Set of Rules in Order to Develop Control Systems Bases of Domestic Policies Using Renewable Energy

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Abstract: The purpose of this paper is to establish a set of prime rules which could enable the further development of the control and monitoring installation for domestic systems using microgeneration systems fundamented upon the use of renewable energies, particularly the solar energy. As a prime engine – for the development of such systems - we propose in this paper the Stirling engine as being highly adaptable to the diversity of fuels (gas, biomass, solar energy, etc.)

Key-Words: mCHP; Stirling Engine; renewables energies; building automation.

1 Introduction
The economic efficiency of a cogeneration/trigeneration installation depends decisively on the quality of the control program of the process. This is why the organization of the control unit with all the necessary know-how is one of the most important activities in the development of any application for a cogeneration/trigeneration system. All the important input parameters such as the type of fuel for the prime mover, the daily dosage quantities and the supplying timeline can be preset. The temperature values at various segments should be automatically supervised and monitored as well, the heating and cooling subsystems should be automatically controlled thus reducing operation costs.

The monitoring and control system – for a cogeneration/trigeneration system – is structured in principle on 3 structural levels:
- level 1 - a computer which should monitor all the thermal and electric processes in the system based on the information collected from the inferior level (level 2) over optic fiber and should control the thermal processes in the main hot water boiler, in the auxiliary hot water boiler, in the heat shifters, and in all subordinated installations etc.;
- level 2 – a PLC to collect the process data through field elements (level 3) and using a personal application program, it should transmit information to level 1 and receive commands which should be transferred to the execution elements at level 3;
- level 3 – the field elements consist of 3 categories: transducers – with the purpose of gathering data concerning the technical parameters of the process (pressure, temperature, electric power, etc.), converting them into electric signal (usually electric power 4-20 mA or tension -10 V – +10 V), and transmitting them to level 2;
- data transfer elements from level 3 to level 2;
- execution elements (valves, switches etc).

All these interconnected elements can ensure a long-lasting functioning of the cogeneration/trigeneration installations.

Of particular importance in achieving a monitoring and control facility - in the domestic systems - is developing a database of rules, which is the foundation for achieving its program, application-specific, information gathering and transmission of orders. The power system (production of electricity, heat and cold) is more complex and consequent this program to be implemented in system monitoring and control becomes more developed and there is a danger, without mentioning (and hence complying later) the specific rules of failure to attain the major objectives for the developed application (reducing costs, effectively reducing the environmental impact, etc.). This aspect becomes even more problematic when using sources of renewable energies in the development of the application (wind, solar, etc.). The application which represents the objective of the international project RO 0054, that is a representative house for the south-eastern region of Romania, using for its current needs (electric power, domestic hot water, climatizing) microtrigeneration installations based on both classic fuels (gas) and sources of renewable energy (biomass, solar) represents a good case study for stating the rules specific to controlling the domestic...
systems. In the following chapters, the analysis will be reduced to the level of a microcogeneration system, a necessary exercise for the development of a set of rules through an inductive method, from simple to complex.

2 Structural schemes of the monitoring and control systems

The development of domestic systems using microcogeneration installations to the detriment of the classic systems (conventional systems) is due to some fundamental assets: the reduction of energetic loss and efficiency enhancement, the reduction of nox emission (CO\textsubscript{2}, NO etc), the consequent reduction of environment impact; the possibility of using new prime engines and new fuels (biogas, biomass, solar radiation etc); the fulfillment of local consumer’s needs (for the most exigent requests).

The development of domestic systems using microcogeneration installations - to the detriment of traditional systems (conventional) - is due to several fundamental advantages: reducing energy waste and increase efficiency, reducing noxious emissions (CO\textsubscript{2}, NO etc.) and hence decreasing, the environmental impact, the use of new engines and new primary fuels (biogas, biomass, solar radiation, etc.) witch meet local consumers’ needs (for the most demanding requirements). Figure 1 presents comparatively the power diagram for a conventional domestic system and a microcogeneration domestic system [1] using gas as fuel for the prime mover. A notable advantage of microcogeneration systems (comparison to the traditional centralized systems) is their ability to be used on isolated sites.

Knowledge of the architectural particularities of domestic microcogeneration systems is essential for the development of the monitoring and control system. The heart of this microcogeneration system is the prime mover, differentiated by the type of fuel that is used. These structural features are highlighted in fig. 3 a,b,c for the 2 classes of domestic microcogeneration systems.

Such a capability is easily implemented if, instead of using a fuel that requires - in turn - making bus and connection to a centralized system (bus gas), one makes use of renewable energy sources (biomass, solar energy wind, etc.).

The diagram of fuel and energy flow for a microcogeneration installation (equipped with a Stirling engine) that uses gas as main fuel [1] and for the microcogeneration installation (equipped with a Stirling engine as well) that uses the solar radiation as source of primary energy is shown in figure 2 a, b represents [2].
Starting from these architectural features, we can determine a block diagram for the monitoring and control system configuration [4] (fig. 4).

In turn control and monitoring group has a three-tier architecture, as noted already in the introductory chapter (Riser Diagram [5]) - fig. 5.

The control and monitoring system of the microcogeneration units has the following main functions:
- ensures a proper unit functioning under high safety standards and productivity;
- allows the heat generation process to be integrated into the global heating system of the building;
- synchronises, operates in parallel and disconnects the electric generator under safety condition;
- allows monitoring the operating performance of the microcogeneration unit, ensures a steady functioning under the user requested parameters.

It is worth mentioning that all the 3 groups highlighted in figure 4 are interconnected by means of the 3rd level of control group.

3 Algorithms specific to monitoring and control systems

The establishment of a set of rules for the domestic systems control requires first of all the identification of the physical measurements within the microcogeneration unit which would account for the functional reliability of the whole system should they be kept within precise limits. Taking as a starting point the fundamental principle of a cogeneration (microcogeneration) system, that is the energy transformation of a prime mover into 2 energetic components – electric power and heat – it would follow that the most important units within such a system are the electric units – tension, electric current, power – specific to the electric generator on the one hand, and the temperature units – for the thermal subsystem – on the other. Keeping the measurements of these units under control ensures without doubt the functional reliability of the microcogeneration system as a whole and furthermore, it allows user satisfaction. Once the measurements of interest defined, there is need for specific algorithms to be created and implemented in order to monitor and control these measurements within the installation (according to the diagram in fig 5). In the case of electric generators, 2 types of electric power can be monitored and controlled: active power $P$, and total power $S$. The active power control requires the measurement/acquisition of the global power factor of the receivers connected to the generator terminals, which is a difficult and expensive operation. Total power is though specific to the electric generators which is easier to control. The organization chart for the implementation of the active power monitoring and control diagram is shown in figure 6. And the organization chart
allowing the implementation of the total power monitoring and control diagram is shown in figure 7.

![Diagram Image]

Fig. 6. Organizational implementations of monitoring and control scheme of active electrical power delivered by generator

Temperature monitoring and control is of crucial importance for the microcogeneration system. The temperature control inside a dwelling is of course necessary both during the warm season but especially during the cold winter. Remaining for now at the level of a cogeneration system, the temperature control is necessary and possible only during winter time. Many times, in order to satisfy the customer’s demands during the months when the ambient temperature is very low, the current microcogeneration system – based on the Stirling engine as prime mover (especially the one that uses the solar energy as fuel) – should make use of an auxiliary small heating unit at the most favorable parameters of the heating agent. As shown by the studies undertaken in this project, it is difficult to constantly keep an imposed temperature inside a dwelling due to various perturbations and interactions between the constitutive subsystems. The surrounding temperature $T_a$ (fig. 9) represents of course a major perturbation factor but it is coupled with the particular way in which the thermal installation has been built and the specific materials used for the walls of the building (as perturbation factors: the interaction area of the heating pipeline with the surrounding, the different heat conducting coefficients of the structurally heterogeneous materials, the length of the transporting pipeline and the imminent heat losses). A temperature variation diagram within a room, structured on hours is shown in figure 8. The implementation organization chart of the temperature monitoring and control diagram inside a dwelling that uses a microcogeneration system based on renewable energy is shown in figure 10.

![Diagram Image]

Fig. 7. Organizational implementation of the scheme to monitor and control the total power supplied by generator
under safety conditions, with reduced costs, and reduced environment impact.

4 Primary rules for the optimal functioning of the plant systems based on renewable energy

The monitoring and control systems that are to be implemented require compliance with some primary rules for each physical measurement to be controlled. If the monitoring and control of the active power delivered by the generator is required, the system must enable the following primary functions:

- imposing physical quantities - voltage, current intensity and the active power - the values prescribed by the manufacturer of the generator, respectively $U^*, I^*, P^*$ (fig. 6);
- acquisition instantaneous values of quantities voltage / current supplied by generator;
- determining the maximum - a semiperiod - the quantities purchased;
- determining the actual values of electrical quantities voltage / current: $U_g, I_g$;
- comparing values determined by values flocks of the same size as required in the facility for reasons of operational stability;
- the acquisition (or measured) power factor of the global burden connected to the generator output, - determining the active power supplied by generator at the user load;
- constant power required load generator, the amount required by this power generator manufacturer, to ensure operational stability and ensuring greater duration of life of the subsystem.

If it is to monitor and control the total power generator, the system must enable the following core functions:

- imposition of physical quantities - voltage, current intensity and the active power - the values prescribed by the manufacturer of the generator, respectively $U^*, I^*, P^*$ (fig. 7);
- acquisition of instantaneous values of the quantities voltage / current supplied by generator;
- determining the maximum – during a semi period - the quantities purchased;
- determining the actual values of electrical quantities voltage / current: $U_g, I_g$;
- comparing values determined by the actual values of the same size as required in the facility for reasons of operational stability;
- determining the total power delivered at the load generator user;
- constant power load required by the generator, the amount required by this power generator manufacturer, to ensure operational stability and ensuring greater duration of life of the subsystem. As it can be seen, the monitoring and control system has to carry out the same functions as in the case of the active power control, except for the rule regarding the acquisition/measuring of the power factor within the electric installation of the building. The monitoring and control of the temperature inside a room implies establishing a correlation between the user’s requirement (fig. 8) and the capacity of the thermal energy manufacturer (fig. 10). The correlation between the two diagrams requires the transfer of the user’s demand (the temperature in the room) toward the producer (the quantity of thermal energy which has to be ensured by the auxiliary small thermal unit); this transfer is also reflected on the prime engine inlet (situation shown in fig. 9 by the Stirling engine block).

Based on the temperature control and monitoring algorithm – in fig. 9 – the physical system to be constructed has to carry out the following functions:

- imposing physical quantities - temperature inside during the winter days, that the temperature limit (the threshold), related to architectural features and materials used to achieve both building and installation of heat transmission - the values prescribed by the manufacturer of these materials, respectively \( T_{inW} \), \( T_i^* \) (fig. 9);
- acquisition of temperature values of heat delivered out of the auxiliary thermal heating, \( T_{off} \), respectively ambient \( T_a \);
- acquisition value of temperature inside the room, \( T_{in} \);
- determining the actual temperature of the heat value in simplistic terms of a direct interaction with the environment, \( \Delta T \);
- comparing the actual temperature with the temperature threshold value (required);

- constant temperature inside the chamber and compared with the value required by the user. It notes that failure threshold conditions and user requirements require direct interventions on auxiliary heat and micro unit by transfer, the prime mover (Stirling Engine).

5 Conclusion

The following conclusions can be drawn as a result of the study undertaken above:
- the domestic systems which use renewable energy are worth developing in isolated areas where the costs for implementing classic systems would be too high and there would be a major impact on the environment;
- the architecture and the materials used for building the living place and those used for the small cogeneration unit have great importance in the later creation of the monitoring and control system for the physical measurements of interest in terms of costs but also the functional stability and the long lasting life of the system;
- the creation of a monitoring and control system performance requires the development in advance of a set of basic rules, rules based on some specific algorithms for each size is made monitoring and control. The rules meeting will form the basis of rules for domestic system (like a database), the critical role both in achieving control system as well, especially in his later exploitation.

References:
[4] *** Stirling Home Microgeneration, KEIMEI Catalog, Rome, Italy

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