Setup and preliminary results of an Online Thermal Condition Monitoring System for MV Cable Joints

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Abstract— **Collaboration with the Electricity Authority of Cyprus (EAC) and the University of Cyprus (UCY) has allowed development of an experiment in a distribution substation. Temperature condition monitoring units were installed on selected underground cable joints within MV sub-station in Cyprus. Real-time current loading data, weather conditions as well as surface temperature by the cable joints are used for the development of the thermal prognostic models. This paper introduces a novel thermal condition monitoring system and presents the first preliminary results.**

Keywords—Condition Monitoring; Support Vector Regression; Diagnostic; Prognostic; Insulation System.

I. INTRODUCTION

The power network distributors aim to provide a safe and reliable electricity supply to all of their consumers. Unfortunately failures in the power networks are still very common and difficult to predict [1].

Due to the growing number of failures within the power networks, development of a reliable condition monitoring predictive capabilities is of a great importance as utility companies will achieve a better performance in their asset management and could identify possible weaknesses within their power networks.

The aging process in underground cables starts once they are put into operation. A combination of mechanical, thermal and electrical stresses as well as environmental conditions [2] are the main aging factors affecting the lifetime of a cable. The most common location of cable failures is by the cable joints [3, 4].

The aging of the underground cables is mainly affected by the thermomechanical aging process. The cyclical heating and cooling of the cable due to the daily load demand causes movement and bending of the underground cables. That process can cause formation of microvoids inside the joints which under wet or dry environmental conditions can result in water or electric trees [5] and therefore can cause failure of the joints.

A combination of high ambient temperatures and high cable loading demands can cause drying out and movement of the soil around the cable joint which can lead to the overheating of the cable joint and thus breakdown of insulation of it [6].

For research into condition monitoring of power cables, Cyprus represents an ideal system to study as it is an islanded network that sees heavy demand during the tourist season as well as being far smaller and less complex in design compared to UK distribution networks.

The environmental conditions in Cyprus (dry hot summers, mild winters) are different to the ones of UK and can be beneficial not only to investigate the lifetime of the underground cables in different environments, through the analysis of the data collected in these locations, but can as well contribute towards the development of a reliable condition monitoring thermal prognostic indicator system which can effectively operate in a various environmental conditions.

Collaboration with the University of Cyprus (UCY) and the Electricity Authority of Cyprus (EAC) has allowed the development of an experiment in the field. Field measurements in MV substations in Cyprus have taken place. It involves monitoring of weather conditions such as solar radiation and air ambient temperature, temperature by the underground cable joints and circuits current loading in order to gain data which is used for the development of the condition monitoring thermal prognostic indicator system. Joints closest to the substations are chosen as local experience shows that they have the highest potential risk of failure and have the easiest accessibility.

This work is the first step towards the development and implementation of an online condition monitoring thermal prognostic indicator system for underground cable joints. The main objective of this system is to identify the performance and the possibility of developing a prognostic capability which is able to evaluate real-time the health state and the long term performance of the monitored distribution cable circuits. Development of such a prognostic models will improve drastically the prognosis accuracy and will allow EAC to plan more effectively the maintenance of the cable circuits and to reduce the in-service failures of the MV cable joints.

It is assumed that an increase of the local cable temperature is indicative of accelerated aging of the cable insulation due to thermomechanical, electrical and environmental factors.

This work is supported by the Research Councils UK, through the HubNet consortium, www.hubnet.org.uk (grant number: EP/I013636/1)

II. EXPERIMENTAL SETUP

The installation took place at Agios Georgios substation in Larnaca (132/11KV), Cyprus. EAC found and exposed four cable joints. The first cable joint is a straight 3-phase PILC, the second is three XLPE straight joints and the last two cable joints are transition joints XLPE to PILC. Figure 1 shows the corresponding joints.


PILC-PILC
Circuit 1
XLPE-XLPE
Circuit 2
XLPE-PILC
Circuit 3
XLPE-PILC
Circuit 4

Fig. 1 Cable joints under investigation

First the cable joints where uncovered and exposed by EAC, then a power outage took place for each of the joints in order to install the thermocouples (TCs) in different locations along the exposed cable joint length. As a final point cable joints were covered by inserting the appropriate backfill and placing the condition monitoring units inside the ground.

A monitoring unit, shown in Figure 2, consists of a datalogger which logs the temperature of the TCs distributed across the cable joint length. The datalogger can be accessed remotely over a dedicated Internet connection via TCP/IP protocol. The four monitoring units, one for each cable joint, were assigned to a unique public IP address and connected via ethernet cable to a router. The data are collected from the dataloggers twice per day by communication over the Internet connection.

Fig. 2 Monitoring unit

In addition to the temperature logging of the cable joints, a current loading of the four cable joint circuits is monitored as well. Four 3-phase Rogowski coils are used to measure the current loading through the cables for each of the circuits of the cable joints in real-time. The secondary output from the Rogowski coils is an instantaneous DC voltage proportional to the measured primary current. A multiplexer was used to log the current measurement for each of the circuits.

A power control unit is located inside the substation which consists of four 18 VAC transformers which are connected to four mains. The transformers are connected to four regulator units. The regulator unit is responsible for charging the 12V battery, which powers up the datalogger, as well as to supply a constant regulated 12 V output to the datalogger. In case of a power interruption the batteries are enabled and back-up power is provided to the data loggers.

An underground pipe for each data logger was installed for an ethernet cable and the power lead cable to pass. The ethernet cable connects the datalogger to the router, communication unit, and the power lead cable connects the datalogger to the power control unit. For the last datalogger, assigned as Datalogger_4, extra connection wires were required to pass through the underground pipe in order to establish the connection between the outputs of the Rogowski coils, the multiplexer and the Datalogger_4. The schematic shown in Figure 3 represents the overall connection in the substation.

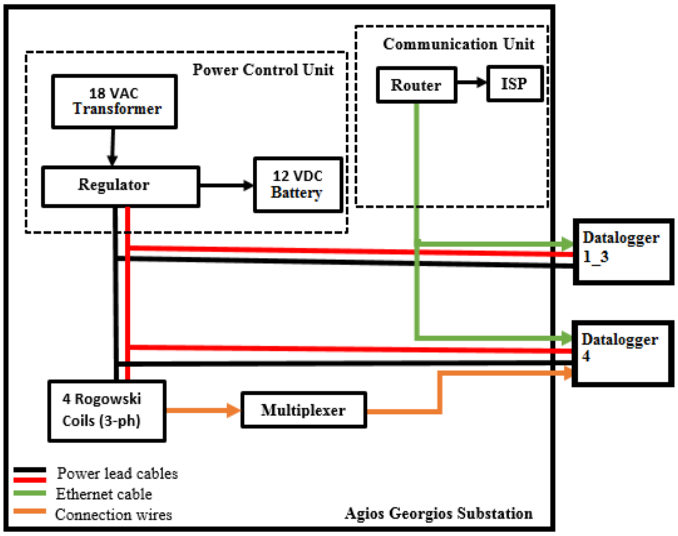

Fig. 3 Schematic diagram of the connection inside the substation

III. THERMAL PROGNOSTIC MODEL

Support Vector Regression (SVR) is a machine learning algorithm which uses a non-linear mapping to transform data into a high dimensional feature space where linear regression is performed [7]. The main advantages of SVR over other machine learning algorithms used for regression is that SVR avoids overfitting problems and is able to create models which are less complex and always converge to a solution [8].

A thermal prognostic model developed using the SVR algorithm is able to predict the possible temperatures along the cable joint length 30 minutes into the future. Anomalies in temperature measurements along the cable joint compared to model output temperature prediction can indicate a possible sign of degradation activity in the cable. The LIBSVM toolbox [9] in Matlab was used for the development of the thermal prognostic model. The Figure 4 shows the flowchart used to develop the thermal prognostic cycle.

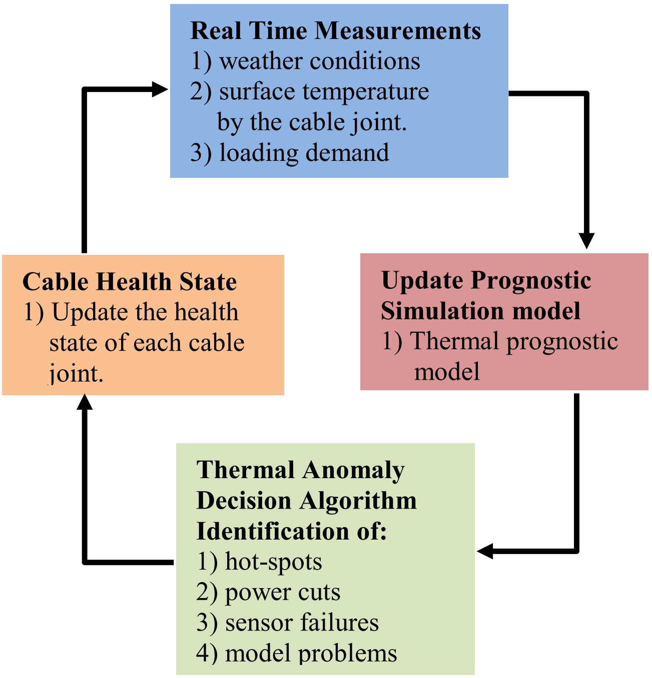

Fig. 4 Thermal Prognostic Cycle

The thermal prognostic model was developed for Circuit 4. The surface temperature of TCs located faraway form the cable joint, solar radiation, air ambient temperature and cable loading are the input parameters to the SVR model which predicts the temperature of the TC located on the surface of the cable joint. Initially the model is trained for 14 days, tested for 3 days and the corresponding Mean Absolute Percentage Error (MAPE) is calculated as defined by:

$$\mathrm{MAPE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{y_a(i) - y_p(i)}{y_a(i)}\right| \qquad (1)$$

where y_a is the real value of TC temperature, y_p is the predicted value of TC temperature and n is the total number of samples. This stage is vital for the prediction accuracy of the model as it identifies the performance of the newly trained model on the unknown tested data set. After the confidence gained during the testing period the model continues to run unchanged.The first initial results for the cable joint of Circuit 4 are presented in Figures 5 and 6.

The obtained results show the satisfactory performance of the themal prognostic model. During the investigated period of time there were not detected any possible signs of hot-spots in the underground cable joint. The MAPE during the testing period is 0.87% and for the unknown data period is 0.90% which is very close to the previous value. Furthermore it can be clearly seen that the predicted temperature very closely matches the measured temperature.

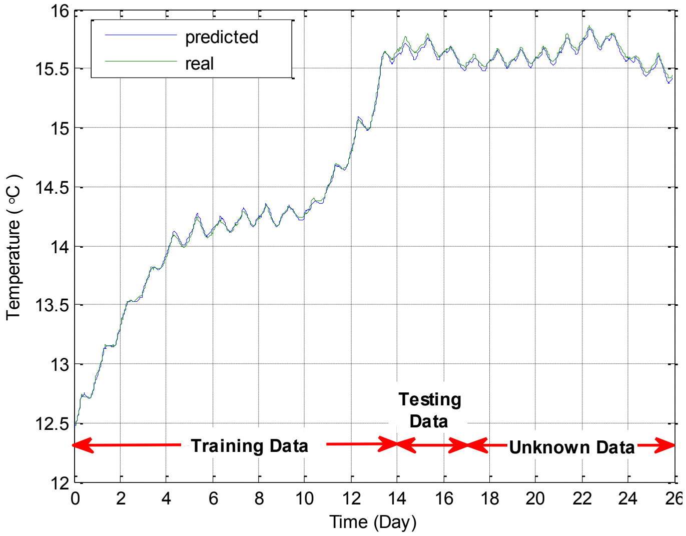

Fig. 5 Comparison between predicted temperature on testing data (MAPE=0.87%) and unknown data (MAPE=0.90%) with the real temperature of TC located on the surface of joint of Circuit 4.

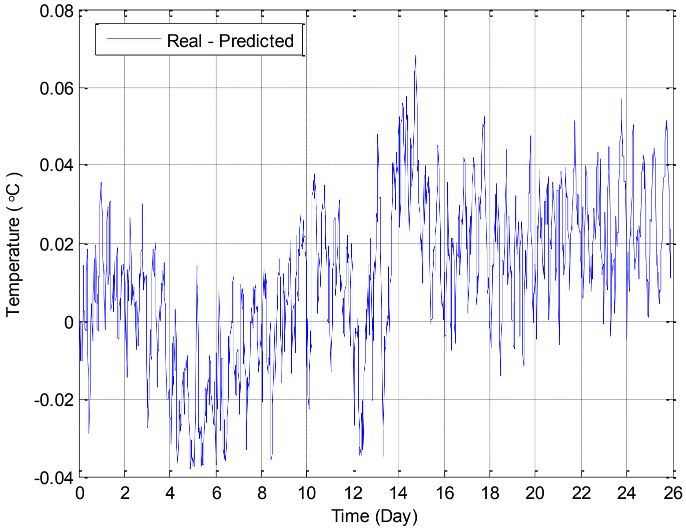

Fig. 6 Temperature prediction error for TC located on the surface of joint of Circuit 4

IV. CONCLUSION

This paper describes the development of an online thermal prognostic tool based on the SVR algorithm. The developed model is able to detect and identify abnormal temperatures along the cable joint length in a time prediction horizon of 30 minutes into the future.

The performed temperature prediction of the model can be used to detect the possible degradation activity in the cable and the cable joints at an early stage. Implementation of such models will enable to monitor and observe online the health state of the cable joints where hot-spots tend to appear due to constant exposure to the thermomechanical stresses and the fragile nature of the cable joints.

The application of the developed online thermal prognostic condition monitoring systems propagates the smarter way of the condition monitoring within the power networks and can be beneficial for the power network operators to improve the reliability of their assets and reduce the maintenance costs by measuring less and modeling more.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support of this work by the Research Councils UK, through the HubNet consortium, www.hubnet.org.uk (grant number: EP/I013636/1). The authors gratefully acknowledge the contributions of the team from the EAC for their work on installing the monitoring systems as well as the University of Cyprus.

REFERENCES

[1] H. Liu, Y. Bai, M. Liang, H. Chen, and X. Ren, "Research of state monitoring and pre-warning system of cable joint in distribution power grids," Int. Conf. Power Syst. Technol. POWERCON 2006, pp. 1–5, October 2006.

[2] J. Densley, "Ageing mechanisms and diagnostics for power cables - an overview," IEEE Electrical Insulation Magazine, vol. 17, no. 1, pp. 14–22, January 2001

[3] R.N. Hampton, R.A. Hartlein, J. Perkel, M. Begovic, J.C. Hernandez, and Y. Del Valle, "Diagnostic Testing of Underground Cable Systems" (Cable Diagnostic Focused Initiative) – Final Report DOE Award No. DE-FC02-04CH11237, pp 1-328, 2011.

[4] K. Uchida, S. Kobayashi, T. Kawashima, H. Tanaka, S. Sakuma, K. Hirotsu, and H. Inoue, "Study on detection for the defects of XLPE cable lines," IEEE Trans. Power Deliv., vol. 11, no. 2, pp. 663–668, April 1996.

[5] E. F. Steennis, P. Buys, R. Meier, J. Mosterd, P. Soepboer, P. Oosterlee, and L. Bokma, "The effect of high current loads on joints in MV cable systems," in *International Conference on Electicity Distribution*, 2011, pp. 6–9.

[6] R. Jongen, E. Gulski, and J. Smit, "Failures of medium voltage cable joints in relation to the ambient temperature." pp. 1–4, 2009.

[7] V. Vapnik, "The Nature of Statistical Learning Theory," Springer,1995.

[8] E.G. Ortiz-García,et al., "Accurate local very short-term temperature prediction based on synoptic situation Support Vector Regression banks," Atmospheric Research, Volume 107, pp. 1-8, April 2012.

[9] C. Chang and C. Lin. "LIBSVM: a Library for Support Vector Machines", April 2005, http://www.csie.ntu.edu.tw/~cjlin/libsvm.