MÜHENDİSLİK FAKÜLTESİ
Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Niğde Ömer Halisdemir University Journal of Engineering Sciences
Araştırma makalesi / Research article
www.dergipark.org.tr/tr/pub/ngumuh / www.dergipark.org.tr/en/pub/ngumuh

Detection of micro-cracks in PV system using electroluminescence (EL) testing

Elektrolüminesans (EL) testi kullanılarak FV sistemindeki mikro çatlakların tespiti

Hale Bakır[1,*]

[1] Department of Electronics and Automation, Sivas Cumhuriyet University, Sivas, Türkiye

Abstract

With the increase in the use of solar energy, the investigation of the failures that cause the decrease in efficiency and loss in production is increasing day by day. It is extremely beneficial to conduct on-site testing of solar systems in order to evaluate the plant's actual performance and identify potential problems. There are important methods for on-site and fast detection of failures. In this study, the failures in the panels were analyzed using the Electroluminescence test, which is one of the most reliable methods for the detection of micro-cracks, and 11 failures were detected as a result of the EL imaging. The EL test, which is the most reliable method for detecting micro-cracks, has been compared with infrared thermal images and its superiority has been proven. Energy losses were prevented by intervening in the field with rapid fault detection.

Keywords: Detection of failures, Electroluminescence test, Energy losses, Solar energy

Öz

Güneş enerjisi kullanımının artması ile birlikte verimin düşmesine ve üretimde kayıplara sebep olan arızaların araştırılması gün geçtikçe artmaktadır. Tesisin gerçek performansını değerlendirmek ve potansiyel sorunları belirlemek için güneş enerjisi sistemlerinin yerinde test edilmesi son derece faydalıdır. Arızaların yerinde ve hızlı tespiti için önemli yöntemler mevcuttur. Bu çalışmada mikro çatlak tespiti için en güvenilir yöntemlerden biri olan Elektrolüminesans test kullanılarak panellerdeki arızalar analiz edilmiş ve EL görüntüleme sonucunda 11 arıza tespit edilmiştir. Mikro çatlakları tespit etmede en güvenilir yöntem olan EL testi kızılötesi termal görüntüler ile karşılaştırılmış ve üstünlüğü kanıtlanmıştır. Hızlı arıza tespiti ile sahada müdahale edilerek enerji kayıplarının önüne geçilmiştir.

Anahtar kelimeler: Arıza tespiti, Elektrolüminesans testi, Enerji kayıpları, Güneş enerjisi

1 Introduction

Photovoltaic (PV) modules are the core of every PV system and the malfunctioning of these panels, which represent power generation, affects the overall plant performance. It is one of the elements in a PV site with a higher failure outlook, which is essential to produce reliable, efficient and safe energy. Maintenance of large-scale PV power plants has been viewed as an outstanding challenge for years. Quantitative analysis and characterization of fabrication, soldering, and PV defects is accomplished by electroluminescence (EL) visual inspection [1]. EL imaging has become some test procedure for fault detection of solar modules throughout the manufacturing, operating phases and installation. Defects such as micro-cracks, finger cuts and broken cells in k-modules can be quickly detected using this test, and PV potential power loss issues can be addressed powerful. The EL test is a very effectively examination method [2]. EL imaging is an embedded non-destructive technology for fault analysis of PV modules with the ability to display solar modules at a much higher resolution [3]. Defective cells appear darker on EL imaging, as disconnected portions do not irradiate. An EL image is obtained by applying a current that induces EL emission at a wavelength of 1150 nm to a PV module. The emission can be monitored with a silicon charge coupled (CCD) sensor device. Spatial image with high resolution enables detection of micro-cracks [4] and no blurring in EL imaging as there is lateral heat dissipation. However, visual inspection of EL images at night or in laboratories takes time, and this is done by trained professionals. Comprehensive knowledge of the properties of defects requires techniques to extract electrical data by providing information on physical origin, spatial distribution, or defect concentration [5].

Some studies used a combination of thermal and EL measurement techniques [6]. Such measurement techniques provide images with two-dimensional distribution of the properties of PV fast, high-resolution modules and real-time [7-8]. EL is excellent for series resistance monitoring, lifetime mapping, link fault zone monitoring [9]. EL is an effective technique for intermittent contacts, detecting micro-cracks or a series of operating faults, arguably a good method for determining the effect of these defects on module power output [10]. It can be used in the production process, the modules are disassembled from or in the field and shipped to the laboratory, or by going to the power plant at night, with EL cameras mounted on UAVs or a structure or a special tripod. As a result of this test technique, the emission intensity captured by an EL camera, thanks to the radiative recombination of charge carriers, is determined as

* Sorumlu yazar / Corresponding author, e-posta / e-mail: halebakir@cumhuriyet.edu.tr (H. Bakır)
Geliş / Recieved: 22.06.2023 Kabul / Accepted: 25.10.2023 Yayımlanma / Published: 15.04.2024
doi: 10.28948/ngumuh.1318611

the brightness displayed in the cell and indicates whether the cell or panel is defective and works accordingly. The EL test can give better results than the IRT test in detecting some faults, but it is weak in detecting some faults [11]. While the rate of detecting micro-cracks is 90-95% with the EL test, this rate is between 5-10% in the IRT test [12-13]. In terms of cost, the IRT test performs thermal imaging of many airborne panels at the same time and is more cost-effective. In the EL test, each panel must be examined in a laboratory environment or individual panel images must be taken even in the field, which results in higher costs [12-13]. In this study, EL test images and thermal images were compared and the advantages of the EL test and the weak points of the IRT test regarding the detection of micro-cracks are given.

2 Material and methods

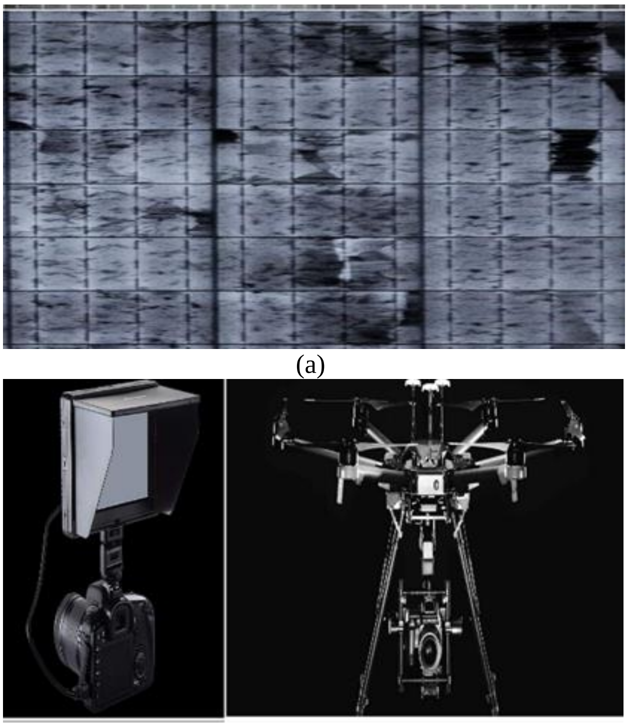
2.1 Solar power plants

Solar power plants are power plants that convert energy particles from sunlight into electrical energy. Solar cells are used in power plants, similar to those in calculators, but in larger sizes. Solar cells are photovoltaic. They convert incoming sunlight into electricity. The main ingredients of these batteries are crystalline silicon and gallium arsenide. Solar power plants are a profitable energy way in terms of construction-operation costs and efficiency. It is widely used for these reasons. It is one of the energy production systems of the future in terms of minimizing the damage to nature. A 300 kW solar power plant is shown in the Figure 1.

Figure 1. Solar power plant

2.2 Electroluminescence (EL) test

The electroluminescence imaging technique is based on the principle that the energy obtained by the re-combination of the electron in the forward polarized state of the C-Si semiconductor emits photons. Fault detection is made by capturing photons by suitable digital cameras [3]. In this fault detection, a certain current of the module passes through the PV cell. Radiation emitted from the module in this test, which is carried out in a dark environment, is determined by an EL camera. Radiation has a wavelength of about 1100 nm and is in the invisible spectrum and can be considered near infrared [14]. Solar panels, which produce electricity during the day, are connected to a power source and emit radiation in the form of infrared light spectrum that is impossible to see in the dark. EL images, similar to x-ray images, have high resolution. Active cells appear bright grey, damaged or inactive cells appear dark-black as shown in Figure 2(a). The grey scale in the acquired images provides to determine the extent and cause of the damage in your SPP site. In this method, problematic solar panels can be detected for further laboratory testing. With this qualified imaging method, damages reasoned by mechanical stresses such as installation, transportation, hail, snow, and faulty bypass diodes can be detected quickly. However, deterioration in cells, broken cells, short circuits and malfunctioning panels can be easily detected. On-site Electroluminescence testing is currently the most cost-effective method on the market for the early and clear detection of potential or existing problems of PV panels. Figure 2 (b) shows a EL camera mounted on a drone.



(a)

(b)

Figure 2. (a) Damaged cells, (b) EL camera on a drone

3 Results and discussion

Electroluminescence imaging is a method that provides information about the crystal structure on the cells that make up the module by analyzing the light in the upper infrared wavelength emitted by the PV modules as a result of voltage feedback. Micro cracks on the module, problems during cell and module production (soldering defects, ohmic contacts, etc.), malfunctions in module assembly and non-operating areas are easily determined.

In this study, according to the EL imaging conditions in Table 1, applied voltage is 49 V, applied current is 2 A, camera resolution is 6000x4000 pixel, focus length is 18 mm. Panel specifications and electrical values are given in Table 2. Values such as short circuit current and open circuit current are given according to bifacial gain values. It is also seen that the panel efficiency increases proportionally.

Panels tested by EL camera are shown in Figure 3. EL images taken with an electroluminescence test device are shown in Fig. 4-5. In Figure 4(a), the broken cells are seen in the darkest black areas with the EL test. In total, 8 broken cells were detected, as can be seen in Figure 4 (a-d). The problem cell is shown in Figure 5(a) with the EL test. In total, 3 problematic cells were identified, as can be seen in Figure 5 (a-c). With the EL test method, fast and precise resolution of failures is achieved. Cracks and breakages are visible. How-ever, the type of failure occurring in the problematic cells is determined and energy losses are prevented by on-site intervention. Micro-cracks are cracks that occur on the panels and are difficult to see with the naked eye. Micro-cracks of the panel; may occur during production, transportation and installation phases. Although these cracks do not show their effect during the first installation and electricity generation, they may cause a decrease in the efficiency of the panel with the increase in the size of the cracks in the following periods. Any defects in solar cells, such as cracks, poorly soldered connections, and mismatches, cause higher resistance and become hot spots in the long run. A typical EL imaging setup is shown Figure 6. As a result, in this study, the number of samples displayed is 4, the number of cells displayed is 576, the number of damaged (broken / cracked / possible problem etc.) cell is 11. It is observed that the fractures/cracks detected in the panels have similar characteristics. This situation is not due to manufacturing defect, but rather transportation or assembly. It seems that the pressure applied to the panels during the process was created by impact. This should be compared and confirmed with their current condition by requesting the panel manufacturer's ex-factory electroluminescence images and IV measurements of the panels. Although it is thought that the detected “Possible Faulty” cells are not of the type that will affect the production at the moment, they are checked periodically. It is recommended to follow their development/progress.

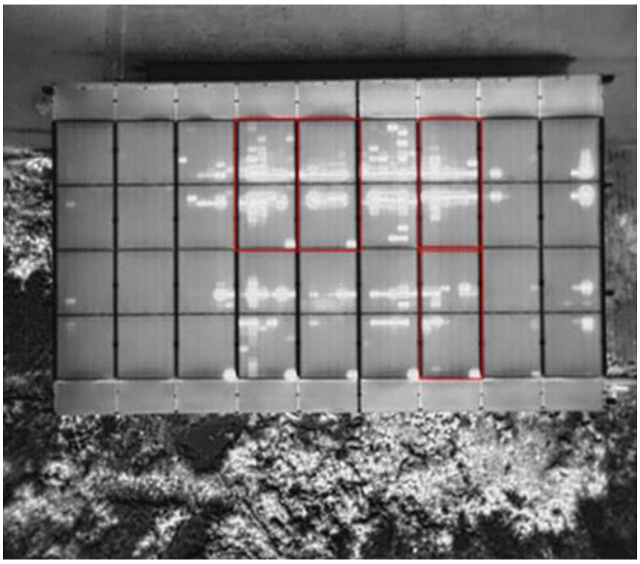


Figure 3. Solar power plant

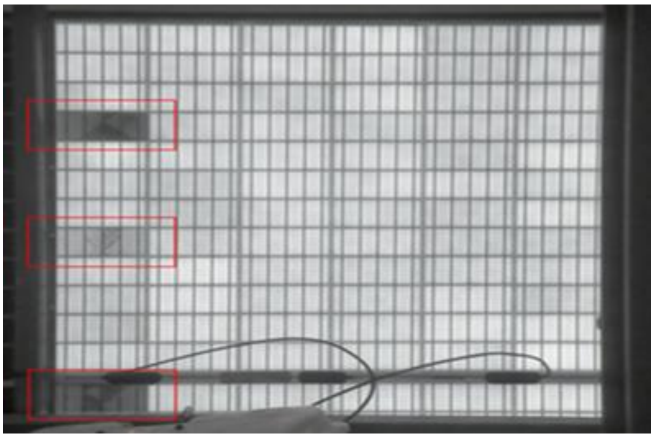
Although measurements with infrared thermal cameras in Figure 7 are very popular, they are insufficient in detecting micro-cracks. According to the tests performed, the images obtained with the thermal drone are given in the Figure 8 (a)-(b). The detected fault type is the hot spot, that is, the point heating fault, which occurs with the square geometry in a single cell [15]. The fault is detected as point brightness. What kind of fault type there is must be determined again by going to the field. However, according to these results, the EL test is more effective, reliable and superior to infrared thermal imaging in detecting micro-crack defects. And this is clearly seen from the images [15].

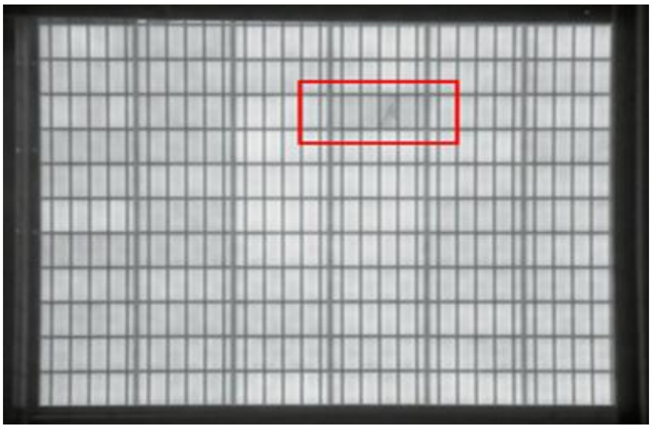
Table 1 EL imaging conditions

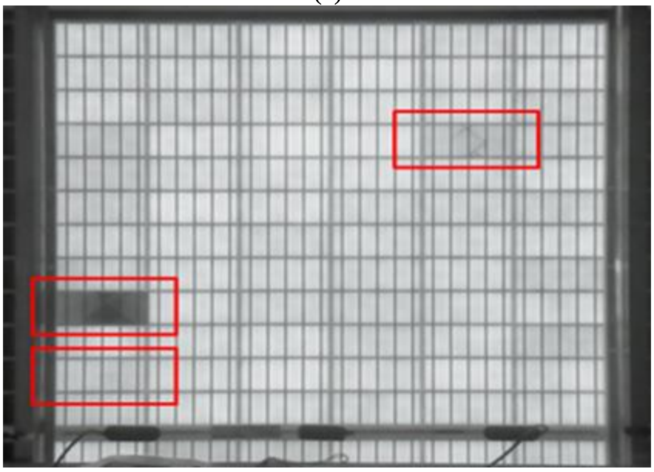
Applied Voltage	Applied Current	Camera Resolution	Focus Length
49 V	2 A	6000x4000 pixel	18 m

Table 2. EL imaging conditions

Bifacial gain	Nominal power (Pmpp)	Nominal current (Impp)	Nominal voltage (Vmpp)	Short circuit current (Isc)	Open circuit voltage (Voc)	Panel efficiency
%5	414.75	10.24	40.52	10.11	49.72	20.23
%10	434.5	10.73	40.52	10.55	49.72	21.19
%20	474	11.70	40.52	12.05	49.72	23.12
%30	513.5	12.67	40.52	13.05	49.72	25.05


(a)


(b)


(c)

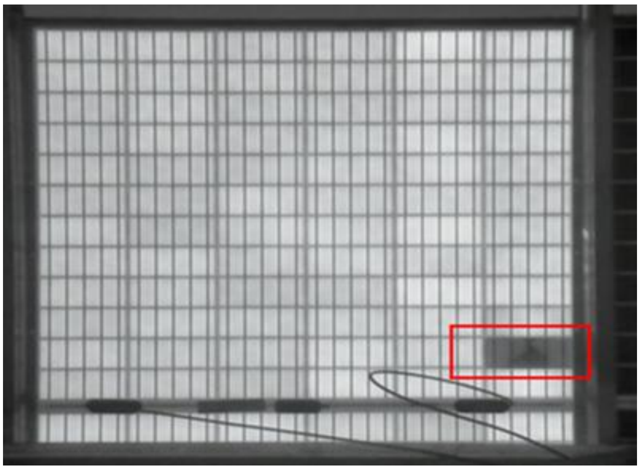
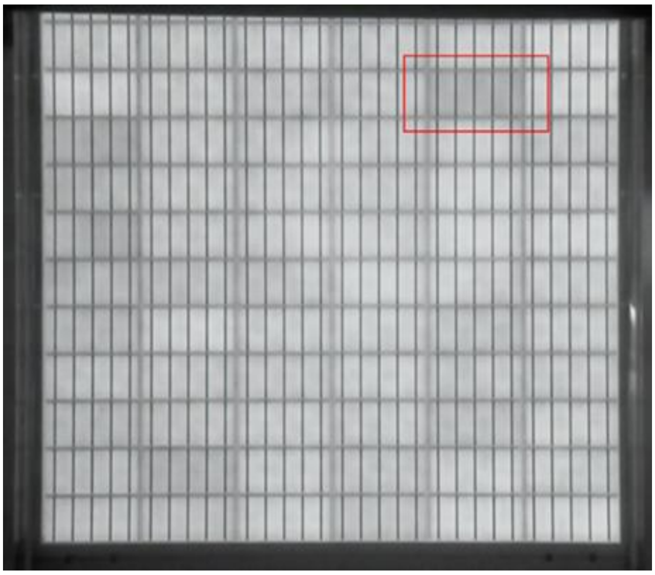

(d)

Figure 4. (a-d): EL images of broken cracked cells taken with an EL test device [16]


(a)

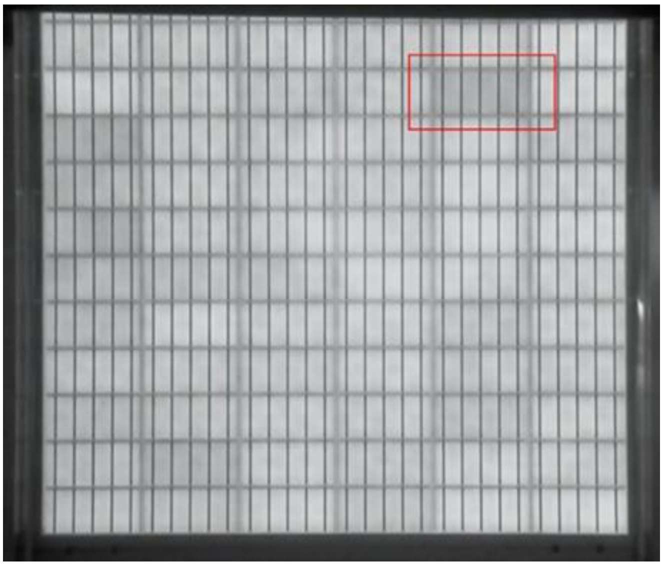
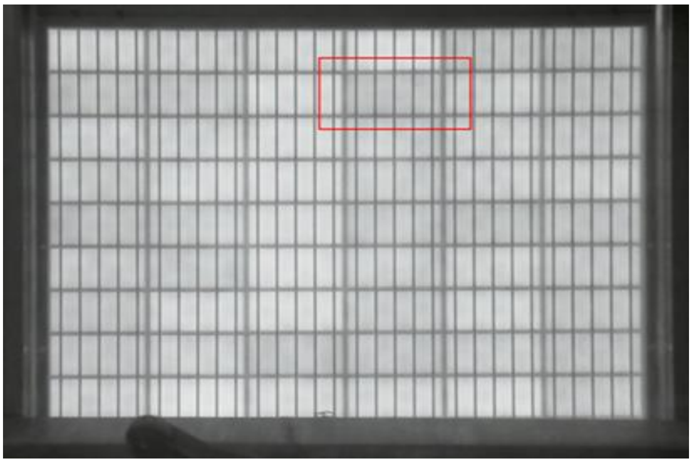

(b)

Figure 5. (a-c) EL images of problem cells taken with an EL test device



(c)

Figure 5 (continue). (a-c) EL images of problem cells taken with an EL test device

Figure 6. A typical EL imaging setup

Figure 7. Thermal camera (Thermal drone)

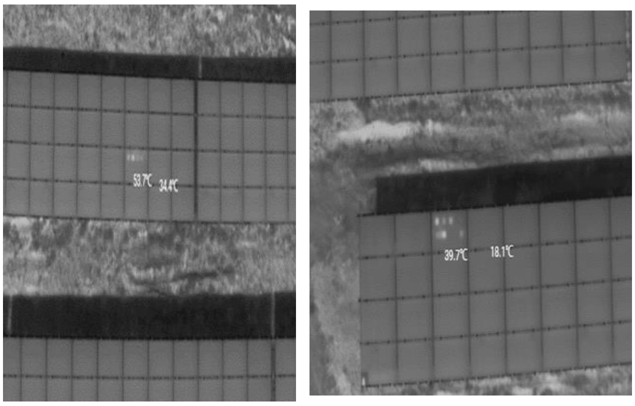


Figure 8. Thermal camera (Thermal drone)

4 Conclusions

While it can be used in the production process, the modules are dismantled from the field or field and sent to the laboratory, measurements are made with EL cameras mounted on UAVs or a structure or a special structure by going to the power plant under night conditions, and the images are shown in this study. As a result of this testing technique, the emission intensity captured by an EL camera, thanks to the radiative recombination of charge carriers, is determined as the brightness displayed in the cell and indicates whether the cell or panel is faulty and operates accordingly. The EL test can provide 90-95% better results than the IRT test in detecting some faults (micro cracks). In the IRT test, this rate is very low because it is insufficient to detect miro cracks. In the images provided, it is seen that it is faster and more affordable in terms of cost since remote measurements are made with a thermal camera, but the ability to detect micro cracks from such a distance is between 5-10%. The IRT test, which is advantageous in detecting other faults, is insufficient at this point and the tendency towards EL testing is increasing. The methods used for fault detection have various advantages and disadvantages, and based on these, PV plant operators who apply only one of these techniques generally aim for rapid fault detection and rapid problem resolution in operation and maintenance activities. Considering the structure of the parameters to be measured, the project site and other factors, it is recommended to use the most appropriate method for failure detection.

Acknowledgement

The companies that provided the thermographic images are thanked: Bakır Automation and Energy company and PETA Aerial Analysis company

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Similarity rate (iThenticate): 13%

References

[1] S. Gallardo-Saavedra, L. Hernandez-Callejo, MD. Alonso-Garcia, JD. Santos, JI. Morales-Aragones, V. Alonso-Gomez, A. Moreton-Fernandez, MA. Gonzalez-Rebollo, O. Martinez-Sacristan, Nondest ructive characterization of solar PV cells defects by means of electroluminescence, infrared thermography, I-V curves and visual tests: Experimental study and comparison. Energy, 205, 2022. https://doi.org/10.1016/j.energy.2020.117930

[2] M. Y. Demirci, N. Besli, A. Gumuscu, Efficient deep feature extraction and classification for identifying defective photovoltaic module cells in Electroluminescence images. Expert Systems with Applications, 175, 2021. https://doi.org/10.1016/j.eswa.2021.114810

[3] T. Fuyuki, H. Kondo, T. Yamazaki, Y. Takahashi, Y. Uraoka, Photographic surveying of minority carrier diffusion length in polycrystalline silicon solar cells by electroluminescence. Applied Physics Letters, 86 (26), 2005. https://doi.org/10.1063/1.1978979

[4] O. Breitenstein, J. Bauer, K. Bothe, D. Hinken, J. Muller, W. Kwapil, MC. Schubert, W. Warta, Can Luminescence Imaging Replace Lock-in Thermograph y on Solar Cells IEEE Journal of Photovoltaics, 1 (2), 159-167, 2011. https://doi.org/10.1109/Jphotov.2011.2169394

[5] S. Duenas, E. Perez, H. Castan, H. Garcia, L. Bailon, The role of defects in solar cells: Control and detection Defects in solar cells. Proceedings of the 2013 Spanish Conference on Electron Devices Valladolid, Spain, 2013. https://doi.org/10.1109/CDE.2013.6481402

[6] R. Ebner, S. Zamini, G. Újvari, Defect analysis in differ rent photovoltaic modules using Electroluminescence (EL) and Infrared (IR)-thermography, 25th European Photovoltaic Solar Energy Conference and Exhibition / 5th World Conference on Photovoltaic Energy Conversion, Valencia, Spain, 2010. https://doi.org/10.4229/ 25thEUPVSEC2010-1DV.2.8

[7] R. Ebner, B. Kubicek, G. Ujvari, S. Novalin, M. Rennhofer, M. Halwachs, Optical characterization of different thin film module technologies. Interna tional Journal of Photoenergy, 2015. https://doi.org/ 10.1155/2015/159458

[8] I. Pvps, I. Tsanakas, JS. Stein, KA. Berger, S. Ranta, T. Tanahashi,. Z. Bayern, Review on Infrared and Electroluminescence Imaging for PV Field Applications, Technical Report T10-13, 2018.

[9] W. Warta, MC. Schubert, W. Kwapil, J. Müller, D. Hinken, K. Bothe,. O. Breitenstein, Luminescence Imaging versus Lock-in Thermography on Solar Cells and Wafers, 26th European Photovoltaic Solar Energy Conference and Exhibition, 2011 https:/doi.org/10.4229/26thEUPVSEC2011-2CO.13.5.

[10] S. Deitsch, V. Christlein, S. Berger, C. Buerhop-Lutz, A. Maier, F. Gallwitz, C. Riess, Automatic classification of defective photovoltaic module cells in electroluminescence images. Solar Energy, 185, 455-468, 2019. https://doi.org/10.1016/j.solener.2019.02.067

[11] H. Bakir, Detection of Faults in Photovoltaic Modules of SPPS in Turkey; Infrared thermographic diagnosis and recommendations. Journal of Electrical Engineering & Technology.18(3), 1945-1957, 2022. https://doi.org/10.1007/s42835-022-01245-6

[12] M. Cubukcu, A. Akanalci, Real-time inspection and determination methods of faults on photovoltaic power systems by thermal imaging in Turkey Renewable Energy, 147(1) 1231-1238, 2020. https://doi.org/10.1016/j.renene.2019.09.075

[13] H. Açıkgöz, D. Korkmaz, Elektrolüminesans görüntülerde arızalı fotovoltaik panel hücrelerin evrişimli sinir ağı ile otomatik sınıflandırılması, Fırat Üniversitesi Müh. Bil. Dergisi, 34(2), 589-600, 2022 https://doi.org/10.35234/fumbd.1099000

[14] R. Evans, Interpreting module EL images for quality control Proceedings of the 52nd Annual Conference, Australian Solar Energy Society, 2014 http://solar.org.au/papers/14papers/%23117_final.pdf

[15] H. Bakır, Thermal image analysis for fault detection of PV systems in Ankara/Turkey. European Journal of Science and Technology, 41-44, 2022. https://doi.org/10.31590/ejosat.1098973

[16] P. A. Analysis. Test ve Ölçüm Hizmeti, Retrieved from. 2022 https://www.petaaerial.com