phase induction motor……………………………………… 3

    2.1.2. Three-phase induction motor…………………………………….. 3

  2.2. Basic working principle of an induction motor…………………………... 4

3. Over-current protection…………………………………………………… 5

  3.1. Motor protection ………………………………………………………. 7

  3.2. Transformer protection ………………………………………………... 7

  3.3. Characteristics of relay…………………………………………….…... 8

4. Diagnostic methods used for induction motors protection……………………. 10

  4.1. Temperature measurements……………………………………………... 11

  4.2. Motor-current signature analysis (MCSA)……………………………… 12

5. Detection methods of arc fault in power networks……………………………. 13

  5.1. Characterization of chaotic motion in arc faults………………………… 14

  5.2. Types of arc faults……………………………………………………….. 14

    5.2.1. Series faults…………………………………………………………….. 15

    5.2.2. Parallel faults…………………………………………………………… 15

  5.3. Arc fault circuit interrupters……………………………………………… 16

    5.3.1. Types arc fault circuit interrupters…………………………………… 17

6. Specify protection methods for low and high power motors…………………. 18

  6.1. Specify protection methods for high power motors………………….. 19

    6.1.1. Current cut off……………………………………………………….. 19

    6.1.2. Differential protection…………………………………………… 20

    6.1.3. Thermistor relays………………………………………………. 20

  6.2. Specify protection methods for low power motors…………………... 23

    6.2.1. Thermal relay……………………………………………………….. 24

    6.2.1.1. The operating principle of thermal relays……………………… 24

    6.2.1.2. Time-current characteristics of a thermal relay………………… 25

    6.2.1.3. Selection of thermal relays…………………………………….. 26

            - 6.2.1.4. Effect of ambient temperature on the operation of a thermal relay… 26
            - 6.2.1.5. Devices and operation of an electro thermal relay…………………. 26
            - 6.2.1.6. Electronic thermal relays…………………………………………… 28
        - 6.2.2. Fuses……………………………………………………………………… 29
            - 6.2.2.1. Material of fuse links of fuses………………………………………….. 31
            - 6.2.2.2. Advantages of fuses…………………………………………………….. 31
- 7. Laboratory work……………………………………………………………….... 31
- 8. Conclusion ……………………………………………………………………..... 37

- 9. References……………………………………………………………………… 38

1. Introduction.

Protection of induction motors is important because most industrial applications use induction motors from the market due to their high robustness, reliability, low cost and maintenance and high efficiency. They are also critical components in many commercially available equipments and industrial processes.

Controlling an induction motor is difficult due to its strong nonlinear behavior stemming from magnetic saturation effects and a strong temperature dependency of the electrical motor parameters. Especially, the rotor time constant of induction motors can change in a wide range due to rotor temperature. These factors make mathematical modelling of motor control systems difficult. In real applications, only simplified models are used. The commonly used control methods are voltage/frequency, stator current flux and field oriented controls.

2. History of induction motor.

Faraday discovered the electromagnetic induction law around 1831 and Maxwell formulated the laws of electricity (or Maxwell's equations) around 1860. The knowledge was ripe for the invention of the induction machine which has two fathers: Galileo Ferraris (1885) and Nicola Tesla (1886). Their induction machines are shown in Figure 1 and Figure 1.1.

.

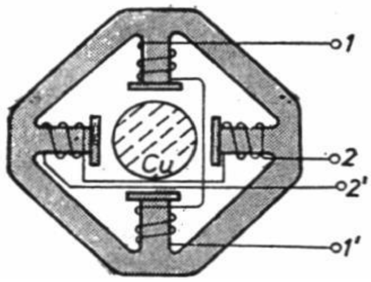


Figure 1 Ferrari's induction motor (1885)

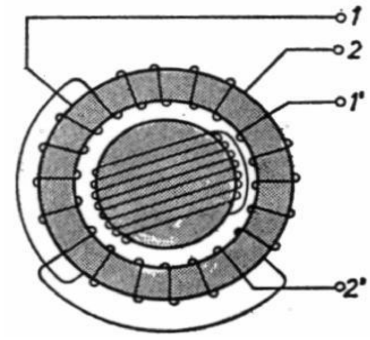


Figure 1.1 Tesla's induction motor (1886)

The motors have been supplied from a two-phase a.c. power source and thus contained two phase concentrated coil windings 1-1' and 2-2' on the ferromagnetic stator core.

In Ferrari's patent the rotor was made of a copper cylinder, in the Tesla's patent the rotor was made of a ferromagnetic cylinder provided with a short-circuited winding.

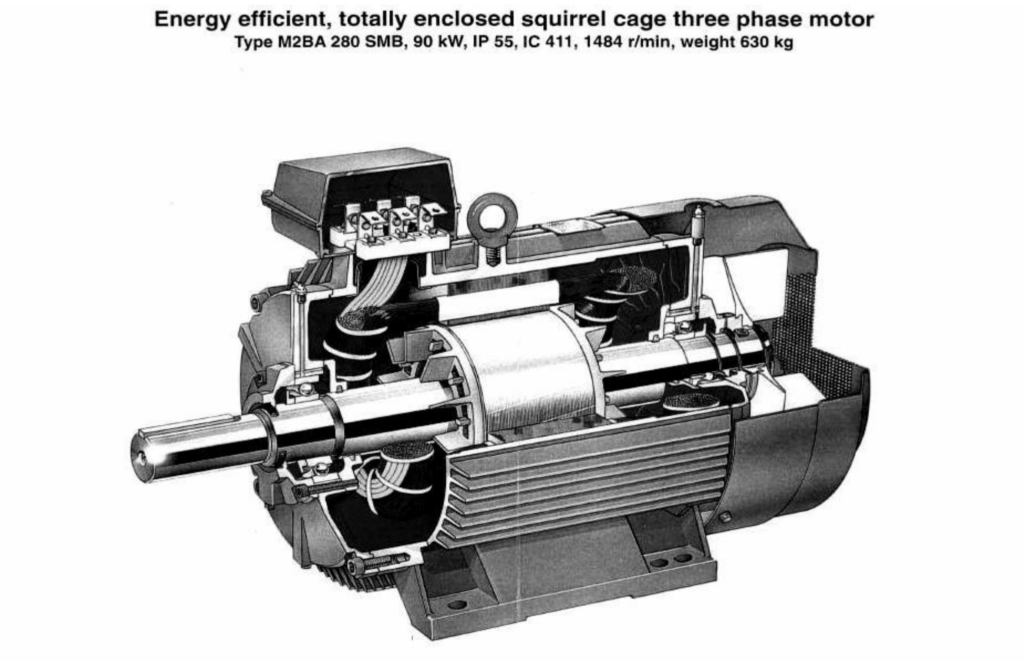
The modern induction motors have more elaborated topologies (Figure 1.1) and their performance is much better, the principle has remained basically the same.

That is, a multiphase a.c. stator winding produces a traveling field which induces voltages that produce currents in the short-circuited (or closed) windings of the rotor. The interaction between the stator produced field and the rotor induced currents produces torque and thus operates the induction motor. As the torque at zero rotor speed is nonzero, the induction motor is self-starting. The three -phase a.c. power grid capable of delivering energy at a distance to induction motors and other consumers has been put forward by Dolivo-Dobrovolsky around 1880.

Dolivo-Dobrovolsky invented the induction motor with the wound rotor in 1889 and subsequently the cage rotor in a topology very similar to that used today. Also invented the double-cage rotor.

That, around 1900 the induction motor was ready for wide industrial use. Before 1910, in Europe, locomotives provided with induction motor propulsion, were capable of delivering 200 km/h.

At least for transportation, the d.c. motor took over all markets until around 1985 when the IGBT PWM inverter was provided for efficient frequency changers. This promoted the induction motor spectacular comeback in variable speed drives with applications in all industries.



Energy efficient, totally enclosed squirrel cage three phase motor

Type M2BA 280 SMB, 90 kW, IP 55, IC 411, 1484 r/min, weight 630 kg

Figure 1.2 A state-of-the-art three-phase induction motor (source ABB motors)

2.1.Types of induction motor:

There are basically two types of induction motor that depend upon the input supply – single-phase induction motor and three-phase induction motor. Single-phase induction motor is not a self-starting motor and three-phase induction motor is a self-starting motor.

2.1.1. Single phase induction motor:

The single-phase induction motor is not self-starting. When the motor is connected to a single-phase power supply, the main winding carries an alternating current. It is logical that the least expensive, most reduced up keep sort engine ought to be utilized most regularly. These are of different types based on their way of starting since these are of not self-starting. Those are split phase, shaded pole and capacitor motors. Again capacitor motors are capacitor start, capacitor run and permanent capacitor motors.

In these types of motors the start winding can have a series capacitor and/or a centrifugal switch. When the supply voltage is applied, current in the main winding lags the supply voltage because of the main winding impedance. And current in the start winding leads/lags the supply voltage depending on the starting mechanism impedance. The angel between the two windings is sufficient phase difference to provide a rotating magnitude field to produce a starting torque. The point when the motor reaches 70% to 80% of synchronous speed, a centrifugal switch on the motor shaft opens and disconnects the starting winding.

Applications of Single-Phase Induction Motor:

These are used in low power applications and widely used in domestic applications as well as industrial. And some of those are mentioned below

- Pumps
- Compressors
- Small fans

Single-Phase Induction Motor types:

- Split phase induction motor (with centrifugal switch);
- Capacitor start induction motor;
- Capacitor start capacitor run induction motor;
- Shaded pole induction motor;

2.1.2. Three-Phase Induction Motor:

These motors are self-starting and use no capacitor, start winding, centrifugal switch or other starting device. Three-phase AC induction motors are widely used in industrial and commercial applications. These are of two types, squirrel cage and slip ring motors. Squirrel cage motors are widely used due to their rugged construction and simple design. Slip ring motors require external resistors to have high starting torque.

Induction motors are used in industry and domestic appliances because these are rugged in construction requiring hardly any maintenance, that they are comparatively cheap, and require supply only to the stator.

Applications of three-phase induction motor:

- Lifts
- Cranes
- Hoists
- Large capacity exhaust fans
- Driving lathe machines
- Crushers
- Oil extracting mills
- Textile and etc.

Three-Phase Induction Motor types:

- Squirrel cage induction motor
- Slip ring induction motor

2.2. Basic working principle of an Induction Motor.

In a DC motor, supply is needed to be given for the stator winding as well as the rotor winding. But in an induction motor only the stator winding is fed with an AC supply.

- Alternating flux is created around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field" (RMF).
- The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, the Faraday's law of electromagnetic induction. The rotor conductors are short circuited, hence rotor current is produced due to induced emf. That is why such motors are called as induction motors. (This action is same as that occurs in transformers, hence induction motors can be called as rotating transformers.)
- The induced current in rotor will also create alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production.
- As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity.

However, the rotor never succeeds in catching up the synchronous speed. This is the basic working principle of induction motor of either type, single phase of three phase.

Synchronous speed:

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$N_s = \frac{60 * f}{P} \text{ (RPM)}$$

(2.1)

where, f = frequency of the supply

P = number of pole pairs

Slip:

Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there won’t be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, and the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

The difference between the synchronous speed (N_s) and actual speed (N) of the rotor is called as slip.

$$\%\text{slip } s = \frac{N_s - N}{N_s} * 100$$

(2.2)

3. Over-current protection.

Over-current protection is that protection in which the relay picks up when the magnitude of current exceeds the pickup level.

The main element in over-current protection is an over-current relay.

The over-current relays are connected to the system, normally by means of CT's, for small power motors direct to supply line.

Over-current relaying has following types:

- High speed Over-current protection.

- Definite time Over-current protection.
- Inverse minimum time Over-current protection.
- Directional Over-current protection (of above types).

Over-current protection includes the protection from overloads. This is more widely used protection. Overloading of a machine or equipment generally means the machine is taking more current than its rated current. So with overloading, there is an associated temperature rise. The permissible temperature rise has a limit based on insulation class of stator winding.

Over-current protection of overloads is provided by thermal relays.

Over-current protection includes short-circuit protection. Short circuits is the earth faults, phase faults or winding faults. Short-circuit currents are usually several times (5 to 20) full load current. So fast fault clearance is always desirable on short-circuits.

When a machine is protected by differential protection, the over-current is provided in addition as a back-up and in some cases to protect the machine from sustained through fault.

Several protective devices are used for over-current protection these include:

- Fuses
- Circuit-breakers fitted with overloaded coils or tripped by over-current relays.
- Series connected trip coils operating switching devices.
- Over-current relays in conjunction with current transformers.
- Winding temperature protection

The primary requirements of over-current protection are:

- The protection should not operate for starting currents, permissible over-current, and current surges. To achieve this, the time delay is provided (in case of inverse relays). If time delay cannot be permitted, high-set instantaneous relaying is used.
- The protection should be coordinated with neighboring over-current protections so as to discriminate.

Applications of Over-current Protection.

Over-current protection has a wide range of applications. It can be applied where there is an abrupt difference between fault current within the protected section and that outside the protected section and these magnitudes are almost constant.

The over-current protection is provided for the following:

3.1. Motor Protection.

Over-current protection is the basic type of protection used against overloads and short-circuits in stator windings of motors. Inverse time and instantaneous phase and ground over-current relays can be employed for motors above 1200 W. For small/medium size motors where cost of CT's and protective relays is not economically justified, thermal relays and HRC fuses are employed, thermal relays used for overload protection and HRC fuses for short-circuit protection.

3.2. Transformer Protection.

Transformers are provided with over-current protection against faults, only, when the cost of differential relaying cannot be justified. However, over-current relays are provided in addition to differential relays to take care of through faults. Temperature indicators and alarms are always provided for large transformers.

Small transformers below 500 kVA installed in distribution system are generally protected by drop-out fuses, as the cost of relays plus circuit-breakers is not generally justified Line Protection.

The lines (feeders) can be protected by

- Instantaneous over-current relays.
- Inverse time over-current relays.

Directional over-current relay.

Lines can be protected by impedance or carrier current protection also.

Protection of Utility Equipment.

The furnaces, industrial installations commercial, industrial and domestic equipment are all provided with over-current protection.

Relays used in Over-current Protection.

The choice of relay for over-current protection depends upon the Time / current characteristic and other features desired. The following relays are used.

- For instantaneous over-current protection. Attracted armature type, moving iron type, permanent magnet moving coil type and static.
- For inverse time characteristic. Electromagnetic induction type, permanent magnet moving coil type and static.

- Directional over-current protection. Double actuating quantity induction relay with directional feature.
- Static over-current relays.
- HRC fuses, drop out fuses, etc. are used in low voltage medium voltage and high voltage distribution systems, generally up to 11 kV.
- Thermal relays are used widely for over-current protection.

3.3. Characteristics of relay units for over current protection.

There is a wide variety of relay-units. These are classified according to their type and characteristics. The major characteristic includes:

- Definite characteristic
- Inverse characteristic
- Extremely Inverse
- Very Inverse

In definite characteristic, the time of operation is almost definite *i.e.*

$$I_0 * T = K \quad (2.3)$$

Where:

I = Current in relay coil
T = Relay lime
K = Constant.

In inverse characteristic, time is inversely proportional to current *i.e.*

$$I_1 * T = K \qquad (2.4)$$

In more inverse characteristic

$$I_n * T = K \, (2.5)$$

The n can be between 2 to 8 the choice depends on discrimination desired.

Instantaneous relays are which have no intentional time lag sod which operate in less than 0.1 second, usually less than 0.08 second.

The relays which are not instantaneous are called Time Delay Relay'. Such relays are provided with delaying means as drag magnet, dash poss. bellows, escape mechanisms, back-stop arrangement, etc.

The operating time of a relay for a particular setting and magnitude actuating quantity can be known from the characteristics supplied by the manufacturer. The typical characteristics are shown in (Fig. 2.6)

An inverse curve is one in which the operating time; becomes less as the magnitude of the actuating quantity is increased. But for higher magnitudes of actuating quantity the time is constant. Definite time curve is the in which operating time is little affected by magnitude of actuating current. However even definite time relay has a characteristic which is slightly inverse.

The characteristic with definite minimum time and of inverse type is called Inverse Definite Minimum Time (IDMT) characteristics (Fig.2.6).

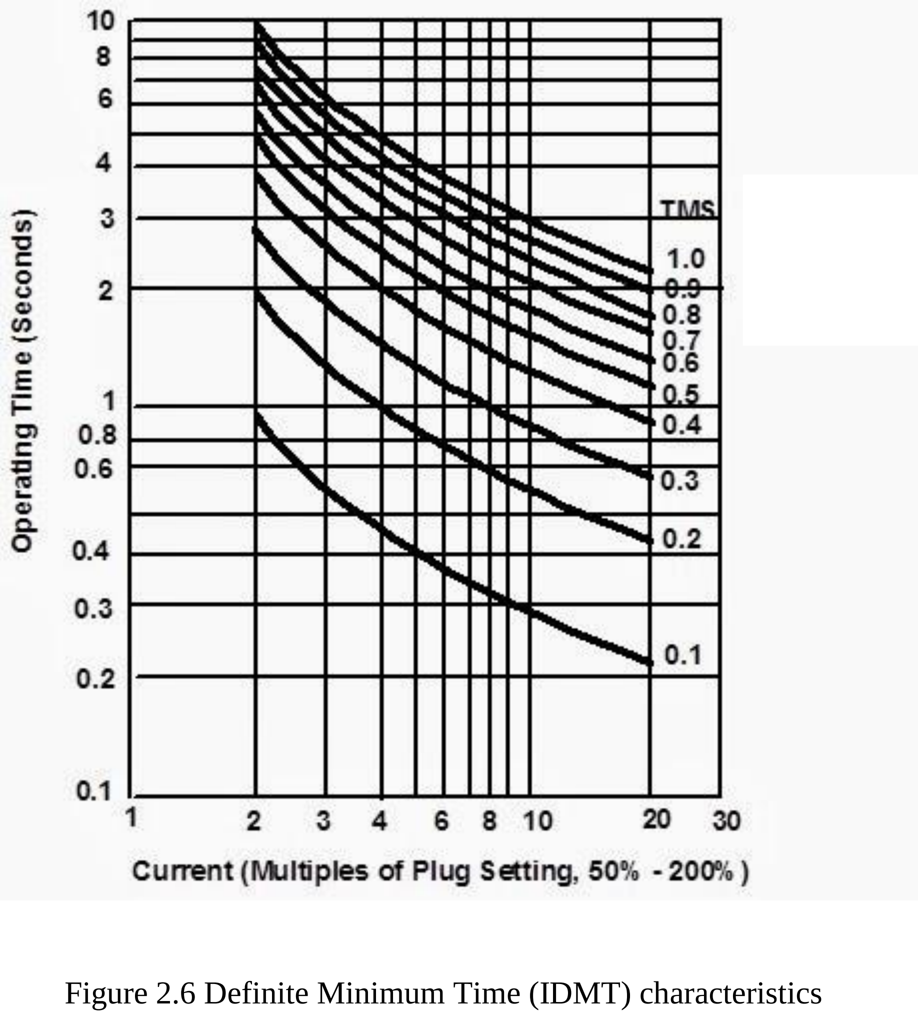


Figure 2.6 Definite Minimum Time (IDMT) characteristics

4. Diagnostic methods used for induction motors protection.

In recent years, condition monitoring as well as fault diagnostics of squirrel cage induction machines received considerable attention from both industry and academe. A number of different techniques that address various types of the most common failures have been developed and implemented. Researchers were able to gain a better insight into the mechanisms of these failures and use this knowledge to both improve the design of the machine itself and develop the means to diagnose machine faults more effectively.

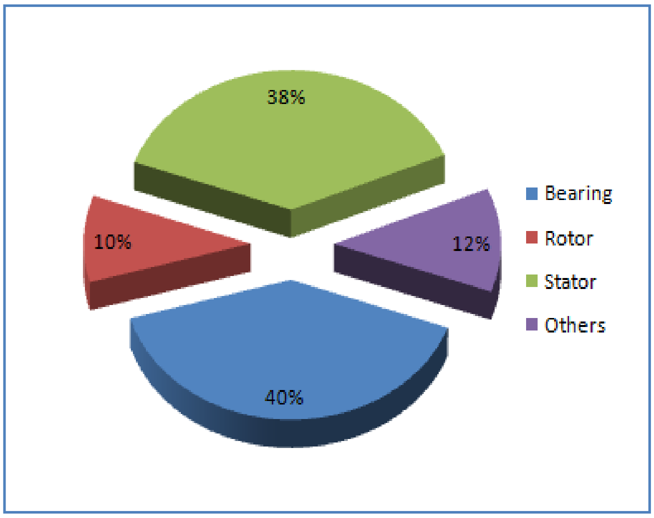


Figure 2.7-Common Faults in Induction Motors

Induction machine failures are commonly divided based on the main machine components, into three main groups, namely, stator, rotor and bearing faults. As can be seen in Figure 2.7, around 40% of faults associated with induction machines are due to bearing failures, whereas faults associated with stator windings account for 38% of induction machine failures, and failures associated with rotors account for approximately 10% of induction machine failures.

These faults produce one or more of the symptoms as follows:

- unbalanced air-gap voltages and line currents
- increased torque pulsations
- decreased average torque
- increased losses and reduction in efficiency
- excessive heating

For the purpose of detecting such fault-related signals, many diagnostic methods have been developed so far. These methods to identify the above faults may involve several different types of fields of science and technology. They can be described as follows:

- motor-current signature analysis (MCSA)
- model, artificial intelligence, and neural-network-based techniques
- noise and vibration monitoring
- chemical analysis
- electromagnetic field monitoring, search coils, coils wound around motor shafts (axial flux-related detection)
- temperature measurements
- infrared recognition
- radio-frequency (RF) emissions monitoring
- acoustic noise measurements

4.1. Temperature measurements

The temperature of a motor winding is measured or monitored by measuring the resistance of the winding. This is done by introducing a small direct current component into the motor current, which can be done by connecting an asymmetric resistance device in the motor circuit. The resistance of the motor winding can then be determined from measurements of the direct current component and the corresponding voltage. This can also be done by using a magnetic amplifier with a bias winding excited in response to the voltage of the asymmetric resistance and a control winding excited by the motor current. A signal or indication can then be obtained when the current falls below a level which indicates a resistance corresponding to an over temperature condition.

$$\mathrm{T_t} = \mathrm{T_c} + \frac{\mathrm{R_h} - \mathrm{R_c}}{\mathrm{R_c} * (\mathrm{T_c} + 234.5)}$$

(2.8)

Where:

T(t) = total winding temperature

T(c) = Cold motor (ambient) temperature, C (The motor should be in the ambient environment long enough to reach that temperature.)

R(h) = Hot motor resistance

R(c) = cold motor resistance

234.5 = constant for copper windings

4.2. Motor-current signature analysis (MCSA).

Motor Current Signature Analysis (MCSA) is a technique used to determine the operating condition of AC induction motors without interrupting production. . MCSA detect the faults at an early stage and avoid the damage and complete failure of the motor. By using MCSA, accurate analysis of fault is possible. An idealized current spectrum is shown in Fig.2.9.

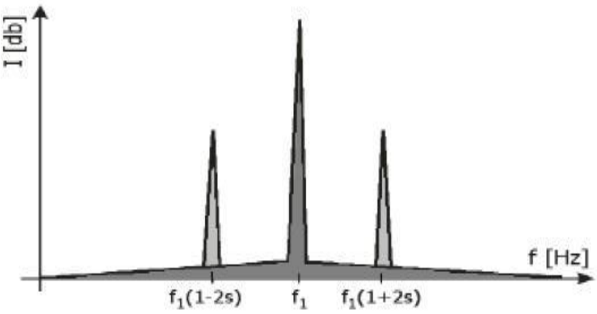


Figure 2.9 An idealized current spectrum.

Usually a decibel (dB) versus frequency spectrum is used in order to give a wide dynamic range and to detect the exclusive current signature patterns that are characteristic of different faults.

The MCSA uses the current spectrum of the machine for locating the fault frequencies. When a fault is present, the spectrum of the line current becomes changed from healthy motor. Motor current signature analysis can diagnose problems such as broken rotor bars, abnormal air gap eccentricity, shorted turns in low voltage stator windings, and certain mechanical problems/drive train.

However, there are some handicaps which may degrade performance and accuracy of this fault diagnosis. The first limitation comes from the stator current sampling and FFT, for example, noisy sensor signals, finite number of samples and finite frequency interval in the FFT. Secondly, the current could be sampled only after the motor reaches steady state. In other words, the variation of the motor may result in fluctuation in stator current frequency spectrum. Last but not least, other unexpected factors could induce ambiguous harmonic frequencies, which will affect the judgment of abnormal harmonics. In light of the shortcomings of MCSA, a considerable amount of research work has been based on advanced signal-processing techniques.

5. Detection methods of arc fault in power networks.

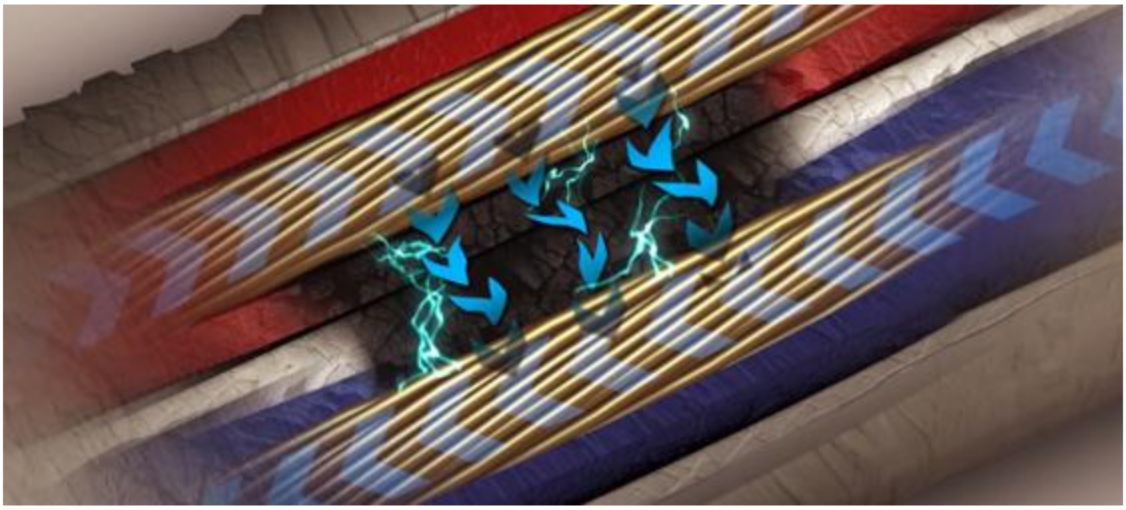


Figure 3 Arc faults.

Arc faults are electrical problems waiting to happen whenever a wire (and its insulation) is cut, pinched, cracked or broken Fig.3. Arcs can occur in damaged or aging wiring present in homes, factories, automobiles, telecommunications installations, or aircraft. Electrical arcs are a major cause of electrical fires in homes and are suspected in some aircraft disasters. Application of power to damaged wires can cause heat build-up and then electrical arcs that can ultimately escalate to fire.

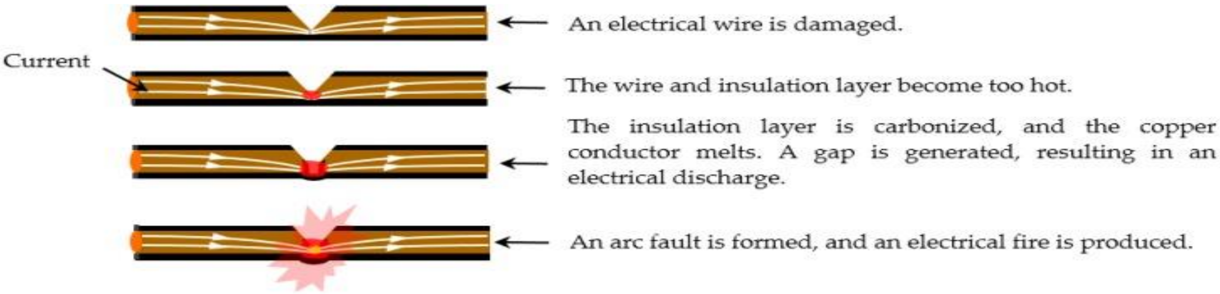


Figure 3.1 An electrical fire resulting from an arc fault

Damaged insulation can expose the copper, giving rise to arcs, shorts and electromagnetic emission and interference Fig. 3.1. Arcing occurs when current flows from the wire through ionized air to another conducting object, such as a second wire or the structure. As wire ages, the insulation becomes brittle and cracks. Vibration can also chafe the insulation as wires vibrate against each other or any hard surface. Maintenance can also be hard on wires, as they may be damaged by workers’ pliers, bent, or sprinkled with metal shavings, chemicals or water. The tiny arcs that happen tend to carbonize the insulation and once enough carbon has built up there can be a large explosive flashover, with exposed wires spewing molten metal.

Arcing faults are high impedance short circuits in power systems. Presently, each circuit is provided with overcurrent protection devices that detect overloads and short circuits. When this overcurrent protection device is properly applied, it might seem that no other form of protection is required. But the networks are usually heavily loaded so that they conduct sufficient current to sustain an arc but remain below the trip threshold of circuit breakers.

5.1. Characterization of chaotic motion in arc faults.

In any electrical system, an arc fault can occur because of a number of reasons. Some of the main reasons that lead to such a fault are insulation aging, loose connections or even accidental damage during routine maintenance. These faults are prone to happen in vehicles the more they're exposed to factors like water, dust, vibration and frequent maintenance.

Furthermore, the probability of occurrence and the intensity of such faults will become greater in the future as the electrical system's power levels keep increasing.

Once it starts sparking, the wire surface will heat up and release conductive material. As an electrical arc is produced and sustained, extremely high pressures are generated in the arc that in turn, will blow hot, ionized gas and particles onto nearby materials that may be flammable. In due course nearby conductors may also get involved and the arc will escalate. According to Paschen's law, the electrical breakdown characteristics of a gap is a function of gas type, gas pressure and gap distance. For air gaps on the order of 1 mm, the relationship is approximately linear and is given by

$$V = (3pd + 1.35)\ \text{kV}. \quad (3.2)$$

where p is air pressure in atmospheres and d is gap distance in mm. So, for air at one atmosphere, a potential of about 4 kV is needed to establish an arc across a one millimeter gap. Even though a high voltage is required to start an arc over a gap of 1 mm, it is easy to create an arc with lower voltage, by separating two charged electrodes. Once the arc is created, it may be sustained by a much lower voltage because it passes through a conductive path of heated plasma where there are many free electrons available for conduction.

5.2. Types of Arc Faults.

An arc fault is a high power discharge of electricity between two or more conductors.

Although the arcing phenomenon remains the same in most cases, the faults can be broadly classified into two categories, namely series faults and parallel faults.

5.2.1. Series Faults.

A series arc can occur when the conductor in series with the load breaks. The series configuration means the arc current cannot be greater than the current drawn by the load the conductor serves. Typically, series arcs don't develop sufficient thermal energy to create a fire. A series arc fault can occur when a current carrying path which is in series with a load is broken. It can also occur when two lines are loosely connected as well as plugging and unplugging connectors under load. In a series fault, the fault current is equal to the system current. In most of the cases a fuse is used to trip the supply when a fault occurs. The fuse is designed to trip when the current exceeds a fixed current rating. But in the case of series faults the current tends to decrease rather than increase, as there is a possibility of the arc to cause an open circuit. As a result of the decrease in the current the fuse never breaks the circuit even when a fault occurs. Figure 3.3 illustrates the circuit with a series arc fault.

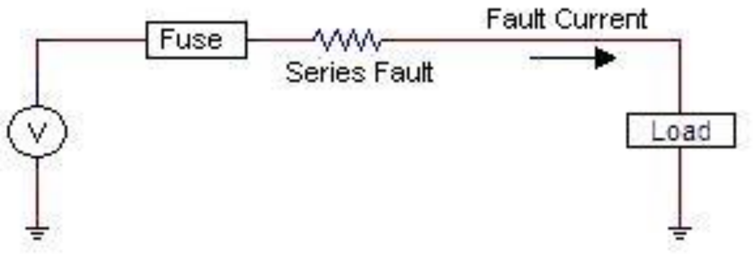


Figure 3.3: A series arc fault situation (fault current is limited by the load)

5.2.2. Parallel Faults.

A parallel arc fault occurs when two distinct conductors, having a different potential, are brought into close proximity or direct contact. A parallel arc fault, which can occur as a short circuit or a ground fault, is more dangerous. A short circuit arc decreases the dielectric strength of insulation separating the conductors, allowing a high-impedance, low-current arc fault to develop that carbonizes the conductor's insulation, further decreasing the dielectric of the insulation separating the conductors. The result is increased current, exponentially increased thermal energy, and the likelihood of a fire. The current flow in a short circuit, parallel arc fault is limited by the system impedance and the impedance of the arc fault itself. Figure 3.4 illustrates the circuit with a parallel arc fault.

Usually the magnitude of the parallel arc current is much higher than the breaker rating. Even though it only flows intermittently, the average current may be sufficient to eventually trip a conventional breaker due to heating of the bimetal strip or the peak current may be large enough to trigger the magnetic sensor.

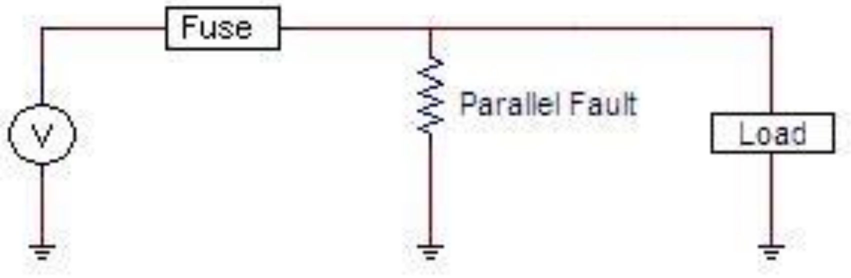


Figure 3.4: A parallel arc fault situation (no current limit by the load)

Therefore, these protection devices cannot be used to protect circuits from arc faults. Moreover, arc faults are often latent, intermittent and transient; thus, one should monitor circuit states in real-time to detect such faults to prevent electrical fires. Hence, an arc fault detector (AFD) represents an urgent need in electrical fire detection.

5.3. Arc fault circuit interrupters.

Arc fault circuit interrupters (AFCIs) represent an important AFD for preventing fires. AFCI was developed to eliminate certain unwanted arcs a potential, electrical fire causes. Electric arcs operate at several thousand degrees Celsius at their center. They also generate a pressure wave that will blow molten metal or burning material from their center on to ignitable materials. Either the high temperature or the materials discharged from the center of the arc can cause a fire. The intent of the AFCI is to detect hazardous arcing and turn off the circuit in order to greatly reduce the potential of fire from an arc.

Since an overcurrent protective device (OCPD), a circuit breaker or fuse, will detect and interrupt an arc above the OCPD characteristic curve, circuits are already protected against these higher current arcs. The AFCI addresses arcs below and to the left of the characteristic curve of an overcurrent protective device. The blue colored area in figure 3.5 represents the unprotected area in which the AFCI detects potentially harmful arcs.

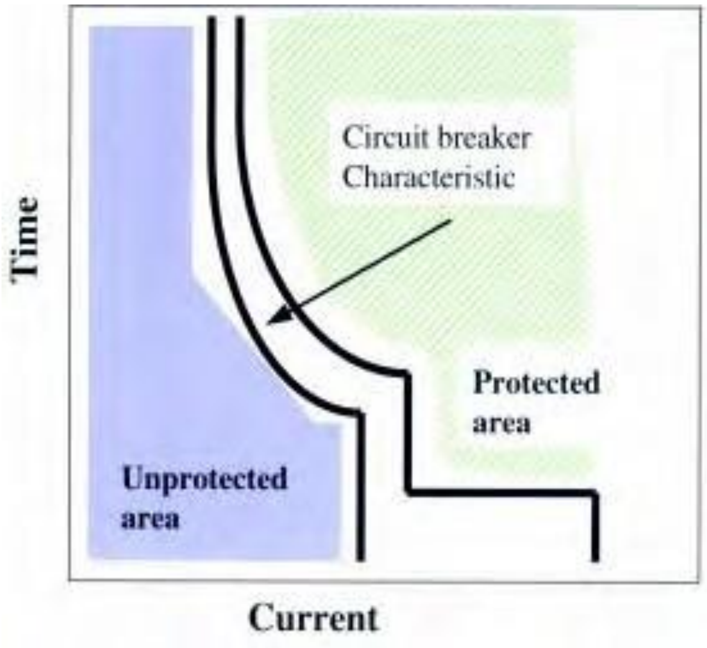


Figure 3.5- Typical time-current characteristic of a circuit breaker

The UL 1699 Standard covers a number of types of AFCI, each to protect against unwanted effects of arcing.

The Branch/Feeder AFCI is a device installed at the origin of a branch circuit or feeder to provide protection of branch circuit and feeder wiring. This device also provides limited protection to appliance and extension cords. The B/F AFCI is available in circuit breaker form today but is not limited to that form.

5.3.1. Types arc fault circuit interrupters.

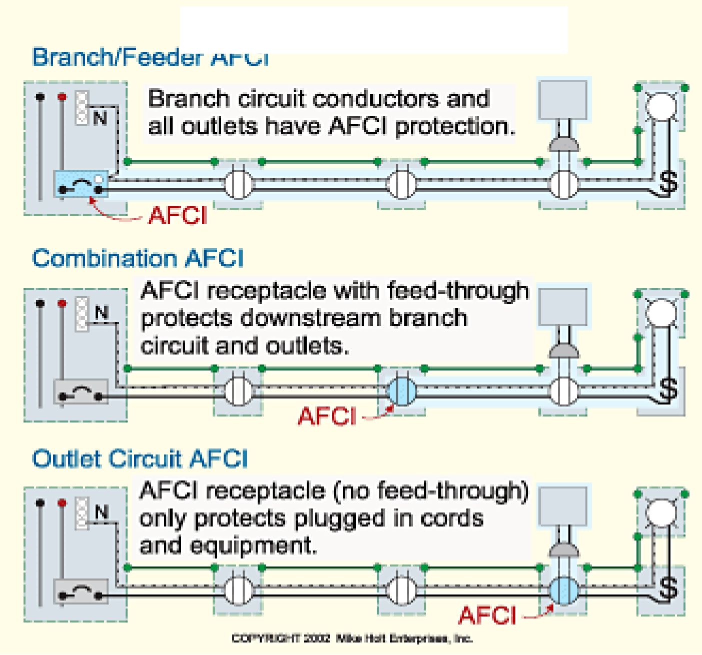


Figure 3.6 Types of AFCI devices

The Outlet Circuit AFCI is a device installed at a branch circuit outlet to provide protection of appliance and extension cords. A likely form is a receptacle outlet. It may provide feed-through protection to cords connected to receptacles on its load side. Fig. 3.6

The Combination AFCI combines the functions of the B/F and OC AFCI in a single device. It is intended to protect branch circuit and feeder wiring and appliance and extension cords.

The Portable AFCI is a plug-in device intended to be connected to a receptacle outlet and which is provided with one or more outlets. It is intended to provide protection to connected appliance and extension cords.

The Cord AFCI is a plug-in device connected to a receptacle outlet, to provide protection to the cord connected to it.

The Standard does not specify the form of any of the types, which will allow them to emerge into the market place as needed for a specific application. This discussion will focus on the B/F AFCI, since it is the type the inspector may expect to see to meet the new National Electrical Code requirement. The B/F AFCI is presently available in the form of a circuit breaker that also incorporates the AFCI function

6. Specify protection methods for low and high power motors.

The protection of electric motors should be simple and reliable, since the use of complex protections is expensive for capital costs and is not justified. For motors with a power of more than 2 MVA, more complex protections can be used, since these engines are usually expensive, or they are used in critical places for the needs of power plants and the mechanisms of industrial enterprises.

Some electric motors for safety and production technology allow only a short-term outage from the network only for the time of switching on the backup power source ABP. If the power is lost, the motors start to brake, but when the backup power source is turned on, the motors are accelerated again, but this happens faster than normal starting from a stationary state, since the motors start to rotate from some initial speed. This mode is called the self-starting mode of electric motors. When mass starting of electric motors when applying voltage from a backup power source, they consume self-starting currents that are greater than the current of their normal operation.

The most common types of motor damage are phase-to-phase short circuits. Single phase stator earth faults are less dangerous as usually electric motors are powered from a network with an isolated neutral (6 ÷ 10kV). The most frequent abnormal mode of operation is over-current, etc.

Motor protection against phase-to-phase faults.

To protect against phase-to-phase short circuits, a current cutoff and differential protection. The current cutoff is recommended for the protection of electric motors with a power of up to 5000 kW if it has the required sensitivity to damages at the terminals. If the sensitivity of the current cutoff is insufficient, differential protection must be used. The use of differential protection is advisable starting from a power (3500 – 4000) kW.

6.1 Specify protection methods for high power motors.

6.1.1 Current cut off.

Current cut-off for motors up to 2000 kW, excluding electric motors of the power plant's own needs, is performed by a single-circuit scheme (figure 3.7-a)

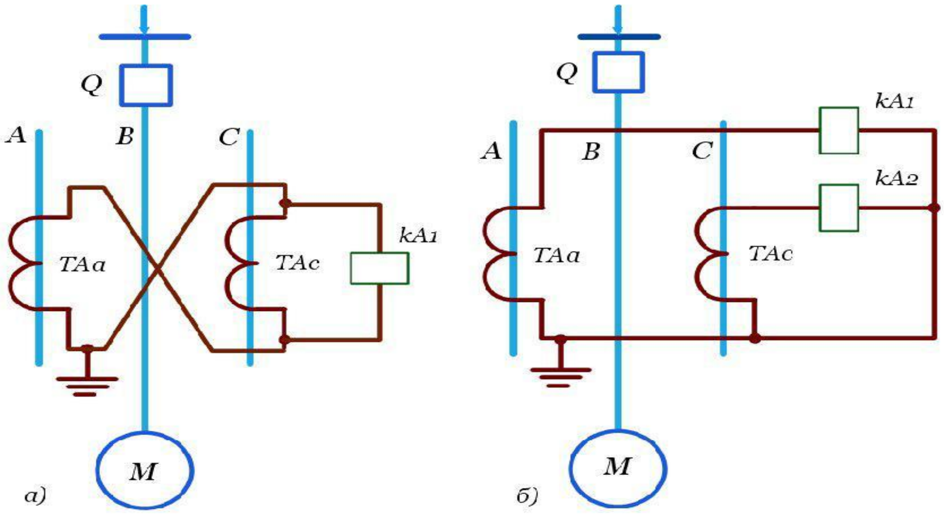


Figure 3.7 Current cutoff scheme:

a - single-relay, b - double-relay

On electric motors with a power (2000-4000 kW), the current cutoff is performed using a two-relay circuit (figure 3.7-b). If the sensitivity factor of a single-circuit circuit is less than two, then a two-circuit scheme should be used on engines up to 2000 kW.

The primary actuation current of the cut-off, which is set on the asynchronous motors, is tuned from the starting current:

$$\mathrm{I_{ac}} = \mathrm{k_r I_{start}} \ (3.8)$$

where $\mathrm{k_r}$ - coefficient of reliability, taking into account the errors of the relay and calculation, depending on the type of relay can take the value of 1.4 to 2; $\mathrm{I_{start}}$ - the starting current of the motor.

The sensitivity of protection is estimated by the current of a two-phase short circuit at the motor terminals in the minimum operating mode of the system.

6.1.2 Differential protection.

On motors with a power of 4000 kW or more, longitudinal differential protection is installed without braking or with braking. To perform protection with braking, the braking is performed from current transformers mounted on the side of the zero terminals of the stator winding.

The protection operation current is selected from the condition of reliable failure in the start-up, self-starting, external short-circuit or non-synchronous synchronous motor switching.

6.1.3 Thermistor relays.

And also for protection of high power motors use thermistor relays. The thermistor protection relay monitors the motors based on the posistors built into the motor winding. The sensors integrated into the motor windings directly measure the degree heating of the motor, which allows to directly monitor and analyze following operating conditions:

- Heavy start
- Frequent on and off
- Single phase operation
- High ambient temperature
- Insufficient cooling
- Braking mode
- Phase asymmetry

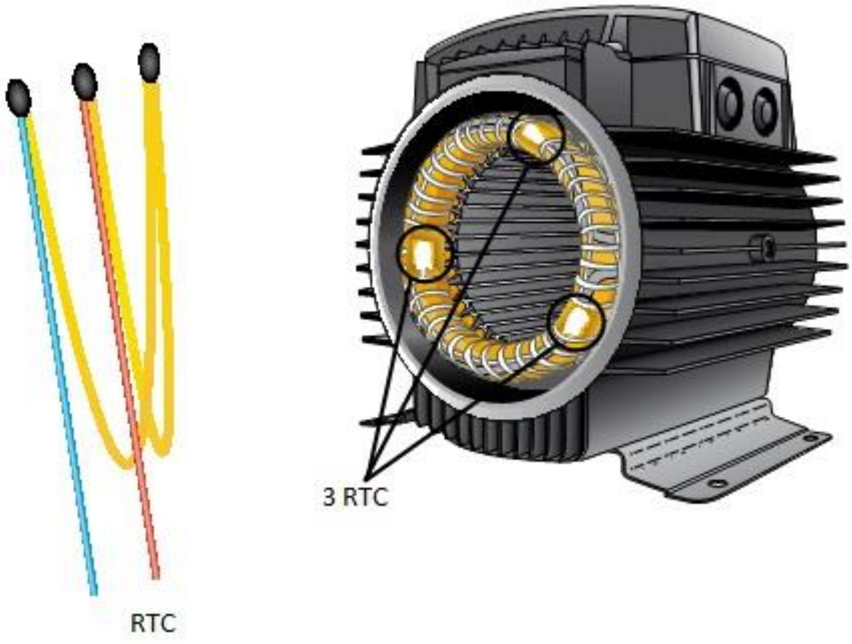


Figure 3.9. RTC

On the front panel of the device there are: a green power-on indicator "U", a yellow indicator of activation of the built-in executive relay "", red indicators "Short-circuit sensors" and "Overheating" for visual analysis of engine emergency conditions. Fig. 3.9

Thermistors are basically divided into two classes:
RTC-type - semiconductor resistors with a positive temperature coefficient of resistance and
NTC-type - semiconductor resistors with a negative temperature coefficient of resistance.

For the protection of electric motors, RTC thermistors are used that have the property of sharply increasing their resistance when a certain characteristic temperature is reached (Figure 4)

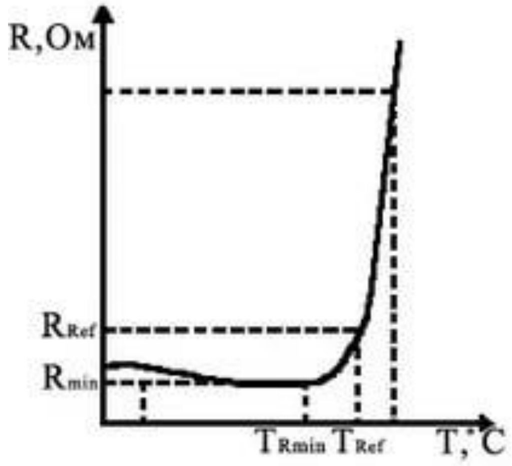


Figure 4 Thermistors temperature characteristic

The thermistor protection relay functions independently of the rated current of the motor, the class of electrical insulating materials and the type of start-up.

Connection of RTC sensors is performed in series, their number is limited by the sum of the resistances of individual resistors to each measured circuit. For example:

$$RG = R1 + R2 + RN \leq 15 \text{ Om} \quad (4.1)$$

The thermistor protection relay is installed in the electrical cabinet, and the sensors installed on the site are connected to the corresponding terminals PT-M01-1-15 by means of electrical wiring. Temperature-dependent protection is preferable in cases where it is not possible to accurately determine the temperature of the motor with sufficient accuracy. This applies in particular to engines with a long start-up period, frequent operations of switching on and off (re-short-time) or motors with a variable speed using frequency converters.

Thermistor protection is also effective in cases of severe engine contamination or forced cooling failure.

The next area of application of thermistor protection is temperature control in transformers, fluids and bearings to protect them from overheating. If the temperature and supply voltage are within normal limits, the contact of the executive relay is closed and the power supply of the electrical installation is switched on.

As sensors use series-connected thermistors (from 1 to 6), located in the temperature control zone. The resistance of the sensors (sensor) is less important at "normal temperature" and greater when the temperature rises (the temperature at which the sensors are installed ... + 70 ° C, + 80 ° C, + 90 ° C, + 100 ° C, + 110 ° C, + 120 ° C ...). When the temperature of the monitored object is normal, the built-in relay is turned on, if one of the sensors is heated at a temperature above the set temperature, the relay is switched off and on when it cools down.

The thermistor relay in combination with the posistors can also be used for temperature control:

- fans of hot air;
- bearings;
- oils;
- air;
- heating plants;
- transformers.

Advantages and disadvantages of thermistor (posistor) protection.

- Thermo sensitive motor protection is preferable in cases where the current can not be determined with sufficient accuracy by the temperature of the motor. This applies, first of all, to electric motors with a long start-up period, frequent operations of switching on and off (short-time operation) or motors with a variable speed (using frequency converters). Thermistor protection is also effective when there is a strong contamination of the motors or the failure of the forced cooling system.
- Thermistor protection is also effective in cases of severe engine contamination or forced cooling failure. The next area of application of thermistor protection is temperature control in transformers, fluids and bearings to protect them from overheating.
- Disadvantages of thermistor protection is that not all types of electric motors are produced with thermistors or posistors. Thermistors and posistors can be installed in electric motors only in the conditions of stationary workshops. The temperature characteristic of the thermistor is rather inertial and strongly depends on the ambient temperature and on the operating conditions of the motor itself.
- Thermistor protection requires the presence of a special electronic unit: a thermistor motor protection device, a thermal or electronic overload relay, in which there are tuning and adjustment units, as well as output electromagnetic relays serving to disconnect the starter coil or electromagnetic release.

6.2. Specify protection methods for low power motors.

For protection of low-power motors use mainly thermal relay and fuses.

6.2.1.1. Thermal relay.

Thermal relay - the most common type of motor protection. The principle of its operation is based on the possibility of an electric current to heat a conductor through which it flows. The main part of the thermal relay is a bimetallic plate. Which, when heated, curves and thus breaks the contact. Heating plate occurs when the current exceeds its permissible value.

Thermal relays are electrical devices designed to protect electric motors from current overload. The most common types of thermal relays are TRP, TRN, RTL and RTT.

6.2.1.1. The operating principle of thermal relays.

The longevity of power equipment in full depends on the overloads to which it is exposed during operation. For any object it is possible to determine the duration of the current flow from its values, provided that they provide reliable and long-term operation of the equipment. This dependence is shown in the figure 4.2 (curve 1).

At the rated current, the permissible duration of its flow is equal to infinity. The flow of current larger than the rated current leads to an additional increase in temperature and additional aging of the insulation. Therefore, the greater the overload, the shorter it is permissible. Curve 1 in the figure is determined based on the required lifetime of the equipment. The shorter his life, the greater the overloads are permissible.

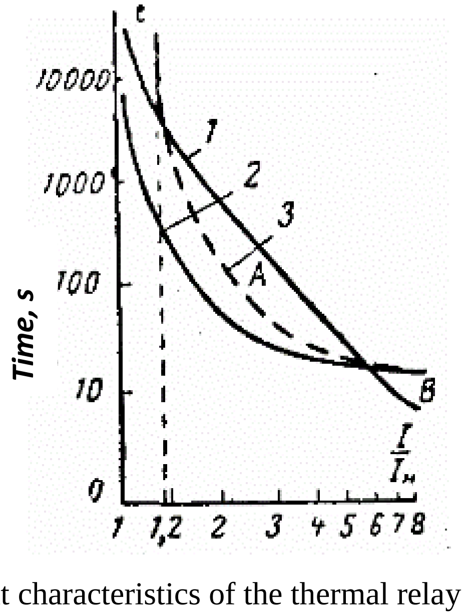


Figure 4.2 Time-current characteristics of the thermal relay and the protected object

With an ideal protection of the object, the tcp (I) dependence for the thermal relay should go a little bit below the curve for the object.

To protect against overloads, the most widely used thermal relays with a bimetallic plate.

The bimetallic plate of the thermal relay consists of two plates, one of which has a larger temperature coefficient of expansion, the other is smaller. In the place of abutment to each other, the plates are rigidly fastened either by rolling in a hot state or by welding. If this plate is fixed and heated, the plate will bend towards the material with a smaller one. It is this phenomenon that is used in thermal relays.

Widely distributed in thermal relays were Invar materials and non-magnetic or chromium-nickel steels.

Heating of the bimetallic element of the thermal relay can be made by the heat generated in the plate by the current of the load. Very often bimetal heating is carried out from a special heater, through which the load current flows. The best characteristics are obtained with combined heating, when the plate is heated and due to the heat generated by the current passing through the bimetal, and due to the heat generated by the special heater, also streamlined by the load current.

Bending, the bimetallic plate with its free end acts on the contact system of the thermal relay. Fig. 4.3

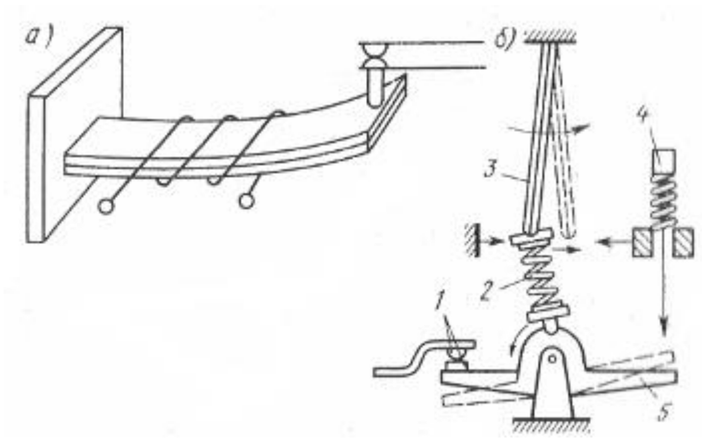


Figure 4.3 Thermal relay: a - sensor, b - bouncing contact,
1 - contacts, 2 - spring, 3 - bimetallic plate,
4 – button , 5 – bridge.

6.2.1.2 Time-current characteristics of a thermal relay

- The main characteristic of the thermal relay is the dependence of the response time on the load current (time characteristic). In general, before the start of the overload, a current Io flows through the relay, which heats the plate to a temperature of qo.

- When checking the time characteristics of thermal relays, it is necessary to consider from which state (cold or superheated) the relay trips.
- When checking thermal relays, it must be borne in mind that the heating elements of thermal relays are thermally unstable at short-circuit currents.

6.2.1.3. Selection of thermal relays.

The rated current of the thermal relay is selected based on the nominal load of the motor. The selected current of the thermal relay is (1,2 - 1,3) the rated current of the motor (load current), i.e. the thermal relay operates at 20-30% overload for 20 minutes.

The time constant for heating the motor depends on the duration of the current overload. During short-term overload in heating, only the winding of the electric motor and the heating constant take 5-10 minutes. With a long overload in the heating, the entire mass of the electric motor participates and is constant heating 40-60 minutes. Therefore, the use of thermal relays is only advisable if the switching time is longer than 30 minutes.

6.2.1.4. Effect of ambient temperature on the operation of a thermal relay.

The heating of the bimetallic plate of the thermal relay depends on the ambient temperature, therefore, as the ambient temperature rises, the relay tripping current decreases.

At a temperature very different from the nominal, it is necessary either to carry out an additional (smooth) adjustment of the thermal relay, or to select the heating element taking into account the actual ambient temperature.

In order for the ambient temperature to be less affected by the thermal relay tripping current, it is necessary that the operating temperature be selected as much as possible.

For correct operation of the thermal protection of the relay, it is desirable to locate the relay in the same room as the protected object. It is impossible to locate the relay near concentrated heat sources - heating furnaces, heating systems, etc. Currently, relays with temperature compensation (TPN series) are manufactured.

6.2.1.5. Devices and operation of an electro thermal relay.

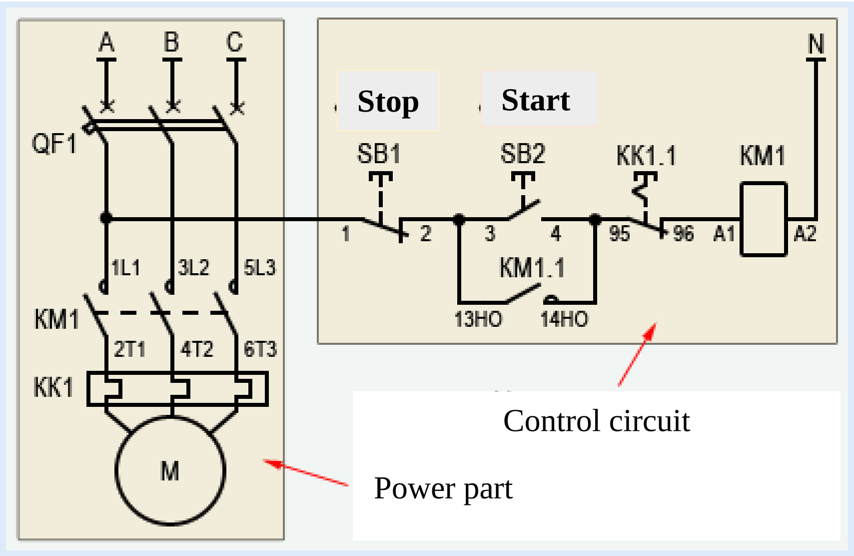
Electrothermal relay works in conjunction with a magnetic starter.

Inside the thermal relay there are three bimetallic plates, each of which is welded from two metals having different coefficient of thermal expansion. Plates through a common "rocker" interact with the mechanism of the mobile system, which is associated with additional contacts involved in the motor protection scheme:

- Normally-closed NC (95 - 96) is used in starter control circuits;
- Normally-open NO (97 - 98) is used in signaling circuits.

The operating principle of the thermal relay is based on the deformation of a bimetallic plate when it is heated by a passing current.

For example, consider the scheme in which a three-phase motor rotates in one direction and the activation control is carried out from one place by two buttons STOP and START (Fig. 4.4)



Control circuit

Power part

Figure 4.4 Connection scheme 3-phase motor with magnetic starter and thermal relay

In the circuit with the thermal relay, a normally-closed contact of the relay KK1.1 in the control circuit of the starter is used, and three power contacts KK1, through which the power is supplied to the motor.

When the circuit-breaker QF1 is switched on, the “A” phase, supplying the control circuit, via the SB1 button “Stop” goes to the contact No. 3 of the SB2 “Start” button, the auxiliary contact 13 of the starter KM1, and remains on duty at these contacts. The circuit is ready for operation.

When the button SB2 is pressed, the phase through the normally-closed contact KK1 goes to the coil of the magnetic starter KM1, the starter trips and all its normally open contacts are closed, and normally-closed contacts are opened.

When the button SB2 is pressed, the phase through the normally-closed contact KK1 goes to the coil of the magnetic starter KM1, the starter trips and all its normally open contacts are closed, and normally-closed contacts are opened.

When the button SB2 is pressed, the phase through the normally-closed contact KK1 goes to the coil of the magnetic starter KM1, the starter trips and all its normally open contacts are closed, and normally-closed contacts are opened.

Disadvantages of simple thermal relays.

Three-phase thermal relays are more versatile, they monitor currents in all three phases, and are applicable for single-phase circuits, for AC and DC.

But if the phases are heavily asymmetric? Then the temperature of one of the phases will increase more rapidly, and the equipment is dangerously overheated, since the current value of the current of the three phases will not reveal the danger. As a result, the tripping time and the critical current of the thermal relay setpoint will actually be lower than the actual position.

To solve the problem more quickly, the thermal relay is more sophisticated, with integrated protection against current asymmetry in phases. In such relays, in the case of a skew or phase loss, the time and the operating current will change accordingly, and the protection will still remain reliable.

Usually thermal relays are made on the basis of bimetallic disconnectors. The plate is bent when heated by current, and drives the release mechanism, the relay is triggered – switches to the “off” state. When the plate has cooled, the mechanism will return to the initial “on” state. The simplicity of the design of conventional relays is captivating with low cost and good noise immunity.

Thermal relays are simple in design and inexpensive. Their disadvantage is the instability of their characteristics over time, so the thermal relays need to be periodically adjusted.

Thermal relays should not be used to protect motors with a power exceeding 10 kW, the windings of which are connected in a triangle. At a load of 65% of the nominal and with a break in one of the phases, the current in the linear wires increases to 117%, and in the most loaded phase – up to 144%. The probability of an electric motor outage increases.

But for more sophisticated equipment, more accurate thermal relays are required – electronic relays.

6.2.1.6. Electronic thermal relays.

Electronic non-volatile heat relays, such as the Siemens series 3RB20 and 3RB21, are equipped with built-in current measurement systems up to 630 A. These relays are current-sensitive, and are able to protect loads in any mode, even with a heavy start, and with phase break or unbalance.

When current is overloaded, if one phase is broken or if it is skewed, the current, for example in the motor, increases and becomes higher than the set point. The integrated current transformer registers the current, and the electronics processes the current value, and if it exceeds the set point, the tripping pulse is transmitted to a switch that disconnects the load by breaking the external contactor. The relay itself is mounted on the contactor. The decoupling time is strictly related to the ratio of the tripping current and the setpoint current.

The Siemens 3RB21 electronic thermal relay can not only protect against overheating due to phase asymmetry, overcurrent or phase failure, it also has an internal ground fault detection system (except for star-delta combinations). For example, incomplete ground faults due to damage to insulation or humidity will be instantly fixed and the load circuit will open.

When the relay is activated, the indicator on the tripping state will light up. There is an option to automatically reset or reset manually. Automatic reset occurs after a certain time, after which the relay closes the contactor again.

6.2.2. Fuses.

Fuses are the simplest and most common protection device. The purpose of the fuses is to disconnect the consumer (part of the lighting system, engine, etc.) from the mains with an unacceptably high overload or short circuit. At the same time, a large amount of heat melts the fusible insert of the fuse and thus breaks the electrical circuit. Being the most common protective devices, fuses at the same time are very imperfect. Fuses have a relatively small limiting-breaking capacity. To protect low-voltage electrical installations, fuses of series PRS and PN.

The fuses of the PRS series are manufactured for rated currents of 6, 20, 63 and 100 A. Fuse links have a more fractional scale of rated currents: 1, 2, 4, 6, 10, 16, 20, 25, 40, 63, 80 and 100 A. The following requirements are imposed on the protective characteristics of fusible inserts. With a nominal current of 1.3, it should not melt for 1 hour, and at a current of 1.6 rated during the same time it should melt. Consequently, current overloads of 30% or less by fusible inserts are not disconnected, and with respect to overloads of 30 to 60% nothing definite can be said. And only with overloads of 60% or more, the fuse-link fires in less than 1 hour. If we require that the fuse-link burns with small overloads, then at the rated current it will be heated to a state close to melting. This will lead to a rapid oxidation of the material and subsequently to combustion at a rated current. It should also be borne in mind a significant variance in characteristics due to the unequal cross-sectional area of the insert, the heterogeneity of the material, and other factors.

Fuses PN-2 have a closed cartridge, filled with filler (fine purified quartz sand). The purpose of the filler is to accelerate the cooling and rupture of the electric arc that occurs when the chain is broken at the moment of combustion of the fuse-link. Better cooling allows you to reduce the dimensions of the cartridge. Fuse links of fuses PN-2 are made of copper wire or thin copper tape. In the middle part, a tin ball is soldered. When heated, tin melts first and copper dissolves. Due to this, the wire burns out at lower currents. This improves its protective characteristic.

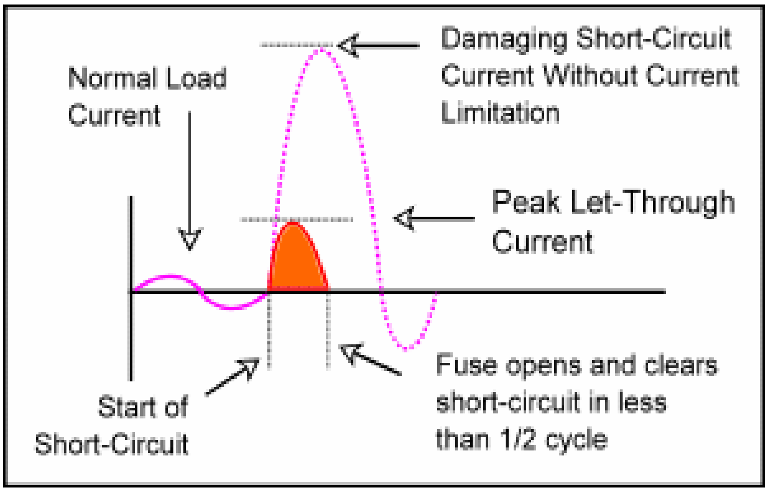


Figure 4.5 Characteristic of current disconnection by a fuse-link

Fusible inserts in the circuits of short-circuited motors are selected according to the working current and checked by starting. By the first condition

$$I_B \geq I_{r.d}; \quad (4.6)$$

Where $I_{r.d}$ is the rated current of the motor; I_B - rated current of the fuse-link; On the second condition:

$$I_B \geq \frac{I_s}{2.5}; \quad (4.7)$$

where I_s is the starting current of the motor.

The above expression is suitable for engines, the acceleration of which lasts no more than 5-10 seconds (normal starting conditions).

The incubation lasts for 30-40 seconds (severe starting conditions) the selection of the fuse current is made from the condition

$$I_B \geq \frac{I_s}{1{,}6+2}; \quad (4.8)$$

Fuses are cork, plate and tubular. Cork fuses are manufactured for voltage up to 500 V and for currents from 2 to 60 A and are used to protect lighting networks and low-power electric motors.

Plate-type fuses, which have great disadvantages (splashing of the insert metal in the event of a burn-out, difficulty of replacing them), are currently not being used.

Tubular low voltage fuses are manufactured for voltage up to 500 V and for currents from 6 to 1000 A. Design tubular fuses can be made with an open porcelain tube and with a closed glass, fiber or porcelain tube. Pipes with fused inserts passed through them are often covered with quartz sand (type PN - fuse bulk). When the fuse blows, the sand breaks the arc into a series of small arcs, cools the arc well and it quickly goes out.

6.2.2.1. Material of fuse links of fuses.

Fusible inserts are made of copper, zinc, lead or silver. In modern advanced fuses, preference is given to copper inserts with a tin solvent. Zinc inserts are also widely used.

Copper inserts for fuses are most convenient, simple and cheap.Improvement of their characteristics is achieved by fusing a tin bulb.In a certain place, around the middle of the insert. Such inserts are used, for example, in the mentioned series of bulk fuses PN2. The tin melts at a temperature of 232 °, much less than the melting point of copper, and dissolves the copper of the insert at the point of contact with it. The arc that appears at this point already melts the entire insert and is extinguished. The current circuit is turned off.

6.2.2.2. Advantages of fuses.

1. The fuse blown time depends on the current passing through the thread. So, with a short circuit, when the current is very high, the fuses burn out quickly enough, and in this most dangerous case they are simple, cheap and reliable.

2. In most fuses, fuses can be safely replaced by a fuse-link under voltage.

7. Laboratory work on disconnecting characteristics of the overcurrent protection relay.

How I explained earlier the overcurrent protection operates when the current of the protected element increases beyond the set pickup current. Also the overcurrent protection is the simplest and cheapest protection and is therefore widely used for the protection of generators, transformers, electric motors.So I would like to show in my thesis this method protection. This laboratory work the disconnecting characteristics of the overcurrent protection relay will give basic characteristic of the operation the relay.

The task of the measurement:

1. Measure „ warm 1" time-current characteristic Tv1=f(I) of the overcurrent protection relay from the starting temperature delta theta 20 K. (equal υ ambient + 20 K)

2. Measure „ warm 2" time-current characteristic Tv2=f(I) of the overcurrent protection relay from the starting temperature delta theta 30 K. (equal υ ambient + 30 K)

3. Plot both characteristics and compare their differences.

Measurement current response: 1,5 – 10 A
Tv1, Tv2 corresponding to disconnecting times.

Measurement instruments

1. Testing bench with tested overcurrent relay and control circuits
2. Supply insulating transformer 230/24 V
3. Loading resistors Rz

Schematic diagram of the testing circuit

„High current“ part of the testing bench

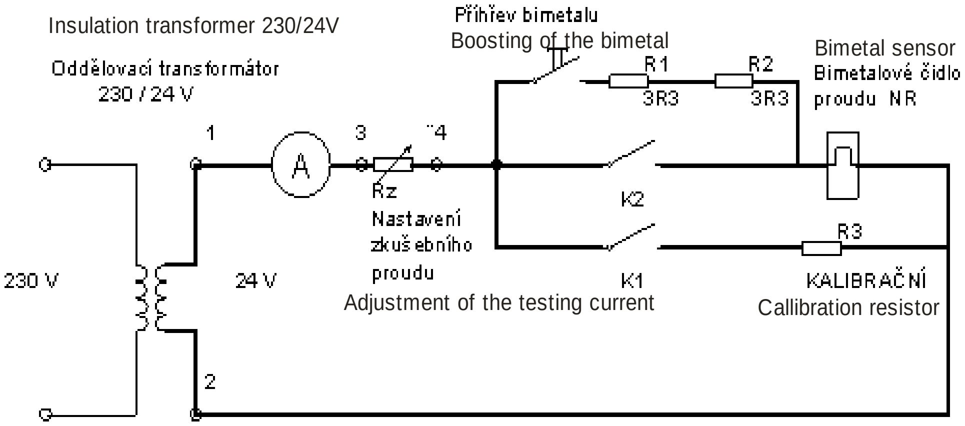


Fig. 1 Schematic diagram of the “high current” part of the testing bench

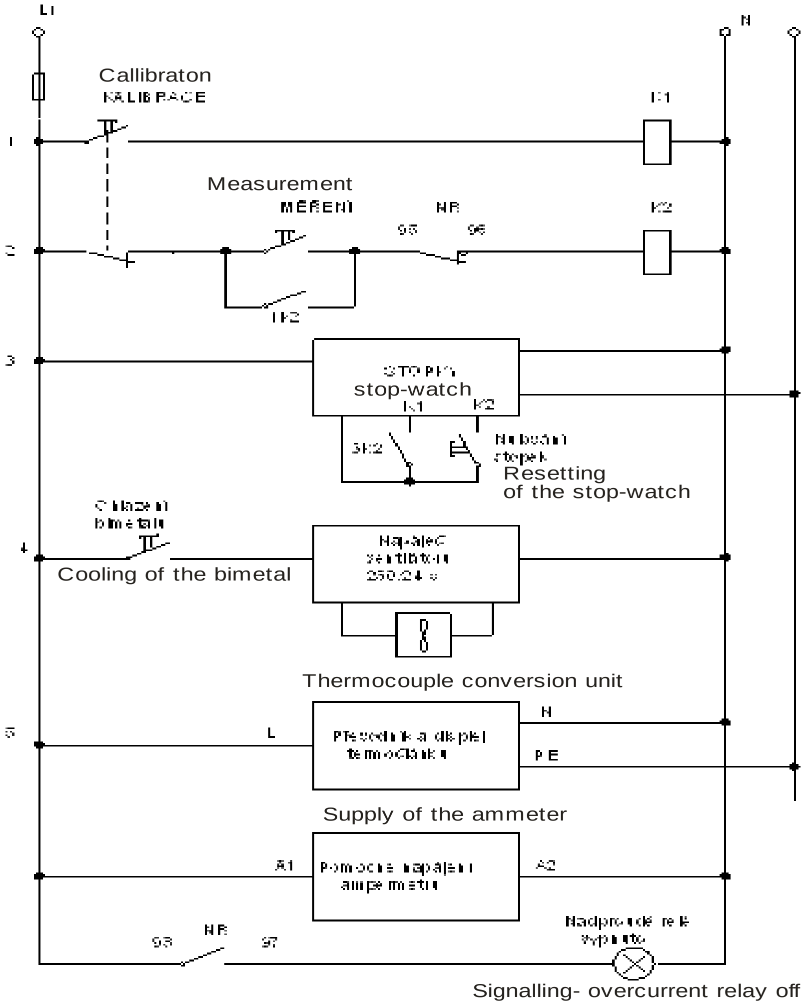


Fig.2 Schematic diagram of the testing bench controlling part

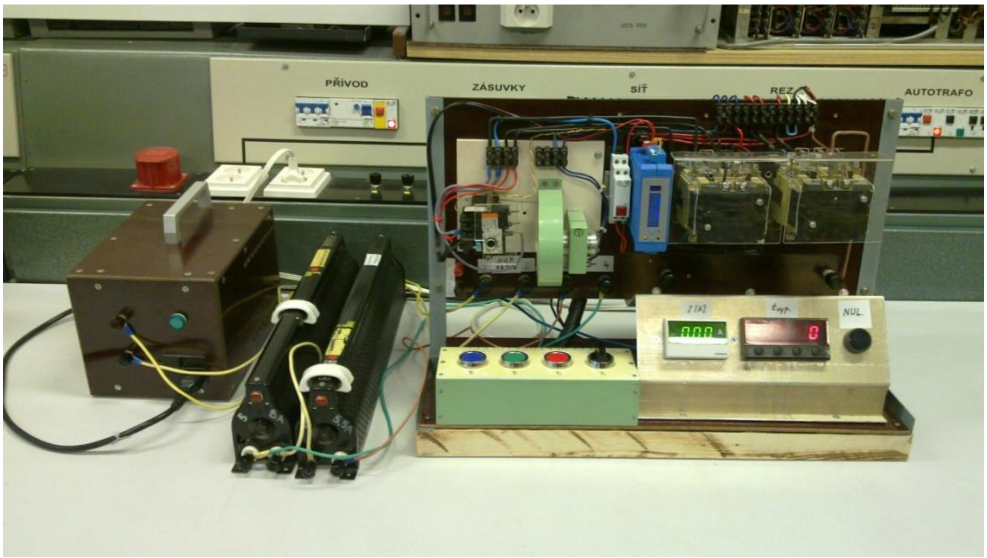


Fig.3 View of the complete testing bench for overcurrent protection relay measurement

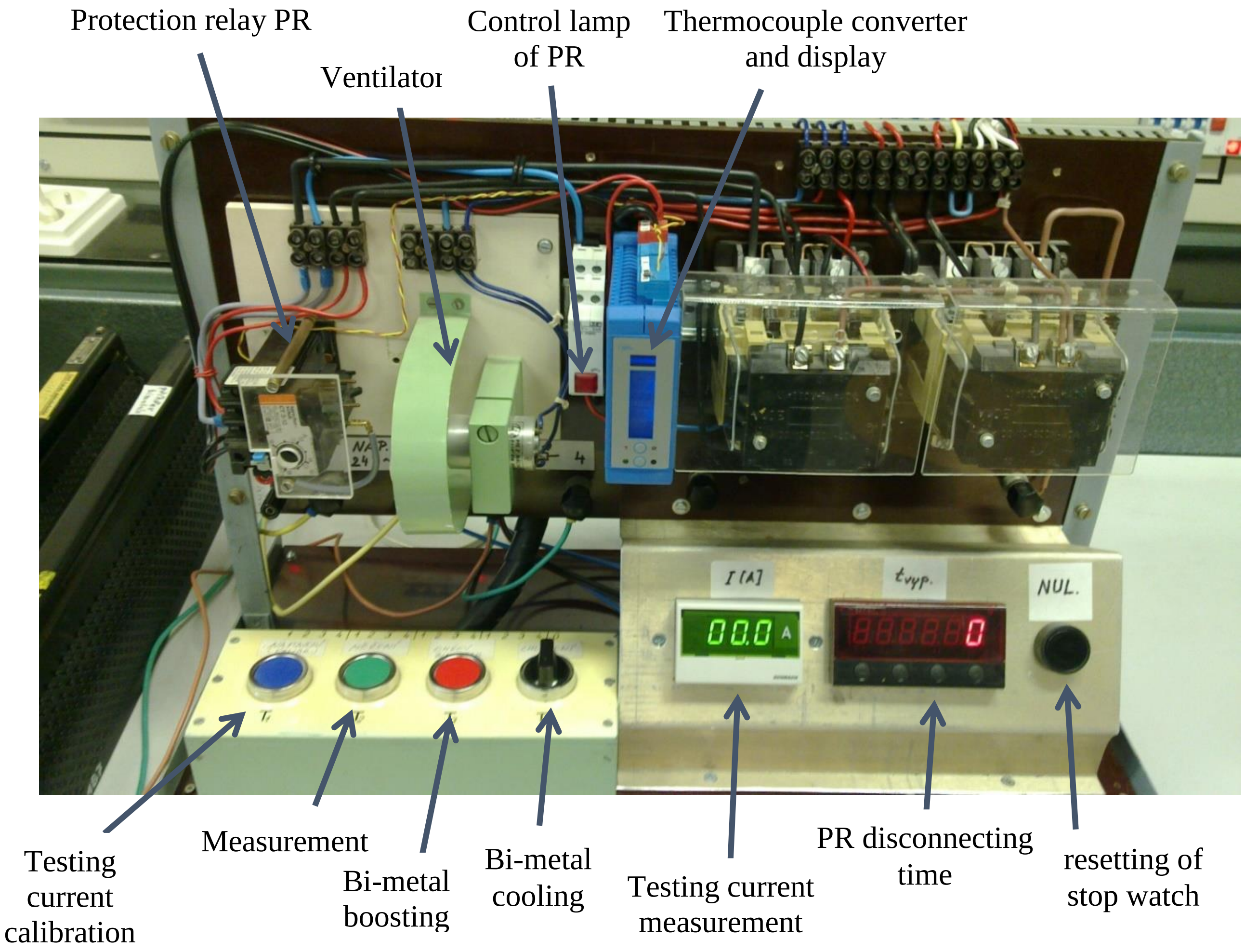


Fig.4 Detail view of the testing bench with description of construction elements.

The plot of the characteristics

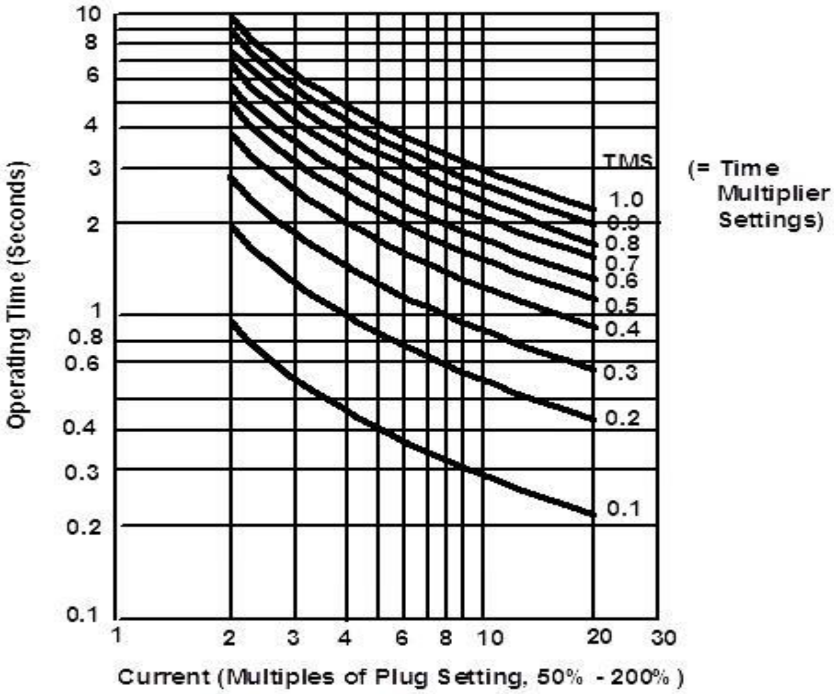


Figure 5 Definite Minimum Time (IDMT) characteristics

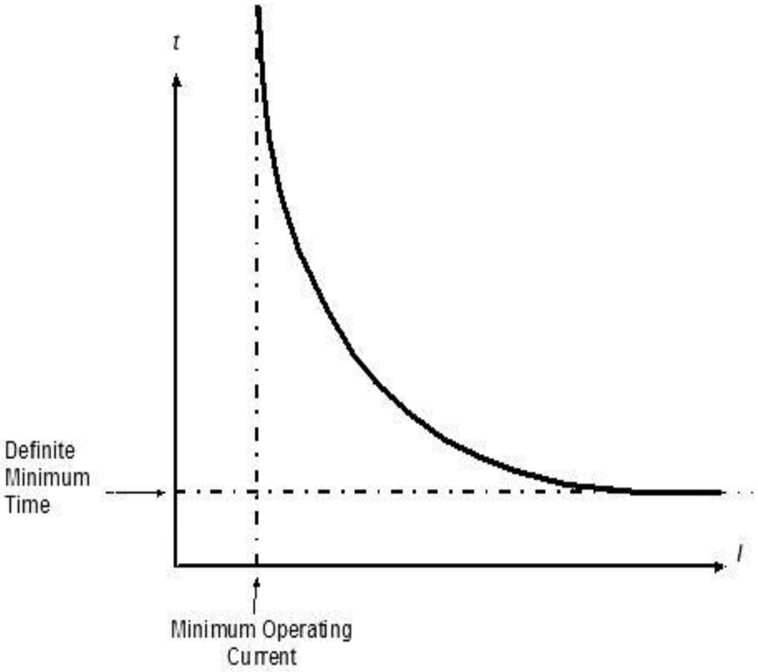


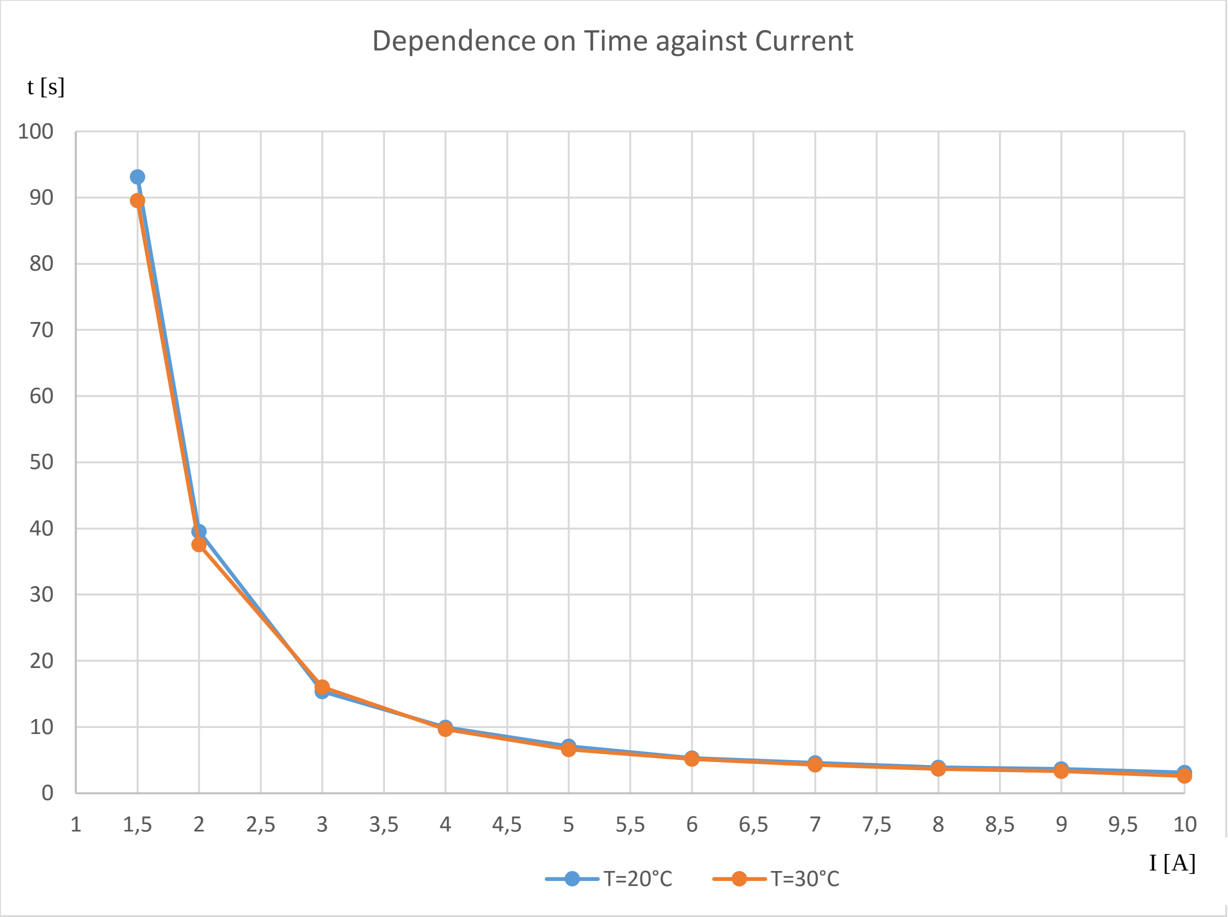
Fig.6 The plots of the characteristics according to theory

Obtained data

I [A]	t [s] for T=20°C
1,5	93,14
2	39,57
3	15,38
4	9,94
5	7,09
6	5,29
7	4,56
8	3,92
9	3,65
10	3,13

I [A]	T [s] for 30°C
1,5	89,57
2	37,57
3	16,04
4	9,65
5	6,61
6	5,15
7	4,3
8	3,64
9	3,31
10	2,6

Graphs



8. Conclusion:

In my thesis I wrote basic information about protection of induction machine. In the first I explained what the induction motor is , how it works and how it is constructed. I started theoretical principles and I explained what kind of damage there are and what methods of protection apply. Protection of induction machine is important for long use motor. So I did measurement and determined characteristics relay overcurrent protection when it is disconnected.

In the laboratory work I measured in two temperature 20°C and 30°C. As we can see in the graph the disconnecting characteristics time-current in this two difference temperature was different.The minimum operation current in two temperature was same 1.5 A. In the temperature 30°C was the quickly disconnected than temperature 20°C. Because in the temperature 30°C the bimetallic plate is very fast heated. So it is disconnected very quickly and the disconnecting minimum time was 2,6 s. The temperature 20°C the disconnection was slowly and the minimum time was 3,13 s. The process of heating was longer to the 0.53 s.than temperature 30°C.

Comparing the plot from the theory and the plot, which was obtained, we realize that we took the measurements properly. Also, the graph has the exponential dependence between operating time and current. The closer the current to 1 Amp, the closer the operating time to infinity.

References:

1. http://www.edisontechcenter.org/inductionMotors.html;
2. Dr. Yaduvir Singh and Mandhir Verma, 2010“Fundamentals of Electrical Engineering”;
3. http://www.teslasociety.com/strasbourg.htm;
4. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1454598;
5. http://197.14.51.10:81/pmb/ELECTRONIQUE/The%20Induction%20Machine%20Handbook%20-%200849300045/0004_PDF_C01.pdf;
6. http://www.electricaleasy.com/2014/02/working-principle-and-types-of.html;
7. http://static.schneider-electric.us/docs/Circuit%20Protection/0600DB0301.pdf;
8. http://www.electrical4u.com/over-current-relay-working-principle-types/;
9. http://www.sayedsaad.com/Protection/files/Over_current/1_Overcurrent.htm;
10. http://www.maintenancetechnology.com/2004/07/temperature-monitoring-is-key-to-motor-reliability/;
11. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1547550;
12. https://bib.irb.hr/datoteka/779323.2_Brief_Review_of_Motor_Current_Signature_Analysis.pdf;
13. http://www.reliableplant.com/Read/28633/motor-current-signature-analysis;
14. http://www.naun.org/main/UPress/saed/saed-5.pdf;
15. http://ecmweb.com/content/basics-arc-fault-protection;
16. http://www.afcisafety.org/qa.html;
17. http://www.electrical-installation.org/enwiki/Arc_Fault_Detection_Devices_(AFDD);
18. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4851014/;
19. http://electricalschool.info/main/elsnabg/781-tokovaja-otsechka.html;
20. http://www.ceerelays.co.uk/brochures/CEE%20PRAG.pdf;
21. http://rza.org.ua/rza/read/7-9--Tokovaya-otsechka_46.html;
22. http://enargys.ru/tokovaya-otsechka-shema-printsip-deystviya/;
23. http://www.aes.pp.ua/5.htm;
24. http://meandr.ru/rele-zashhity-ehlektrodvigatelej-rt-m01-1-15;
25. http://www.electrocentr.com.ua/products/motor-control/protection-relays/tesys-lt.html;
26. http://www.sovras.com/images/File/relay_electricmotor.pdf;
27. http://circuitglobe.com/thermal-relay.html;
28. https://books.google.cz/books?id=mW3LBQAAQBAJ&pg=PA317&lpg=PA317&dq=Thermal+relay&source=bl&ots=ZPSFr3ZZl2&sig=2Xq6O3Qqc4L_Iboo3kOesT1e

DFg&hl=ru&sa=X&ved=0ahUKEwjR7aewy_HTAhWsFJoKHW5ADxc4HhDoAQgnMAE#v=onepage&q=Thermal%20relay&f=false;

29. http://zametkielectrika.ru/teplovoe-rele-ustrojstvo-sxema-podklyucheniya/;
30. http://elektrica.info/ustrojstvo-i-printsip-dejstviya-teplovogo-rele/;