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# CONSIDERATIONS REGARDING THE OPTIMIZATION OF A RENEWABLE ELECTRICAL ENERGY GENERATION SYSTEM'S FUNCTIONING

Remus Vladimir GHINCU[1], Andrei Romulus GHINCU[2] and Ovidiu Gheorghe MOLDOVAN[3]
[1] S.C. Audit Serv S.R.L, remusghincu@gmail.com
[2] University of Oradea, romusghincu@gmail.com
[3] University of Oradea, omoldovan@uoradea.ro

ABSTRACT: 1 Considering the current changing climate conditions, the use of electrical energy generated from renewable sources is of great importance. This paper proposes a new method for integrating a solar based energy generation system (composed of photovoltaic panels and power inverters), when used in conjuncture with the national power grid, in such a way as to maximize the use of renewable energy as opposed to energy from the grid and thus increase economical efficiency and lower environmental effect.
KEYWORDS: economical efficiency, renewable energy, solar power, photovoltaic panels, power inverter

## 1. INTRODUCTION

This paper studies the optimization of an electrical energy generation system based on renewable energy sources. The paper presents both the method used to increase the economical efficiency of the electrical energy generator and considerations regarding the construction of the automation equipment which realizes this task.

The electrical energy generator is powered by solar energy and consists of two photovoltaic panel banks and two three-phase inverters connected in parallel.

Each solar panel cluster is composed of 48 solar panels, each with a nominal power of 200W, giving each cluster a nominal power of 9.6kW and a total nominal power of 19.2kW for the whole system.

To change the DC voltage provided by the solar panels to an AC voltage compatible with the national power grid we have utilized two three-phase power inverters, each with a nominal active power of 10kW, connected in parallel.

The three-phase outputs of the two inverters are connected both to the electrical grid and to the local consumer [1].

This system is the property of S.C. Audit Serv S.R.L. in Oradea and it is destined to cover the owner's own energy requirements and to inject the surplus in the national power grid. When the energy requirements surpass the photovoltaic system's capabilities, the difference is taken from the power grid.

The two power inverters are grid-connected type and are produced by the Austrian company FRONIUS INTERNATIONAL GmbH, model number SYMO 10.0-3-M. The two inverters are set to the Romanian electrical grid parameters: three-phases, 400V, 230V between phases, at 50Hz, with neutral and protective earth connections.

The two power inverters are presented in Fig. 1.

**Figure 1.** The two power inverters used.

The FRONIUS inverters, because of their advanced technical characteristics, obtain an efficiency between 87.9% and 98.0%; the inverters have an Ethernet interface, an USB type A socket, a floating contacts relay for energy management and data logging capability.

A more in-depth view of the technical specifications of the Fronius inverters is possible by consulting the manufacturer's documentation [2].

**TECHNICAL DATA FRONIUS SYMO (3.0-3-S, 3.7-3-S, 4.5-3-S, 3.0-3-M, 3.7-3-M, 4.5-3-M)**

| INPUT DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| Number MPP trackers | 1 | | | 2 | | |
| Max. input current ($I_{dc\ max\ 1}$ / $I_{dc\ max\ 2}$ 1)) | 16.0 A | | | 16.0 A / 16.0 A | | |
| Max. array short circuit current ($MPP_1$/$MPP_2$ 1)) | 24.0 A | | | 24.0 A / 24.0 A | | |
| DC input voltage range ($U_{dc\ min}$ - $U_{dc\ max}$) | 150 - 1,000 V | | | | | |
| Feed-in start voltage ($U_{dc\ start}$) | 200 V | | | | | |
| Usable MPP voltage range | 150 - 800 V | | | | | |
| Number of DC connections | 3 | | | 2+2 | | |
| Max. PV generator output ($P_{dc\ max}$) | 6.0 $kW_{peak}$ | 7.4 $kW_{peak}$ | 9.0 $kW_{peak}$ | 6.0 $kW_{peak}$ | 7.4 $kW_{peak}$ | 9.0 $kW_{peak}$ |

| OUTPUT DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| AC nominal output ($P_{ac,r}$) | 3,000 W | 3,700 W | 4,500 W | 3,000 W | 3,700 W | 4,500 W |
| Max. output power | 3,000 VA | 3,700 VA | 4,500 VA | 3,000 VA | 3,700 VA | 4,500 VA |
| AC output current ($I_{ac\ nom}$) | 4.3 A | 5.3 A | 6.5 A | 4.3 A | 5.3 A | 6.5 A |
| Grid connection (voltage range) | 3-NPE 400 V / 230 V or 3-NPE 380 V / 220 V (+20 % / -30 %) | | | | | |
| Frequency (Frequency range) | 50 Hz / 60 Hz (45 - 65 Hz) | | | | | |
| Total harmonic distortion | < 3 % | | | | | |
| Power factor ($\cos \varphi_{ac,r}$) | 0.70 - 1 ind. / cap. | | | 0.85 - 1 ind. / cap. | | |

| GENERAL DATA | SYMO 3.0-3-S | SYMO 3.7-3-S | SYMO 4.5-3-S | SYMO 3.0-3-M | SYMO 3.7-3-M | SYMO 4.5-3-M |
|---|---|---|---|---|---|---|
| Dimensions (height x width x depth) | 645 x 431 x 204 mm | | | | | |
| Weight | 16.0 kg | | | 19.9 kg | | |
| Degree of protection | IP 65 | | | | | |
| Protection class | 1 | | | | | |
| Overvoltage category (DC / AC) 2) | 2 / 3 | | | | | |
| Night time consumption | < 1 W | | | | | |
| Inverter design | Transformerless | | | | | |
| Cooling | Regulated air cooling | | | | | |
| Installation | Indoor and outdoor installation | | | | | |
| Ambient temperature range | -25 - +60 °C | | | | | |
| Permitted humidity | 0 - 100 % | | | | | |
| Max. altitude | 2,000 m / 3,400 m (unrestricted / restricted voltage range) | | | | | |
| DC connection technology | 3x DC+ and 3x DC- screw terminals 2.5 - 16 $mm^2$ | | | 4x DC+ and 4x DC- screw terminals 2.5 - 16$mm^2$ 5) | | |
| AC connection technology | 5-pole AC screw terminals 2.5 - 16 $mm^2$ | | | 5-pole AC screw terminals 2.5 - 16$mm^2$ 5) | | |
| Certificates and compliance with standards | ÖVE / ÖNORM E 8001-4-712, DIN V VDE 0126-1-1/A1, VDE AR N 4105, IEC 62109-1/-2, IEC 62116, IEC 61727, AS 3100, AS 4777-2, AS 4777-3, CER 06-190, G83/2, UNE 206007-1, SI 4777 1), CEI 0-21 1), NRS 097 | | | | | |

**Figure 2.** Technical specifications of the FRONIUS SYMO power inverter [2].

Regarding the software capabilities provided by the product, it allows through the use of the provided Fronius Datamanager application to remotely monitor the functioning of the system; the device also provides an algorithm for automatically finding the optimal operating point.

The inverters are capable of various electrical energy management functions, such as the programmable switching level of a relay accessible to the user, and the 'zero feed' facility which allows for a dynamical reduction in the power injected in the grid after the energy requirements of the consumer are met [2] .

In Romania, due to the current economical and legislative context, entities that have both an electrical energy consumer and supplier function are in a difficult situation because of the large difference in prices between the energy consumed from the power grid(expensive) and the energy injected in the grid(very cheap).

## 2. APPLICATION

For the most efficient use of the solar power based energy generation system, it is necessary for the system to be utilized in such a manner that the consumer's energy requirements are maximally covered by the own produced energy from the renewable source and the consumption from the power grid is kept to a minimum.

In solving this problem, one has to be aware of objective factors relating to the environment such as: the power generated by the photovoltaic panels is very dependent by season (minimal in the winter, maximal in the summer), by the day-night cycle (0 kW at night; between 0 and 20kW during the day), by the weather (the cloud coverage, the sunlight's intensity and the ambient temperature) and by the time of day (which determines the incident angle of the solar rays on the photovoltaic panels).

While some of the factors mentioned above have a high degree of predictability, such as the season and the day-night cycle, others such as the cloud coverage and the sunlight intensity at a specific moment are hard or impossible to predict over a large time period.

The energy requirements of the consumer are also showing a large variation, between 9 kWh and 17kWh per day in our case.

The optimization method for the functioning of our electrical energy generation system we have chosen is based on comparing permanently, in real-time the power generated by the photovoltaic system to the consumer's energy requirements and connecting consuming devices to the solar-produced energy system as indicated by an algorithm designed in such way that it minimizes the consumption of power from the national grid, while maximally covering the consumer's energy requirements.

With this system in mind, we have separated the consumers in two categories:

1. Essential consumers: the consumers need to be provided with electrical energy in any situation, regardless of where the power comes from (power grid or solar generator)

2. Non-essential consumers: these consumers will be powered only with the photovoltaic generated electrical energy; they are assigned different priority levels, being connected one by one based on the available power, starting with the ones with the highest priority while of course taking into account their nominal power requirements.

Regarding the issue of determining the instantaneous power generated by the photovoltaic system, the FRONIUS Symo inverters allow the user to see this information, as shown in Fig. 3, where the active power generated is shown on the display; unfortunately, this information can only be used for informative/statistical purposes since the user does not have access to the measured power values needed to control a process (such as connecting/disconnecting consumers).


**Figure 3.** Real time produced power display

Another method for indirectly determining the generated power of the system is by measuring the degree of illumination of the solar panels, but the method shows large disadvantages due to the large number of light sensors that need to be placed and summed when the solar panels have different placement. Another disadvantage this method has is the fact that the correlation between the illumination measurements from the sensors and the power generated by the system has a low precision. It should also be taken into account the fact that, in time, the efficiency of the photovoltaic panels decreases and such degrading the correlation between the light sensor's signal and the actual generated power.

In our case, for measuring the generated power we have utilized the following method: we have measured the phase current of our three-phase system; it is known that the instantaneous consumed power in a symmetrical three-phase system is given by the following formula:

$$P = 3 \cdot \left(U_f \cdot I_f \cdot \cos(\varphi)\right) \quad (1)$$

Where Uf is the voltage on the phase, If is the current and cos(φ) is the phase difference between voltage and current. Due to the fact that the inverters used in this system are grid-connected and so the outputs are directly tied to the power grid, at least in theory, the voltage levels (Uf) are constant and each have the value of 230VAC; also, since in our particular case the consumers are mainly resistive in nature (as opposed to inductive), cos(φ) will be constant. In this way we are able to get precise information regarding the generated power of the photovoltaic system.

The measurement of the currents was done using three current transducers with proportional outputs, manufactured by LEM, which are shown in Fig. 4; their technical specifications are shown in detail[4] and briefly in Fig. 5. The control algorithm was implemented on a PICO 1760-L18 PLC from ALLEN BRADLEY; the technical documentation for the PLC is shown in [5].

**Figure 4.** Current transducer[4]

The internal electronic schematic of the current transducer is presented in Fig. 6

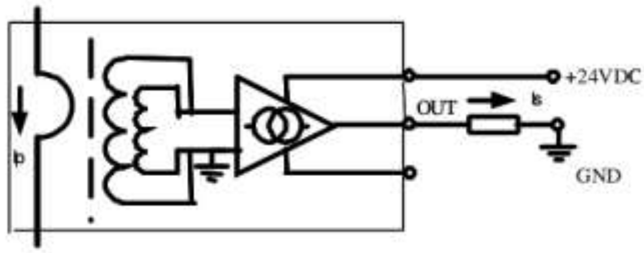


**Figure 5.** Internal schematic of the current transducer

**Electrical data**

| Primary Nominal Current $I_{PN}$ (A.t.rms) | Output Current $I_{OUT}$ (mA) | Type | RoHS since date code |
|---|---|---|---|
| 10,25,50 | 4-20 | **AP 50 B420L** | 47129 |
| 50,75,100 | 4-20 | **AP 100 B420L** | 47113 |
| 100,150,200 | 4-20 | **AP 200 B420L** | 47150 |
| 200,300,400 | 4-20 | **AP 400 B420L** | 47150 |

| | | | |
|---|---|---|---|
| $R_L$ | Load resistance, with $V_C$ = + 24 V DC [1] | < 350 | Ω |
| $V_C$ | Supply voltage (loop powered) | + 12 .. 24 | V DC |
| $I_{SL}$ | Output current limitation [2] | < 25 | mA |
| $\hat{I}_P$ | Overload capability [3] | no limitation | |

**Accuracy-Dynamic performance data**

| | | | |
|---|---|---|---|
| X | Accuracy @ $I_{PN}$, $T_A$ = 25°C (excluding offset) | < ± 1 | % of $I_{PN}$ |
| $\varepsilon_L$ | Linearity error (0 .. ± $I_{PN}$) | < ± 0.5 | % of $I_{PN}$ |
| $I_{OE}$ | Electrical offset current @ $T_A$ = 25°C | 4 | mA |
| $TCI_{OE}$ | Temperature coefficient of $I_{OE}$ | ± 1 | μA/K |
| $TCI_{OUT}$ | Temperature coefficient of $I_{OUT}$ (% of reading) | ± 0.1 | %/K |
| $t_r$ | Response time to 90 % of $I_{PN}$ step | < 150 | ms |
| BW | Frequency bandwidth (± 1 %) | 30 .. 2000 | Hz |

**Figure 6.** Current transducer specifications

**Figure 7.** PICO 1760-L18 PLC

| Cat. No. | Line Power | Input Voltage Category | Number of Inputs (Digital) | Number of Outputs | Analog | Pico Variation |
|---|---|---|---|---|---|---|
| 1760-L12AWA | 120/240V ac | 120/240V ac | 8 | 4 (relay) | No | |
| 1760-L12AWA-NC | 120/240V ac | 120/240V ac | 8 | 4 (relay) | | no real-time clock |
| 1760-L12AWA-ND | 120/240V ac | 120/240V ac | 8 | 4 (relay) | | no display |
| 1760-L18AWA | 120/240V ac | 120/240V ac | 12 | 6 (relay) | | |
| 1760-L18AWA-EX | 120/240V ac | 120/240V ac | 12 | 6 (relay) | | I/O expandable |
| 1760-L18AWA-EXND | 120/240V ac | 120/240V ac | 12 | 6 (relay) | | I/O expandable, no display |
| 1760-L12NWN | 24V ac | 24V ac or 24V dc | 8 | 4 (relay) | 2 (0...0V dc) | |
| 1760-L12NWN-ND | 24V ac | 24V ac or 24V dc | 8 | 4 (relay) | | no display |
| 1760-L18NWN-EX | 24V ac | 24V ac or 24V dc | 12 | 6 (relay) | 4 (0...10V dc) | I/O expandable |
| 1760-L18NWN-EXND | 24V ac | 24V ac or 24V dc | 12 | 6 (relay) | | I/O expandable, no display |
| 1760-L12DWD | 12V dc | 12V dc | 8(1) | 4 (relay) | 2 (0...10V dc) | |
| 1760-L12DWD-ND | 12V dc | 12V dc | 8(1) | 4 (relay) | | no display |
| 1760-L18DWD-EX | 12V dc | 12V dc | 12(1) | 6 (relay) | 4 (0...10V dc) | I/O expandable |
| 1760-L18DWD-EXND | 12V dc | 12V dc | 12(1) | 6 (relay) | | I/O expandable, no display |
| 1760-L12BBB | 24V dc | 24V dc | 8(1) | 4 (transistor) | 2 (0...10V dc) | |
| 1760-L12BBB-ND | 24V dc | 24V dc | 8(1) | 4 (transistor) | | no display |
| 1760-L12BWB | 24V dc | 24V dc | 8(1) | 4 (relay) | | |
| 1760-L12BWB-NC | 24V dc | 24V dc | 8(1) | 4 (relay) | | no real-time clock |
| 1760-L12BWB-ND | 24V dc | 24V dc | 8(1) | 4 (relay) | | no display |
| 1760-L18BWB-EX | 24V dc | 24V dc | 12(1) | 6 (relay) | | I/O expandable |
| 1760-L18BWB-EXND | 24V dc | 24V dc | 12(1) | 6 (relay) | | I/O expandable, no display |
| 1760-L20BBB-EX | 24V dc | 24V dc | 12(1) | 8 (transistor) | 4 (0...10V dc) | I/O expandable |
| 1760-L20BBB-EXND | 24V dc | 24V dc | 12(1) | 8 (transistor) | | I/O expandable, no display |

**Figure 8.** Main characteristics of ALLEN BRADLEY's PICO family of PLCs

## 3. CONCLUSION

With economical efficiency being of great importance, the integration of electrical energy generated from renewable sources together with the national power grid presents a large opportunity for automation and optimization.

By separating the essential and non-essential consumers and supplying them with energy on a one-by-one basis in correlation with the level of produced energy, we can increase the use of our own produced green energy to power our own consumers.

In this way the energy consumption from the national power grid is minimized, allowing the consumer to obtain a greater level of economical efficiency and to optimize the usage of renewable energy sources.

## 4. FUTURE WORK

In a future work, we hope to be able to present in greater detail the automation equipment, both from a hardware point of view, and a software point of view by describing the priority based algorithm used to switch the consumers based on the level of power generated.

We also want to bring measurement data after a long period of time (at least 6 or 12 months so we will have data from the system under multiple functioning conditions, such as in different seasons and various environmental conditions) and economical efficiency calculations.

## 5. REFERENCES


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