

Three-phase systems under control

Multi and single functional devices for the monitoring of individual system parameters

The availability of electrical installations has meanwhile become a crucial factor for successful manufacturing where just-in-time production is the key, because downtimes often result in excessive extra cost. It is both useful and important to monitor three-phase systems. This can be implemented with minimal effort, making equipment and processes safer, preventing damage and effectively helping to save cost. **MATTHIAS ESCHLE, RAPHAELA MÖHRER**

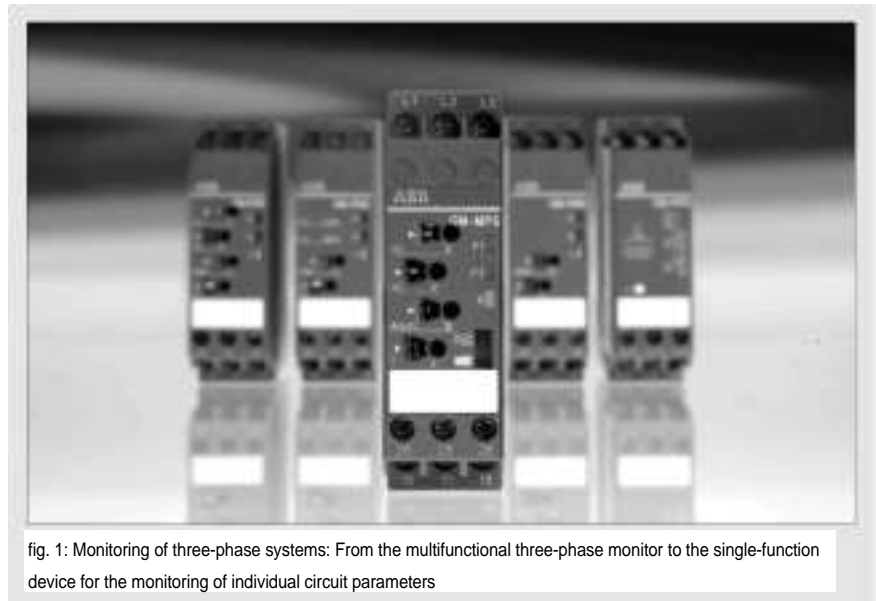


fig. 1: Monitoring of three-phase systems: From the multifunctional three-phase monitor to the single-function device for the monitoring of individual circuit parameters

Since long, industrial users have identified the benefits of three-phase supply systems: more than any other existing system type, they are suitable for the generation, transport and practical application of electrical energy. Three-phase AC is e.g. used as it allows highly economic transport of high currents and simply designed, robust and efficiently working electric motors.

The most common types of connection in three-phase systems are the star connection and the delta connection. In a star connection, the three phases of the three-phase system are interconnected at the star point, which is also connected to the neutral connector. This design allows

the collection of two different voltages: In Germany, the voltage between one of the three phases and the neutral conductor is usually 230 V (r.m.s.); the voltage between two phases is $\sqrt{3}$ times this value, i.e. 400 V (fig. 2). In delta connections, the three phases are connected in series. The voltage between any of the points u1, v1 and w1 is 400 V. No neutral is necessary (fig. 3).

Parameters of the Three-Phase System

To ensure a fault-free supply of power, three-phase systems are monitored with respect to various parameters. To do so, three-phase monitoring relays (single-function or multifunctional) can be used. The following parameters are tested:

- Phase sequence: The phase sequence determines the rotational direction of a motor. An incorrect phase sequence when switching on a device leads to an incorrect rotational direction. The reversal of the phase sequence during operation causes the rotational direction of the motor to change, too.

In both cases, safety-relevant incidents may occur and destroy the connected motor / plant. Timely detection of phase sequence errors is therefore particularly important in the case of machinery that includes rotating and movable parts, pumps and spindle drives as well as portable loads, e.g. construction machinery.

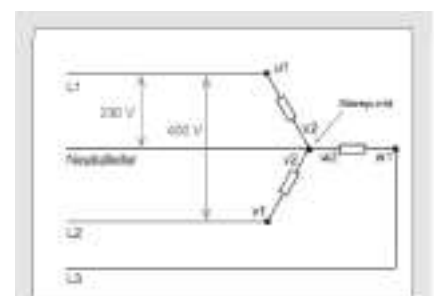


Abb. 2: Sternschaltung

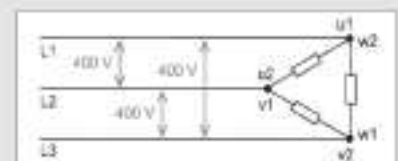


Abb. 3: Dreieckschaltung

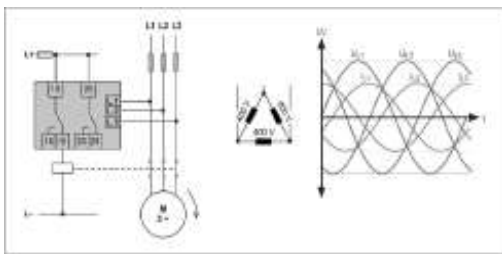


fig.4:
Three-phase motor with monitoring relay in full operation: Circuit diagram, motor equivalent diagram, current /voltage charts

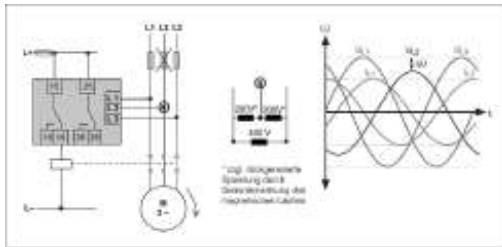


fig.5:
Three-phase motor with line regeneration and a monitoring relay prior to tripping due to a phase loss: Circuit diagram, motor equivalent diagram, current /voltage charts

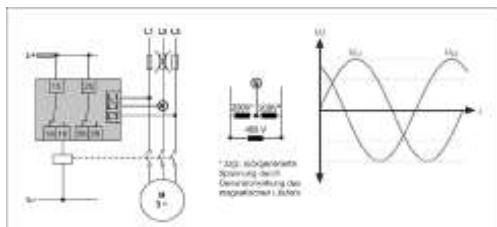


fig.6:
Three-phase motor with phase loss in L2 after monitoring relay has tripped: Circuit diagram, motor equivalent diagram, current /voltage charts

- ▶ **Phase loss:** Failure of one or more phases may occur if a circuit-breaker trips. Phase loss may result in undefined states of the installation. Motors may e.g. fail to start or they draw the necessary current from the remaining phases. The latter leads to uneven loads on the winding and may cause damage to the motor.
- ▶ **Undervoltage and overvoltage:** Overvoltage causes connected loads to heat up. Unless readily identified, this may damage or even destroy the connected load. Undervoltage may be just as dangerous. Undervoltage may lead to undefined states of the installation if e.g. a contactor is in an undefined switching position due to the operation in a “prohibited” voltage range.

- ▶ **Unbalance:** If the supply from the three-phase system is unbalanced due to an uneven distribution of the load, the motor will convert a part of the energy in reactive power. The efficiency is reduced. Furthermore, the motor is exposed to higher thermal strain and may be destroyed if ongoing unbalances are not detected by other thermal protection devices.
- ▶ **Series fault:** Whether a series fault has an impact on the installation or not, depends on whether the system has a balanced or unbalanced load. Symmetrical loads often exist where motors or three-phase heaters are connected loads. In most other cases, loads are unbalanced. In the case of a balanced load, a series fault will have no impact on the circuit. If, however, a series fault, occurs

in a system with unbalanced load, voltage fluctuations occur in the individual phases that may cause considerable damage to connected loads. This is why, in such a case, adequate protection measures need to be implemented, as is shown by the “Detection of Series Fault” example.

Application “Motor with Line Regeneration”

A phase loss, e.g. in a running three-phase motor (with line regeneration), can be detected with the help of unbalance phase monitoring. In its nominal condition, a motor cannot be switched on, unless the connected monitoring relay detects the correct phase sequence L1-L2-L3 and the voltage is in the preset range of U_{min}/U_{max} . That means that no overvoltage or undervoltage or phase loss has occurred (fig. 4).

If a fault occurs as a result of a phase loss (in the example, phase L2) caused by the tripping of a circuit-breaker, the phase current I_{L2} goes back to 0 and the phase voltage U_{L2} is reduced by $\square U$. The remaining voltage U_{L2} can be as high as 95% of the initial phase voltage, depending on the motor used, the motor load and other factors. Thus, phase loss in a running motor cannot be detected reliably just by a phase loss or undervoltage monitoring device. Phase unbalance monitoring is required to reliably detect faults of this kind. Once phase unbalances are detected, the monitoring relay will switch off the motor to prevent any damage to the motor (fig. 5).

Application “Series Fault”

The consequences of a series fault will depend on the type of load on the three-phase current. In any case, the current flow through the neutral conductor I_N can be calculated according to the First Kirchhoff Law as the sum of all phase currents. In a system with a phase balance, a series fault has no consequences, because the value of the phase currents I_{L1} , I_{L2} and I_{L3} is identical with each phase-shift by 120 electrical degrees. The current flowing through the neutral conductor I_N is therefore zero at any given time (see current / voltage charts in fig. 4). It is not necessary to monitor the device for any series fault.

In systems with phase unbalances – which is the more common type –

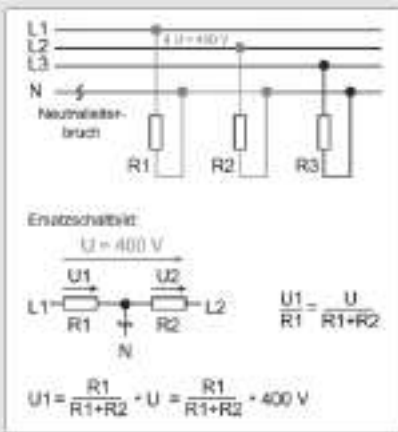


fig. 7 Series fault in three-phase system

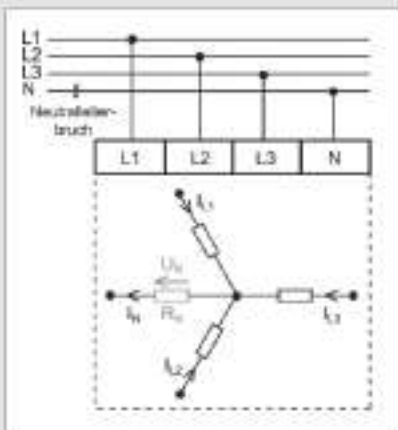


fig.8: Connection of a three-phase monitoring device with neutral conductor monitoring.

phase currents I_{L1} , I_{L2} and I_{L3} vary as to their value and phase angle; phase voltages U_{L1} , U_{L2} and U_{L3} with respect to U_N are – still – identical. The difference between the phase currents necessitates a compensatory current I_N through the neutral conductor. A fault in the neutral conductor prevents the compensatory current from flowing and leads to a displacement of the star point, i.e. to a different allocation of voltages to the individual phases (fig. 7).

That means that the phase voltage in the branch with the lowest Ohmic load goes down and increases in the one with the highest Ohmic load. This is how overvoltage occurs in one of the branches that may damage or even destroy the connected load. While there is an undervoltage in the other branch that, depending on the load connected, may have various consequences. If the load, e.g. a running motor, draws the same amount of energy from the system, the current augments in this branch and subsequently heats up,

and maybe even destroys the connected load. If, however, switching devices are connected, “prohibited” voltage states may occur through the undervoltage and lead to an unforeseeable switching behavior of the connected load. A contactor may e.g. no longer pick up properly or does not pick up at all, no longer switches off, or starts to “hum” (constantly switches on and off). This may allow dangerous states to occur in the installation.

Three-phase monitoring relays with connection to the neutral conductor offer safe and reliable protection in the case of a series fault. As is shown in figure 8, these relays are connected to the three phases of the supply system and the neutral conductor. Inside the relay a star connection with a load is simulated in the neutral conductor circuit. The measurement of the U_{RN} voltage via the resistance in the neutral conductor branch makes it possible to identify the state of the neutral conductor. If the neutral is connected, a compensatory current I_N occurs and causes a voltage drop U_{RN} . If the neutral is disconnected, I_N cannot flow. U_{RN} becomes zero and the outgoing relay reports the disconnected neutral.

Conclusion

It is both useful and important to monitor three-phase systems. This can be implemented with minimal effort, making equipment and processes safer, preventing damage and effectively helping to save cost. The CM-MPS made by ABB is a multifunctional monitoring relay for three-phase currents. It is available with or without neutral conductor monitoring, and monitors phase parameters, phase sequences, phase loss, over/undervoltage, and unbalances. Seven more devices from the CM range, each with targeted functionality, allow for particularly economic monitoring of three-phase systems.