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ELECTRICITY SUPPLY TO AFRICA AND DEVELOPING ECONOMIES – CHALLENGES AND OPPORTUNITIES

TECHNOLOGY SOLUTIONS AND INNOVATIONS FOR DEVELOPING ECONOMIES

THE WORLD'S FIRST RADIOMETRIC TECHNOLOGY CAMERA PLATFORM IN BOTH THE UV AND IR SPECTRUMS TO QUANTIFY POWER LINE FAULTS

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ABSTRACT

Polluted or broken insulators and faulty connections on power lines induce corona and thermal (heat) radiation. The corona and heat build-up causes long term degradation of the high voltage electrical components, which leads to voltage drops, tripping, mechanical failure and eventually a complete power line outage. These power outages have disastrous consequences for the local industry and the economy. Eskom incurs power line outages at a cost of approximately R1,000,000.00 per hour for faults on a 400kV line. In more critical power lines outages, the losses to the economy can run into the billions.

Power lines are regularly inspected by electrical utilities or contracted service companies, once or twice a year, in order to locate and report on potential insulator and structural/component failures. These inspections are by no means an easy task due to the location, height, design and the number of components which make up the power line network. There are two inspection parameters which indicate symptoms of degradation in the integrity of power line components, one is the presence of corona (suggesting that there is an emerging surface insulation problem); the other is the presence of thermal radiation (heat) which indicates an internal defect or poor connection. Corona radiation is a function of voltage induced ionization of the air and usually occurs before the build-up of heat. Heat build-up is a result of leakage current through a resistance to earth (i.e. I^2R losses), indicating a more advanced fault or fault propagation. It is difficult for utilities or service companies to determine the severity of these faults, which can easily lead to excessive maintenance actions or worse, an incorrect service response, with disastrous power outage consequences.

The current state of the art power line fault detection equipment, as developed by the CSIR and other international companies(as manufactured by UVIRCO (RSA) and OFIL (USA)), can only locate a fault by detecting corona and heat radiated by the faults. This equipment cannot quantify the thermal (IR) and ultraviolet (UV) radiation of the fault in radiometric dimensions (i.e. watts per square centimetres W/cm^2).

The CSIR has over the past 10 years become the leading corona research and development group in the world and has set the pace for new detection technology and camera products. The CSIR intends to develop the world's first radiometric technology camera platform in both the UV and IR spectrums ("QUVIR") in order to quantify power line faults. The underlying radiometric technology was recently patented by CSIR. This paper will provide a brief description on the new UV quantification algorithm.

KEYWORDS: Corona, UV quantification, IR, CSIR, MULTICAM, HV Power lines

1. INTRODUCTION

Power lines need to be regularly inspected in terms of the mechanical and electrical integrity of the line hardware so that corrective maintenance can be applied to the parts that may fail if not attended to and so preventing costly outages. Power lines are inspected by corona and infrared cameras. The cameras will reveal thermal and electrical problem areas in the format of a picture. The picture shows only relative information of the severity of the corona or thermal hotspot. The current commercially available corona detection cameras have reached a plateau in terms of detector sensitivity, where individual emitted photons from the fault source can now be detected [1].

2. PROBLEM STATEMENT

Utility or distribution line inspectors can detect most corona discharges on high voltage electrical equipment, but can still not accurately determine the magnitude of the discharge and possible severity and consequences of these discharges. Line inspectors also currently experience difficulties in interpreting the camera readings as these readings vary each time that new recordings are taken [1].

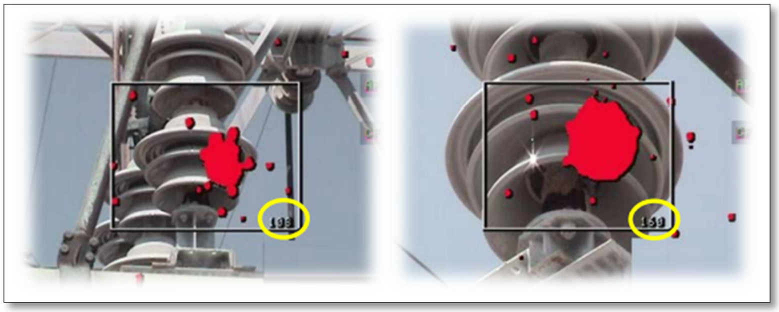


Figure 1: Recordings on bushing: left: count 108, right: count 169 [1]

The recordings in Figure 1 show that two different radiation photon counts are recorded from the same object, namely 108 and 160 counts [1].

Three problems have been identified with regards to photon counting [2]:

1. At low image intensifier gains the photons are not visible.
2. At high gains the photons combine into one big blob and cannot be separated and counted.
3. The image intensifier gain varies with input irradiance.

These problems confuse the line inspector as the reason for the difference is not clearly understood, making it difficult for the inspector to interpret the recordings and make a judgement call on the integrity of the high voltage line/component experiencing the fault. The query raised then is, should the utility be advised to clean/repair the component or can this specific corona occurrence be neglected as the conventional belief is that small discharges do not compromise the equipment. This is not necessarily true. This uncertainty has led to the perception that line inspectors tend to ignore many corona discharges. This practice is compounded when it comes to the interpretation of corona discharges on the polymeric insulators on transmission power lines [1].

Figure 2:A polymeric insulator inundated with fungus and stressed at 101.5 kV
From Left-Right VIS image, UV image and IR image [1]

The infrared recording in Figure 2 (right image) indicates there is some damage. The heating up of the core could eventually lead to a mechanical failure and hence line outage [1].

The requirement in the industry now, is to interpret what these recordings mean and to establish how one interprets these recordings from a maintenance perspective. Whatever decision is taken, it costs money and the cost for a wrong decision is detrimental to the utility company, especially if there is a major line outage. Consequently the industry proposes cameras that measure and quantify the observed corona in quantifiable/physical units [1].

IR cameras exist that detect infrared energy (heat) and convert it into an electronic signal which is then processed to produce a thermal image on a video monitor. This allows inspectors to identify and evaluate the relative severity of heat-related problems [1].

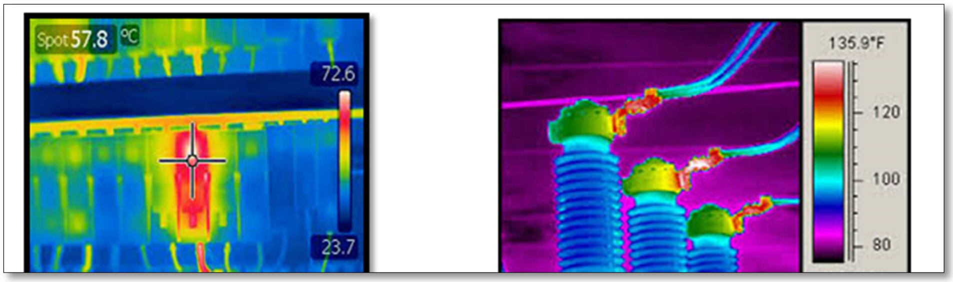


Figure 3: IR recordings [1]

However there is no indication of the severity of the fault in the UV spectrum.

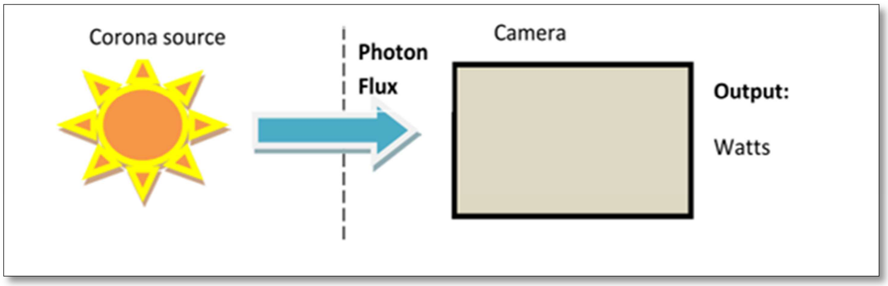


Figure 4: Required technology [1]

3. POSSIBLE SOLUTION - UV QUANTIFICATION ALGORITHM

The foundation of the UV quantification hypothesis is established on the concept of utilising UV photon energy to quantify the corona.

The image intensifier of the QUVIR receives photons in the ultraviolet spectrum of 240nm – 280nm. The image intensifier is operated at a “set point” (i.e. a pre-specified photon area per frame). This area is achieved by gating the image intensifier. By determining the photon area, the UV photon energy is used to quantify the corona. Calibration of the QUVIR is essential for corona UV quantification [2].

In the QUVIR processing, environmental factors such as humidity, visibility, scattering, temperature, pressure and distance are included in the model which affects the power of the corona calculated.

3.1 CALIBRATION

In order for the QUVIR to be quantifiable it must be calibrated. The CSIR has decided to use a black body instrument to calibrate the camera in the UV spectrum. The reason is that such a source radiates energy / photons consistently at a specific temperature and its radiance can be precisely calculated by applying Planck’s radiation law [3]. A black body is defined as an idealised physical body that absorbs all incident electromagnetic radiation and, in thermal equilibrium, emits electromagnetic radiation, called black body radiation [3].

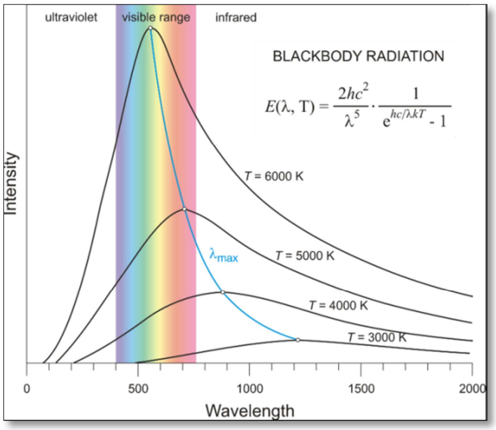


Figure 5: Plank's radiation curve for different temperatures [4]

Figure 5 shows the blackbody recordings at five different temperatures, the higher the temperature, the higher the black body radiance in the ultraviolet corona spectrum. All objects with a temperature above absolute zero (Kelvin) emit radiation. The German physicist Planck determined this law of radiation experimentally. The energy (radiance) that a body of temperature T radiates according to the Planck's distribution law [3] is:

$$\boxed{L_\lambda(T) = \frac{c_{1L}}{\lambda^5}\left(\frac{1}{e^{c_2/\lambda T} - 1}\right)} \qquad (1)$$

Where

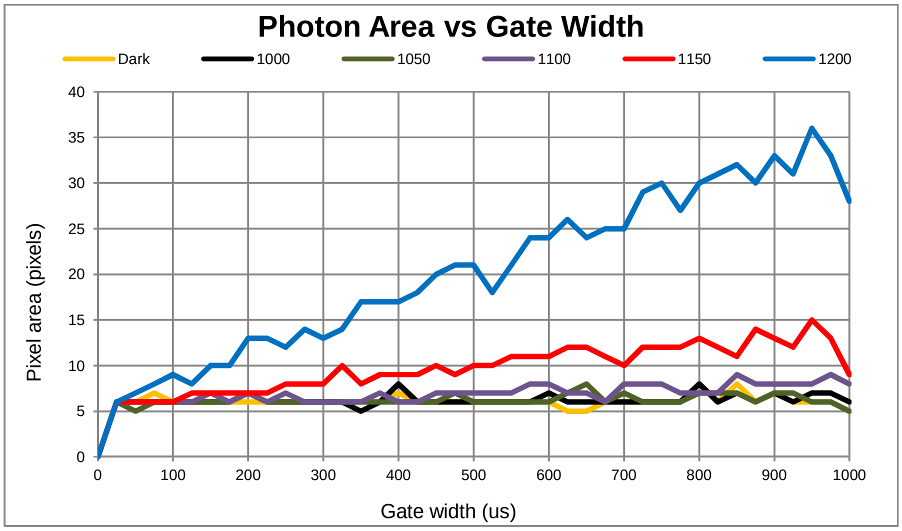
- h is Planck's constant $= 6.6252 \times 10^{-34}\,(\mathrm{J/s})$
- c is the speed of light= $2.998 \times 10^{8}\,(\mathrm{m/s})$
- $c_{1L} = 2hc^2$
- $c_2 = \dfrac{hc}{k_B}$
- k_B is the Stefan Boltzmann constant
- λ is wavelength (m)

3.2 SET POINT DETERMINATION

The word "Set point" refers to the fixed state of the image intensifier.

The set point is the total area of photons on the screen at which calibrations and measurement are done. This should be as small as possible (to increase sensitivity) and yet large enough to be distinguishable from noise. The set point is important to ensure that the current and voltage of the intensifier is constant and hence the gain is constant e.g. if there is a weak corona source less current will be drawn. This has an effect on the voltage in the image intensifier and hence the gain [2].

The set point is determined by ramping the image intensifier gate signal from 0% (0% = 0µs) to 100% (100% = 1000µs) while recording the total photon area for a number of different black body temperatures [2].



Graph 1 :Photon area vs gate width for varying temperatures 1000°C,1050°C ,1100°C,1150°C,1200°C [2]

In Graph 1 a set point of 10 could be selected. This would make it possible to measure a black body at 1150^{o}C (the red graph) while still rejecting the noise (all temperatures below 1150^{o}C) [2].

3.3 GATE WIDTH DETERMINATION

At low gains the photons are too dim and small to be distinguished from noise and at high gains the photons are all clustered together and cannot be distinguished from one another hence gating allows the intensifier to be kept at maximum gain all the time while preventing the clustering of photons for strong sources. Gating also allows for the set point to be reached hence constant gain [2].

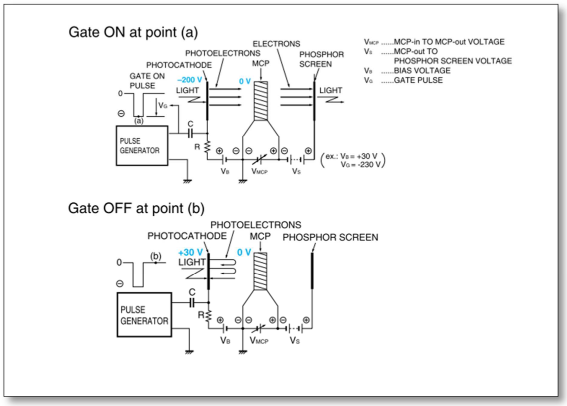
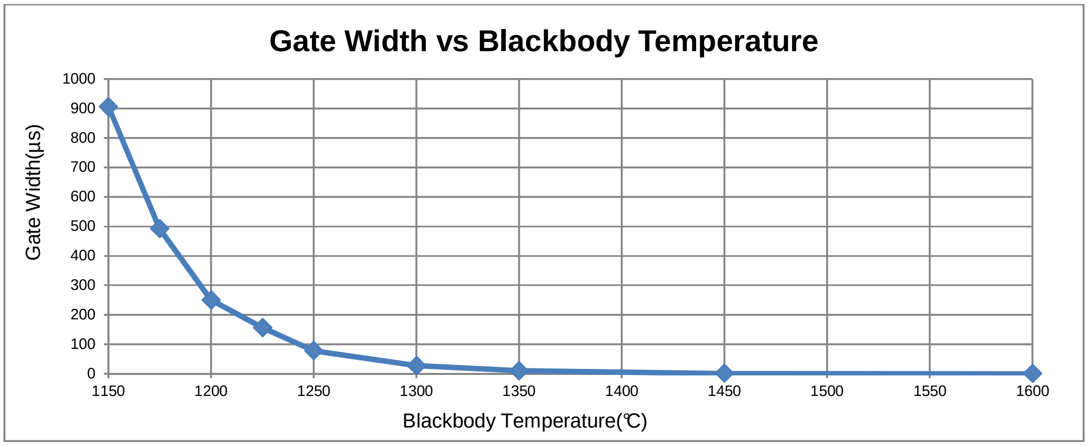


Figure 6: Gate operation circuits [5]

The gate function depicted in Figure 6 is very effective when analysing high speed optical phenomena [6].

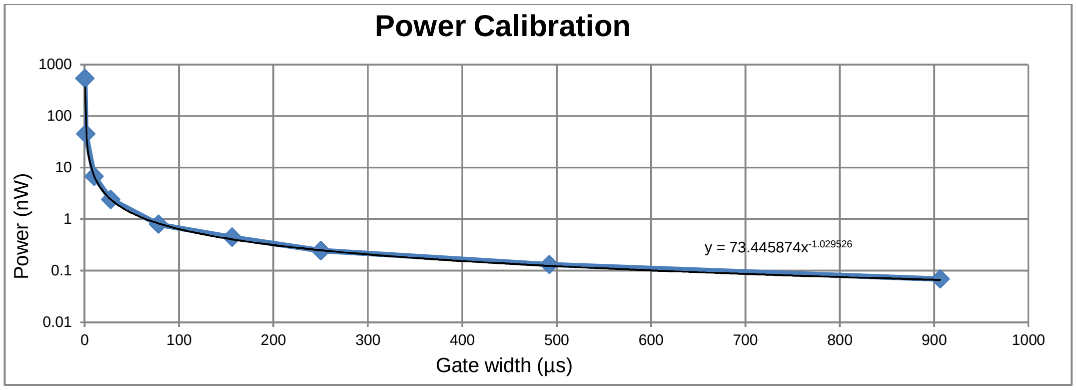
The idea behind set point calibration and measurement is to adjust the image intensifier gate pulse width until the set point area is reached. The calibration was done with the black body at temperatures between 1150°C and 1600 °C as shown in Graph 2 [2].



Graph 2: Gate Width vs Blackbody temperature [2]

The gate pulse width will automatically be adjusted using a binary search in order to achieve the set point area at each black body temperature [2].

Using Planck's law the power is automatically calculated. The power calibration is shown in Graph 3 [2].



Graph 3: Power calibration graph [2]

The results of the calibration are saved to the flash memory on the QUVIR.

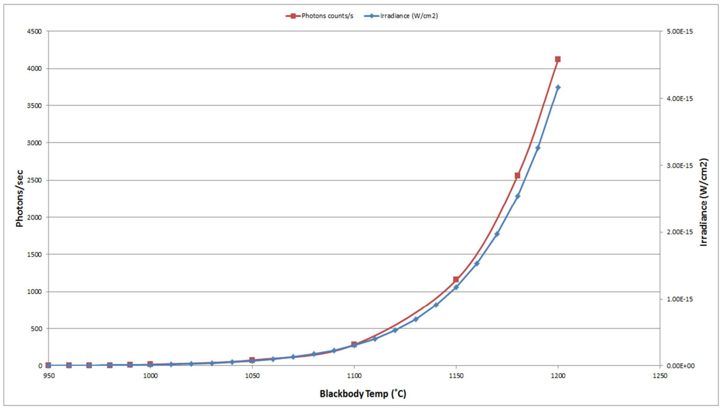
To make a measurement, the same algorithm for finding the required gate pulse width that results in the set point area for an unknown source is used. The equivalent black body temperature is then interpolated from the look up table and the corona emittance is then calculated from this temperature using Planck's black body law [2].

4. TESTS AND RESULTS

4.1 LAB TESTS

Actual measurements were done with a corona camera and a blackbody as a calibration source. The measurements were done from 950 ° C to 1200° C. For each temperature the irradiance in watts/ per square meter (W/cm^2) was calculated and the photon-count/sec of the camera was recorded. The plot is shown in Graph 4 [1].

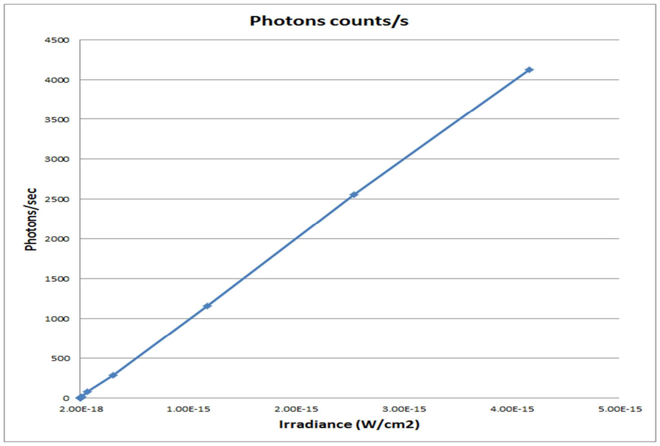
4.1.1 RESULTS



Graph 4: Irradiance (blue) and photon counts/sec (red) against blackbody temperature [1]

The irradiance in Graph 4 is calculated using Planck’s distribution law.

Next the plot photons/sec was plotted against irradiance as shown in Graph 5.



Graph 5: Photon/sec against Irradiance [1]

Graph 5 shows that there is a linear relationship between calculated irradiance and the QUVIR camera photon count/sec measured readings.

This shows that there is a direct correlation between the calculated irradiance and the reading measured by the QUVIR camera.

4.2 FIELD TESTS

A number of readings on different insulators were done at the KIPTS insulator test station [2].

Figure 7:KIPTS insulator testing station [2]

4.2.1 RESULTS

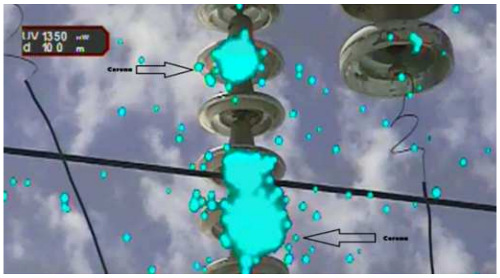


Figure 8: Insulator No: 132 24, Time: 14h11, 33kV(No Gating i.e. Image intensifier is open) [2]

- Measured =1350nW

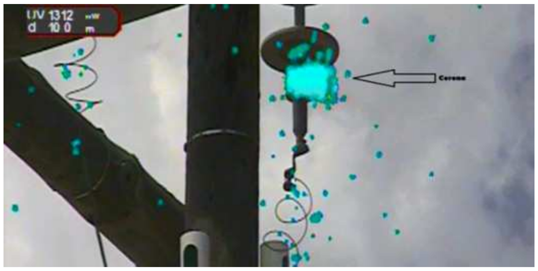


Figure 9: Insulator No: 132 26- Top, Time: 13h20(Gate on) [2].

- Measured =1312nW

5. RECOMMENDATIONS FOR FUTURE WORK

- Verifications of the UV quantification algorithm using a standardised source.
- Machine learning code to interpret whether to repair/replace/leave.

6. CONCLUSION

Success has been achieved in the calibration of the QUVIR using photon counting. This technology development and the resulting product is market driven. This product will help to significantly reduce maintenance cost and improve on maintenance operations. The potential customer's most important requirement is to ensure sustainability and security of the supply of power to industry and the economy. In essence the calibration of the QUIVIR camera by means of a blackbody is a scientific and reliable method that can be used by any corona detection manufacturer and standards/calibration authority [1].

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