Overhead Transmission Line Thermographic Inspection Using a Drone

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***Abstract*—Thermovision is a technique used to measure an object temperature. A drone equipped with such technology will provide an ability to solve the problems in particular related to overheating of the components of the transmission line (focus on a conductor) as well as throughput capacity issues. The proposed simplified inspection system ensures aerial thermal imaging under particular weather conditions and power line loading. The solution provides safe, high quality and cost-effective examination of the overhead power lines in the remote and flexible way. The system consists of two parts: hardware and software design. Hardware part combines drone and thermal camera circuit in order to capture and transmit the required data. Software part includes interpretation of the received data (thermal photo) and calculations of the throughput current of a power line. The verification and validation results are presenting in a paper by considering a particular case study.**

Keywords—conductor temperature, drone, design, overhead power line, current, thermovision.

I. Introduction

Nowadays transmission network is challenged, in particular, overhead power lines, since integration of the renewable sources need to be considered, load growth leading to interconnection capacities increase as well as aging of the existing grid infrastructure. Therefore all above-mentioned changes force to reconsider existing ways of inspection and monitoring of the transmission lines (TL) as well as related planning problems that could solved beforehand by using advanced technologies.

Adaption of an unmanned aerial vehicle (UAV), simply drone, provides many technical possibilities in order to solve transmission grid problems. This application is a quite new direction and consideration topic in the electric utilities from a power system point of view.

It is worth to notice, that in spite of that Kuwait is relatively a small country, it has rapid growth of the generation capacities along with an expansion of the transmission and distribution network as well as there is a need to facilitate stable and secure interconnection with Gulf Cooperation Council (GCC) grid [1].

Thermovision is a method used for detecting the infrared radiation of the object and creating an RGB (Red Green Blue) image based on the collected data. This method is used in several fields such as medicine and health care, military, oil and gas operators, routine delivery operations, scientific monitoring purposes and electric utilities. For instance, PV system [2] as well as overhead power line (OHL) inspection and monitoring (clearance measuring, TL corridor mapping, inspection hazardous areas, thermal inspection, etc.) [3-8].

This study focuses on the thermal monitoring and inspection of a power line in order to prevent the maintenance and operation problems as well as decrease their appearance risk by considering the potential issues in advance. In general, these problems related to overheating of the TL components and throughput capacity issues. Consideration of a conductor temperature detection and inspection is examined in this work.

There are several studies related to thermal inspection of the OHL such as given in [9-12]. However, neither of them considers the proposed simplified way of the detection of the conductor temperature in order to calculate the throughput current of the TL.

The main goal of the considered study is to design a simplified thermographic inspection system for the OHL in order to increase transmission network safety, reliability and efficiency as well as decrease maintenance issues (conductor overheating under different operating conditions of the power line along with the weather conditions by proposing a less-cost solution). The proposed solution considers two objectives. First, build the thermal camera circuit, which connects to the drone and as a result transmits data (thermal photo) wirelessly to the ground server (user). Second, develop a program for both transmission of the required and captured data from the drone to the ground server and calculations of the throughput current of the OHL based on received thermal photo by interpreting and identifying conductor temperature.

Existing traditional inspection methods adapt more static monitoring and inspection ways of the power lines. However, the application of the drone will provide an effective, flexible and remote way to inspect and manage power lines in a real time-scale with improved speed, efficiency, safety and systems for data management.

The rest of the paper is organized as follows: Section II explains the theoretical concept of the proposed simplified inspection system and the applied computation technique used in a study. Section III shows the hardware and software design of the proposed system. Section IV reviews testing and computation results of a final solution (designed prototype). Section V presents potential design enhancements. Conclusions are drawn in Section VI.

II. THEORETICAL BACKGROUND

The proposed idea, as well as a design concept, presented in this Section by revealing the main highlights of used computation technique.

A. The Concept of the Proposed System

The proposed system consists of two parts:

1. Hardware, which uses a drone equipped with a thermal camera as a tool (partial design) in order to capture data (thermal photo) of the conductor of the TL at specific inspection points and under onsite conditions (weather and line operating load) in a real-time scale and transmit these data (thermal photo) to the user's machine.
2. Software, the program that uses these captured data (thermal photo) of the conductor temperature of the OHL under particular examined conditions with further interpretation of received results by considering constant and variable impacting parameters. For instance, by assuming or adapting from the existing grid the constant parameters such as conductor specification (type, diameter, DC resistance at 20°C), thermal expansion coefficient of the conductor material, heat emission constant, and by capturing the variable parameters – ambient temperature, wind velocity, the conductor temperature, when a process proceeds in a real-time. Moreover, conductor specification is subject to change depending on the examined TL, but this study considers it as known constant in order to verify and validate the proposed simplified inspection system.

Once the required parameters defined, the throughput current of the TL evaluated based on different considerations. The computational approach explained further in a detailed manner.

B. The Computational Technique

The applied technique includes the following calculation steps:

1. Capture the variable input parameters such as the ambient temperature, wind velocity, conductor temperature by using the drone. This step based on the measuring process (thermal photo and wind speed) and organization of transmission data chain between hardware - transmitter and the user machine - receiver with further application of the developed program.
2. Perform the calculation process in order to define required parameters such as [13, 14]:
   a) Temperature difference, which depends on the conductor temperature (T_c) and the ambient temperature (T_a) presented in °C:

$$\Delta T = T_c - T_a. \tag{1}$$

   b) Average temperature ($T_{avg.}$) in K is calculated as follows:

$$T_{avg.} = \frac{T_c + T_a}{2} + 273. \tag{2}$$

   c) Conductor AC resistance (R_{tc}) depends on the examined conductor type and physical characteristics. In order to calculate this parameter, the conductor DC resistance at 20°C (R_{20} in Ω/m) should be given as well as the thermal temperature coefficient of resistance (α in °C-1):

$$R_{tc} = \frac{R_{20}\left(1+\alpha T_c\right)}{1.08}. \tag{3}$$

   d) A Coefficient for heat exchange through radiation (λ_h in W/m·°C) additionally takes into account ζ, which is a constant of a heat emission (reflects the conductor's ability to radiate thermal energy - surface "darkness") and conductor diameter (d in mm), the following formula used:

$$\lambda_h = 7.24\zeta d\left(\frac{T_{avg.}}{1000}\right)^3. \tag{4}$$

   e) A Coefficient for heat exchange through convention (λ_c in W/m·°C) considers wind velocity (v in m/s) impact, and can be found as follows:

If v≥1.2 m/s, then λ_c calculated as:

$$\lambda_c = 1.1\sqrt{vd}; \tag{5}$$

If v<1.2 m/s, then λ_c calculated as:

$$\lambda_c = 0.16 d^{0.75} \Delta T^{0.3}. \tag{6}$$

   f) Conductor absorbed heat power from solar radiation (Q_r in W/m) depends on the solar radiation value (q_s in W/cm^2) according to the power line location and it is determined as follows:

$$Q_r = 100\zeta d q_s. \tag{7}$$

3. Computation of the throughput current of the examined OHL (I_c in A):

$$I_c = \sqrt{\frac{\left(\lambda_h + \lambda_c\right)\Delta T - Q_r}{R_{tc}}}. \tag{8}$$

The described concept and computation approach adapted to the proposed simplified thermographic inspection system of the power line (both hardware and software parts). The whole system design and the practical application explained in upcoming Sections.

III. Design of the Proposed System

Let us find out main design highlights as well as technical specifications for each part of the proposed system.

A. Hardware Design Specification

The proposed conceptual design of hardware has two main parts:

1. Drone part, which is already finished product available in a market.
2. Electrical circuit part, which is a thermal camera circuit (including additional used components explained further in this Section) connected to a drone part.

In spite of that drone is not developed in this solution, a great effort has been done for its' selection and application.

Different criteria considered while selecting drone such as cost, weight, capacity, safety, efficiency, dimensions, reliability, flight time, etc. The selection of a drone based on the above-mentioned criteria, but taking into account the purpose of a system - a drone is a tool carrying the electrical circuit for the conductor temperature capture (thermal photo capture). The final choice of a drone contains an electronic stability control (ESC) system, ultrasonic and MPU6050 sensors. The idea is to make the final design of the simplified system (prototype) as light and safe as possible by taking into account an ability to control the drone under different circumstances. Mainly to avoid the drone to collide with the phase conductors of the OHL and to stay stable onsite under different weather conditions (preferable under low winds in order to reduce damage risk of the drone and a phase conductor). The safety distance defined from 1.5 m until 2.5 m from the conductor in order to ensure required data capture and transmission.

Quad-copter (DJI Phantom 4 Pro) drone has been chosen for the final prototype design, which provides extra technical possibilities such as five direction of obstacle sensing, six camera navigation system, infrared sensing system (can be used for additional purposes), long flight time that reaches up to 65 minutes and it has remote control (see Fig. 1) [15].

Fig. 1. Visual presentation of the Phantom 4 Pro drone.

The second part includes the designed thermal camera circuit, which connected and attached to the drone. It consists of such main components as AMG8833 IR 88 Thermal Imager Array Temperature Sensor Module (8x8 Infrared Camera Sensor) [16], Raspberry Pi model B microcontroller [17, 18] and some optional components such as assembled pi T-cobbler, connection wires, construction parts.

Raspberry Pi module B is the brain of the prototype and used in order to arrange a connection with the thermal camera (to power on). It has many technical features, for instance, two pins for a normal camera and a thermal camera (pin seven and eight), pin thirteen and pin fourteen are responsible for distance sensor, and required power supply voltage is either 3.3 V or 5 V. Moreover, it could supplied by using an external source such as a battery or from the drone itself. The battery used as a preferable way in order to avoid an effect on the drone flight time in this solution. Other sensors connected to the microcontroller could negatively affect a resolution of the thermal image camera too. The use of Raspberry Pi is simple and it has advantages specifically for the robotics projects and particular drones' applications (see Fig. 2 (a)).

a) b)

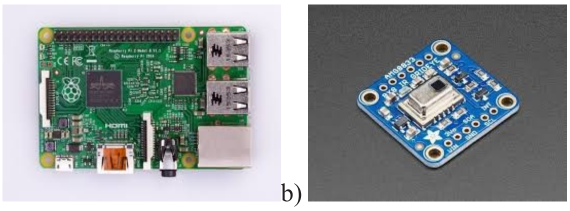

Fig. 2. A visual presentation of the microcontroller (a) and thermal camera (b).

Another core component of the proposed hardware design is the thermal camera, which has a relatively acceptable resolution for a design need and is a low-cost solution. This camera contains six pins. Pin one is a VIN - takes 5V as input. Second pin takes 3V from the thermal camera. The third pin is for the ground. Pin four and five that are SDA (the data line), SCL (the clock line) responsible for dealing with data. Last, pin INT, which provides an attribute to zoom in or to zoom out the thermal image. However, this pin neglected since the Raspberry Pi model B does not have this feature (see Fig. 2 (b)).

B. Software Design Presentation

A huge part of the final prototype related to programming. Four different functions developed in order to perform an optimum solution for the proposed system - code for data capture, streaming, thermal photo capture while the prototype is streaming, and computation the throughput current capacity of the OHL.

The software design ensured the connections with Raspberry Pi module B and included two functions: the first part considers the transmission of the thermal photo that the thermal camera captures (for Raspberry Pi), and the second part performs computations of the throughput current of the examined OHL.

The developed program arranges the following main steps of a procedure of the software application:

1. Call up the file "thermal programmed" from the user desktop.
2. Run the streaming code by clicking on right, click "streaming.m", and then run. It will open and show the graphical user interface.

3. Click on the “streaming” button (it will run the thermal camera and show the live thermal streaming video).
4. Click on “stop streaming” button to take a capture.
5. Run the “thermal image’s”, call up the thermal capture (thermal photo).
6. Select the interested area (overheating location points) in the thermal photo.
7. Input required parameters related to the throughput capacity calculations (for more detail check Section II).
8. Calculate the throughput current of the power line.

C. *Final Prototype Design and Implementation*

Let us explain the operating procedure of the final prototype of a proposed system. The final prototype presented in Fig. 3.

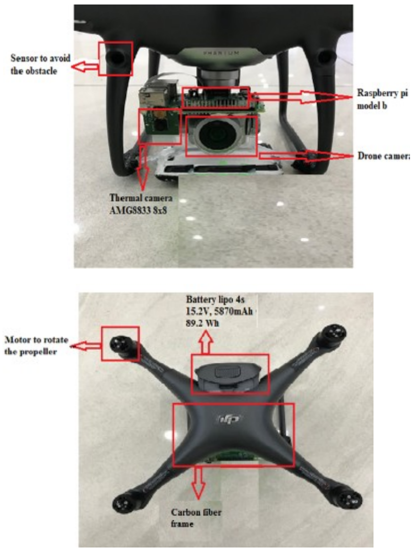

Fig. 3. Presentation of the final prototype design.

In order to perform the operation process of the proposed simplified inspection system, the specific drone used (see the specification above). The function of the drone is to carry the designed electrical circuit to the specific interested area (examined OHL location) nearby a phase conductor in order to ensure data capturing (safety distance ensured).

Raspberry Pi module B connects to the thermal camera and transmits the thermal photo from this camera to the ground server (user). It has a Wi-Fi range of 50 m, which is an optimum solution since phase conductors of the TL located at quite high elevations. For instance, the lowest conductor can be at 10 m from the ground level and up to 50 m and even more, which depends on the power line voltage, construction design, and others. In this way, the drone needs to fly relatively high in order to capture data. Another feature is that it has a fast processing speed and it is easy to use.

The thermal camera has a relatively acceptable resolution, but not fully, as expected at the beginning of the solution realization. Nevertheless, it captures a thermal photo of the conductor and transmits it to the ground server.

Additionally, the power bank batteries used in order to supply Raspberry Pi. This battery has a small weight (8 g) and capacity of 5000 mAh with a low-cost.

Once the required data captured, it sent to the ground server (user), which applies program for the calculations of the throughput current of a power line by interpreting the thermal photo pixels into the conductor temperature under considered weather and TL loading conditions (real-life streaming).

In this way, the final prototype of the proposed simplified inspection system has a high technology safety drone that has a reasonable price, adding a low-cost electrical circuit with a relatively acceptable thermal camera resolution. A combination of this equipment ensures a high-quality prototype. The cost of the proposed system is around 1100 USD, which includes primary components such as drone, thermal camera and Raspberry Pi model B, secondary components (related to the construction of a carbon fiber frame) and shipping costs.

IV. A Realization of Testing of the Proposed Simplified Inspection System

Since the proposed simplified inspection system has two main parts: hardware and software, they tested accordingly.

Testing of the hardware part mainly based on the drone stability as well as capture and transmission of the required data – thermal photo.

The software part tested in terms of interpretation of received data (thermal photo) and computations of the power line throughput current.

Initially, when the thermal camera circuit attached to the drone, the system had a problem with a balance (unstable), thus the extra weight added to drone in order to fix this problem. However, still the drone untenable to fly. Therefore, another drone (the final choice of DJI Phantom 4 Pro) delivered with better technical possibilities, by providing the ability to carry the designed circuit and this was the optimum solution to overcome the barrier.

A lot of work and effort did for ensuring a solution for data (thermal photo) transfer between a drone and ground station. Nevertheless, the appropriate coding developed, and the settled target achieved.

Furthermore, the testing results of a developed program for the calculations of the throughput current of the power line presented in Table I as well as in Fig. 4 and Fig. 5.

Data (thermal photo) used for the program validation are taken from [19], where measurements of the conductor temperature have been done by using thermovision camera so-called FLIR ThermaCAM P65 [20]. However, such measurements done from the ground level, but the drone can ensure the same process directly onsite the examined OHL.

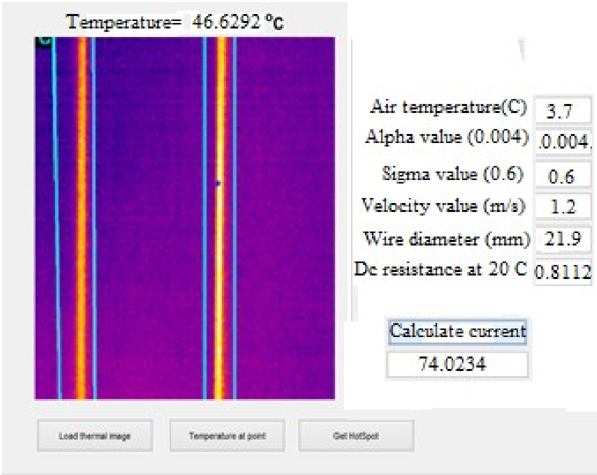

Fig. 4. Thermal photo for the phase conductor 1 of the examined power line.

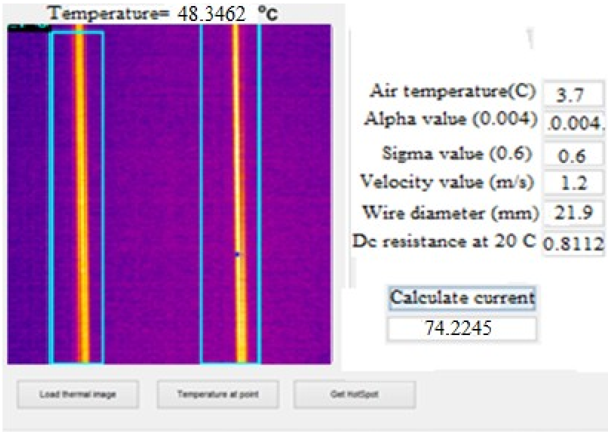

Fig. 5. Thermal photo for the phase conductor 2 of the examined power line.

TABLE I. POWER LINE PARAMETERS, WEATHER CONDITIONS AND VALIDATION RESULTS

Parameter	**Input and output results of the OHL estimation**	
	Phase No. 1	***Phase No. 2***
OHL voltage, kV	110	
Ambient temperature, °C	3.7	
Wind velocity, m/s	1.2	
Conductor diameter[a], mm	21.9	
DC resitance at 20 °C[a], Ω/km	0.8112	
Measured througput current, A	73	
Calculated conductor temperature based on data of a thermal photo, °C	46.63	48.35
Calculated througput current, A	74.02	74.23
Difference, %	1.4	1.7

[a.] The conductor type is AS-240/32 mm^2 (two conductors per phase).

As a result, the difference between calculated and actual throughput current of the OHL is quite small for the conductor phase 1 – 1.4 % and for the phase 2 – 1.7 % due to a little bit different conductor temperatures, which is reasonable since conductor phases are located with a distance between each other (TL design requirements). Moreover, calculations performed considering specific weather conditions and the power line loading. Worth to notice that the proposed simplified inspection system should use for other experimental measurements (different case studies); hence, this is a basis for future research.

Unfortunately, the authors could not use the designed inspection system fully for a settled target because of a required license in Kuwait. To avoid any problem with using the drone and thermal vision technology (thermal camera), the user has to get a license from the Ministry of Interior (MOI) to be able to use the drone and thermal camera. The drone could applied only in specific areas [21, 22]. In spite of the above-mentioned shortage in terms of adapted experimental data for the testing results, partial verification and validation process applied as planned before.

V. POTENTIAL DESIGN ENHANCEMENTS

Several options and features need to add and improve for the proposed simplified inspection system prototype. Some of them are the following:

1) Replace existing thermal camera with another one, which has higher resolution.

2) Consider drone, which has a higher safety level and adds a notification about the emergency case of any technical problem of the drone by ensuring its' safe landing.

3) Add the autopilot system. When the user interested in an examination of the specific OHL, the drone automatically flies there (power line location) and starts capturing the required data onsite.

4) Create adaptable databases for different conductor types in order to ensure rapid access to the transmission network parameters. Moreover, it will provide a possibility to identify rapidly problems related to overheating of the TL components as well as to evaluate throughput capacity issues.

VI. CONCLUSIONS

1. The prototype designed successfully for the simplified thermographic inspection system of the OHL by achieving the design requirements.

2. Use of a designed drone provides an effective, remote and flexible way to inspect power lines in a real time-scale with improved speed, efficiency, safety as well as accuracy.

3. The drone maintains stable after the circuit of a thermal camera attached.

4. The capture and transmission of data performed relatively accurate (pointed drawback is a thermal camera type). The developed program for the throughput current estimation of the power line verified.

5. Testing results show the validity of the calculated throughput current as compared to the actual one by presenting the quite a small difference between them, which justify computations.

6. Many problems appeared in the designing process of the prototype. Therefore, the proposed simplified system for the OHL inspection needs technical

enhancements mentioned above in order to perform an accurate and automatic computation process.

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