Infrared Thermography and Solar Energy – “Green” Maintenance

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ABSTRACT

This paper illustrates how infrared technology can be utilized as a resource to determine the operational status of photovoltaic electrical systems, specifically solar panel arrays.

The solar utility arrays that are being designed and built to meet today’s thirst for ‘green power’ are immense. All the cells within a single panel of a module and all modules within an array must operate in order to gain the most efficient production of energy. Otherwise an array can draw against itself. In a solar energy “farm”, finding a single non-functioning cell can be a daunting task for maintenance personnel. Most large systems will warn of power losses within an array. Then typically it is a matter of going out and finding the panel within that array by testing the leads of each panel or using a clamp-on meter. Alternatively, a thermographer could walk along the array site with an IR camera and visually ‘see’ the panels and their cell operation, easily detecting a faulted panel. Then power output testing could be completed to verify if the panel requires replacement.

INTRODUCTION

According to articles published on the web and in other industry journals, there have been a multitude of advancements that have taken place that have resulted in manufacturing of solar panels with much higher performance levels. With this new technology comes the responsibility to test and maintain these installations that are also continually growing in size and capacity at a phenomenal rate.

Many automated testing methods have been developed and utilized in the manufacturing of Photovoltaic (PV) cells since the mid-1980s. Many of these have been created for the aerospace industry in regards to solar power systems for satellites. Now that this technology has literally ‘come down to earth’ there has to be a more pragmatic service oriented method for testing and identification of failed units. Confidence and reliability of these systems as the future primary utility sources to the public sector will inevitably have to meet some upcoming strict maintenance standards. These standards will ultimately have to be met or the technology will fail. Maintaining solar farms that produce peak energy output will be a vital part of the total equation for efficient and cost effective production of electric power demand for energy consumers.

PHOTOVOLTAIC TECHNOLOGY

To properly make use of IR thermography within the solar energy producing industry, it is necessary to understand the types of construction of the solar panels used within the arrays. There are two major types within the industry being widely used today; crystalline type and thin film type. All module types produced use cells based on silicon or cadmium.

Most of the cells produced today are made of silicon of the following three types;

- Single-crystal silicon – AKA Monocrystalline
- Multi-crystal silicon – AKA Polycrystalline
- Amorphous silicon – AKA Thin Film

Mono- or poly-crystalline cells are produced with the same materials and processes used to manufacture integrated circuit chips for computers, cell phones, watches and such. This technology is used due in part to its ability to transfer electrons efficiently without interruptions. These cells have to be installed onto a rigid substrate with a frame. The module assemblies are most often encapsulated with a covering of glass on the sun side allowing light to pass while protecting the semiconductor wafers from the elements; rain, hail, dirt, animal excrement etc. The power output and additional specifications of the module are not consequential to the thermal testing of the units.

Crystalline type modules come in many different shapes and sizes, power outputs and voltage specifications depending on the specific design of the overall system. Examples of monocrystalline and polycrystalline modules are shown in Figure 1.

Figure 1. Mono & Poly Crystalline products use rigid substrates, framework and a glass covering

Thin-film PV modules are Amorphous silicon and have no crystal structure. The modules are created by depositing very thin layers of photo-reactive materials onto any type of substrate backing material such as metal, plastics or fiber. The unique advantages of thin-film PV Modules include installation in areas of high-temperature (above 30°C), flexibility, light weight and dynamic shade tolerances. Crystalline type panels are produced with series-wired cells where each is dependent on the next to help reach the total rated voltage of the module at any given time. Partial shading of a crystalline PV module due to a tree, building or dirt buildup on the module surface can result in near-zero current output. The Thin-film PV Modules' output will only be reduced by the amount of surface area shaded.

The use of non-rigid encapsulation techniques (i.e., no glass covering) on the newer generation of Thin-film modules is what allows these products to be made in various lightweight and flexible shapes. Thin-film has been used in the production of roll-out laminate modules for consumer electronics, metal roofs, and roofing shingles.

An example of building-integrated-photovoltaic (BIPV) solutions is blending semi-transparent thin-film PV into architectural glass that acts in two ways; an electrical energy source and window tinting. It is anticipated that many developing uses of thin-film PV will play a significant role within the building finishes market.

Figure 2. Thin Film Products can be formed to meet any architectural shape.

STANDARD TESTING CRITERIA

How to Measure the Power Output of Solar Panels [1]: A photovoltaic solar electric panel generates DC power when it is exposed to sunlight. A natural question to ask is 'How much power?' The relationship between current, voltage and resistance is referred to as Ohm's law. The following explains how to test a solar panel for output and how to determine the maximum power point. DC electrical power wattage is the product of voltage times current.

Watts = Voltage multiplied by Current: E x I = P

- Power is measured in units of Watts (Symbol P)
- Voltage is measured in units of Volts (Symbol E)
- Current is measured in units of Amps, (Symbol I)

The power generated by any solar panel in full sunlight depends on the resistance of the electrical load connected to it. The current through a resistor is the applied voltage divided by the resistance.

Current = Voltage divided by Resistance: E / R = I

- Resistance, R, is measured in units of Ohms, Ω.

The method of measuring the power output of a solar panel is to connect resistors of various values to the panel and measure the voltage. The measurements can be used to calculate the power output. The same measurements can be used to plot the power output and create a performance graph for the panel. A digital multimeter for measuring DC voltage is required for this test. An assortment of power resistors is also needed. In practice, each resistor is connected and the voltage is measured with the meter as shown in Figure 3.

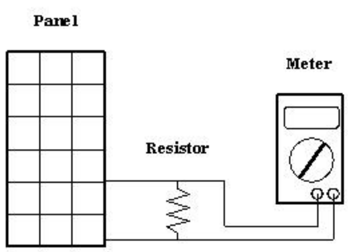

Figure 3. DC Volt Meter Measurement using inline Resistor

The meter is also used to measure the open circuit voltage and the short circuit current. In the following example table of data (Figure 4) measurements from a set of 3 large solar panels connected in series were taken. In the example, power resistors of 100, 50, 25 and 3 ohms were used. The current through each resistor is calculated by dividing the measured voltage by the resistance. The power is calculated by multiplying the voltage times the current.

Resistance	Voltage	Current	Power
Open Circuit	61.8	0.00	0.0
100.0	57.5	0.58	33.1
50.0	54.0	1.08	58.3
25.0	45.0	1.80	81.0
3.0	6.6	2.15	15.5
Short Circuit	0.0	2.20	0.0

Figure 4. DC Voltage Table Created from Readings

Note that no “power” is generated when the open circuit voltage and short circuit current is measured.
In Figure 5 we can see a more intuitive view of the data gained by plotting a graph of the voltage versus current. The output of this solar panel shows the characteristic behavior that is common to all solar panels.

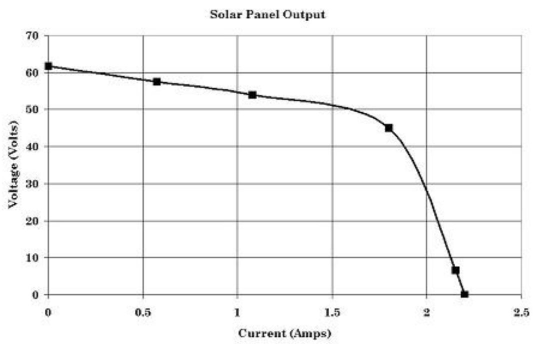

Figure 5. Meter Readings in Graph Form

The maximum power is generated at the operating point which forms the 'knee' in the curve. In our example, this is at approximately 81 watts, corresponding to a load resistance of 25 ohms. The maximum power point is where the product of current and voltage is a maximum. Expressed graphically, the maximum power point is where the largest area rectangle can be formed beneath the curve.

Testing solar panels requires an assortment of power resistors capable of handling the power. In most cases, ordinary 1/4 and 1/2 watt resistors are NOT suitable for this type of measurement. Small resistors overheat and burn out. Power resistors are made to handle more wattage, although they will become hot over time and can burn out also. Adjustable power resistors (called rheostats) are also useful, although they require a meter for measuring the resistance after each adjustment. The simplest way to avoid problems with overheating is to use high wattage resistors and to make individual measurements as quickly as possible.

An assortment of POWER RESISTORS for testing small solar electric panels is available from different manufacturers and suppliers. The assortment shown in Figure 6 contains 10 different fixed power resistors, each with a 5 Watt rating. The fixed resistance values included are: 200, 100, 50, 25, 10, 5, 2, 1, .5 and .1 ohms. Each power resistor is individually labeled with the resistance value.

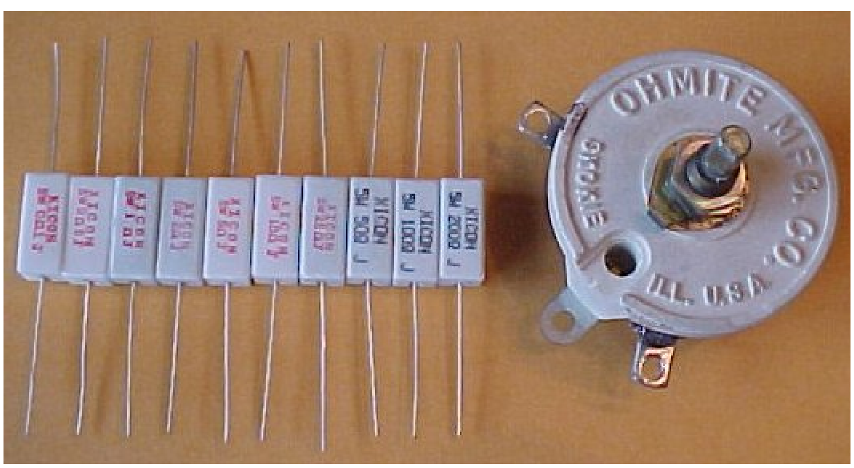

Figure 6. Resistor Assortment for Producing Power Output Readings

THERMOGRAPHIC TESTING

The cells within any panelized PV modular system operate to create a synergy so that the most efficient power is created. If all of the cells are not generating power as a collective, then they begin to de-generate the efficiency of the array as a whole. With solar arrays being designed as "Farms" and producing megawatts of power, the inefficiencies can be monumental.

Maintainability will ultimately be a crucial factor involved with profitability. Data acquisition and the labor spent in acquiring the test data will have a major cost impact on any size project. When you consider that each array could involve testing an average of 10-15 panels each, multiplied by 1000 to possibly 5000 arrays… it would be far too labor intensive to check every panel with the standard test method as explained above.

IR thermography offers an attractive time saving alternative. The infrared camera and the use of IR thermography as a quick-find tool can locate and identify a possible problematic array or even a single module. Then the arduous process of power output testing of the single panel can be instituted to verify the condition.

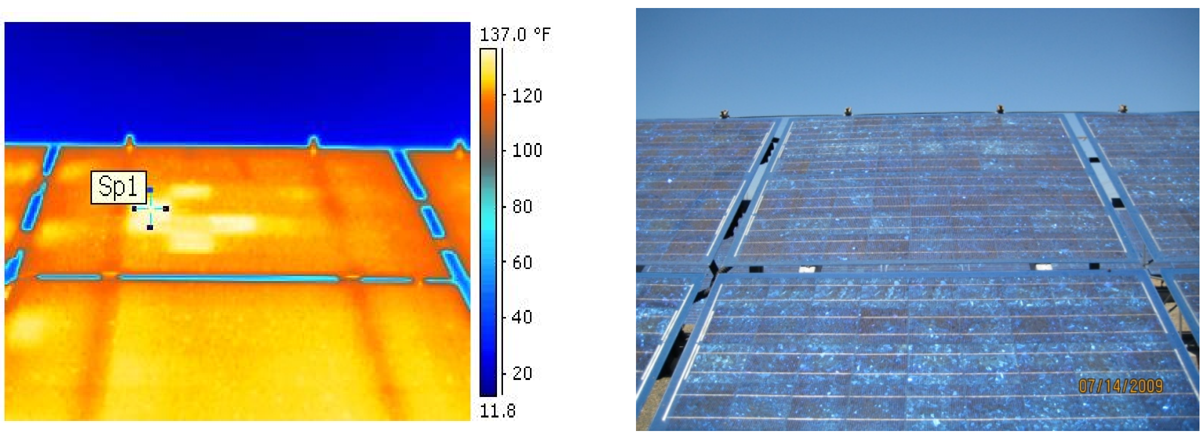

Figure 7. IR image (left) and visual photo (right) of a polycrystalline module showing cellular level anomalies. These modules are glass coated.

Figure 7 depicts multiple cells in a possibly failed module. Upon checking the back of the module we did not find any burned solder points but the temperatures were elevated to touch. This could become a failure point in the very near future.

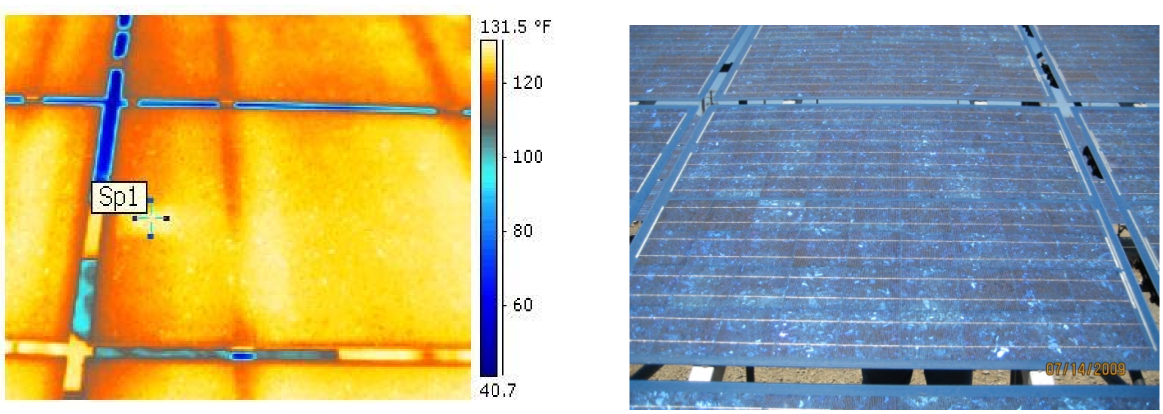

Figure 8. IR image (left) and visual photo (right) of polycrystalline module with single cell anomaly

Figure 8 shows a single cell area that would be considered a Level 1 Priority for further testing.

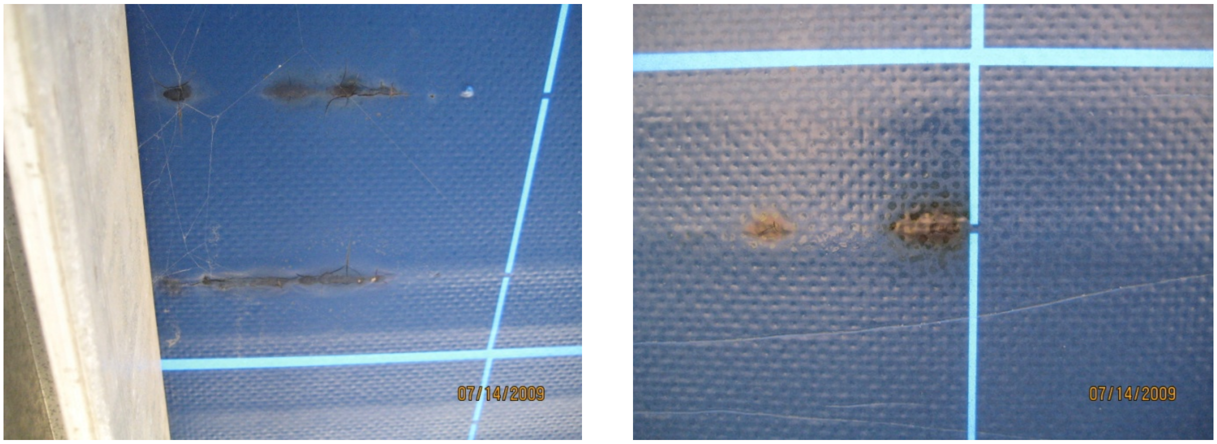

Figure 9. Polycrystalline Module Substrate Material with Burned Solder Joints

Figure 9 shows the burned solder joints between cells from the backside of the module. This would be obvious confirmation of a defective cell within a module.

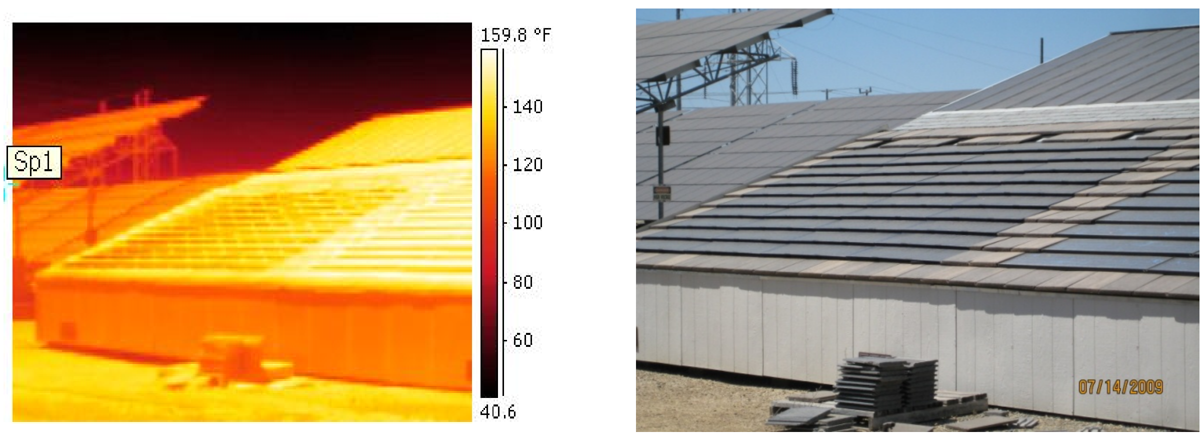

Figure 10. IR image (left) and visual photo (right) of thin film modules on concrete roof tile substrate material.

Figure 10 is an example of thin-film applied to concrete roofing tiles.

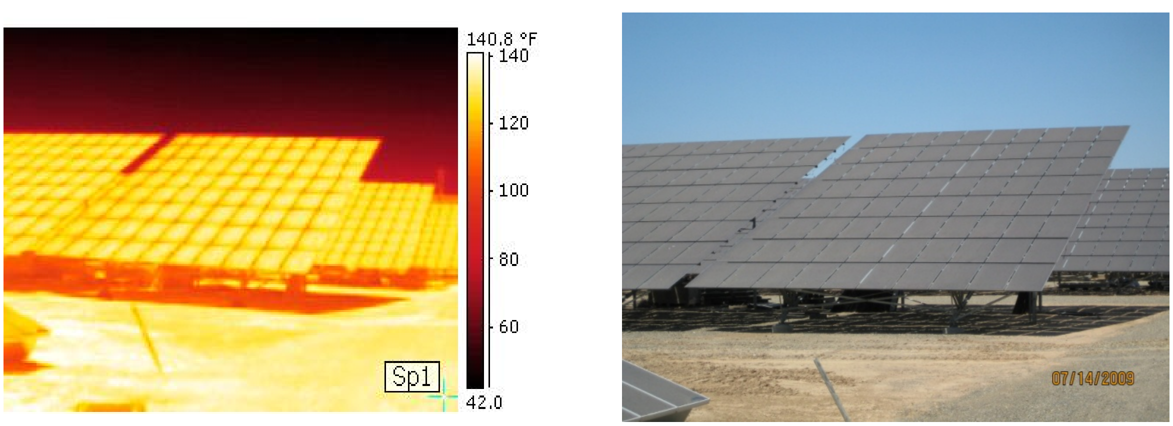

Figure 11. IR image (left) and visual photo (right) of thin film modules on stainless steel substrate material.

Figure 11 shows thin-film PV modules on a metal substrate on a ground mounted array.

INSTALLATIONS

Figure 12 shows the PG&E's first rooftop solar farm utility source. This is a 600,000-square-foot distribution warehouse roof in Fontana, CA which has been fitted with 33,700 advanced thin-film solar panels. This is now the largest single rooftop solar photovoltaic array in California and generates enough power during peak output conditions to meet the needs of approximately 1,300 homes.

Figure 12. PG&E Rooftop Solar Farm

Since this system was designed entirely with thin film products, infrared thermography could be a vital tool in providing data acquisition for future trending of the system performance.

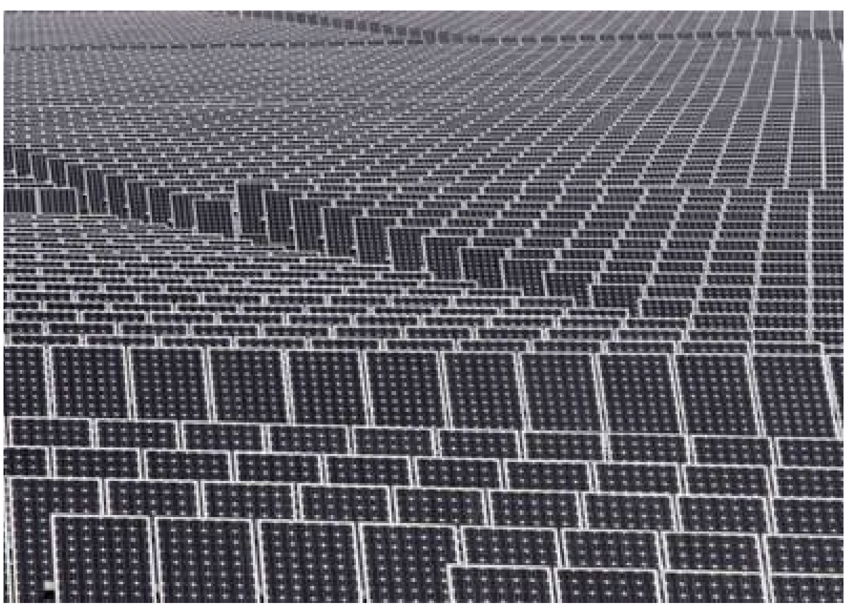

Figure 13. Ground Mounted Solar Farm in Tempe Arizona

Figure 13 shows monocrystalline solar panel arrays installed in formation on a ground based site.

SUMMARY

In consideration of the technology of PV modules in use at the time of this study, there was a concern that there would be limitations to the use of infrared thermography on monocrystalline, polycrystalline and thin film systems with glass coatings. However, our field examples of poly systems did reveal consistent anomalies that were correlated with dead cells even when infrared was employed on the glass coatings. The reasoning behind this application working is further explained by the following reference:

Solar cells operate as quantum energy conversion devices, and are therefore subject to the "Thermodynamic Efficiency Limit". Photons with energy below the band gap of the absorber material cannot generate a hole-electron pair, and so their energy is not converted to useful output and only generates heat if absorbed. For photons with energy above the band gap energy, only a fraction of the energy above the band gap can be converted to useful output. When a photon of greater energy is absorbed, the excess energy above the band gap is converted to kinetic energy of the carrier combination. The excess kinetic energy is converted to heat through phonon interactions as the kinetic energy of the carriers slows to equilibrium velocity [2]. If photons aren't converted to usable electricity, then they are converted into a heat source.

Therefore it would appear that whatever type of cell material utilized, a thermal differential can be detected with the infrared camera due in part to this phenomena. The thermal signature the camera is detecting is actually the heating of the glass surface from the underside from the cell. The thermal readings in all of the anomalies we found were higher in temperature then their surrounding cells. Some of the anomalies found showed physical damage to the cell and others presented documentable physical heat stresses at the equipment. Extreme precautions must be taken in interpreting what the camera is actually detecting in that shading and cooling of the cell, substrate, mounting brackets and hardware, can give many different types of false readings. This study did not have the opportunity to test any newer generation thin film PV modules but an assumption can be made that it would most likely present the same or possibly better results than glass coated modules.

Based on this limited study evaluation we can presume that savings in labor for data acquisition will equate directly to dollars saved on maintenance and troubleshooting costs. Cost-effective performance of solar utility systems can be enhanced by quick and accurate fault detection. Any company looking to advance their solar energy maintenance programs would benefit greatly using infrared technology. This is another viable conditional assessment survey use for this tool to save time and maintenance dollars in the “green” field of solar energy production.

REFERENCES

1. *“How to Measure Power Output of Solar Panels”; supplied by permission with MTM Scientific, Inc. P.O. Box 522, Clinton, MI 49236;* www.mtmscientific.com
2. Cheng-Hsiao Wu and Richard Williams*; Limiting efficiencies for multiple energy-gap quantum d*evices; American Institute of Physics; J. Appl. Phys. p. 6721; (1983)
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ABOUT THE AUTHOR

Paul Christoferson is a Level I thermographer and has been practicing the technology for about 9 years. The areas of application he has been working with are electrical, mechanical and building sciences. He has been involved with the electrical construction industry for more than 23 years and is now employed as an electrical consultant for a national construction consulting firm.