Hardware and Software Functions of Standalone Field Data Acquisition Devices for the Low Voltage Power Distribution Grid

Krisztián Lamár
Óbuda University
Institute of Automation
Budapest, Hungary
lamar.krisztian@kvk.uni-obuda.hu

György Morva
Óbuda University
Institute of Electric Power Engineering
Budapest, Hungary
morva.gyorgy@kvk.uni-obuda.hu

***Abstract*— This paper is dealing with the data acquisition instruments, which are necessary nowadays for the optimal operation of low voltage power distribution networks. It introduces the requirements of data acquisition instruments, the proper choice of data acquisition time step and the solutions for real-time placement of the acquired data. It describes the most common hardware architectures and the calculations that are fundamental for the usual software solutions of the data acquisition instruments. At last, it gives some practical advice to the application of data acquisition instruments.**

Keywords*— *data acquisition, data processing, low voltage grid, microcontroller, communication

I. Introduction

The standard makes strict claims on electric power distribution and service. Out of these, keeping the voltage, continuous supplying and sinuosity are significant. It is a duty of an electricity supplier to provide a supplying power-line with a "cross-section" sufficient even during maximum consumption. The estimation of the load and voltage drop of a low voltage network is extremely difficult, because there is no commissioned measurement at the medium/low voltage stations.

The practice of the public electricity suppliers is, that the network areas needing reconstruction are narrowed by ad hoc measurings, and short and middle term plans are made accordingly. The basic decision has to be made for the operative (short-term) period, but for the outcome to be optimal, the effect of the decisions on the so called "post-effect period" cannot be passed by. An accountable decision can only be made having the results of proper measurement. This way, it can turn out in some cases, that a network scheme with minimal loss can be developed even with simple and low-cost actions (e.g. relocation of a decoupling point).

For performing such measurings, a proper instrument or set of instruments is necessary. These are the data acquisition instruments. Their main characteristic is that they record the states occurring during the measurement period in a way that they can be recalled with the necessary accuracy after the measuring. The results they provide can not only be used in the example above, but also give many support during the operation of the electric power supply. For example, in the inspection of consumer complaints, in the elimination of asymmetric load distribution, in the estimation of power needs and last but not least, in the finding of irregular power consumers, or idiomatically "power thieves".

There are many kinds of solutions for data acquisition instruments in literature. At first, data was acquired graphically with mechanic devices. Today, modern, digital, micro-computer data acquisition instruments based on sampling signal processing are used exclusively. This paper introduces the theoretical architecture and the properties of these instruments from hardware and software points of view.

II. Requirements of Data Acquisition Instruments

A. Electrical parameters

- It has to comply with IEC regulations.
- Sufficient storage capacity (storing the acquired data)
- Proper data transfer between the instrument and the data processing computer (RS-232 or RS-485; additionally, standard protocol, e.g.: MODBUS)
- Accuracy, speed, reliability

B. Geometry, mechanical parameters

- Robust housing and small size in the case of pylon-mountable data acquisition instruments
- Protection against environmental impacts, e.g.: it has to be water proof
- Provided possibility of mounting (e.g. to a pylon)

C. Economical parameters:

- Low price
- Provision of repair service
- Per unit cost of the measurement has to be low

At the selection of the proper data acquisition instrument it also has to be taken into account that what electrical parameters have to be known for the accomplishment of the given task. By this, mainly voltage and current measuring have to be considered. Modern data acquisition instruments provide more functions, but for data acquisitional mass-measurement, mostly these are not needed. These instruments are suitable for unique inspections. Such are: harmonic-content inspection, power measurement, consumption gauging, etc.

III. Data acquisition time step

In the case of digital data acquisition instruments, data is stored in a so called non volatile memory. Therefore, data acquisition is not continuous. The time between two data acquisition moments is the data acquisition time step. The data acquisition time step should not be mistaken for the sampling time. The latter one is at least two orders of magnitude less than the other one, so the measurement itself can be considered being continuous in spite of the discrete data acquisition.

It is a highly important issue, that how many shall be stored from the continuously measured values. The largest and smallest data acquisition time step that is interpretable have to be defined. A too frequent data acquisition would require a pointlessly large storage, its processing would be more difficult and, because of the electric inertness of the system, it would generate huge amounts of unnecessary data. Quick changes (blackout, voltage breakdown) have to be stored with timestamps anyway. If, however, the data acquisition time step is set too large, the movement and dynamics of the examined system is missing from the measured data. The 15-minute average and the smallest and largest RMS values within the given 15 minutes show for the operator and engineer if an intervention is needed in a network region or not. In the Hungarian practice, a 15-minute time step has been most common, but considering the IEC recommendations, it is practical to change to a 10-minute time step.

In order to prevent the problems resulted by the improper choice of time step, the acquisition of four-quarter slid average is used. The average of the one-hour sequence of measurings is calculated from the average values of four sequential 15-minute-long sequences of measurings. After another quarter, the new value is added into the result taking the average of one hour, but omitting the first quarter (Figure 1).

IV. Settling the acquired data in real time

A. Data acquisition with real time clock

In this case, there is an industrial clock within the data acquisition instrument. The difficulty of this method is that a current time and date have to be stored at any time, which requires unnecessary storage capacity.

B. Data acquisition with time grid

In this case, the data acquisition instrument does not have a real time clock, it only measures the time between two data acquisition moments, thus the data acquisition time step. The real time is determined at the reading or at parametrization.

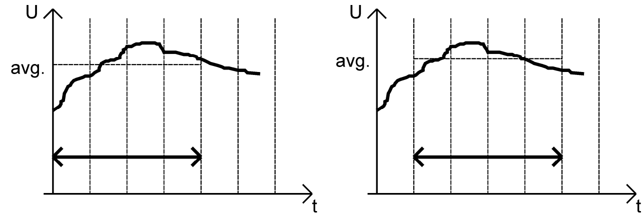

Fig. 1. Data acquisition of four-quarter slid average values

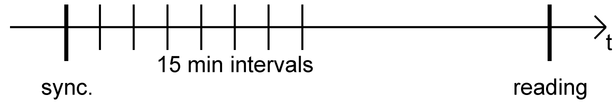

Fig. 2. Synchronization before measuring

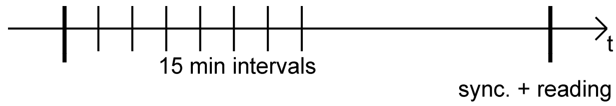

Fig. 3. Synchronization before reading

Synchronization at parametrization: In this case, the starting time of the sequence of measurings is stored in the memory. The n^{th} acquired data shows the states existing $n \cdot 15$ minutes from this moment (Figure 2). Its advantage is that starting and ending time of the measuring can be determined with it. Its disadvantage is that its implementation is more complex and often impossible in the case of mass-measurement. This is because the technician may have to parametrize tens of data acquisition instruments when installing the instruments.

Synchronization at reading the acquired data: In the case of reading phase the last (n^{th}) result is assigned to the moment of reading, the $(n-1)^{th}$ is assigned to the moment 15 minutes before, and so on. (Figure 3) Advantages: the instruments do not have to be parametrized before the start of measuring, thus the installation is simpler. Additionally, in case of balckout, only the low-consumption time generator has to be supplied with power. Today, this can be solved with super capacity condensers (SUPERCAP) successfully applied in load-control receivers.

V. Hardware architecture of data acquisition instruments

The block diagram of the three typical hardware architectures are shown in Figures 4, 5 and 6.

The signal sensors can be galvanically isolated or non isolated. Solutions providing galvanical isolation by current measuring are: current-transducer, Hall-effect transducer, closed loop Hall-effect transducer (providing DC measurement also). Solutions providing galvanical isolation by voltage measuring are: voltage transformer, isolation amplifier, linearised optocoupler. Solutions not providing galvanical isolation are: current shunt and voltage divider [5][7].

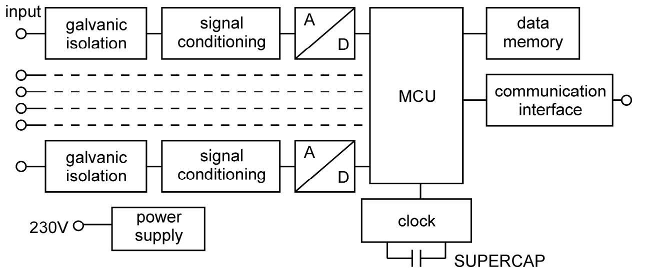

Fig. 4. General block diagram

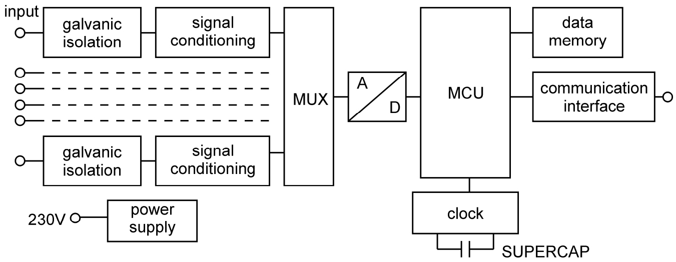

Fig. 5. Multiplexer using block diagram

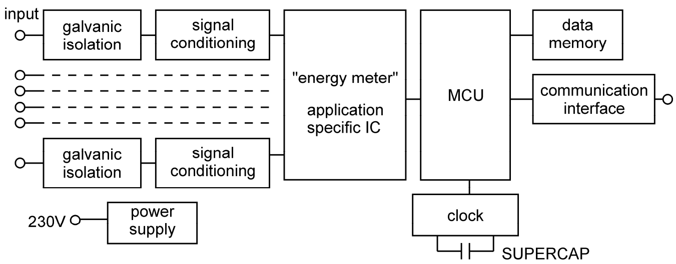

Fig. 6. Application specific integrated circuit using block diagram

The resolution of the A/D converter basically determines the minimal accuracy of the instrument. Today, 12-bit converters are used mostly. The integrational operations can be made more accurate by increasing the frequency of sampling, but the time needed for computing will grow dramatically. Speaking of 4 kHz sampling frequency, the effect of harmonics will appear in the sampled signal with the necessary accuracy.

In the case of the variant shown in Figure 5, the measured parameters did not get an A/D converter individually, but a multiplexer selects which signal is sampled by the A/D. By this solution, it has to be taken care of, that the conversion time of the A/D has to be small that the sampling delay between the channels could be neglected.

In the cases of Figures 4 and 5, the sampled, digitalized signal is processed directly by the micro-computer, which is supplied with a high-speed microprocessor, usually a digital signal processor (DSP) because of the computing demands of certain mathematical operations - especially the square root extraction.

Figure 6 shows a fundamentally different concept. Accordingly, there is no need for a costly A/D converter nor for an extremely high-speed micro-computer, as the sampling of the signals is performed by an application specific integrated circuit – mostly called energy meter – and it also takes over the majority of the computing demanding operations.

The data acquisition instrument gets the power from the measured network, as its minimal consumption does not deprave the measurement.

As it has already been mentioned, the measured data is stored in a so called non volatile memory, which has mostly EEPROM or FLASH-EPROM architecture nowadays.

The time base providing the data acquisition time step can be derived also from software, but it is practical to implement a separate, low-consumption CMOS-technology clock generator. This way, in case of power failure – shutting down the whole measurement system – it will not fail the accurate data acquisition timing. The power for the low-consumption clock generator can be provided by a battery or the already mentioned super capacity condenser.

The instruments communicate with the data processing computer mostly via an RS-232 (V24) or RS-485 standard asynchronous serial port.

According to the experiences, galvanic connection between a PC and an external hardware device can be problematic. There can be tens of volts difference between the grounds of the two circuits which are evened at the moment of connection with a current spike that can be several amperes. This may cause the sudden death of a couple of ICs or even the burning of the foil of the ground plane. This problem has to be avoided anyway. It is prevented by galvanic isolation, which is implemented by applying optocouplers. Sad to say, but the maximal signal transmission speed of the optocouplers is limited, as the transmitted signal suffers significant deformation. There are, however, special optocouplers, e.g. the 6N139 type, which have been designed for high-speed data transmission. With the application of these and Schmitt trigger signal conditioners, a transmission speed of 38400 bps (bit/sec) can be safely achieved.

VI. INTERNAL SOFTWARE OF DATA ACQUISITION INSTRUMENTS

As the heart of a data acquisition instrument is some kind of a micro-computer, it needs a program to operate. This program serves many functions, such as supervision of communication, managing memory, display and peripheral functions, etc. In this section, however, those parts of the software are dealt with that provide the electric quantities demanded by the user from the raw measured data, namely, that does the calculations [1][2][3].

A data acquisition instrument provides the following functions: it measures and acquires the RMS values of the voltage and current of each three phases according to formulas (1) and (2).

It does the integrations numerically according to the measured instantaneous values. The numerical integration can be performed with forward or backward Euler method as well as Tustin's rule (aka trapezoidal or the bilinear rule) or Simpson's rule.

The real power can also be calculated from the measured instantaneous values (3).

$$U = \sqrt{\frac{1}{T}\int_0^T u^2(t)dt} \quad (1)$$

$$I = \sqrt{\frac{1}{T}\int_0^T i^2(t)dt} \quad (2)$$

$$P = \frac{1}{T}\int_0^T u(t)\cdot i(t)dt \quad (3)$$

Based on the basis values calculated this way, further single- and three-phase parameters can be calculated.

A. Single-phase parameters:

$$S = U \cdot I \quad (4)$$

$$Q = \sqrt{S^2 - P^2} \quad (5)$$

$$\cos\varphi = \frac{P}{S} \quad (6)$$

It has to be mentioned, that if the current and/or voltage vaveforms are not sinusoidal, then the $S^2 = P^2 + Q^2$ formula is not valid, because a fourth kind of power is present because of the distortion of the signals. This power is called distortion power ($Q_{distortion}$) by Budeanu, a Romanian teacher [4]. In this case, the $S^2 = P^2 + Q^2 + Q^2_{distortion}$ formula is valid. According to certain apprehensions, the distortion power can be considered to be reactive power, as it cannot be utilized for work. Therefore, if the signal patterns are not sinusoidal, the Q quantity displayed by the data acquisition instrument is the square root of the squared sum of the reactive power and the distortion power, which is usually called general reactive power:

$$Q_{displayed} = \sqrt{S^2 - P^2} = \sqrt{Q^2 + Q^2_{distortion}} \quad (7)$$

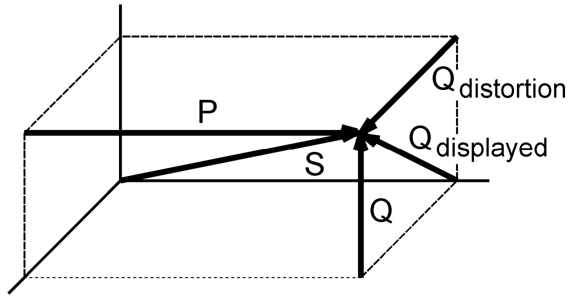

Fig. 7. The vector diagram demonstrating the relations of power components

The relation between the individual power components is demonstrated by the 3D vector diagram in Figure 7.

Similarly, the φ looses its meaning in the symbol of the power factor (cosφ), as definite phase angle cannot be defined between the current and the voltage.

B. Derived three-phase parameters:

$$S_e = S_1 + S_2 + S_3 \quad (8)$$

$$P_e = P_1 + P_2 + P_3 \quad (9)$$

$$Q_e = Q_1 + Q_2 + Q_3 \quad (10)$$

$$\cos\varphi_e = \frac{\cos\varphi_1 + \cos\varphi_2 + \cos\varphi_3}{3} \quad (11)$$

The derived power factor is a physically non existing quantity, it is only informative, and it has meaning only if the the phase angles of the loads on the three phases are nearly the same.

C. Measurement of energy consumption

By definition, the electric power (consumption), namely the work is:

$$W = \int_0^t p(t)dt = \int_0^t u(t)\cdot i(t)dt \quad (12)$$

In effect, the calculation is mostly not performed this way. If the instrument refreshes the power data in every second exactly, then the measurement of consumption can be solved simply with a summarization.

$$W_P = \sum_{i=1}^{n} P_i \cdot 1\sec \ [Ws] \quad (13)$$

The reactive consumption can also be calculated with a similar thinking, to which, in fact, there is no integral formula to assign:

$$W_Q = \sum_{i=1}^{n} Q_i \cdot 1\,\text{sec}\ \ [\text{var s}] \tag{14}$$

The meaning of this equation lacking real physical content is, that the electric power supplying companies can force the consumers to optimally manage the reactive power by measuring this.

VII. Processing of the Acquired Data

The communication takes place between the data acquisition instrument and a program run on a PC, mostly via an RS-232 serial interface. This program is the control program of the instrument. Its main tasks are the reading of the measured data, its processing according to the demands of the user and its tabular and graphical displaying [6]. Certain data acquisition instruments are able to store the instantaneous values of the measured signals besides acquisition. The storable period depends on the memory capacity and the sampling time and varies from a couple of periods to tens of periods. If the instantaneous values are also available, the control program can also display the oscillograms of the measured signals, and based on the data, it is capable of forming e.g. Park vectors or spectrum analysis.

Additionally, it is a task of the program to parametrize the instrument (e.g. setting the time constants of the measurement) and to provide possibility to calibrate the instrument.

Certain manufacturers tend to define their own communication protocols, but the demand for global compatibility forces them to give up their own method and switch to certain popular, almost standardized communication protocols. One of the most widespread is the MODBUS protocol developed by the MODICON Company [8].

MODBUS protocol is a highly reliable messaging procedure designed for mutual data transfer between PLCs in industrial environment. Individual devices communicate with each other according to master-slave technique. There can be only one master at a time, but several slaves. The master identifies the slaves by their unique address. Messaging can only be initiated by the master. The initiation is answered by the addressed slave(s), while they accomplish the task asked by the master or send the required data attached to the answer.

VIII. Conclusion

A one-week-long, quarter periodical data acquisition has to be considered as basic activity. In order to ensure that the sequence of measurings is evaluatable from every point of view, the simultaneous acquisition is necessary of minimum three values (supply voltage, supply current, endpoint voltage). If having the sufficient amount of instruments, a smaller area can be decided to be measured at a time, but with better accuracy. Accordingly, the states can be recorded not only at the endpoints and the transformer, but at critical nodes and junctions.

There are some cases, when there is no need for one-week-long data acquisition, a two- or three-day period is sufficient to determine the competent parameters. This depends on the nature of the consumers. Prior to the measurement, it has to be got to know, what the structure of the consumers is like, what result can be expected at that place, is there a point in acquiring data for one week, is a shorter-term measurement sufficient.

Here are some examples where the time and length of measurement have to be analysed:

- **Industrial areas:** it is practical to measure at work hours, because the maximum load is at that time in that area. In this case two or three days are long enough to perform the measurement. In the case of three-shift work order, a smooth load will show. In many plants, control equimpmet supervises not to exceed the contracted amount of power.
- **Office blocks:** those are characterised by lace loads during workdays, in work hours. Graphically displaying the acquired data, the beginning and ending of work hours are spectacular. A shorter measurement time is sufficient, because the load of the rush-hour is fairly constant.
- **Week-end houses in the area:** Used only in the week-ends, mainly in spring and summer. The measurement has to be performed at this time.
- **Holiday resort:** measurement can take place in the summer, but at that period, the load is constant on each day of the week.
- **Holidays (e.g. Christmas):** If the measurement is performed at this time among the personal consumers, properly high values are measured. If the network is prepared for this load, it will be sufficient for any other period. It is not oversized either, because the future load growth also has to be calculated with.

References

[1] Horváth, E. (ed.), Measuremet techniqe, Volume 1-2, KKMF-1161, Budapest, 1994.

[2] Istvánfy, Gy. (ed.), Electric instruments and measurements, Műegyetemi Kiadó, Budapest, 1997.

[3] Schnell, L. (ed.), Mesuerement technique of Signals and Systems, Volume 2, Műegyetemi Kiadó, Budapest, 1998.

[4] Liska, J., Retter, Gy., Theory of Alternating Currents, Tankönyvkiadó, Budapest, 1955.

[5] Haddad, R., Errors occuring during the accounting measurements with three-phase transducers, Elektrotechnika Vol.93, No.1, p.36, 2000.

[6] Haddad, R., Molnár, S.,: New modem-based procedure for handling the IEC 1107 communications, Elektrotechnika Vol.93, No.3, pp119-120, 2000.

[7] Tamus, Z. Á., Koller, L., Modern Current-transducers, Elektrotechnika Vol.93, No.7-8, pp.282-287, 2000.

[8] Modicon Modbus Protocol Reference Guide, Revision J, MODICON, Inc., North Andover, 1996.

[9] Analog Devices' ADE energy measurement ICs, http://www.analog.com/en/analog-to-digital-converters/energy-measurement/products/index.html (acessed: 24-07-2013)

[10] Kiraly, I., Determination of correction coefficients of the slot leakage inductance for multi-phase machines, COMPEL-The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, Vol.32, No.3, pp. 961-976, 2013

[11] Varga, A., Rácz, E., Kádár, P., New Experimental Method for Measuring Power Characteristics of Photovoltaic Cells at Given Light Irradiation, Proceedings of 8th IEEE International Symposium on Applied Computational Intelligence and Informatics, SACI-2013, Timisoara, Romania, pp.405-409, 2013

[12] Fuerstner, I., Gogolak, L., Pletl, S., Solution Diversity for a Specified Project in Mechatronics, Proceedings of the International Conference Science in Parctice, 2012

[13] Novak-Marcincin, J., Janak, M., Barna, J., Torok, J., Novakova-Marcincinova, L., Fecova, V., Verification of a program for the control of a robotic workcell with the use of AR, International Journal of Advanced Robotic Systems, Vol.9, Art. No. 54, 2012

[14] Rădac, M.-B., Precup R.-E., Petriu, E. M., Preitl, S., Experiment-based Performance Improvement of State Feedback Control Systems for Single Input Processes, Acta Polytechnica Hungarica, Vol.10, No.3, pp.5-24, 2013

[15] Sárosi, J., Accurate Positioning of Humanoid Upper Arm, International Journal of Engineering, Annals of Faculty of Engineering Hunedoara, Vol. 9, No. Extra, pp. 33-36, 2011

[16] Durovsky, F., Fedak, V., Integrated mechatronic systems laboratory, Proceedings of the 14th International Power Electronics and Motion Control Conference (EPE-PEMC 2010), pp.S51-S55, 2010

[17] Suto, J., Oniga, S., Remote controlled data collector robot, Carpathian Journal of Electronic and Computer Engineering., Vol.5. pp.117-120, 2012

[18] Györök, Gy., Seebauer, M., Orosz, T., Makó, M., Selmeci, A., Multiprocessor Application in Embedded Control System, Proceedings of the 2012 IEEE 10th Jubilee International Symposium on Intelligent Systems and Informatics SISY 2012, pp.305-309, 2012

[19] Szénási, S., Vámossy, Z., Implementation of a Distributed Genetic Algorithm for Parameter Optimization in a Cell Nuclei Detection Project, Acta Polytechnica Hungarica, Vol.10, No.4, pp 59-86, 2013

[20] Balázs, G. Gy., Horváth, M., Schmidt, I., New Current Control Method for Grid-Connected Inverter of Domestic Power Plant, Proceedings of the 15th International Power Electronics and Motion Control Conference (EPE-PEMC 2012), pp.1-5. 2012

[21] Gyeviki J., Sárosi J., Csikós S., Position Control of Pneumatic Actuators with PLC, Proceedings of the IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM2011), pp.742-747, 2011

[22] Kádár, P., Varga, A., Power trade simulation, Proceedings of the 16th IEEE International Conference on Intelligent Engineering Systems INES-2012, 2012

[23] Mester, Gy., Matijevics, I., Szepe, T., Simon, J., Wireless Sensor-Based Robot Control, in: Application and Multidisciplinary Aspects of Wireless Sensor Networks Concepts, Integration, and Case Studies: Computer Communications and Networks, pp. 275-277, Springer, 2011

[24] Horváth, L., Rudas, I.J., New Method of Knowledge Representation and Communication for Product Object Modeling, Proceedings of the 12th WSEAS International Conference on Applied Computer Science ACS-12, pp. 75-80, 2012

[25] Bencsik, A.L., Gáti, J., Kártyás, Gy., Maintenance of Complex Automated Systems, 7th IEEE International Symposium on Applied Computational Intelligence and Informatics SACI-2012, pp. 223-227, 2012

[26] Hunyár, M., Schmidt, I., Veszprémi, K., Vincze, Gyné., A megújuló és környezetbarát energetika villamos gépei és szabályozásuk, Műegyetemi Kiadó, Budapest, 2001.

[27] Ronay, K., Dumitru, C., Gligor, A., Management of a Power System Based on Renewable Energy, Scientific Bulletin of the „Petru Maior" University of Tîrgu Mureş, Vol.9, No.1, pp.38-42, 2012

[28] Dumitru, C., Gligor, A., Modeling and Simulation of Renewable Hybrid Power System Using Matlab/Simulink Environment, Scientific Bulletin of the „Petru Maior" University of Târgu Mureş, Vol.7, No.2, pp.5-9, 2010