PHOTOVOLTAIC MODEL IN THE LABI SYSTEM

F.Hruska

***Abstract*—**New model is prepared to extend the system LABI. It is marked as DE10, a photovoltaic system. Utilizing of model is into the field of university studying and as a pilot test system for all extern experts. A special parts of model are measurement and control system. Mechanical configuration can use a track system to control of position according to run of sun during a day and a month. In the future period new photovoltaic panels can be added into model and to extend the model. The user can study power of sun energy, efficiency of photovoltaic principles, dependence of position on power during day. The photovoltaic model is useable in remote access via the Internet.

***Keywords*—** automation, control, measurement, photovoltaic system, sun energy.

I. INTRODUCTION

THE experiment laboratory system LABI [1,2,4] is extended of a new real system - photovoltaic laboratory experiment system of DE10 [3,5,6]. These days there are installed o lot of photovoltaic devices to product of electrical energy. The experimental model DE10 is a small photovoltaic system of area about 0,5 m^2 and it is to use to study and test.

The preparing has three aspects. The system is equipped a specifical measurement and control subsystem. Very interested part of DE10 there is a track subsystem for studying the function of rotation and learning problem with efficiency of photovoltaic principles. The remote access is realized in the way of Internet from PC or PDA technique.

We will plan to do as next a extension of a new kind of PV panels and a intensification of using of DE10 as a pilot plant.

II. DESCRIPTION OF THE MODEL

The main functions of the DE10 are the control of position of photovoltaic (PV) panel according to position of sun in the day and studying of efficiency of energy production.

The scheme of the system is in fig.1. The one has three parts: solar PV cells (1) as the PV panel, mechanical construction (2), measurement and control system (3,4,5) and lead battery (6).

At the present time there is used the PV panel (position 1) with monocrystal technology and materials. The area is 1x0,45 m and the power 60 W. In the next time there is going to extend the panel area by a panel with concentrated PV cells or other new technologies. Then model DE10 will serve for study two or more kinds of PV cells.

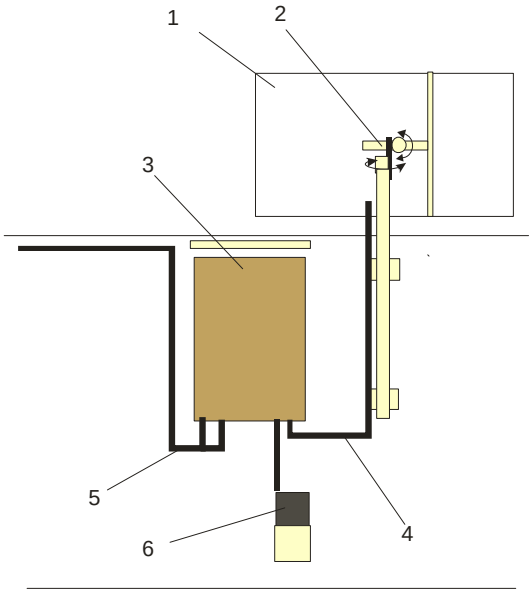

Fig. 1. Block scheme of the system DE10

The mechanical construction is based on tracker system. Schema is in fig.2. It is a two axis´s rotation system. The azimuth position is from 0 to +/- 90°. The elevation position is in the range from 0 to 90°. The tracker system is set on two mechanical gearboxes for azimuth (2a) and elevation (2b) with ratio 1:80. The all subsystem is carried by one spindle (2c), it is anchored into wall of building. The motors are for both axis and used step motors.

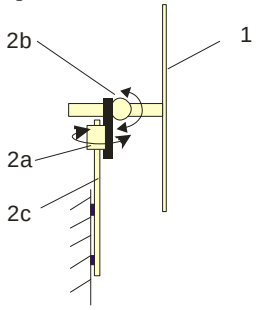

Fig. 2. Scheme of the mechanical part of system DE10

The photographical view of all mechanical system is in fig.3. There is visibly to see all part of mechanical subsystem. In the DE10 the mechanical part is very precise. The reason was to have the high-quality track system for studying.

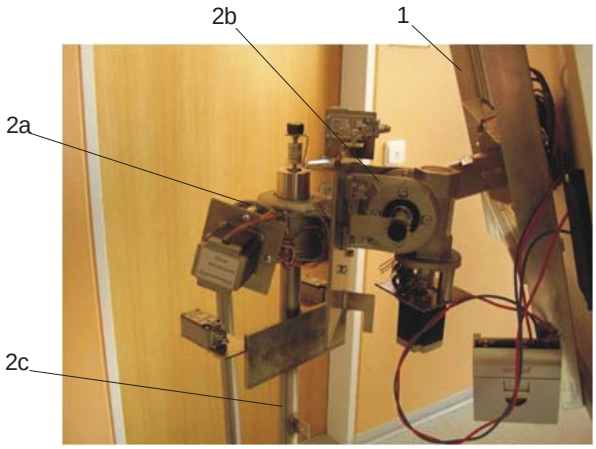

Fig. 3. Photograph of the track system of DE10

The measurement and control system is a next main part of DE10. The one is used to give a measured date, to control of position in difference modes and to connect DE10 into network of Internet.

The measured date is:

- Global energy flow from sun radiation for the panel position.
- Direction and force of wind.
- Temperature and moisture of ambient area (range -40 to +50°C and 0 to 100%).
- Azimuth and elevation position (range 0 to 360° and 0 to 50 km/h).
- End position of azimuth and elevation (range 0 to +/- 90°and 0 to 90°)
- Output voltage of panel and of input battery (0 to 25 V).
- Current from the photovoltaic panel (0 to 3A).

III. TECHNICAL EQUIPMENT OF SYSTEM

The computer centre of DE10 is DataLab system. That is two parts: industrial personal computer (DataLab IPC and input/output unit (DataLab I/O). Scheme is in the fig.4.

The industry compatible personal computer (IPC type) suits the industrial indoor environment: by temperature, moisture, vibration, shock, EMC and other parameters. The decision about the using of IPC was done according to new trends of automation technique.

The part of DataLab IPC is a main unit of system. A single card industrial computer assembles a full compatible IPC (industrial personal computer), (pos.1 in fig.4). Condition of its operation is suitable in industrial or exterior environment as is temperature, moisture, vibration.

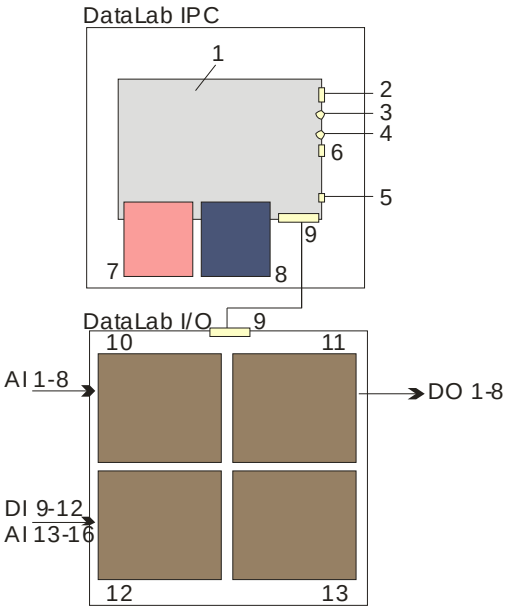

Fig. 4 Scheme of central unit of DE10

The unit of IPC can connect to monitor unit via output (2), to mouse (3), to keyboard (4), to LAN (5) and to units with USB´s interface (6). The HDD (7) or SSD card (8) presents next part of IPC. There is used the HDD unit as a main memory of system. The HDD has a special performance and it can run up to -25°C.

The extern plant of photovoltaic panel is connected to IPC via input/output part of system (9). It is called the DataLab I/O. It has up to four subunits: a units for 8 analogue inputs (10), a unit for 8 digital outputs (11) , a unit for 4 digital and 4 analog inputs (11) and one (12) is reserve in the application.

The analog input unit (10) have optimal parameters for the DE10´s application. The inputs are as a differential connection they can be connected to standard or non-standard inputs. They are 0-10V DC or from 0-0,1VDC to 0-0,2V, 0,05VDC or 0-1VDC, 0-2VDC, 0-5VDC of signals. They can connect the current signals from some measurement, for example 4-20 mA. The inner ADC (analog digital converter) has resolution of 16 bits, the frequency of scanning is around 6,25 Hz. The input signal come from sensor of:

1. Radiation: of sun (the signal of 4-20 mA)
2. reserve
3. reserve
4. temperat.out: air temperature (the signal of 4-20 mA)
5. moisture: air moisture (the signal of 4-20 mA)
6. U panel: voltage of panel output (the signal 0-10V)
7. I panel: current of panel output (the signal 0-10V)
8. U batery: voltage of accumulating battery (the signal 0-0,1V).

Schema of connection to input terminal of unit is in the picture 5.

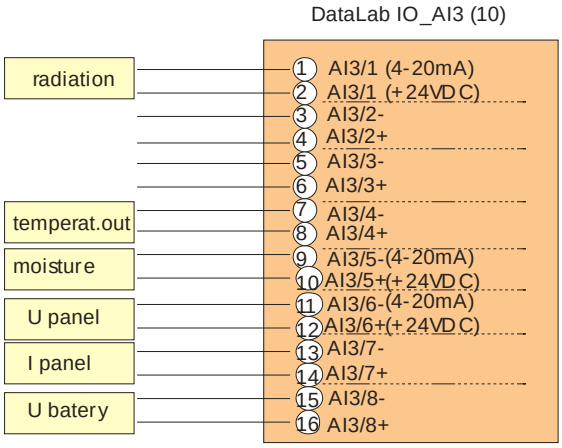

Fig. 5 Connection scheme of analog input unit AI3

The combined input units(11) have designed to connect digital and analogue inputs. The digital inputs are a type for logical one=7-12V and logical zero 0 to 3,5 V. Analog inputs are different according to the type of sensor. The inner ADC (analog digital converter) has resolution of 12 bits, the frequency of scanning is around 10 Hz. The input signal come from sensor of:

1. end position contact of east side
2. end position contact of west side
3. end position contact of down side
4. end position contact of up side
5. position of azimuth (the signal of 0-100 □)
6. position of elevation (the signal of 0-100 □)
7. voltage of reference (the signal 0-10V)
8. temperature of inner room of switchboard (the signal 0-0,2V).

Schema of connection to input terminal of unit is in the picture 6.

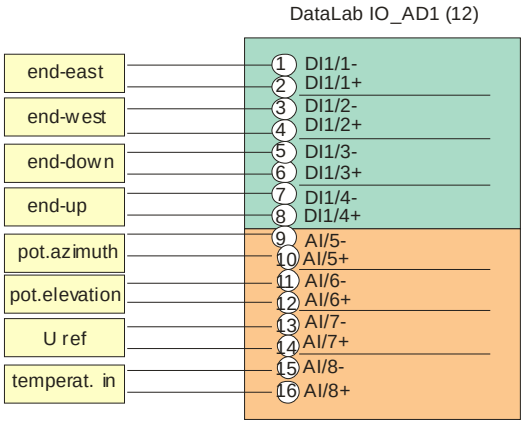

Fig. 6 Scheme of digital and analogue input unit of AD1

The unit (12) serves as a digital output unit it is called DO3. It can connect up to 8 digital inputs in range log.zero 0-3,5V and log.1=7-12V. The output signals go to controller of step motors. Output signals are for turning round for elevation (output DO1 to DO4) and for rotation by azimuth position (outputs DO5-DO8). Schema of connection to input terminal of unit is in the picture 7.

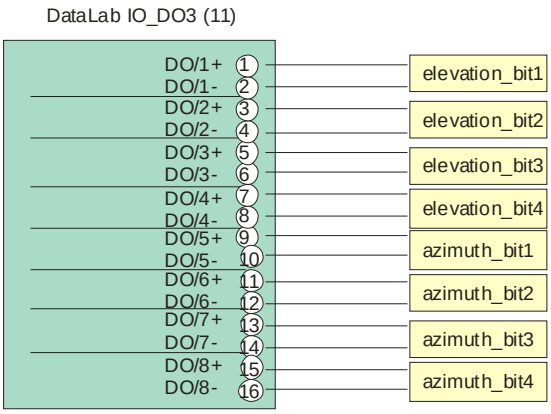

Fig. 7 Connection scheme of digital output DO3

There was projected standard sensors of measured parameters of system. In the first period there are the base value for visualisation and evaluation of system. There are: power of sun radiation, voltage and current of panel. The temperature, moisture of air ambient, temperature of inner area of switchboard and in the future orientation and speed of wind are auxiliary parameters.

The measurement of wind is oreoared in the system. The development work was orientated to use of strain gauges principle. At the moment there isn´t achieved good results. Other methods are tested and evaluated.

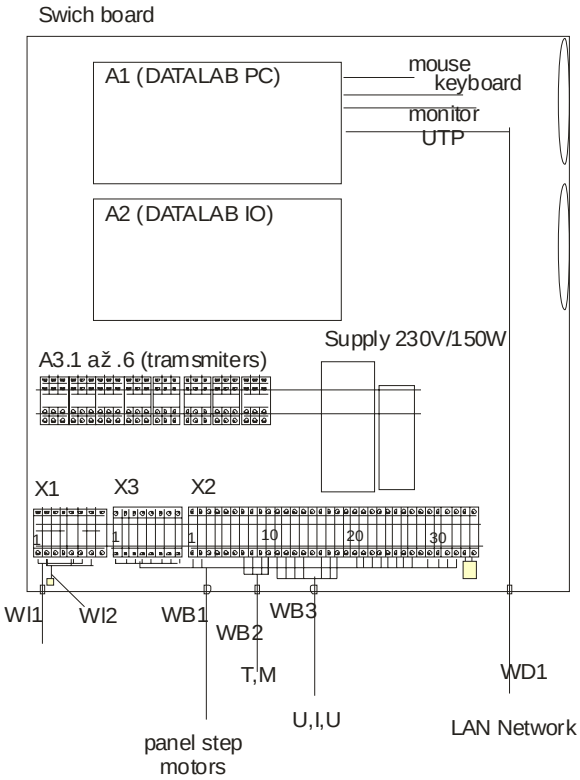

Fig. 8 Scheme of the applicated switchboard

The all units are centered in a switchboard. A right protecting of its was the main goal. The schema of the used board is in figure 8.

The switchboard is supplied with electrical power by cable WI1 and WI2. The voltage is 230VAC and it is transformed to smaller voltage in the supply unit 230V/1500W.

The central unit A1 (DataLab PC) can have interface for mouse, keyboard, monitor, USB´s units and with the cable WD1 can be connected on the Internet. The input and output units are use the cables WB1 to control of panel step motors, the cable WB2 from temperature and moisture sensors and the cable WB3 is for measurement the voltage and current of photovoltaic panel.

IV. Software of the System

Very important part of system is application software. Software is developed under a SCADA system, it is called Control WEB (CW) software. The CW system helps to write the application for measurement, acquisition, control, visualization, archiving and remote connecting on the Internet.

Control Web can work as simple and accessible tool for implementation of small system. It can also work as a tool for creation of large-scale enterprise distributed application capable to communicate over tenths of thousands of input/output points, containing hundreds of operator panels, working on number of distributed computers within a network. CW can also act as software bridge among SQL database, WWW browsers and GSM mobile phone network. CW is a fun tool saving a lot of work in school laboratories, performing automatic measurement and creating protocols for many students. For this advantage there was elected the CW to solve the software problems in the system DE10.

CW solves predominantly mathematical operation in the system. It is for example conversion of value of signals into physical date and unit by the measurement processes. CW does very important task in control function of system. The control of panel position is done according to the actual time and date of day. As a alternative or option will be control of position according the maximum radiation of sun. It is the extreme control into maximum of radiation and calculation of the position. There is possibility the manual control of position for given position of azimuth in range 0-+/-90°and of elevation 0- 90°). Change of position of solar system is realized via two axis tracker system, one in azimuth ratio and other in the elevation.

The next function of CW is visualization of system in the computer monitors. It is in two version: as a figure and schema and as graphs.

The main figure in the system visualization is showed in the figure 9.

The figure shows the measured data. There are the value of:

- position (required, current and from, the potentiometers),
- radiation in the unit of lux=lumen/m2
- temperature and moisture of the ambient of panel
- voltage in output of panel, current in ampere and voltage of battery.

Fig. 9 Main picture of the visualisation

The figure shows the measured data. There are the value of:

- position (required, current and from, the potentiometers),
- radiation in the unit of lux=lumen/m2
- temperature and moisture of the ambient of panel
- voltage in output of panel, current in ampere and voltage of battery.

Below the main picture of visualization there are graphs of time processes. Example is in the figure 10a and 10b.

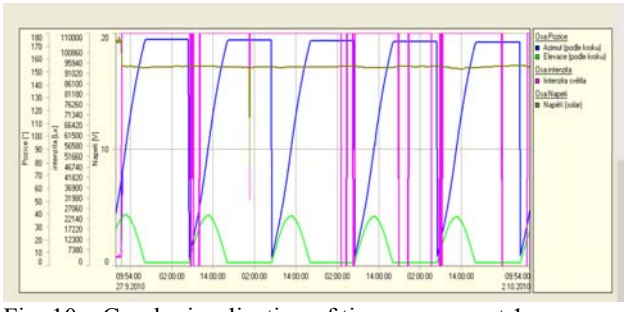

Fig. 10a Graph visualization of time range, part 1

The figure 10a has time relation of data of position: azimuth, elevation and the value of radiation. In the figure it is for 5 days. There is seen as blue graph the change of azimuth position. About 4 o´clock there is start of daily automatical regime. The track system turn over from east in the morning to west in the evening and waiting for the next morning. The time relation (green graph) of elevation is from zero in the morning to maximum in the midday and to minimum in the evening. The rosy graph is the time relation of sun radiation.

Time history of other measured parameters is showed in the figure 10b. For the same relation there are the graph of

ambient temperature and moisture, the real position from potentiometers, electrical value about panel about energy production.

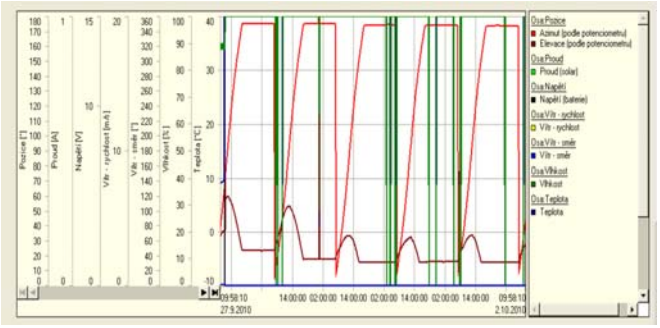

Fig. 10b Graph visualisation of time range, part 2

The application software performs the archiving function too. All measured date are scanned and saved in the memory for next inspection, evaluation and control. The concrete user has access to true date as a client.

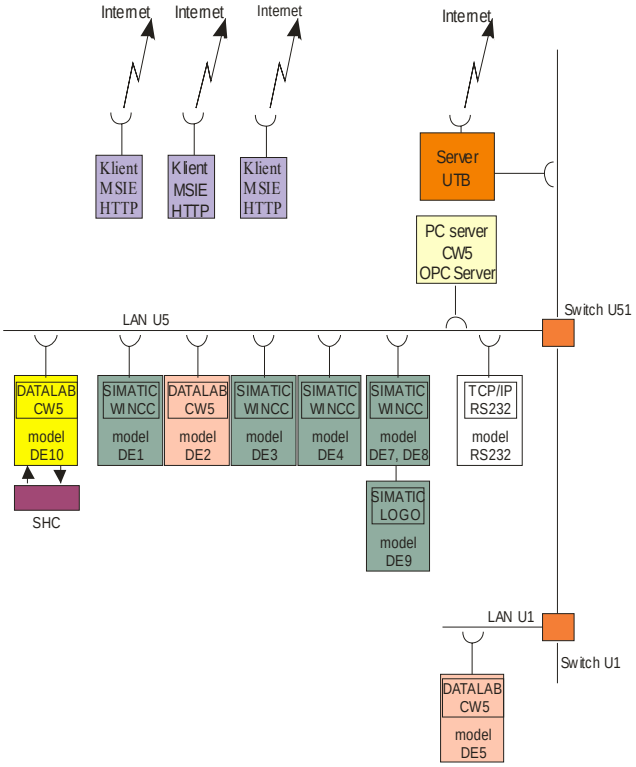

Fig. 11 Scheme of LABI system

There is using the remote access in the way of the Internet. The system DE10 is a part of greater system of LABI (LABoratory of Integrated automation) (Hruska…). The scheme of LABI system is in the figure 11.

The LABI system contents:

- the open part of real physical models,
- the server system for supervision and communication
- the client´s part.

In the fig. 11 is showed the real models from the DE1 up to DE10. They have a different physical base. For example the DE1 is the thermal system for the temperature control in a exchanger. The system DE3 gives to learning and testing for flow meters with the different principles. The subsystem DE5 is unique system of biochemical processes. More is at http://labi.fai.utb.cz.

The central units of the models are the type of IPC (systems of DATALAB) or of PLC (systems of Simatic). All of the units are connected via LAN to PC Server. The server supervises the models, does the communication between them a gives access extern clients. So the clients can append to LABI and work with selected model via online regime. The software system of CW has great part of the possibility to access of clients via the Internet, it created the special “html server” or “OPC server “ for Simatic units. The main view of system LABI for clients is in fig 12. He can choose a concrete model a communicate via html server of CW software.

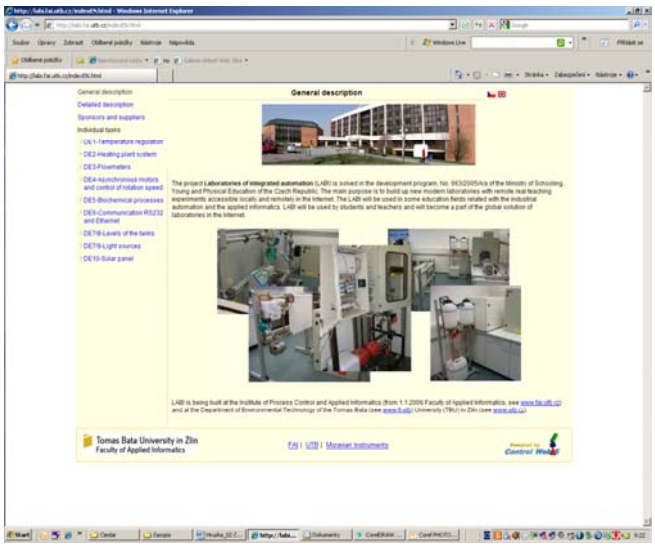

Fig. 12 The main view of system LABI for clients

V. MATHEMATICAL OPERATION

The system CW has prepared several problems with mathematical solving. The main ones are recomputation the parameter of sun radiation from unit lumen/m2 to energy unit W/m2 and calculation of photovoltaic panel position.

The first problem solves evaluation the sun radiation from the measured date in lumen/m2. The measurement of global radiation is very expansive. The device for the direct measurement is a special equipment and has scientific parameters. In system of DE10 is not necessary special measurement, it is used only for informatics using. Therefore there is use a standard device for measurement of irradiation. For the measurement there is used the unit of lux or lumen/m2.

Table 1 Measured date of sun radiation and irradiation

Nr.m	lux	W/m2
1	1180	19
2	1470	17
3	2370	38
4	3990	56
5	4080	59
6	8240	125
7	21800	331
8	21900	333
9	22020	335
10	32400	430
11	33300	440
12	39900	528
13	47700	606
14	48100	605
15	71050	847
16	71600	851
17	71700	853
18	72150	860
19	72400	856
20	73200	840

The recomputation needs to know a mathematical formula. There was a special measurement with laboratory equipment of global radiation and irradiation. The measured date was given in the table 1.

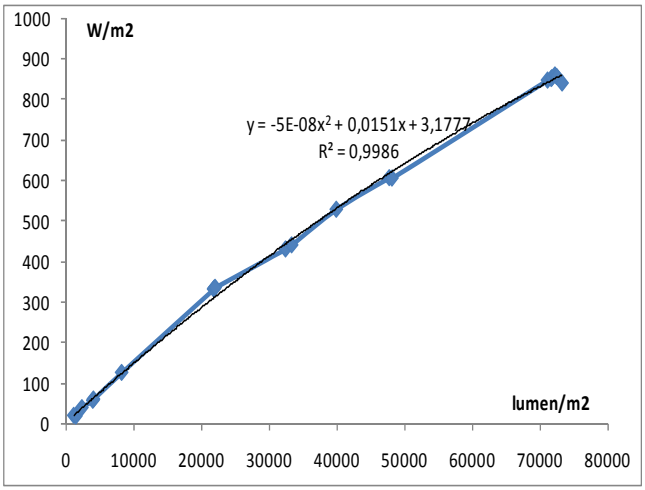

Fig. 13 Graph of relation of measured radiation and irradiation

The graph relation of sun radiation in unit W/m2 onto irradiation in unit lumen/m2 is in fig. 13. It is appeared as a small non linear dependence. It was calculated a regression formula of the relation, it is:

$$y = -5^{-8}.x^2 + 0{,}0151x + 3{,}1772 \quad (1)$$

where is

- y the sun radiation E_R in W/m2
- x the date of irradiation in lumen/m2 =lux.

The important mathematical calculation is for determination the value of photovoltaic panel position according to datum and o´clock time. The calculation is complicated and runs in several steps:

1. time angle (ta) for the midday of the data (d) and month (m) :

$$ta = (0{,}98.d + 29{,}7.m).3{,}14/180 \quad (2)$$

2. declination (dec) for the midday of time angle (ta):

$$dec = (23{,}45.\sin(ta - (109 * 3{,}14/180))).3{,}14/180 \quad (3)$$

3. geographical latitude (lat_r) for the point of panel (lat_°):

$$lat\_r = (lat\_°).3{,}14/180 \quad (4)$$

4. time angle (ta) for the hours of day (h):

$$th = (12:00 - h).1440.0{,}25.3{,}14/180 \quad (5)$$

5. angle of radiation to horizont (ang_rad):

$$ang\_rad = (A + B).3{,}14/180 \quad (6)$$

where

$$A = \sin(dec).\sin(lat\_r) \quad (7)$$

$$B = \cos(dec).\cos(lat\_r)\cos(th) \quad (8)$$

6. High of sun above the horizont (h) in radian:

$$h = \arcsin(ang\_rad) \quad (9)$$

7. azimuth (a_r) in radian

$$a\_r = \arcsin(\sin(th).\cos(dec)/\cos(h)) \quad (10)$$

8. elevation (ele) in ° with correction of angle for elevation k_{ele}

$$ele\_° = h * 180/3{,}14 - k_{ele} \quad (11)$$

9. azimuth (azi) in ° with correction of angle for azimuth k_{azi}

$$azi\_° = a\_r * 180/3{,}14 - k_{azi} \quad (12)$$

According to results of formulas (10) and (11) there is defined the position of photovoltaic panel for the datum (day and month) a for the hours on clock.

Energy balance is calculated according to parameters E_{out} and E_R. There is used a formula for its efficiency (epv):

$$e_{pv} = \frac{E_{out}}{E_R} = \frac{U_z.I_p}{E_R} \quad (13)$$

where is

- U_{out} voltage on the output,
- E_{out} energy power on the output of panel,
- E_R energy of global radiation on the output of panel,
- U_z the voltage on load device in Volt,
- I_p is current from panel in Ampere.

VI. Using of DE10 System

The system DE10 offers the user to study of photovoltaic principle, to test of efficiency of production of electrical

energy, to learn the track system according to theoretical side and to practical realization. The all offer is accessed via the Internet.

Combination of hardware and software give the possibility of remote using. The web side www.labi.fai.utb.cz is prepared to access of user and it is free.

The first step gives generally information about the system, see fig.12. The user enters his login and next side is showed and can select the hand or automatical regime. Standard regime is, the system works automatically according to algorithm of calculation of the position.

In the screen the user shows measured date of PV system in the currently time. The one can see two graphs of measured date. There are the time graphs of all value. The date of the automatical function are served in the system too. The user can download its in his computer and post evaluate in the Excel. The file in format *.cvs is transformed in Excel, date can be calculated in tables, in graphs, according to statistic parameters etc. The results will use in education, in advertising by pilot using.

The second form of using is setting of selectable position. The user can set the azimuth and elevation of position and get the information of energy power. View for this side is in the fig. 14.

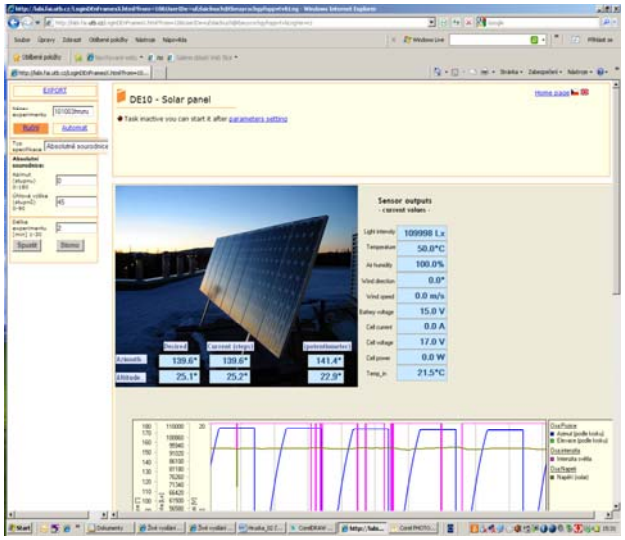

Fig. 14 WEB Side of parameter setting

VII. EXTENSION OF DE10 SYSTEM

At present the system DE10 is processed in range as it is describing. But the system is opened for next extension.

We have planed to add in the system new hardware and to extend the software application. The finish state has scheme in the fig. 15.

In the first step it will be installation of new measurement of direction and speed of wind in the ambient. The development is in state of new state research and development. The last solving used the strain gauges but there was recognized some bad parameters [7]. New solving is prepared a it will be instaled in next time.

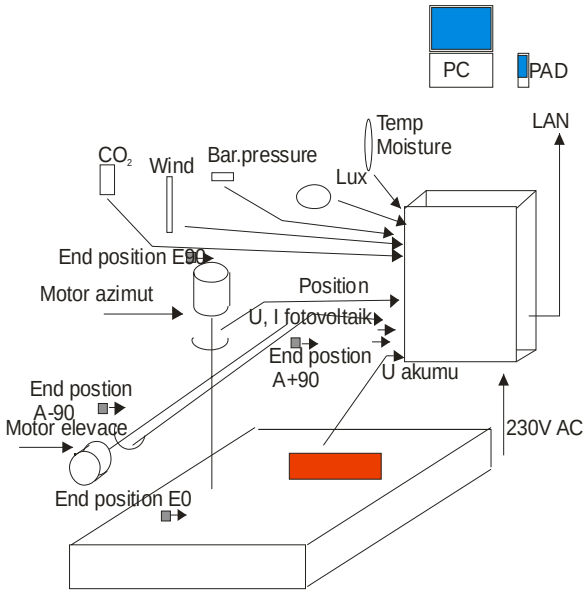

Fig. 15 Scheme of extended DE10 system

At the moment in the system there is used the photovoltaic panel with monocrystalic technology. It is classic type at present. The plane of future has a idea to add the new photovoltaic panel with concentrative modules. The new panel will have greater efficiency. The users can compare two technology.

The new principle of concentrative modules is showed in the figure 16. The module has the Fressnell optic, mirror, efficiency up to 38% with cooling, long time live.

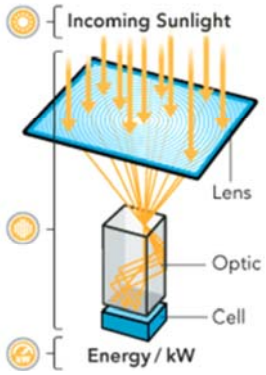

Fig. 16 Scheme of concentrative photovoltaic module

The other idea is to solve modern accumulation of electrical energy. By photovoltaic systems is very important when sun shines the electrical energy to accumulate. At the moment it is not decided which system will be used but the problem is solved in the world.

In the future is planed extension of function. It will be e. the third regime with extreme control of photovoltaic panel

position. The simple algorithms give the optimal position according to measured value of irradiation. The value is given from irradiation sensor. The user can find the optimal position of panel for concrete time moment.

The photovoltaic system produces electrical energy and decreases the concentration of CO2 in environment. In the future is planed to enlarge measurement of concentration of CO2 in ambient area and atmospherical pressure. The measured parameters say how it is in actually and system will answer the rate, how much it decreases.

The new devices from PDA or mobile technique are increased its using. Next idea is to write new application software for clients to use table PC, notebook, net book and PDA or mobile phone devices.

VIII. CONCLUSION

The experimental laboratory system is a result of development and solving the experiment laboratory photovoltaic system.

Next the local control system is the possibility to connect into the Internet and to remote access. The realized project has using as a pilot plant. The photovoltaic system is built as a new next model DE10 in the system LABI, it is very suited to education of problems of technical means and automation theory. The system will be used in professional field. These days there are very positive experiences of laboratory exercises with remote access.

The experiment DE10 has solved several special problems. In the first position there is two axis tracker system for set position of photovoltaic panel according the position of sun. A special development is used for measurement of direction and force of wind. The remote access has developed other function and uses connection in PDA and mobile phone clients.

ACKNOWLEDGMENT

This work was supported in part by the Ministry of Education, Youth and Sports of the Czech Republic under grant No. MSM 7088352102: “Modeling and control of processes of natural and synthetic polymers”.

REFERENCES

[1] HRUŠKA F.: Control system specifics for solar supply of heat energy. In: Proceedings of the 9th International Research/Expert Conference “Trends in the Development of Machinary and Associated Technology” TMT 2005, pp. 1557-1560. ISBN 9958-617-28-5. Antalya, Turkey, 26-30.9.2005.

[2] HRUŠKA,F. Internet a laboratoře integrované automatizace (The Internet and the Integrated Automation Laboratory). Jemná mechanika a optika, 2007, č. 2, s.64-66. Praha: Fyzikální ústav Akademie věd České republiky, 2006. ISSN 0447-6441.

[3] HRUSKA F.: Theory of Solar Supply for Industry. In: Proceedings of the 7th International Carpathian Control Conference, pp. 173-176. ISBN 80-248-1066-2. Rožnov p.R., Czech Republic, 29-31.5.2006.

[4] HRUŠKA F.: Experiment DE1 of LABI and Process Experiences. In: Proceedings of 16th International Conference on - PROCESS CONTROL ´07, ISBN 978-80-227-2677-1, June 11 – 14, 2007, Štrbské Pleso, Slovakia.

[5] Hruska F. Experimental Model of Photovolataic Systems. Proceedings of the 12th International Research/Expert Conference “Trends in the Development of Machinery and Associated Technology” TMT 2008, pp. 645-648, ISBN 978-9958-617-41-6. August/2008, Istanbul, Turkey.

[6] HRUŠKA F.: Experimental Photovolataic System. In: Proceedings of the 20th International DAAAM Symposium “Intelligent Manufactoring &Automation” DAAAM 2009, pp. 923-924. ISBN 978-3-901509-70-4. Vienna, Austria.

[7] HRUŠKA F.-Lkhagvatseren T. Signal Condition of DC Bridges. In: Proceedings of the International Control Conference ICCC´2009, pp. 285-288. ISBN 8389775-51-5. Zakopane, Poland, 24-27.5.2009