EVALUATION OF OPERATIONAL SAFETY OF CHOSEN ELECTRICAL SET ELEMENTS IN CONDITIONS OF BIOGAS PLANTS WITH USING OF INFRARED THERMOGRAPHY METHOD

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The paper is focused on evaluation of operational safety of chosen electrical set elements in specific conditions of agricultural biogas plants with using of infrared thermography method. The goal of the paper is thermography monitoring of the surface temperature of electrical set elements with detection of high warmed parts. Next goal is evaluation measured temperatures with criteria and requirements of standard ISO 18434-1. In terms of measurement was measured surface temperature of every element and compared with reference ambient temperature. Our study claimed suitability of IRT method for monitoring of electrical set elements. Any of measured objects has high surface temperature. This is significant risk factor for fire and related losses.

KEYWORDS

infrared thermography, electrical set element, surface temperature, thermal defect, biogas station

1 INTRODUCTION

Infrared thermograhy (IRT) is modern perspective method for non-contact measuring of surface tepmerature and monitoring and inspecting of electrical set elements. Monitoring with using of IRT method is very effective for prevention of fire and related losses. IRT method can be used for monitoring of thermal defects of electrical eset elements without shutting down, which has important significance for the stability of power systems.

[Jadin 2012] stated that infrared thermography has gained more attention and become an interesting method in electrical preventive maintenance due to its high precision and sensitivity imaging characteristics. [Zou 2015] stated that all objects with a temperature above absolute zero emit radiation and the higher the temperature the more radiation energy. Internal and external faults of electrical equipment such as loose connection, contact problems, overload, load imbalance and improper equipment installation can produce overheating, which may lead to the failure of the equipment. Furthermore, the failure of equipment requires a lot of maintenance cost, manpower and may also cause catastrophic injures or even deaths [Huda 2013]. It is well understood that the life of electrical equipments is drastically reduced as temperatures increase. Condition monitoring using IRT images can reveal the presence of any thermal anomalies in electrical equipments, produced by the defect on the surface of the equipment. The defect will normally alter the thermal signature of the surface due to the change in the amount of heat generated and the heat transfer properties of the equipment [Lizak 2008]. Temperature is an important parameter for evaluating the condition of electrical equipment. Therefore, monitoring the temperature of equipment is undoubtedly one of the best predictive maintenance methodologies. Infrared thermography (IRT) is a non-contact method that measures the temperature of a body remotely and provides the thermal image which represent surface temperature distribution of the body [Bagavathiappan 2013].

Infrared thermography has wide utilization e.g. [Vitazek 2008] reported other application of IRT in food industry and importance of the surface temperature for assessing the effect of the dryer condition on the energy requirements and the economics of its operation. [Karas 2004] reported research about contact and non-contact thermometry in the milk acquisition process milking process.

Biogas is a promising renewable fuel, which can be produced from a variety of organic raw materials and used for various energy services. For example ten percent of Swedish biogas production is currently upgraded and used as vehicle fuel in buses, distribution tracks and passenger cars and the remaining biogas is mainly used for heat or combined heat and power (Lantz 2007).

The goal of the paper is thermography monitoring of the chosen electrical set elements in specific conditions of agricultural biogas plants and evaluation of operational safety with requirements of standards.

2 MATERIAL AND METHODS

The IRT experimental measuring was carried out under operational conditions in three different agricultural biogas plants (BGP) during the winter season (January 2017). Biogas plant is power arrangement for production of renewable energy. Biogas plant are intensively continually exploited. First biogas plant has maximal electric output 999 kW and maximal heat output 1297 kW. Second biogas plant has maximal electric output 1738 kW and maximal heat output 1788 kW. Third biogas plant has maximal electric output 549 kW and maximal heat output 567 kW. The following characteristics were monitored contemporary with IRT imaging:

- air temperature (°C),
- air flow velocity ($m \cdot s^{-1}$),
- air humidity (%),
- distance of measured object (m),
- temperature of electrical set elements (°C)
- emissivity.

The IRT measuring of the electrical set elements temperature was carried out in the three plant areas (machine room, control room and transformer object).

Thermal analyses were performed by FLUKE Ti32 (USA) thermal camera. The air temperature and relative humidity were measured using KIMO AMI 300 (France) multifunction equipment. The air velocity and temperature were measured with using a telescopic vane probe type HET 14 (in the range of 0,8 to 25,0 m/s and -20 to 80 °C) featuring the temperature measurement accuracy of ±1 °C. The relative humidity were measured with using a telescopic hygrometry probe SVTH (in the range of 5,0 to 95,0% relative humidity) featuring the measurement accuracy of ±4%. The temperature and humidity

were measured in the close vicinity of the thermal camera and measuring objects. The reflected temperature was not measured because any heat sources were not in the surroundings, which could influence the measurement. The reflected temperature is caused by close heat source which can influence temperature of measured objects. Conditions of thermography measurement: cloudy conditions, air temperature - exterior (-0,4 °C), interior (20,0 °C), air velocity 0,50 m·s^{-1}, relative humidity 55 %.
The distance of the camera from measuring objects was determined using Leica DISTOtm A5 laser EDM (Germany) device (measurement accuracy: ±1,5 mm at a distance between 0.2 and 200 m). The thermal imaging measurement as such was conducted using Fluke Ti32 thermal camera (FOV: 45°) and Fluke SmartView 3.2 software. Measured temperatures of electrical equipment are evaluated with criteria and requirements of standard ISO 18434-1 (Table 1).

Level	Temperature range	Requirement
1.	>10 °C above ref. temperature	Periodic monitoring
2.	10 – 40 °C above ref. temperature	Repairing of the anomaly when possible
3.	40 – 70 °C above ref. temperature	Urgent corrective action without delay
4.	>70 °C above ref. temperature	Immediate repairing

Table 1. Corrective criteria requirements according ISO 18434-1

3 RESULTS AND DISCUSSION

This chapter present main results of our thermographic measurement and evaluation of measured values. In first part of this chapter there are presented the most interesting examples of IRT measuring. Second part of these chapter present summary results of all measurements.

We can see examples of thermogram at following figures. Next text is word interpretation of thermograms. Fig. 1 shows thermogram of electrical equipment in biogas plant 1 machine room. We can see maximal temperature 45,2 °C of high warmed part. Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 25,2 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

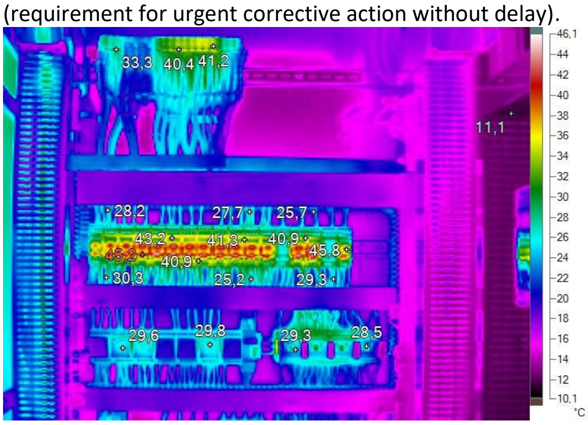

Figure 1. Example of thermogram (biogas plant 1 – machine room)

Fig. 2 shows thermogram of electrical equipment in biogas plant 1 control room. We can see maximal temperature 63,5 °C of high warmed part. Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 43,5 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

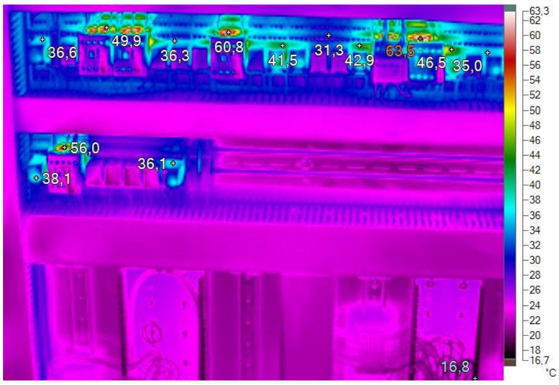

Figure 2. Example of thermogram (biogas plant 1 – control room)

Fig. 3 shows thermogram of electrical equipment in biogas plant 1 transformer object. We can see maximal temperature 62,4 °C of high warmed part and temperature of leading wire about 50,0 °C. Reference ambient air temperature is -0,4 °C. It is evident that temperature of leading wire is about 50,4 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

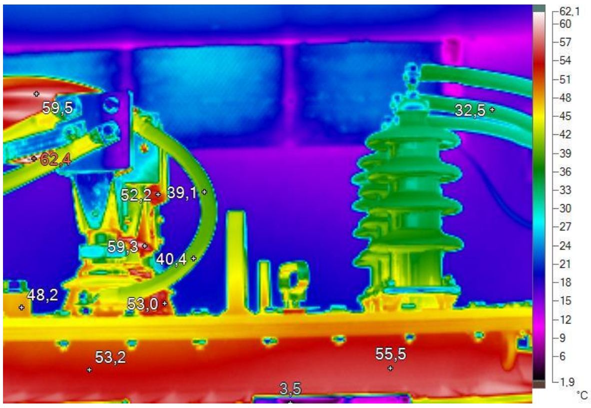

Figure 3. Example of thermogram (biogas plant 1 – transformer object)

Fig. 4 shows thermogram of electrical equipment in biogas plant 2 machine room. We can see maximal temperature 60,0 °C of high warmed part . Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 43,5 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

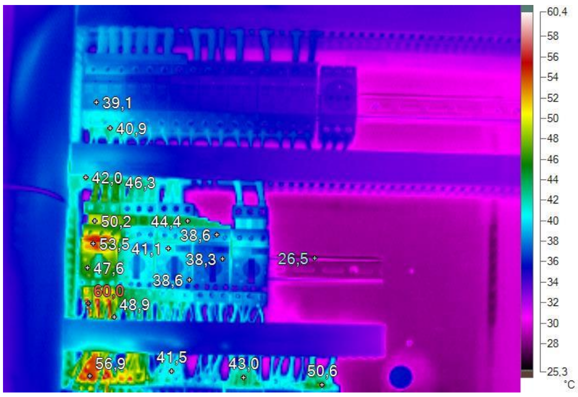

Figure 4. Example of thermogram (biogas plant 2 – machine room)

Fig. 5 shows thermogram of electrical equipment in biogas plant 2 control room. We can see maximal temperature 46,5 °C of high warmed part. Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 46,5 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

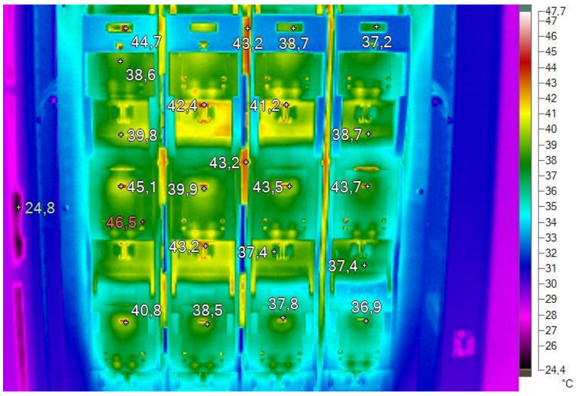

Figure 5.: Example of thermogram (biogas plant 2 – control room)

Fig. 6 shows thermogram of electrical equipment in biogas plant 2 transformer object. We can see maximal temperature 66,9 °C of high warmed part and temperature and temperature of leading wire about 60,0 °C. Reference ambient air temperature is -0,4 °C. It is evident that temperature of leading wire is about 60,4 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 4 (requirement for immediate repairing).

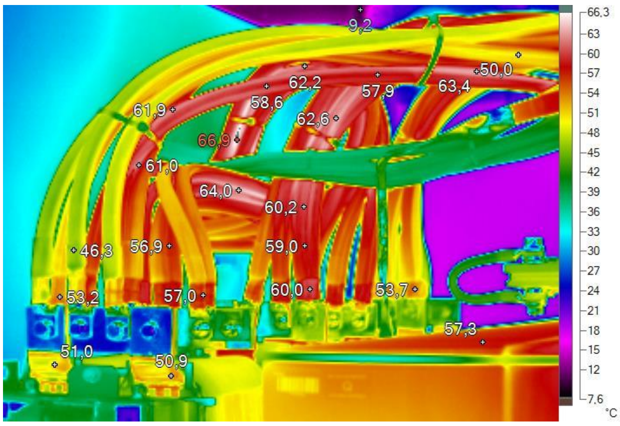

Figure 6. Example of thermogram (biogas plant 2 – transformer object)

Fig. 7 shows thermogram of electrical equipment in biogas plant 3 machine room. We can see maximal temperature 65,6 °C of high warmed part. Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 45,6 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for requirement for immediate remedy).

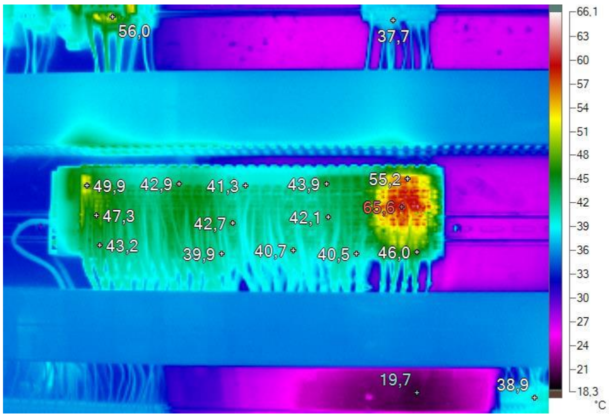

Figure 7. Example of thermogram (biogas plant 3 – machine room)

Fig. 8 shows thermogram of electrical equipment in biogas plant 3 control room. We can see maximal temperature 52,2 °C of high warmed part. Reference ambient air temperature is 20,0 °C. It is evident that temperature of most warmed equipment is about 32,2 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 3 (requirement for urgent corrective action without delay).

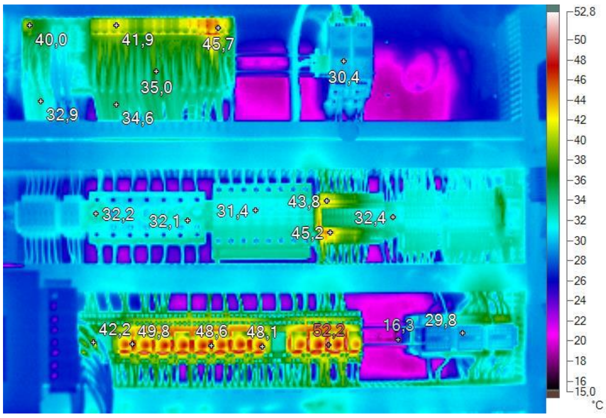

Figure 8. Example of thermogram (biogas plant 3 – control room)

Fig. 9 shows thermogram of electrical equipment in biogas plant 3 transformer object. We can see maximal temperature 37,7 °C of high warmed part and temperature of leading wire about 27,0 °C. Reference ambient air temperature is -0,4 °C. It is evident that temperature of leading wire is about 27,4 °C higher in comparison with reference temperature. Evaluation in according to ISO 18434-1 is level 2 (requirement for monitoring and planned correction action).

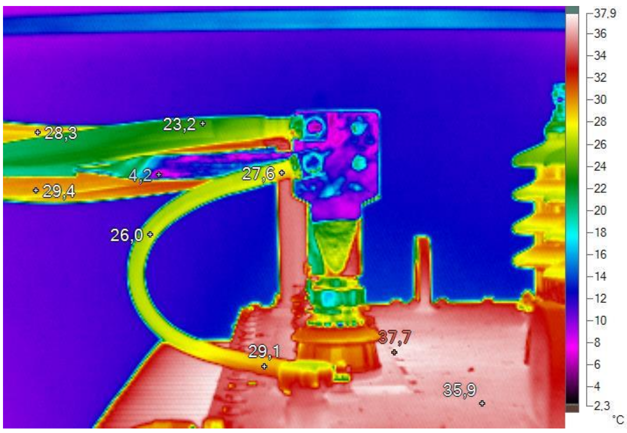

Figure 9. Example of thermogram (biogas plant 3 – transformer object)

Summarized results of all IRT measurements are presented in Table 2, Table 3 and Table 4.

Biogas plant specification	Number of thermograms	Max. temp. [°C]	Min. temp. [°C]	Ref. temp. [°C]	ISO 18434-1 Evaluation			
					L1	L2	L3	L4
BGP 1- machine room	8	95,7	27,0	20	1	2	3	2
BGP 1- control room	19	69,9	21,2	20	4	4	11	0
BGP 1- transformer object	3	62,4	24,0	-0,4	0	1	2	0

Table 2. Summary results of measuring (Biogas plant 1)

Biogas plant specification	Number of thermograms	Max. temp. [°C]	Min. temp. [°C]	Ref. temp. [°C]	ISO 18434-1 Evaluation			
					L1	L2	L3	L4
BGP 2- machine room	6	60,0	33,5	20	0	3	3	0
BGP 2- control room	5	66,9	21,6	20	0	1	4	0
BGP 2- transformer object	3	66,9	33,0	-0,4	0	0	3	0

Table 3. Summary results of measuring (Biogas plant 2)

Biogas plant specification	Number of thermograms	Max. temp. [°C]	Min. temp. [°C]	Ref. temp. [°C]	ISO 18434-1 Evaluation			
					L1	L2	L3	L4
BGP 3- machine room	9	65,6	34,6	20	0	4	5	0
BGP 3- control room	9	74,2	26,0	20	0	5	4	0
BGP 3- transformer object	3	37,7	21,3	-0,4	0	3	0	0

Table 4. Summary results of measuring (Biogas plant 3)

As we can see in summary results, all of measured biogas plant has thermal defects of electrical set elements. Evaluation in according with ISO 18434-1 proved critical level 4 in 2 cases (only at biogas plant 1). The most frequent is warning level 3 (35 cases). These problems can be caused by continuous working of biogas plant arrangement on maximum power output. Similar thermal defects of electrical equipment reported [Zou 2015] and [Ahmed 2015]

4 CONCLUSIONS

Results of our study confirmed that all of measured biogas plants have a problem with thermal defects of any electrical equipment. This is significant risk factor for fire risk and related financial losses. It is necessary to carry out corrective maintenance of dangerous electrical equipment. Our study claimed suitability of infrared thermography method application for monitoring of thermal defects of electrical set elements.

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