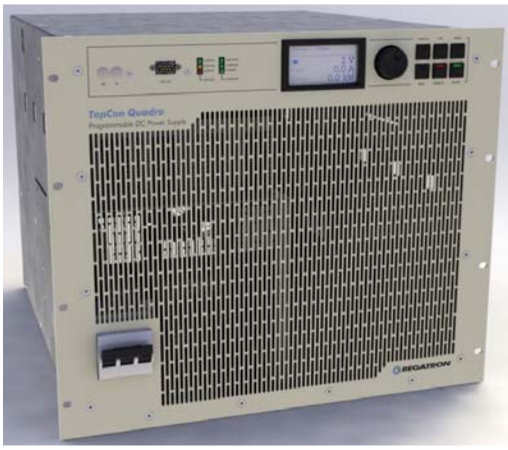
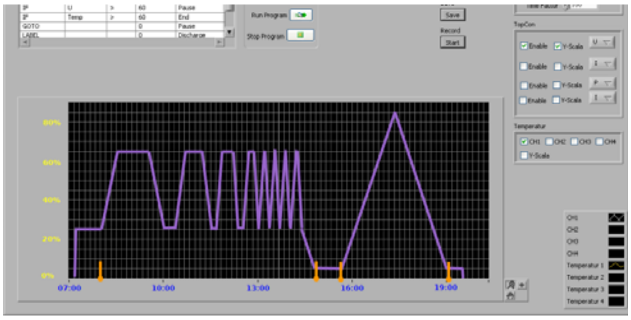
REGATRON APPLICATION NOTE

PV-Simulation for development and equipment testing





Regatron AG
Kirchstrasse 11
CH-9400 Rorschach
Tel +41 71 846 67 67
Fax +41 71 846 67 77
www.regatron.ch
topcon@regatron.ch

Distributor-sticker

1.1 Introduction

In photovoltaic applications, the quality and technical data of the AC-DC-converter is of primary interest. Solar installations are intended for a lifetime of roughly 20 years, so even fractional parts of a percent in efficiency will represent significant amounts of energy losses.

Development and final series testing of AC-DC-converters call both for equipment able to simulate solar arrays of different type as close as possible to the original.

1.2 Requirements

Standards

Today, the international regulation EN 50530 and the SANDIA labs test protocol represent the leading documents for standardisation of test parameters and setup's.

A PV-simulator unit shall be able to support all standard test procedures given in the above-mentioned regulations.

Furthermore, the simulator shall dispose of programming facilities in order to adapt to and add new procedures or further test parameters and setups.

MPP-Tracking-Algorithm: High simulator performance required

The main aim of the DC-AC-converter is to transform a maximum of electrical energy delivered by the PV array into mains. In order to do this, the converter has to find the point of maximum generated power out of the PV array. (MPP = Maximum power point) Any mismatch will degrade the overall system efficiency and therefore increase the losses.

Depending on the MPP-algorithm performed by the converter, the simulator either has to reproduce the so-called ‚ripple voltage' acurately in phase, or in the case of an 'approx algorithm' the dynamic requirements are of second interest. In this latter case the standard TopCon will fit the requirements without any additional equipment.

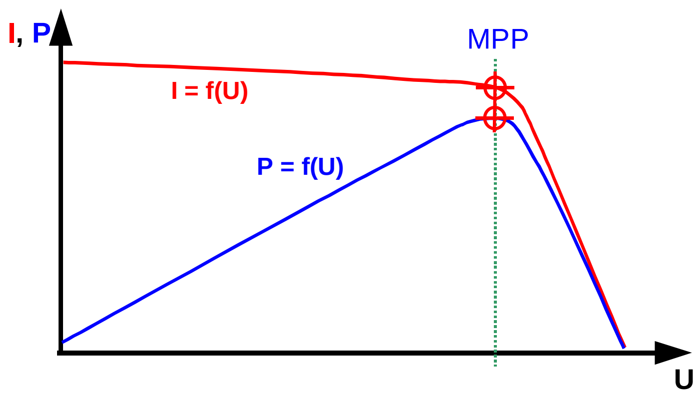


Fig. 1 Characteristic current/voltage/power slopes of a typical PV-array

Manipulation of U/I – slopes: Scaling

Crucial factors for the power of a PV array are the ‘radiation’ and the ‘temperature’ parameters. Based on the popular 1-diode-model of a PV cell, a variation of the radiation parameter corresponds nearly exact to a compression or dilatation of the slope in the direction of the y-axis, while a variation of the ‘temperature’ parameter will cause a compression/dilatation in the x-direction.

> Simulation of variations of temperature or radiation will result in a modification of the initial PV cell (array) characteristics.
>
> Dependent on the required acuracy, either a complete recalculation of the slope is necessary or a much simpler ‘scaling’ process of the slope basic values will be sufficient.

Manipulation of U/I – slopes: Cross-fading / dynamic behaviour

There are several factors causing variations of the basic slope values of a PV array:

- Temporal progression of cloudiness
- Temporal progression of temperature
- Temporal progression of solar radiation geometry as a daily/annual variation
- Partial shade caused by obstacles
- Selective or integral degradation due to moist and pollution
- Panel-failures, resistance of bonding and terminals

Changes between two states will – in the most cases – not be excursive, but more in a continuous manner, depending on the type of disturbance.

> For development and test work on high-grade DC-AC-converters, the solar simulator shall be able to reproduce parameter variations in the most realistic manner.
>
> The PV simulator shall dispose on the most used standard models (e.g. SANDIA, EN 50530). These standards are based on a technical model.
>
> The implementation of real PV-cell or array data shall be possible in a simple way. Data sets may originate from measurements or from manufacturer data.
>
> The PV simulator shall be able to manipulate curve data in order to provide programmable sequences, simulating for example a daily progression.
>
> The transition between two curve states has to be processed:
>
> a) by programmable ‘cross-fading’ with programmable ramp times
> b) as a step function for tracking ability tests
> c) following later or further extensions

Simulation of daily radiation patterns / sequencing of slopes

Dependent on the geographical site and different operational conditions, the simulation calls for variation of the basic cell (array) parameters. Thus, the sequencer section of the PV simulator shall provide a fully programmable tool for modelling complex conditions also.

The sequencer handles several curves or even an entire set of slopes in a pre-programmable manner in order to provide the user with even exceptional slope forms. Such conditions will appear for example, if a partly shaded array generates non-distinct MPP conditions.

The daily course of solar radiation shall be fully programmable. This means also a programmable time basis management, so fast motion and time lapse functions

It is essential that the sequencer dispose of a PAUSE function in order to freeze a given course at a time point. This enables the user to add remarks to the protocol file or to intervene because of a malfunction.
A RESUME command will resume the simulation at the respective time point.

Tests based on normalized procedures (e.g. EN 50530, Sandia Labs)

Normalized procedures are able to perform comparisons between different types of hardware and/or firmware. This in turn calls for highly precise data processing inside the simulator as also for stability and accuracy of the processes. This not only means precision of data, but also reproducible time-dependent actions.

In order to simplify test and development, the simulator shall offer easy-to-use features for slope management, manipulation, scaling, loading and saving of slope parameters.

As a further feature, the PV simulator shall offer an effective, but simple test data management. Drawing of diagrams or spread sheets or simply the import or export of test data shall be possible.

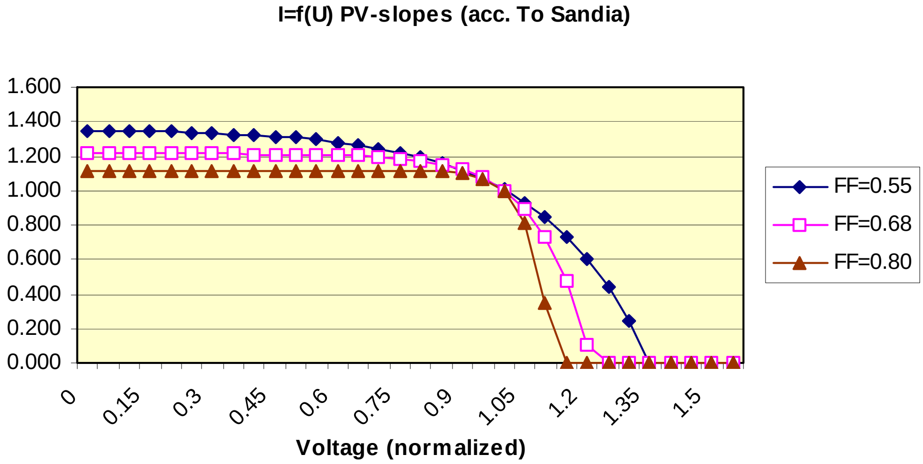


Fig. 2 Normalized PV cell slopes with different form factors (SANDIA)

2 PV simulation equipment from REGATRON

REGATRON PV simulation equipment appears in three functional levels:

1. TopCon DC-power source unit with *AAP-functionality*

2. TopCon DC-power source followed by *Linear-Postprocessor TC.LIN.SER*

3. PC software *SASControl*

Please find more information just below!

2.1 TopCon AAP

The acronym „TopCon AAP“ stands for a standard TopCon DC power supply, functionally extended by the versatile software function generator TFE. This operation mode allows not only running time-dependent functional slopes, but also the famous 'Application area-programming mode'. By this, arbitrary functions like the above stated solar cell slopes can be loaded, manipulated and displayed. Configured with an appropriate U/I-curve, TopCon behaves like a real solar cell array and allows therefore the simulation of nearly any configuration of cells.

TopCon Quadro is a finely graduated family of state-of-the-art DC power supplies in the middle to higher power range. Starting with single units in the 10 kW, 16 kW, 20 kW and 32 kW class and voltages up to 1000 VDC, much higher power levels can be achieved by series or parallel operation of multiple units. This allows for simulation of systems from 10 kW up to 1024 kW DC. In all system configurations, the master unit always is the single communications partner to the environment, while the unit-to-unit communication is realized by a proprietary CAN BUS.

Fig. 3 TopCon power supply

All TopCon QUADRO units work with an exclusive full-digital control structure. This allows for reproduction of even very complex mathematical structures and opens up a high degree of flexibility.

TopCon QUADRO units are thus well suited for solar cell array simulation. A single curve or even an entire set of curves can be stored and edited aboard of TopCon flash memory.

The actual activated curve expresses the functional interdependence of current vs. voltage. TopCon is evaluating the actual system voltage via sensing voltage input and determines the associated current level, which is in turn set and controlled by the digital current controller. The fast sample and program loop cycle time of only 50 usec allows for a quite fast and well-defined simulation.
This AAP functionality not only works with single TopCon units, but also with big arrays of TopCon power supply units: The AAP program module runs on the dedicated master unit, which in turn is controlling the slave units by a bus system. This system architecture has proven reliable and stable operation in a multiplicity of solar industrial applications.

It is important to note, that the AAP functionality may be manipulated and influenced by a number of parameters. For example, the daily progression of solar radiation may be programmed easily in order to check the DC-AC-converter's response to alternating illumination conditions.

Even complex solar array slopes may be run with TopCon DC power supplies: The AAP – curve may either be loaded and edited inside TopCon with the aid of TopControl software, or outside TopCon together with spread sheet software like EXCEL.

In order to keep simulations as versatile as possible, up to 1000 individual curves can be stored permanently inside TopCon. Therefore, sequencing of selected curves becomes a dedicated importance. The sequencer not only sorts and launches the selected curves, but controls also the 'cross-fading' from one to the next curve. Cross fading is a programmable feature allowing for a soft transition from one curve to the next. This feature is necessary to simulate the real solar array more realistically and to allow the DC-AC-converter under test to track the alteration correctly.

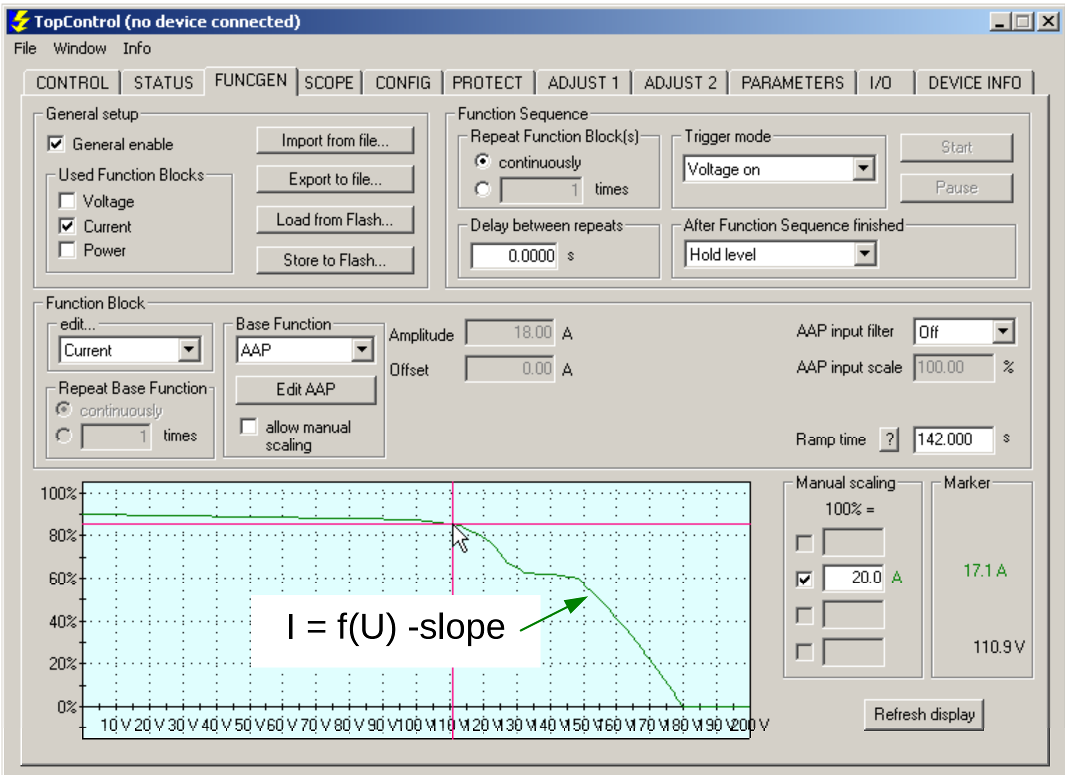


Fig. 4 AAP screen – Curve of a partly shaded solar array

Please note, that the ‚cross fade' runs completely independent from a PC directly aboard TopCon in real-time. Sequencing and cross fading are also accessible via the TCIO.dll, the user program interface of all TopCon units.

Power range	10/16/20/32 kW and multiples, e.g. n times 128 kW
Controller cycle time	20kHz (= 50µs)
Voltage range	Up to1000 VDC, to 1500 VDC with series midpoint earthing
Resolution	12 Bit (0.025% F.S.)
Mains characteristics	3 x 400VAC / 50/60 Hz; 3 x 480 VAC / 60Hz for US
Temperature range	0°C to 40°C; for degrading data sheet of respective unit type
AAP cycle time	20kHz (= 50µs) Resolution 12 Bit

Table 1: TopCon DC power supplies with AAP

2.2 Post-processor unit TC.LIN.SER

For the simulation of low-capacitance solar arrays in time-critical applications, REGATRON offers a Post-Processor unit TC.LIN.SER as an extension to the above-described TopCon AAP system. This post-processing unit consists of an extremely fast current source fed by a full digital controller with a cycle time of only 5 usec! This unit enables the user to simulate low-capacity solar arrays with a phase error of only a fractional part of one electrical degree at a ripple frequency of 100 Hz.

TC.LIN.SER communicates with the leading TopCon via the same proprietary CAN-bus, which is also being used for master-slave-operation. TopCon followed by a TC.LIN.SER unit forms basically a primary switched DC power module with a second precision current controller. By this configuration, the advantages of both systems are combined to benefit from a high efficiency power conversion and a loss-optimized fast acting series controller.

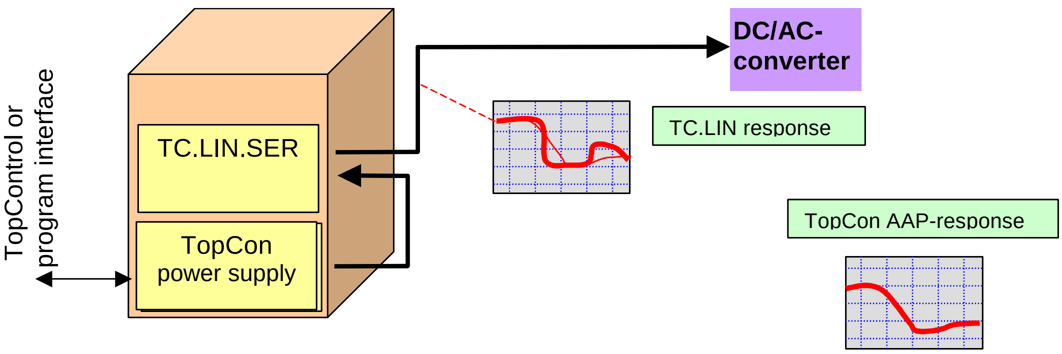


Fig. 5 TopCon power supply followed by TC.LIN.SER post-processor

Dependent on the type of DC/AC-inverter, solar cells are subject to complex load conditions. A high quality solar cell simulator should be able to offer the highest degree of match to the real cell array, therefore short response time, controlled dynamics and a realistic relationship between voltage and current are crucial. This calls not only for very high program loop rates, but also for a suitable resolution of data and parameters.

By the aid of special techniques, the basic TopCon system resolution of 12 bits has been extended to 14.5 Bit, offering a significant advantage in defining the process variables.

At the same time, state-of-the-art processors allow for a complete firmware cycle of only 5 usec – key point for very fast controller response time and for stable phase relationship.

Fig. 6 Combination TopCon/AAP (below) and TC.LIN.SER 25/40 ADC

A very special feature is the programmable CURRENT RANGE switch inside TC.LIN.SER. This feature may switch the current range to the appropriate range in order to have the best possible data resolution.

TC.LIN.SER is prepared for parallel operation of multiple TC.LIN.SER units in order to have again more power at hand. This allows for the realisation of high power / high dynamic PV systems for the simulation of even large PV arrays.

Power range	0-1000V DC, 26/13 ADC current ranges / resp. 40/20 ADC
Controller cycle time	5 µs ; resolution 14.5 bit ; (4.3 * 10E-05)
Controller voltage reserve	programmable , U_{drop} = 30 ... 50 Volt is suggested
Power losses	1.5 kW permanent, up to 3.0 kW temporary, air cooling
Error handling	Overvoltage; overcurrent, SOA-limit surveillance, supply voltages, internal processor/bus errors
Cabinet	Rack 19“, 6 HU

Table 2: Common technical data TC.LIN.SER 26 / 40

2.3 Software SAS-Control

Note: Both ‚TopCon AAP' as also the combination ‚TopCon/TC.LIN.SER' can easily be controlled and parameterised by standard TopControl software. This software is provided with each TopCon delivery and is working through RS232 or alternatively USB interface.

Significant more functionality with a view to SOLAR applications is provided by the new software package SAScontrol. This software allows for the implementation of all functional demands raised in the previous chapters .

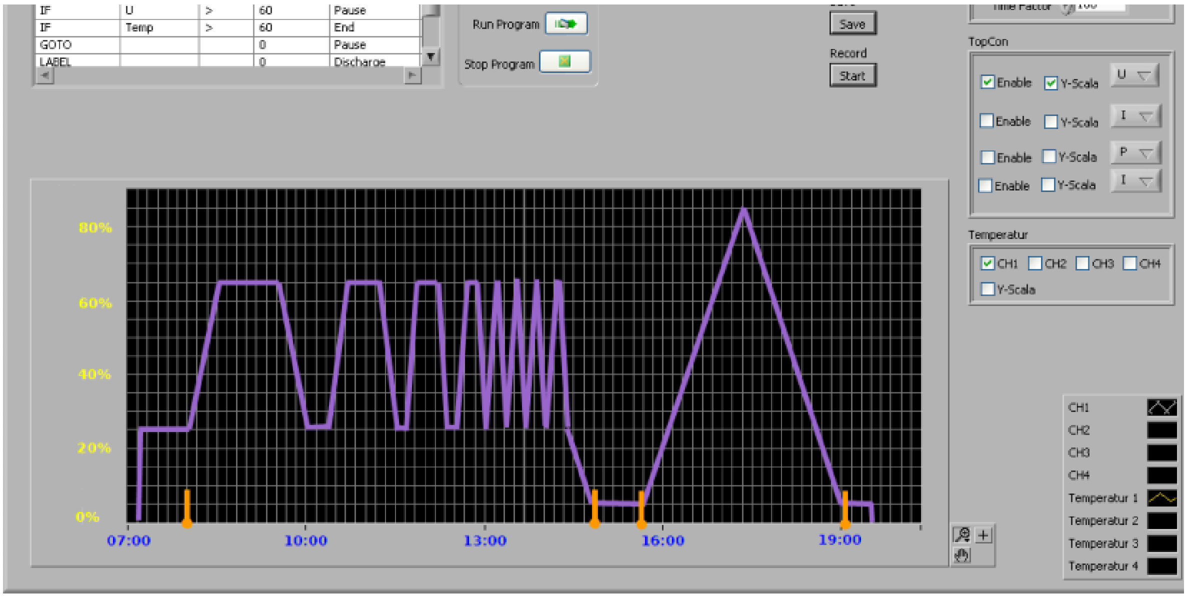


Fig. 7 Part view of SAScontrol, Sequencer Software

TC.SASControl is running on an external PC and is intended to control and parameterise system functions and sequences. The big amount of memory available in PC's allows for storage and handling of high data volumes for test analysis and documentation. Special pages act to define processes as also data. SASControl is highly specialised for all work around development and tests of DC/AC-converters by simulation of solar cell arrays.

Architecture	LabView-application, based on TopCon TCIO.dll
Functional units	Curve generation, editing, sequencer, measurements , data display, data storage, data reporting and management.
References	EN 50530, SANDIA labs, add-on's

Table 3: SASControl technical data

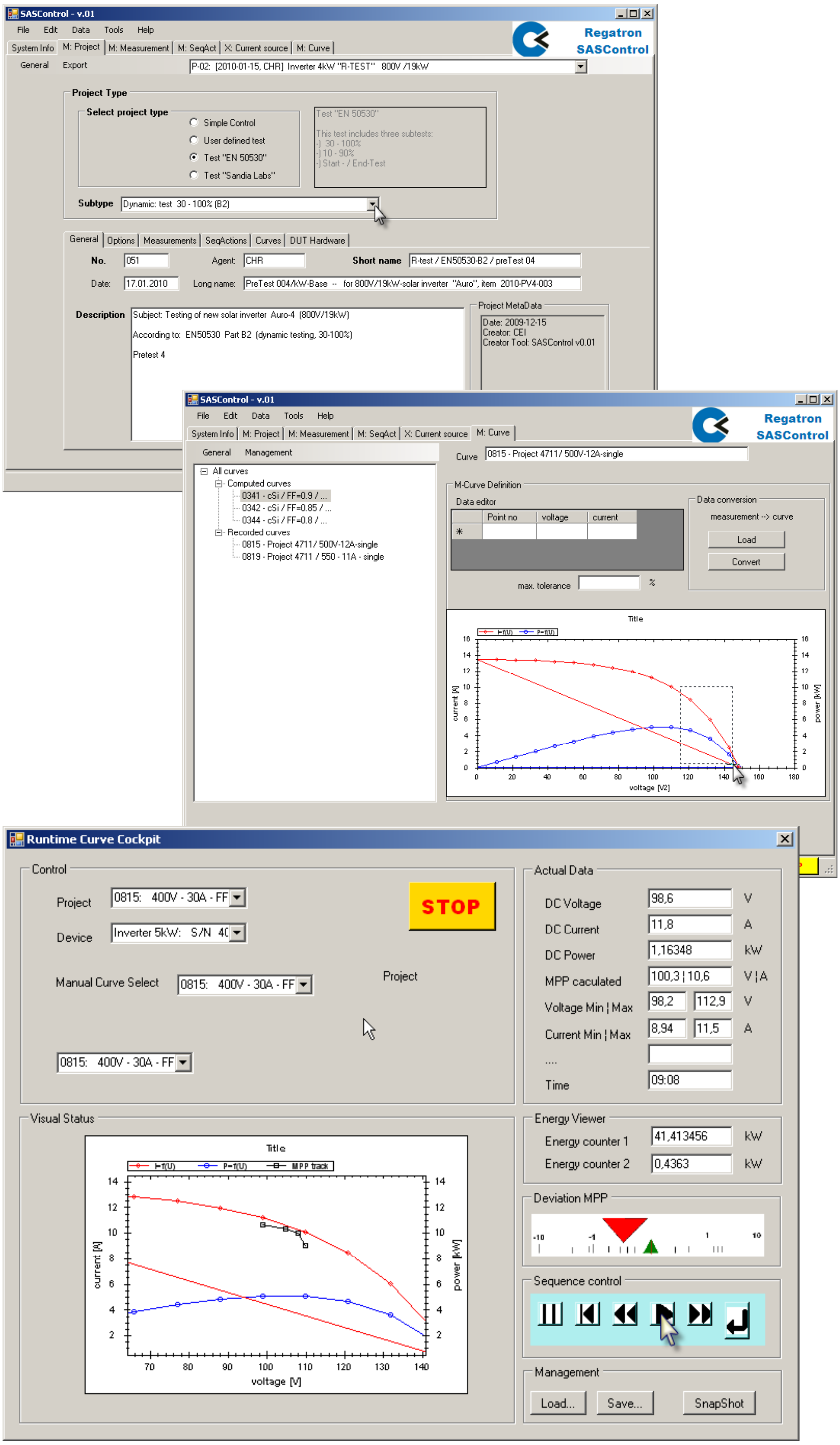


Fig. 8: Some SASControl shot studies at the print time of this brochure

2.4 Programming interface for user-specific software

In addition to the two REGATRON-specific software solutions for Solar Simulation:

a) TopControl control- and service software /or

b) SAScontrol process control software,

TopCon offers a specific user interface API enabling the user to use own application software. REGATRON provides a comprehensive function library inclusive a detailed programming brochure. Source code could be written in C/C++, C#, VISUAL BASIC and LabView.

Connection of TopCon equipment to test- and laboratory systems is ensured by a number of available Interfaces:

Additional to the standard RS-232-interface, REGATRON offers also interfaces for USB, (industrial-)Ethernet, IEEE488/GPIB with SCPI-instruction set and CAN/CANOpen.

Further fieldbus and/or special interfaces can be manufactured upon request, supported by the REGATRON OptionCard system.

Kirchstrasse 11 Tel +41 71 846 67 67
CH-9400 Rorschach Fax +41 71 846 67 77
WWW: www.regatron.ch
Email: topcon@regatron.ch