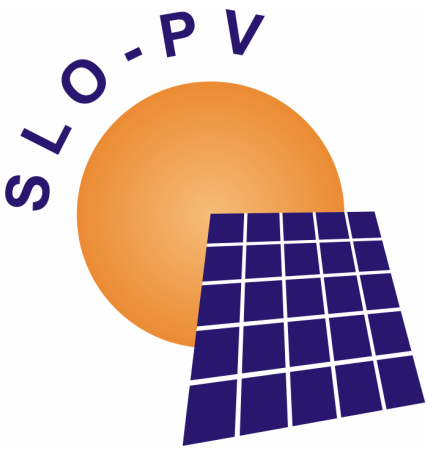
# 4th Slovenian Photovoltaic Conference

# and

# EUROREGIONAL WORKSHOP ON PHOTOVOLTAICS

# SLO-PV 2012

**June 19th-20th 2012**




http://slo-pv.fe.uni-lj.si

University of Ljubljana

Faculty of Electrical Engineering

Tržaška cesta 25, Ljubljana, Slovenia

# BOOK OF ABSTRACTS

## About the workshop

Natural and ecological catastrophes became part of our everyday life and are nature's warning to us to take greater care of environment. This fact stimulates us to develop new ecological solutions to become environment friendly energy source. This energy source is by all means solar cells, since the sun presents inexhaustible and environmentally friendly energy source.



3rd Slovenian photovoltaic conference, 2010

Workshop is intended for a forum of global trends in photovoltaics in the fields of research, industry and market. Especially PhD students are encouraged to participate. You will get the chance to meet researchers from across the Europe, get to know their research projects and share the common issues and challenges.

On the first day the 4$^{th}$ Slovenian photovoltaic conference will be held. The conference will be focused on research trends and market conditions in Slovenia. At the same time an exhibition will be organised, where Slovenian PV industry will be presented.

The workshop will consist of but not limited to the following themes:

1. Photovoltaic materials,
2. High-efficiency photovoltaic devices,
3. Low-cost PV technologies,
4. Performance, reliability and monitoring of PV modules and systems,
5. Costs, markets and grid parity,...

## Organisation

University *of Ljubljana*,
Faculty *of Electrical Engineering*

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# 4th Slovenian Photovoltaic Conference

## Tuesday, June 19th 2012

| | | |
|---|---|---|
| 08:30 – 09:00 | ***Registracija udeležencev*** | |
| | | |
| 09:00 – 09:15 | **Otvoritev konference**<br>*Marko Topič* | |
| | | |
| 09:15 – 10:55 | **Globalni trendi**<br>*Vodja sekcije: M. Topič* | |
| | Uroš Merc<br>ZSFI | ZSFI – Pomen združenja za razvoj celotne panoge |
| | Ivan Gordon<br>IMEC, Belgija | Quo vadis crystalline silicon PV |
| | Mitja Koprivšek<br>ETI, d.d. | Trend razvoja zaščitnih odklopnikov in varovalk v PV sistemih na DC in AC strani |
| | Maja Blejec<br>Slovenski E-Forum | Preklopi na sonce |
| | | |
| 10:55 – 11:25 | ***Odmor za kavo*** | ***Tiskovna konferenca*** |
| | | |
| 11:25 – 12:45 | **Fotovoltaika v Sloveniji**<br>*Vodja sekcije: F. Nemac* | |
| | Ivan Šmon<br>SODO | Razvoj pametnih omrežij v Slovenji |
| | Gregor Kušar<br>SZPV | Smernica o požarni varnosti sončnih elektrarn SZPV 512 |
| | Nina Zalaznik<br>Bisol Group, d.o.o. | Otočni sistemi BISOL |
| | Aleksander Zidanšek<br>IJS | Energija sonca v orbiti |
| | | |
| 12:45 – 14:15 | ***Odmor za kosilo*** | |

| | | |
|---|---|---|
| 14:15 – 16:35 | **Fotonapetostni sistemi**<br>*Vodja sekcije: G. Černivec* | |
| | Tine Andrejašič<br>REC, d.o.o. | Uporaba litijevih akumulatorjev za shranjevanje energije v otočnih fotovoltaičnih sistemih |
| | Luka Vidmar<br>Plan-Net, d.o.o. | Sončne elektrarne s sistemom za optimizacijo, nadzor in zaščito v primeru požara |
| | Miha Flegar, Gorenjske elektrarne, d.o.o. | Izkušnje pri obratovanju sončnih elektrarn |
| | Bojan Horvat<br>Enertec, d.o.o. | Integrirana sončna elektrarna za plus energijsko hišo |
| | Milan Švajger, Elektro Ljubljana OVE, d.o.o. | Rezultati delovanja integrirane SE na poslovnem objektu |
| | | |
| 16:35 | **Zaključek konference**<br>*Marko Topič* | |

| | |
|---|---|
| | **Razstavljavci** |
| | Bisol Group, Plan-net Solar, ETI Elektroelement, REC,<br>Slovenski E-forum, Metronik Solar / Canadian Solar,<br>UL FE Laboratorij za fotovoltaiko in optoelektroniko |

# EUROREGIONAL WORKSHOP ON PHOTOVOLTAICS

## Wednesday, June 20th 2012

| | | |
|---|---|---|
| 08:30 – 09:00 | ***Registration*** | |
| | | |
| 09:00 – 09:10 | **Opening of the workshop**<br>*Marko Topič* | |
| | | |
| 09:10 – 10:25 | **Modelling and Simulations**<br>*Chairman: M. Topič* | |
| INVITED | Benjamin Lipovšek | Advanced optical designs in thin-film silicon solar cells |
| | Martin Sever | 3D optical modelling of thin-film silicon solar cells |
| | Massimo Merenda | Double diode exponential model of photovoltaic modules using SPICE |
| | Antonio Linić | The Midgap State Influence on Space Charge Density of a-Si:H p-i-n i-layer |
| | | |
| 10:25 – 10:45 | ***Coffee break*** | |
| | | |
| 10:45 – 11:45 | **Photovoltaic Materials**<br>*Chairman: U. O. Krašovec* | |
| INVITED | Vasko Jovanovski | Development of novel sustainable ionic liquid sulfide/polysulfide electrolyte for improving the stability of quantum dot sensitised solar cells (QDSC) |
| INVITED | Hristina Spasevska | Solid state dye sensitized solar cells |
| | | |
| 11:45 – 12:45 | ***Lunch break*** | |
| | | |
| 12:45 – 13:45 | **Photovoltaic Devices**<br>*Chairman: J. Krč* | |
| INVITED | Jatin Rath | High efficiency thin film silicon solar cells on plastics |
| | Urša Opara Krašovec | PV and electrochromic windows |
| | Marko Berginc | Assessment of the recombination processes in DSSC by measuring the open circuit voltage in wide illumination intensity range |

| | | |
|---|---|---|
| 13:45 – 15:30 | **PV Systems and Smart Grids**<br>*Chairman: B. Glažar* | |
| INVITED | Dimitar Dimitrev | Photovoltaics within UKIM-FEIT |
| | Massimo Merenda | Self-Powered Wireless CMOS IC for the Real-Time Diagnostics of Basic Parameters of a Solar Cell |
| | Demetrio Iero | An heat flux-based sensor for the measurement of the power dissipated by switching devices |
| | Demetrio Iero | A low cost device for the measurement of conversion efficiency of inverters for photovoltaic plant |
| | Sebastijan Seme | Optimal trajectories of a two-axis sun tracking system determined by differential evolution |
| | Jože Stepan | Technics of PV module temperature monitoring |
| | | |
| 15:30 | **Closing of the workshop**<br>*Marko Topič* | |

# Advanced optical designs in thin-film silicon solar cells

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**Abstract**

Thin-film silicon solar cells have gained an important position in the photovoltaic industry and market. Small material consumption and low-temperature deposition processes applicable to large areas in either batch or roll-to-roll production lines make them competitive to other solar cells, regarding total costs and state-of-the-art performances. In order to boost the conversion efficiency of thin-film silicon solar cells and/or to further reduce the thickness of the absorber layers, advanced light trapping techniques are of great importance. Their aim is to efficiently trap or distribute the light within the cell structure in order to increase the absorption in the thin active (absorber) layers. At the same time, optical losses in the supporting layers (contacts, doped layers) and the reflectance from the cell should be minimised.

In this talk, we will focus on the most prominent light-management techniques applicable to thin-film silicon solar cells. We will present advanced back reflector concepts, such as photonic crystals and diffusive reflectors, efficient light scattering approaches based on random or periodically textured interfaces, and different anti-reflective designs. The concept of multi-junction solar cells, which enables a more efficient utilisation of the solar spectrum, will also be addressed. The discussion will be supported by the description of the most important optical modelling techniques which present an indispensable tool for the design and optimisation of various light-management approaches in thin-film silicon solar cells.

Keywords: Thin-film silicon solar cells, light management, back reflectors, textured interfaces, optical modelling.

# 3D optical modelling of thin-film silicon solar cells

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**Abstract**

While thin-film silicon solar cells can potentially offer lower prices due to lower silicon material consumption and low temperature fabrication processes, thin active layers do not efficiently absorb all of the available light. Texturisation of the substrate surface is commonly used technique for increasing light in-coupling at the front and light scattering and trapping inside the solar cell. Optical modelling of solar cells has become a standard procedure in development and optimization of light management techniques due to their low cost and time consumption in comparison to experimental trials.

In this contribution we present an insight into a three-dimensional optical modelling of a thin-film silicon solar cell. In particular, our aim is to optimise parameters of a 2D sinusoidal substrate texture in order to achieve high solar cell photocurrent and consequently improvement in conversion efficiency. Optical modelling is done using Comsol simulator employing finite-element-method, which is well established numerical solving method and well applicable to the structures of solar cells. Importance of realistic optical properties and non-conformal growth of layers is shown. Results of optical optimisation are justified with restrictions of electrical properties related to different substrate textures.

# Double diode exponential model of photovoltaic modules using SPICE

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**Abstract**

Photovoltaic energy is considered a strategic renewable source for the future. The research is currently, aimed at optimizing the devices for the photovoltaic conversion, also by taking advantage of software tools of considerable power. In this context, this paper describes an advanced simulation of circuits including PV modules and power conditioning section (an MPPT and/or an inverter), to reduce the analysis time and waste of material resources.

Each cell is described by means the double diode exponential model, which allows to describe the internal behavior of the device when it works as a current generator. The circuit is also able to consider the different operating conditions, due to the irradiance and temperature variation.

According to the model representing the each single cell, including their tolerances a macro-model has been implemented to describe the operation of the whole modules. The construction of a photovoltaic string introduces new stray elements in the device, such as soldering and glass transparency, which have been appropriately modeled. The SPICE circuit allows to effectively predict the photovoltaic devices behavior with a maximum error of 2% compared to experimental data.

# The Midgap State Influence on Space Charge Density of a-Si:H p-i-n i-layer

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**Abstract**

The nature and distribution of midgap states in a-Si:H p-i-n solar cell has been investigated using the response measurements on voltage and light pulses out of phase. The experimental results were analyzed using numerical model based on the S. R. Dhariwal and S. Rajvanshi's theory. The energy distributions of midgap states were obtained from fitting the measured responses on simultaneous light and voltage pulses to exponential curves. Further, the space charge density and recombination rate are numerically simulated.

It is found that the midgap densities of states, which are exited with voltage and light pulses, are located in vicinity of the p-i junction. The responses shape changes with the increasing voltage magnitude at given light intensity. For a small voltage magnitudes, less than critical voltage, space charge density decrease in vicinity of p-i junction. For voltages up to threshold voltage of specific response shape, the small changes in width of space charge region occurs. In time after light and voltage excitation, the main changes in space charge density occur in p-i region. Increase of light wavelength increases the space charge density in p-i region and enlarges the neutral region versus n-i junction.

Proposed method can be used for dangling bond midgap states characterization.

# Development of novel sustainable ionic liquid sulfide/polysulfide electrolyte for improving the stability of quantum dot sensitised solar cells (QDSC)

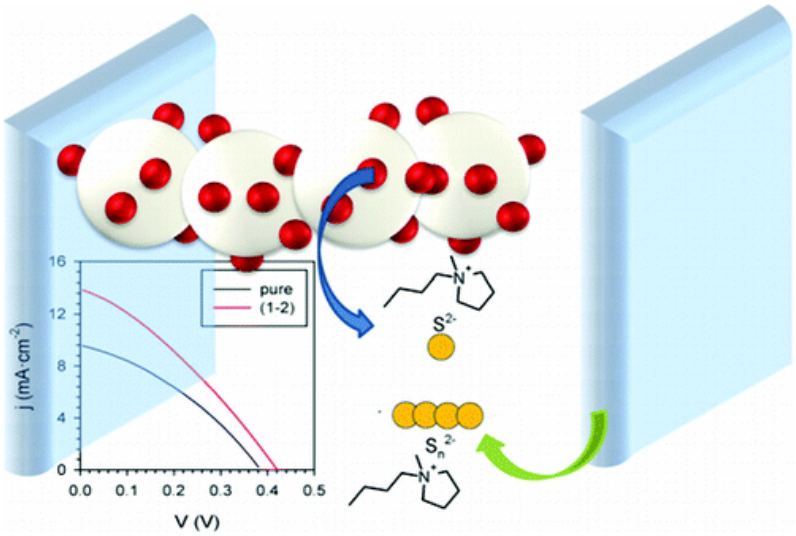
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**Abstract**

The demand for clean energy technologies has spurred academic and technological interest in new and efficient ways to generate electricity from renewable natural resources. Among innovative photovoltaic approaches, semiconductor sensitized solar cells (SSSC), including quantum dot sensitized solar cells (QDSC), exhibited a rapid evolution of the energy conversion efficiencies in the past few years and attract now growing research interest. Since SSSC posses strong similarities to dye sensitized solar cells (DSC), the impressive background gained in the last two decades on the latter may serve to accelerate the advancement of SSSC. However, the electrolytes containing $I^-/I_3^-$, which show the highest performance in DSC, cannot be used in SSSC due to their corrosive character. Electrolytes containing alternative redox pairs, such as $S^{2-}/S_n^{2-}$ and $[Co(o\text{-}phen)_3]^{2+/3+}$, have been thus proposed for SSSC.

Quantum dot solar cells (QDSC) are an emerging field in solar cell research that uses quantum dots as the photovoltaic material, as opposed to better-known bulk semi-conductive materials such as silicon. Quantum dots have tunable bandgaps across a wide range of energy levels by changing the quantum dot size. This property makes quantum dots attractive for multi-junction solar cells, where a variety of different energy levels are used to extract more energy from the solar spectrum.

A robust $S^{2-}/S_n^{2-}$ electrolyte was specifically designed for compatibility with CdSe quantum dots in solar cells. The new pyrrolidinium ionic liquid reaches 1.86 % efficiency and short-circuit current close to 14 mA $cm^{-2}$ under air-mass 1.5 global illumination, and improves the device lifetime with good photoanode stability over 240 hours. Photovoltaic characterization shows that the solar cell limitations relate to poor catalysis of regeneration at the counter electrode and high recombination. Further improvement of these factors in the robust electrolyte configuration may thus have a significant impact for advancing the state-of-art of QDSCs.




Vasko Jovanovski, Victoria Gonzales-Pedro, Sixto Gimenez, Eneko Azaceta, German Cabanero, Hans Grande, Ramon Tena-Zaera, Juan Bisquert, A sulfide/polysulfide-based ionic liquid electrolyte for quantum dot-sensitized solar cells, *J. Am. Chem. Soc.*, 133 (2011) 20156.

# Solid state dye sensitized solar cells

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**Abstract**

The dye sensitized solar cells (DSSC) are the most serious concept that could replace the silicon solar cells. These are low-cost photovoltaics, and represent a technology which could seriously decrease the cost of the electrical energy they produce.

Solid state DSSCs are composed of several layers of materials that belong to the group of inorganic semiconductors. For the efficiency improvement of these cells, there are two basic concepts of research regarding the construction materials. On one side, investigation of new materials that will increase the cell efficiency, as a result of their physical and electrochemical characteristics, and on the other side, use of materials that will contribute to the long term stability of the cell in atmospheric conditions.

Performances of DSSCs are practically sensitive by the size of used $TiO_2$ particles, the thickness of the nanostructured $TiO_2$ layer and effectiveness of hole conducting material. In order to examine the impact of these structural factors on photovoltaic performance, a series of studies have been performed.

The obtained results show that the structural parameters of all thin layers are directly connected with concentration of precursor solution, temperature of the substrate and duration of spray deposition.

# High efficiency thin film silicon solar cells on plastics

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**Abstract**

Solar cells on plastic substrates have the advantage of light weight and roll-to-roll processing. Two methods are used to fabricate cells on temperature sensitive substrates.

Transfer process : In this process, solar cells are basically deposited on a temporary substrate and then transferred to a permanent substrate. One such technique is the Helianthos process in which thin film silicon (single a-Si and tandem a-Si/nc-Si) solar cells are made on flexible aluminum foil and then the cells are transferred to plastics. Stabilized efficiency of 7% has been achieved for the single junctions. Large Scale modules in roll-to-roll process are made by Helianthos b.v.

Direct deposition : This type of fabrication on cheap plastics demands the solar cell processing at or below 120 $^{o}$C, below the optimum temperature for the deposition of thin film silicon. In situ plasma diagnosis identifies reduced ion energy and dusty plasma, among other, two main reasons for bad quality of the materials. Through advanced processing, high quality a-Si materials at even 100 $^{o}$C and solar cells on PET, PEN and polycarbonate substrates have been made. Light confinement in cells by substrate embossing with grating and micro-V structures has led to more than 6% efficiency for solar cells on cheap plastics. Further research is underway to increase deposition rate of a-Si and nc-Si materials, to >1nm/s and exploring quantum dot silicon materials to achieve high efficiency multijunction thin film silicon solar cells above 10% on cheap plastics.

# PV and electrochromic windows

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**Abstract**

In modern buildings large areas of glazing make a high utilization of solar energy possible, but lead also to overheating and glare in case of high solar irradiation. Therefore the future calls for multi-functional windows as part of a multi-functional building envelope, addressing all the needs of the users with respect to daylight, energy efficiency, energy production and occupant comfort.

Photovoltaic (PV) glazing enables harvesting the solar radiation energy and has the capability to produce the electricity, while an electrochromic glazing enables the control of solar irradiation passing through the window while not disturbing the visual indoor-outdoor contact. Both technologies are emerging on the market.

The focus of the presentation will be on the systems combining the optically switching properties and photovoltaic energy harvesting by a synergetic combination of different materials from the field of electrochromics and solar cells which could lead to completely new fenestration products.

# Assessment of the recombination processes in DSSC by measuring the open circuit voltage in wide illumination intensity range

Marko Berginc, Urša Opara Krašovec, Mateja Hočevar, Miha Filipič, Matevž Bokalič, Marko Topič
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**Abstract**

Many recombination paths in the dye-sensitized solar cells (DSSCs) differently affect the open circuit voltage ($V_{OC}$) vs. illumination intensity ($G$) dependence. In the literature contradictive results about the d$V_{OC}$/dlog($G$) gradient ranging from 60 to 120 mV/decade exist. In order to resolve the discrepancies we have studied the influence of the thickness of the active layer ($d_{TiO_2}$) and cell temperature ($T_C$) dependence along with $I_3^-$ concentration (c[$I_3^-$]) of ionic liquid based DSSCs on the d$V_{OC}$/dlog($G$) gradient. The results confirmed that the $d_{TiO_2}$ has only a small effect on the d$V_{OC}$/dlog($G$) gradient while the gradient very strongly depends on the $T_C$ and c[$I_3^-$]; the gradient d$V_{OC}$/dlog($G$) could be as low as 60 mV/decade when the diffusion of the redox couple limits the performance of the DSSCs (low c[$I_3^-$] and low $T_C$) while it may exceed 130 mV/decade at higher c[$I_3^-$] and higher $T_C$. In addition, the assessment of the theoretical models with the experimental results indicates that in the light intensity range between 1 and 100 mW/cm$^2$ the recombination path between the electrons in a tail of shallow traps in $TiO_2$ and the $I_3^-$ ions prevails.

# Photovoltaics within UKIM-FEIT

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**Abstract**

In recent decades, the development of renewable energy sources faced a rapid growth, especially in solar and wind applications. The Faculty of Electrical Engineering and IT at "Sts Cyril and Methodius" University in Skopje, Macedonia (UKIM-FEIT) is actively involved in these fields for almost forty years. Within this, many research projects and applications have been carried out. In 2002, a Solar Energy Laboratory had been established. Several research and educational possibilities of the installed equipment are presented (summary of continuous onsite measurement values of the solar radiation and the ambient temperature, as well as measuring the I-V characteristic of a photovoltaic generator with identification of its parameters). The field of photovoltaics is included in undergraduate, MSc and PhD studies at UKIM-FEIT. Recently a Center for chip cells has been established at UKIM-FEIT.

In order and facilitate the research and educational work, as well as to promote and improve the applications in this field, UKIM-FEIT has initiated establishing a didactic a multifunctional platform for educational, research and promotional activities for renewable energy sources, with special attention to photovoltaic/wind applications. Detailed plans and present status for its implementation, are presented.

**Key words:** Renewable energy sources, photovoltaic systems, laboratory, education

# Self-Powered Wireless CMOS IC for the Real-Time Diagnostics of Basic Parameters of a Solar Cell

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**Abstract**

An approach for measuring and transmission of basic parameters related to a photovoltaic module under illumination has been proposed, allowing to recover information from every individual cell.

The valuable cell parameters, such as voltage drop, temperature and illumination, are measured with a dedicated VLSI integrated circuit (IC) that contains also an RF transmission section and an On-Chip-Antenna (OCA).

The parameters varies in time due to harmful influences such as rapid temperature variations, UV radiation, aggressive chemical substances.

For this reason, an integrated circuit that can be placed nearby each solar cell in a module, providing an online diagnostic of the main parameters of the cell, has been designed. Data from the cells are collected in real-time using a wireless link between the chip, containing an RF module and an on-chip antenna, and a receiver placed on the module backside, able to manage a large number of solar cells and communicate with a centralized unit. Each microchip is powered from the series of five solar cells to reach the appropriate bias voltage (approximately 3 V).

The proposed approach is useful for the online control of the efficiency of solar cells in harsh environments and even for the evaluation of cell degradation due to harmful influences.

# An heat flux-based sensor for the measurement of the power dissipated by switching devices

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**Abstract**

The precise measurement of the power dissipated by a semiconductor device operating in dynamic conditions is an important issue in power conversion circuits to evaluate their overall efficiency, and often requires the use of high cost systems.

When the efficiency is high, a small error in the measurement of current and voltage can lead to macroscopic errors in the calculation of the efficiency itself. For high-frequency switching devices such errors can be introduced by the probes or by instruments that are transparent to high dv/dt and di/dt rates. These issues are particularly relevant in the field of the new generation power converters, e.g. making use of high efficiency SiC power transistors, used in PV plants.

An alternative low cost measurement method, useful for repetitive yet dynamic operating conditions, is the calorimetric one, based on the measurement of the power dissipated as heat. By measuring the heat produced by a device thermally isolated from the ambient, it is possible to directly compute the power dissipated on it.

We present a method based on a properly designed dual-sensor heat-flux measurement device, coupled to a readout circuit, that allows the in-circuit characterization of power devices.

# A low cost device for the measurement of conversion efficiency of inverters for photovoltaic plant

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**Abstract**

A common problem in the field of renewable energies is the measurement of the efficiency of the conversion system and the actual produced energy. Generally speaking, inverters or MPPT's of small-medium size do not allow their owner to be aware at any time of the efficiency of their electronic conversion systems. We propose a low cost and portable device that can measure input power, output power and the efficiency of a system with an error within 2% on a wide range of voltage and current.

The prototype has been realized based on low cost digital signal processor (DSP) that compute in real time the RMS voltage and current, the power and the efficiency. The current is measured though a Hall-effect based sensor. The circuit has an analogic signal conditioning stage with variable gain that adapt to the level of the input signal and maximize the ADC resolution. The results are displayed on a LCD display.

The measured error on the voltage is below 0.5%, while the maximum error of current measure is 1.5%, the maximum bandwidth is around 5kHz, only limited by the used operational amplifier, but there is room for performance improvement at no additional costs.

# Optimal trajectories of a two-axis sun tracking system determined by differential evolution

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**Abstract**

This paper deals with the two-axis sun tracking sys- tem for a photovoltaic system. The trajectories of the sun tracking system are determined in an optimization procedure. The optimization goal is maximization of an electric energy production in the photovoltaic system considering the tracking system consumption. Determination of the tilt angle and azimuth angle trajectories is described as a nonlinear and bounded optimization problem, where the objective function is not available in the explicit form. A stochastic search algorithm called Differential Evolution is used as an optimization tool. In the optimization procedure, the objective function is evaluated by using the models of available solar radiation, tracking system consumption, and the efficiency of solar cells with the appropriate dc/dc converters. The problem bounds are given in the form of lower and upper bounds for both angles and time and angle quantization. The results presented in the pa- per show, that the optimal trajectories for the tilt and azimuth angle depend on the available solar radiation, solar cell efficiency, tracking system consumption and the optimization bounds.

# Technics of PV module temperature monitoring

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**Abstract:**

The temperature is very important environmental parameter in photovoltaics since main electrical parameters of PV cells and modules are strongly temperature dependent. Nevertheless, for comparison of electrical properties of PV devices the measurement has to be performed at the same temperature as suggested by standards.

The aim of this study is to investigate the correlation between the measured temperature, type of temperature sensors and a way of the sensors' attachment to the PV module. For that reason we have laminated special multicrystalline silicon P module together with several PT1000 temperature sensors attached directly on the back surface of solar cells for reference temperature measurement. The PV module was put to the framework of the testing plant on the roof of the Faculty of Electrical Engineering in Ljubljana. We use the testing plant to make the continuous measurements of various PV modules for long term monitoring and comparison. The results were captured in real time with own data logger system. On the basis of measurement results deviations due to different temperature sensors and methods were investigated. The thermal behavior of the sensors and influences of other factors are discussed.

The method which gives the most accurate results at irradiances above 200 W/m2 is the $U_{oc}$ method. The lack of this method is the inaccuracy of temperature coefficients of device under test and required accessible connections of solar cells. Sensors like Pt or TC series also give good results if they are covered by polystyrene thermal isolation at least 5mm wide. The usage of this type of sensors becomes inconvenient when the large number of sensors is used. Each of them needs two long wires and analog port on datalogger device. Long connections wires and A/D conversions adds additional errors. To avoiding these conditions the usage of digital temperature sensors like DS series are recommended. They needed just three wires as we mention earlier. All sensors must be coated with thermal paste to achieve good thermal connections to the back side of PV module and covered by adequate thermal isolation.