The Practice of Troubleshooting and Maintenance in a Small-scale Off-grid Industrial Environment

Bertalan Beszédes
Óbuda University
Alba Regia Technical Faculty
Székesfehérvár, Hungary
beszedes.bertalan@uni-obuda.hu
https://orcid.org/0000-0002-9350-1802

Főző Ladislav
Technical University of Košice
Faculty of Aeronautics
Kosice, Slovakia
ladislav.fozo@tuke.sk
https://orcid.org/0000-0003-4772-1051

Levente Dimén
1 Decembrie 1918 University of Alba Iulia
Faculty of Exact Sciences and Engineering
Alba Iulia, Romania
ldimen@uab.ro
https://orcid.org/0000-0003-2705-5952

Péter Udvardy
Óbuda University
Alba Regia Technical Faculty
Székesfehérvár, Hungary
udvardy.peter@uni-obuda.hu
https://orcid.org/0000-0002-8897-9326

***Abstract*—This paper explains the basic methods of troubleshooting small industrial and residential scale off-grid systems. The article deals with maintenance and diagnostic questions of industrial equipment, which are powered by an off grid system. Eventually conclusions were drawn about the feasibility and requirements of measuring, monitoring and diagnostics algorithms.**

Keywords—off-grid monitoring, off-grid maintenance, off-grid troubleshooting, off-grid diagnostics, industrial maintenance, industrial troubleshooting, industrial diagnostics

I. Introduction

Newly installed electrical appliances begin to degrade immediately. Material fatigue, ageing, vibration, temperature and other environmental conditions contribute greatly to the formation of losses. Every loss of energy is associated with an increase in temperature, the higher the heat load, the greater the loss of energy and the greater the chance and probability that the device will fail. [1]

Industrial rotating electrical machines and equipment make millions of revolutions during their life cycle. Due to the heavy use, they are especially prone to breakdown. Overheating can be caused by weak cooling, many stops and restarts, overload and overvoltage, as well as critical network power quality, including imbalance and distorted signals. Even the smallest voltage imbalance can cause significant motor current. [2]

A. The practice of maintenance

Most of the errors can be detected with the help of planned preventive maintenance. Detecting error-prone places and removing the error can prevent the failure from occurring. Visual inspection is not enough, thermal analysis shows the operating temperature of the devices and wires. [3]

Maintenance should always be performed according to best practice. Aspects of the pursuit of safety must be taken into account. The exact sequence always depends on what equipment is working at the plant and what instruments are available. [4]

First, it is necessary to measure and collect data. After that, it is necessary to determine what is normal operating conditions and what is where intervention is necessary. Then, the repairs to be carried out must be prioritized according to safety considerations, depending on the condition of the machine and the temperature rise. After the repair, the measurements must be performed again, and the measured data must be entered into the database. [5]

II. Diagnostics tools

A. Thermal imager

For maintenance, the thermal camera is a good tool to find and discover abnormal conditions. Thermal data are generated after the measured equipment is put into operation and during periodic reviews. Later, these data can be used during regular reviews and to determine the condition after repairs. In order to apply the correct thermal camera measurement procedure, it is necessary to take into account the related recommendations. [6]

The vast majority of errors can be traced back to undersized wires (see Fig. 1) and poorly made joints, but overloaded or undercooled motors or bearing faults also can cause heat rise. Thermal cameras do not make traditional inspections and electrical safety checks unnecessary.

In all cases, the technical documentation must contain the measured temperatures and other environmental parameters, temperature, lighting, air movement, accumulated contamination, etc. in great detail. Maintenance must know the thermal characteristics of electrical equipment and what temperature changes are caused by individual faults.

It is necessary to observe the equipment when it is switched on, during operation and when it cools down. During monitoring, a peak load must be created in the system (see Fig. 2), but at least 40% load is required.

If possible, the casing of the tested device should be removed, if not, then a surface with a well-differentiated high temperature should be selected as a reference point (see on Fig. 3). A cold spot can also indicate the location of the error.

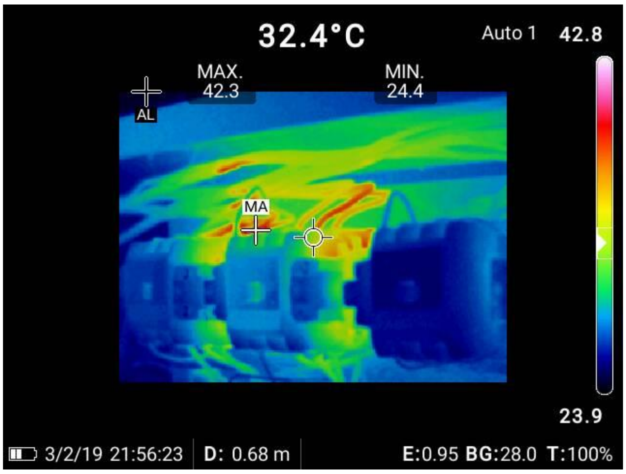

Figure 1. Thermal image of an undersized wire

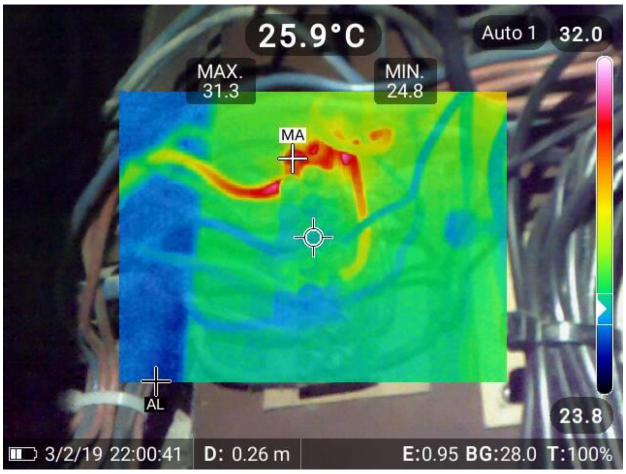

Figure 2. Thermal image of an overloaded connection

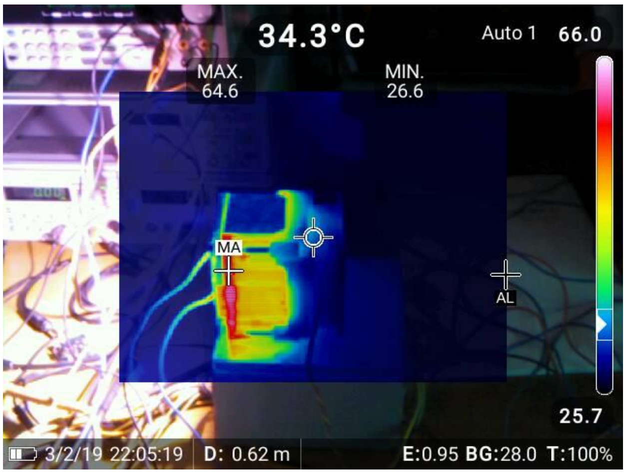

Figure 3. Heat source under the casing

In places where the device to be measured cannot be reached (for example, the top of the device), thermal mirrors can be used, in this case only relative measurement is possible, not exact temperature determination.

Even seemingly insignificant errors can cause malfunctions, contamination further corrodes the equipment, and vibration further loosens the connections. Pollution reduces the efficiency of the cooling fans, reduces the cross-section of the pipes and clogs the filters.

NETA standards recommend an urgent intervention is required if the temperature measured on the device is 40 °C higher than the environment temperature. As well as if the same type devices operate under the same conditions and a temperature difference between the devices is more than 15 °C. [7]

When the thermal imager shows an error in one phase, it is likely that the error is between the coil and the motor housing. When it shows an error on two phases, it is likely that the coil is broken. When it indicates an error on all three phases, we can suspect a bad bearing or a brake error.

B. *Measurement of insulation resistance*

After checking the motor temperature, it is recommended to check the insulation condition of the coils with an insulation tester or megohm meter.

During the measurement, our device generates a voltage of known magnitude and measures the current leaking through the insulation, from which it calculates the insulation resistance. In this way, the resistance value between the phase-phase and the phase-earth wire can be measured. When a device is first switched on, the initial insulation resistance can be as low as 1 Mohm. This value can quickly decrease due to high operating temperatures.

When evaluating the measurement, the temperature and humidity of the air must also be taken into account. If the ambient temperature and humidity increase, the value of the insulation resistance decreases. [8]

Engines should not operate above the designed maximum temperature limit. Every 10°C increase in the motor winding reduces the value of the insulation resistance of the motor winding by 50%. Even if the heat rise is only short-lived. Therefore, the insulation resistance must be checked frequently. [9]

Long-term overload above 1.15 power factor increases the stator temperature by 20 °C. Motors are often run at overvoltage to reduce overcurrent and other errors. This does not greatly reduce heat generation, and can even hide possible sources of error.

C. *Vibration analysis*

Vibration analysis can reveal faults in the bearings of motors and rotating parts. The vibration meter can be used to examine the vibration spectrum, taking into account all three coordinates. The measurement must be performed at both ends of the driven shafts.

Some frequencies of engine vibration often add up to the actual rotation speed and often point to a failed bearing, bent shaft, or loose joints. The higher frequencies are appearing on the grooves of the stator and the rotor shaft.

A bent shaft and weak connection often appear as double the rotational speed. These data are absolutely necessary for accurate measurement. The diameter of the bearing balls and the outer and inner diameter will also affect the vibration. [10]

Moisture and chemicals often cause corrosion. Commonly affected areas are bearings, coils, rotor and shaft. The corrosion that occurs can also be detected in the case of vibration measurements in the motors.

D. Power network analysis

High-voltage network analysis shows the quality of the network voltage, whether there are harmonics, imbalance or other anomalies.

Unbalance can be caused by a lower voltage on one of the supply lines or a decrease in the value of the insulation resistance inside the motor winding. If a motor works in an unbalanced state, its efficiency and torque decrease, it consumes more current, its service life decreases and mechanical disturbances may occur. Increased current values can be the basis of diagnostics.

The voltage shifts of an unbalanced network causes malfunctions for single-phase loads. An imbalance can also be caused by connecting the solar energy system to one phase. A solution may be the regrouping of loads or the use of compensating components. Voltage imbalance also can cause degradation of connections.

Loading a sinusoidal voltage network with non-linear elements creates harmonics on the network. A non-linear load is, for example, the rectifier circuit, in practice they are also found in switching power supplies, variable speed motor drives, LED and compact fluorescent tube drivers.

The transient voltages resulting from these and the variable regulation of their loads cause the appearance of pulse-like electrical signals on the electrical network. A VSD is particularly prone to inducing a magnetic field and adversely affecting the stator and bearings. A possible solution is the use of ceramic bearings, insulation of the motor housings, and grounding of the shafts.

When the network contains many capacitive or inductive elements, resonance can occur, which can cause network disturbances. Disturbances can be mitigated by using filters. [11]

E. Hidden errors

To catch and analyze hidden errors, it is needed to see the signs, whitch can include noises or other abnormal waveforms. Randomly occurring errors can be searched with a digital oscilloscope and a data logger. [12]

The distortion of the signal shapes and their course over time allow us to infer the cause of the error. The simultaneous examination of various incoming and outgoing signals can provide answers to error possibilities such as overload of voltage and current, inappropriate timing of signals, incorrect value of attenuation and input impedances, errors of converters.

F. Random errors

Common causes of random errors are dust, dirt, corrosion and broken wires. Aging of the wires or frequent switching on and off can also be the cause of the error.

In such cases, it is recommended to use an electrical network analyzer and data logger to determine the fault. [13] In such cases, a meter is placed for a longer period of time to monitor consumption. Based on the shape and size of the measured signals, information about energy consumption is available. It is recommended to use measuring clamps and lock clamps to determine current imbalance and load problems.

III. Off-grid methodology

The general operating sequence for error detection is as follows: visual inspection, checking connection points, checking fuses, checking system components, checking cooling system.

It is proposed to check cooling possibilities of electrical components [14], overheat can cause temporarily shut downs. [15] Charge controllers and converters might limit charge current due to increased ambient heat. Contaminated ventilators and filters will cause decreased airflow.

Check installation manuals to verify correct mounting style, spacing and ventilation. Assess that equipment are out of direct sunlight to reduce aging.

Extreme weather conditions can cause poor system performance. Verify that the worst-case sun hours, the calculated battery capacity days with no sun the predicted load usage and average weather conditions are assessed properly. Confirm that solar panel orientation and tilt angle is acceptable. Make sure, that the inverter efficiency and power consumption is calculated in system design. [16]

A. Wires, connections and fuses

Screw terminals can loosen over time due to corrosion, temperature change or vibration. Wire insulations can be damaged due to over temperature or mechanical impact. For wire continuity, connection, fuse, polarity check it is proposed to use a voltage meter, for current measurement, it is proposed to use a clamp current meter, which can measure both AC and DC currents.

In case of troubleshooting, screw terminals need to be tighten, terminal and wire labels need to be checked. In case of repair blown fuses, corroded terminals and wires with damaged insulations need to be replaced. Wires also need to be placed to prevent further exposure to abrasion or mechanical stress.

Voltage drops and power losses can be minimized with the use of robust connectors, terminal blocks and the increase of wire sizes. [17]

B. Charge controller inspection

With PWM type charge controllers the solar voltage should be approximately 1.2 to 2 times of the battery voltage. With MPPT capable charge controllers the solar voltage should be approximately 1.2 to 3.5 times of the battery voltage.

Potential errors worth checking, are the following. Lack of light needed to charge the batteries. Battery capacity decreased in cold weather, especially in case of lithium based batteries. The load is running longer or more loads have been added to the system output than planned. [18]

C. Battery pack inspection

If the battery is cannot be charged through the photovoltaic module or through the mains supply, voltage levels, wiring, terminal blocks, switches, fuses, temperature, mechanical deformations and SoC level should be checked.

In case of multiple error possibilities, they must be tested separately. When the battery reaches full charge, it can't be recharged. Check the manufacturers datasheet for charge voltage, absorption voltage, float voltage, storage voltage, end of discharge voltage levels for different batteries. The charge and discharge currents also must remain within the operating range, to avoid damaging the battery. [19]

For further investigation batteries and battery cells can be tested for capacity, internal resistance and other parameters depending on battery technology.

D. Inverter inspection

If there is no input current, the battery voltage should be measured. If batteries are not used for a longer period, they can self-discharge itself. The battery voltage can be insufficient if there is a lose or corroded connection, and high load currents are flowing.

In case of battery overload, the battery voltage can drop down under the end of discharge value and the BMS or the inverter can break the battery and inverter line.

If the battery is over-discharged, it may cannot start the system, therefore the battery cannot be charged, till it is not charged partially for an external charging source. [20]

It is worth checking out of input voltage polarity and also that the main DC switch is turned on.

If the inverter is overloaded, it will shut down due to too high load power. Inductive loads could have too high inrush current for the inverter. The peak power of the load cannot be greater than ~1.5 times the rated power of the inverter. A soft starter or an inrush current limiter circuit can be used to attach the inductive load to the inverter output.

Motors that can also function as generators cannot be connected to the output of the inverter. For example, with certain electric winches, when lowering the load, back electromotive force is generated, which can damage the inverter. [21]

It is also worth checking if there is no chance that two out of phase inverter output can be connected together. Connecting the output of the inverter and the electrical network also results in the immediate failure of the inverter, if the voltage sources are not identical in frequency, amplitude, phase and null potential. [22]

E. Solar panel inspection

Check the solar panel’s access to the sun, shade can cause significant lost in production. Contaminated panels can lead decrease of energy production. [23] Junction boxes should be checked for blown diodes, loose or corroded connections, solar connectors also should be checked.

The open circuit voltage, short circuit current and power point electrical data should be measured with a reliable and safe instrument on strings and individual solar panels, and compare the results with the manufacturers datasheet. [24]

Visual inspection of the solar panel surface can show some anomalies, like cracks, air bubbles or burned out cells, but a thermal camera can give gives a much more detailed result. [25]

F. Examination of solar panels with thermal imaging

All solar cells have a glass surface, which presents a practical problem in thermal imaging because glass is not completely transparent to the infrared spectrum. Since the thermal camera detects the temperature of the cells located behind it only through a glass surface, a thermal sensitivity of ≤80mK is required.

It is advisable to use a high-resolution camera with a thermal image resolution of 320 x 240 pixels or higher, also a telephoto lens could be handy. [26]

In order to have a sufficient heat difference to find the defects, the solar irradiation level must be greater than 500 W/m2 and the outside temperature must be as low as possible. Damp, wet environmental conditions negatively affect the measurement results, as water can cause false anomalies in the thermal image. Cloudy and windy weather conditions are also to be avoided.

A special property of glass is that the emission also depends on the angle of the observer's position. In order to avoid the reflection of the thermal camera and the operator, the user must close a maximum angle of 85° in relation to the panels, but in the case of an angle closed lower than 30°, the emission will be too high. In some cases, it may also be necessary for examinations carried out from the rear view, if there is no glass cover. [27]

Thermal imaging cameras indicate many problems, such as cell defects (dirt / gas bubbles or cracks), transient shielding (dust, dirt, fogging, bird droppings), faulty bypass diode or faulty connections (see Fig. 4). Most problems appear as hot spots or cold spots, although faulty bypass diodes can be seen as cell spots. [28]

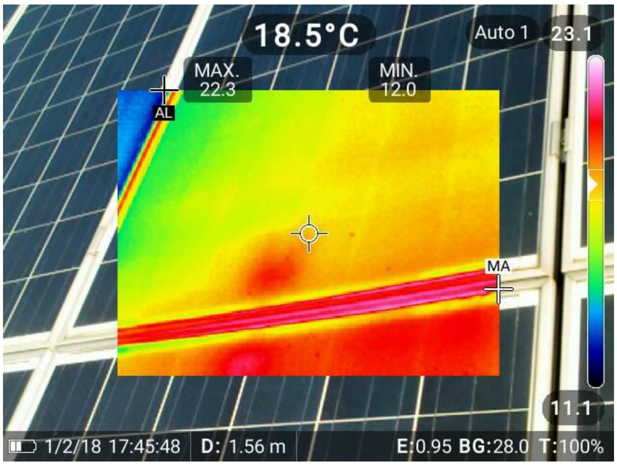

Figure 4. Warming terminal box [14]

IV. CONCLUSION

This paper aimed to show practical solutions for industrial equipment and off-grid power supply maintenance and troubleshooting. The shown diagnostic tools and methods can be used for motoric, solar, power electronics, electrician, and more applications. The proposed problem solving tools and methods are well applicable. The article describes the relationship between the system components and measuring, monitoring, diagnostics algorithms.

ACKNOWLEDGMENT

The authors would like to thank all the faculty staff and member that provide help and assistance throughout the project completion.

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