Application Note

Electrical Grid Problems: Phasemonitoring for Compressors, Pumps and Fans

1. **Introduction**

Machines like compressors, pumps or fans need to be protected against critical influence from harsh environments or being damaged by operation beyond approved limits of operation. The following parameters are typically measured by sensors to detect potential damage at compressors, pumps or fans:

- Discharge gas temperature of the refrigerant (compressor)
- Oil level or oil pressure (compressor)
- Leakage (pump)
- Air pressure or air flow (fan)
- Winding temperature of the motor (all)
- Bearing temperature (all)
- Vibration (all)
- Motor current (all)
- Electrical grid (all)

This application note especially focusses on the last parameter: the electrical grid. The grid voltage drives the electrical current through the motor winding. This causes magnetic flux and torque but is also heating up the winding. In a three-phase grid system with a 120° phase shift between L1, L2 and L3 the sequence of these three phases also determine if the motor is turning left or right. Finally, the speed of the machine is influenced mainly by the frequency of the electrical current (in an asynchronous machine also slip influences the speed). Due to these physical relations the grid voltage is relevant for many effects we can see in an electrical machine and it is of significant importance.

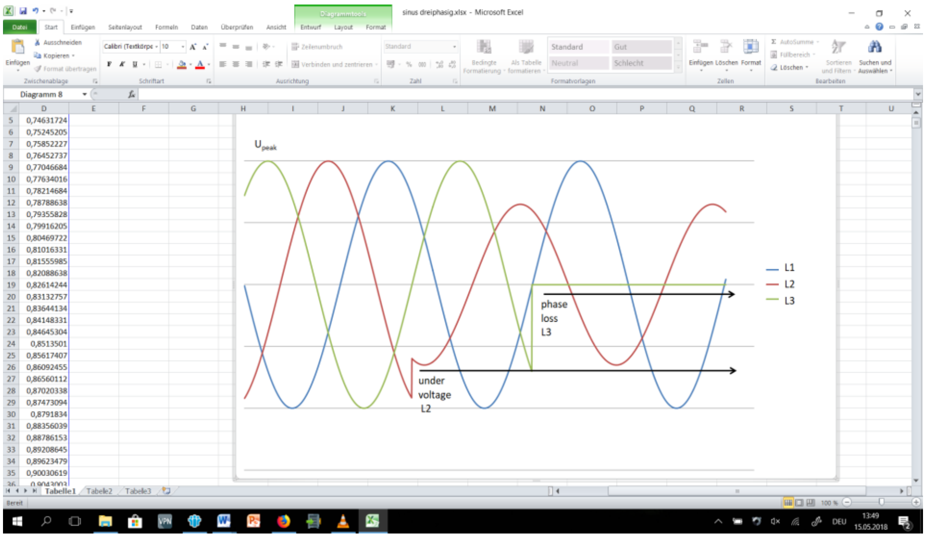

Figure 1: Three phase system with two phase failures

In Figure 1 a three phase grid system with three phases L1, L2 and L3 is shown. L2 has an under-voltage failure and L3 a phase loss failure in this diagram. U_{peak} shows them maximum voltage at the top of the sinus voltage.

A phase monitor typically is not working with the peak value of the voltage but uses the RMS (root mean square) value of the voltage. The equation to calculate the RMS value is given in Equation 1:

$$\tilde{u} = \sqrt{\frac{1}{T}\int_0^T u^2(t)dt} = \frac{u_{peak}}{\sqrt{2}} \approx 0{,}707 u_{peak} \qquad (1)$$

In Figure 2 an application with a phase monitor is shown: on the left side the external grid is indicated by the electrical tower. The voltmeters in the middle show the actual situation of the grid. They might be integrated in a panel or switching cabinet of the local plant or just be virtual. More to the right side one can find a motor representing a compressor, fan or pump. The phase monitor is connected in parallel to the motor and is monitoring all three phases. Modern phase monitors allow a smartphone or laptop to be connected. The visualization of e.g. last failures or current state of the grid can help to identify the root cause of a problem.

Figure 2: Phase monitor connected to the grid

2. Machine failures, Phase monitoring can protect against

Wrong direction of rotation

Some machines like screw or scroll compressors can be damaged quickly if the direction of rotation is not correct. As mentioned above, the direction is determined by the sequence of the phases (e.g. L1, L2 and L3 or L1, L3 and L2). If any two phases are changed in the sequence, the direction of rotation will alter. Some other machines like most fans or centrifugal pumps are not damaged if the machine is turning in the wrong direction but the flow of the fluid (e.g. air or water) is changed or the efficiency of the machine is reduced significantly. Only some machines like piston compressor are not influenced by the direction of rotation.

Under- and over-voltage

If the voltage in the three phases is below the lower threshold (under-voltage) or above the acceptable limit (over-voltage) then the current is increasing. This will cause an improper warming of the motor winding. It also will reduce the torque of the motor. Especially smaller motors (< 1,1kW) are very sensitive to over voltage (Greiner 2003). Under-voltage can also be caused temporarily if a large motor is starting. E.g. a large water pump can be the root cause for a local under-voltage in the grid and e.g. a switching cabinet can be affected by this voltage drop. Those effects are typically transient. This means power is dropping down but automatically coming back to the higher nominal value when the motor has reached its nominal speed. This influence can be minimized using a soft starter for the large motor. In a switching cabinet various electronic components like controllers, frequency inverters, gateways and sensors are mounted. Those electronic devices often react critical on short voltage drops (see also section “Brown out in a switching cabinet” later on). A phase monitor cannot prevent the voltage drop but it can perform a defined reset of the switching cabinet in case of a critical voltage drop.

Phase asymmetry or phase loss

In a low voltage grid (e.g. 400V AC or 190V AC, 3~) loads are often single phase (e.g. illumination or PCs). If the different loads are not balanced an asymmetry between the phases in the grid can be caused. Phase asymmetry or phase loss can on the one hand cause excessive warming of the motor due to increased currents but also due to negative sequence currents (current components which rotate in the opposite direction to the power system). Additionally also vibration can increase because the torque is not symmetrical anymore.
This is an important point to take into account when searching for the root-cause of a phase failure: it is not necessarily the grid or the installation of a compressor, pump or fan itself. Also equipment like a dishwasher in the next room but connected to one or more phases can cause a local voltage drop. To find those failures in the field it is highly recommended to have some data logger available or a phase monitor with data logging functionality which can record those transient events like the motor start of a dish washer. It is often much easier to identify the root cause if timing information is available, e.g. "the voltage drops every day at 8pm when the dishwasher is starting".

Brown-out in a switching cabinet

Next to issues with the motor (as described above) also electronics as controllers or relays in a switching cabinet can be affected by grid issues. Especially very short voltage dips (e.g. 50ms to 200ms) can cause so called "brown-outs". This means a micro-processors in an electronic component like a controller is neither completely on nor completely off. Some parts of a micro-processor continue to work while others have stopped functioning due to under voltage in the power supply. To avoid this, it is necessary to install a phase monitor with a fast reaction time which can detect those dips while itself being not affected and which can do a defined reset of the switching cabinet to bring all components back to a well-defined state.

Opening terminals at the junction plate

The motor is connected to the grid in most cases via terminals at the junction plate. Screw terminals with nuts and ring terminals at the cables are commonly used for this connection. The constant torque of the nuts is important to ensure a secure connection at low ohmic resistance. It can be dangerous if a nut is opening and getting loose because those terminals might heat up due to the higher resistance and also sparking is possible. The torque of the nuts can be reduced e.g. by vibration of the machine but also by continuous temperature changes.
If a phase monitor is connected inside the junction box close to the terminal bolts then this failure can be detected as under-voltage or phase loss. It is not possible to detect this failure if the phase monitor is located in the switching cabinet because the voltage drop is not happening in the switching cabinet on the grid side but in the junction box between the ring terminal of the cable and the terminal bolts. Due to this special phase monitors for mounting in the terminal box are available.

For identification of the root-cause of a phase issue it is important to take into account that not always the grid itself is causing the issue but also the installation on site can be the root cause.

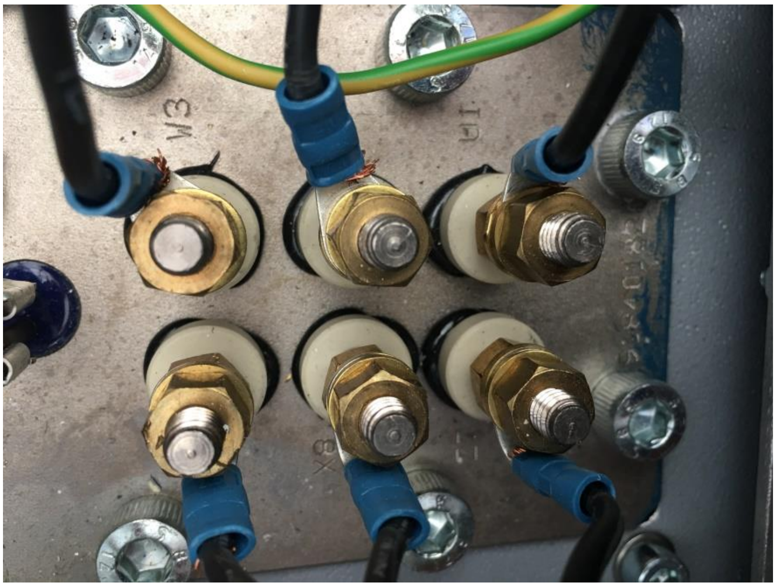

Figure 3: Terminals at the junction plate

3. Common issues during phase monitoring

In the above sections typical failures phase monitoring can protect against have been described. But phase monitoring itself can also create issues if it is not used properly. Some of those issues need a lot of time for trouble shooting. Hence in this section recommendations are given how to use phase monitors properly.

Frequency inverters need special phase monitors

If a frequency inverter is used in an installation the speed of a machine can be adjusted. This is a great advantage for energy saving and load matching. Nevertheless, harmonics created by a frequency inverter are also measured by the phase monitor. Inside the frequency inverter DC voltage is converted into AC voltage at higher frequencies, e.g. 5 kHz – 15 kHz. A sine filter should be installed at the inverter's output to convert this digital PWM (pulse widths modulated) output signal in an analog sine-wave voltage, but there are many installations in the field without a sine filter (Witzsch 2017). Even the normal range of the inverters sine-wave voltage (e.g. 20Hz – 100Hz) can cause issues in some phase monitors. If the phase monitor is not designed and approved for the use with a frequency inverter, these harmonics can create false measurement and false trips of the protection relay. Hence, if a frequency inverter is used to drive the motor it is mandatory to use also a phase monitor designed for this case. Special filters and EMC circuits protect the phase monitor against high frequency input signals and resulting measurement errors.

EMC – Electro Magnetic Compatibility

In most cases the grid voltage is connected via a daisy-chain of resistors on the PCB (printed circuit board) to the microcontroller. This means there is a high resistance galvanically coupled path between the microcontroller and the grid. Due to this EMC is very important. The manufacturer of the phase monitor has to take care to avoid false measurements and false trips. This is of special importance if the products are used worldwide. Many OEMs producing compressors, pumps or fans have faced the situation that a product is working very well in their home region but has power issues in other regions of the world. Stability and quality of the grid can change from region to region and also rules and reality of electrical installations are not the same in different regions of the world. This can include the quality of commonly used frequency inverters, grounding of metal parts but also changes and drops in the power supply from the grid side (Blum 2017). Due to this it is recommended to use phase monitors with a high EMC level if compressors, pumps or fans are used worldwide.

Measurement errors due to humidity

If a machine is used in hot and humid climate also electronic circuits like a phase monitor will be in this environment. When humid air is cooling down during the night it can happen that small drops of water condense inside the electronic component and remain on the PCB. The effect is independent of the protection degree of the housing. Even in an IP65 housing humidity can enter the housing as a gas and condense inside. Hence it is important to protect the PCB by varnishing or potting processes during production process. This is important to avoid corrosion of the electronic components. Additional to corrosion water droplets can also become a parasitic capacity. This means they can influence the design of the electronic circuit by changing the capacity. Software filters can avoid measurement errors cause by those effects.

4. KRIWAN Phase-monitors

To cover the above described needs and challenges KRIWAN has developed a portfolio of phase-monitors (see Figure 4). These products are widely used in different applications and geographic regions. A special feature is the connectivity of both product lines, basis and all-in-one: it is possible to connect these relays via Bluetooth, USB or Modbus to a smartphone (iOS, Android or Windows Mobile) or to a Laptop (Windows 10) or to a PLC or controller. Data about the history (when did a critical situation happen and what happened) is available. Also the actual voltage values are transferred in real time and can be monitored.

Figure 4: KRIWAN phase monitor product lines

5. Summary

Phase monitoring is important in many systems and installations to avoid severe problems and damage. Nevertheless, if phase monitoring is not done properly, it can cause issues itself: measurement errors and false trips need to be avoided by selection of a suitable phase monitor which is able to work under the given circumstances.

6. References

Blum, H. 2017. Sicher geerdet. elektronik informationen 11: 26:27

Greiner, H. 2003. Drehstrommotoren an der neuen Normspannung 400V. Elektropraktiker 57:128:131

Witzsch, M. 2017. Überwachung der Netzqualität schützt elektrische Antriebe. Etz 11: 34:39