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Hybrid Power – Application for Tourism in Isolated Areas

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***Abstract*—**The rapidly increasing costs of power line extensions and fossil fuel, combined with the desire to reduce carbon dioxide emissions pushed the development of hybrid power system suited for remote locations, the purpose in mind being that of autonomous local power systems. The paper presents the suggested solution for a “high penetration” hybrid power system, it being determined by the location of the settlement and its “zero policy” on carbon dioxide emissions. The paper focuses on the technical solution and the power flow management algorithm of the system, taking into consideration local conditions of development.

***Keywords*—**Renewable energy, hybrid power system, wind turbine, photovoltaic panels, bio-diesel cogeneration, bio-fuel.

I. Introduction

ROMANIA is a country located in South-East Central Europe, North of the Balkan Peninsula, on the Lower Danube, within and outside the Carpathian arch, bordering on the Black Sea. Almost all of the Danube Delta is located within its territory.

The Romanian national power system relies mainly on fossil fuel for electric power production, as seen in Fig. 1 [1], being mostly independent as far as energy imports is concerned. Thermal power for heating is supplied in the city areas through local cogeneration, local heating production or

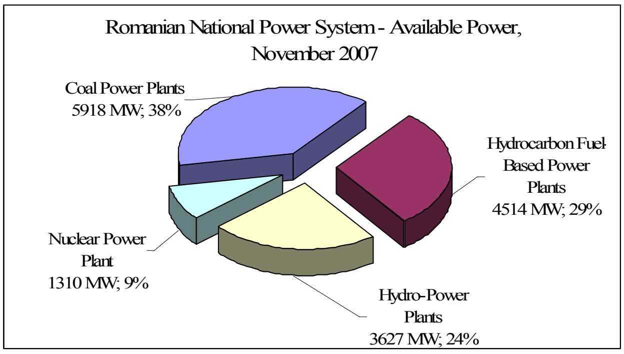

Fig. 1 Romanian Nation Power System – Available Power, November 2007

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independent heat production. The rural area and especially the remote locations are poorly integrated in the national energy sector.

The Romanian national power system relies mainly on fossil fuel for electric power production, as seen in Figure 1 [1], being mostly independent as far as energy imports is concerned. Thermal power for heating is supplied in the city areas through local cogeneration, local heating production or independent heat production. The rural area and especially the remote locations are poorly integrated in the national energy sector.

The paper is a based on the feasibility study regarding the possibility of implementation for a hybrid power system as part of a newly developing touristic resort which is placed between 1600 and 1800 m altitude and does not benefit of any energy development, being mostly a forest area. The touristic potential of the area and natural wild life preservation must amalgamate for the project success. Renewable energy is the answer for maintaining the natural balance of the area, and a hybrid power system addresses the need of an autonomous power supply.

Based on the meteorological local data, of prime interest in renewable energy is the wind energy, followed by solar energy (with lower potential and availability). The local climate measurements taken in the area indicate an average annual wind speed between 10 and 11.5 m / s and an average annual solar energy potential of 3.40 kWh/m^2/day. The local climate satisfies all demands imposed by a “high penetration”, wind energy based, hybrid power system:

- wind speed tends to increase in altitude, thus indicating optimal placement for wind turbines;
- high average wind speeds;
- valleys with air currents are situated near the location.

The primary requirement of the developer relates to the supply of electricity and heat for two hotels, two ski tracks, holiday houses and functional dependency.

Following the calculations related to electrical and thermal power demand and the assessments made according to the area’s special requirements, the main features of the power system are as follows:

1. supplying a maximum active electrical power of 344.28 kW;

2. ensuring stability of the hybrid power system:

- voltage stability;
- frequency supply;
- secondary sources – back-up and control system, AC/DC generator and energy storage.

Fig. 2 Satellite view of the location

3. supplying heat for heating and hot water consumption with the following distribution:

• 1600 m altitude area: 279.08 kW_t maximum instant thermal power;

•1800 m altitude area: 386.42 kW_t maximum instant thermal power;

II. Hybrid Power System – a solution for a Remote Touristic Resort

Considering the existing situation, the solutions to be taken into account are based on the following premises:

- valuing the potential of renewable energy sources, in the area (wind, solar and biomass);
- using clean technologies (environmental friendly) for energy generation;
- ensuring energy supply – security for consumers;
- operating in compliance with related regulations and standards for such systems.

Taking into account the information presented above and considering the potential of renewable energy in the region, known at the time of the study, the following solution was preferred:

- generating electricity using wind power source; as the main source;
- generating electricity using solar energy source; as compensation for un – meet load and main source of energy storage;
- ensuring storage capacity for un – meet renewable output; back – up system component;
- ensuring back-up of the system with cogeneration Diesel units using biodiesel fuel; also supplying heat when operating, thus increasing system efficiency;
- a continuous heat supply from boilers, using biomass as fuel.

Calculation and load prediction, and also accounting all there is to a hybird power system, resulted in the following power supply system:

- Wind Source: Installed power requirement of 300 kW;
- Photovoltaic (solar energy): Installed power requirement of 150 kW;
- back-up using a cogeneration Diesel unit for each altitude consumption zone (Installed requirement of electrical power : 200 kW/per unit);
- primary heat supply: 1600 m altitude consumption area – 300 kW_t Installed power requirement; 1800 m altitude consumption area – 400 kW_t Installed power requirement

Wind turbines are to be placed on the 1800 m altitude plateau, as resulted in the site optimization study.

Photovoltaic panels will be placed on the 1800 m altitude covering an approximate area of 5000 m^2.

Diesel and boiler units will be placed in special buildings for each altitude consumption zone.

The high penetration hybrid system is designed to meet most or all of the electric and thermal demand with renewable energy output. It is considered that the actual average renewable energy output may exceed the average load, so individual energy storage is required for each source.

Typically high penetration systems incorporate some form of energy storage. The high penetration system presented is designed to meet the electrical and thermal load with renewable generated energy at any operating time (wind, solar, bio-fuel and biomass). The main purpose is minimizing the diesel's running time, so that all or most of the wind and solar potential is used. Running on bio-fuel makes the Diesel generator a renewable energy output, cogeneration being an efficiency booster of the system when operating.

The management system or the functioning algorithm of the hybrid system must ensure that at any time the best control strategy is at work. The management of the electrical power system must focus on achieving precise regulation of frequency and voltage when rapidly varying wind and solar power input and load conditions are occurring.

An automated controller of a Wind/Solar – Diesel hybrid power system must be able to perform a wide variety of functions such as: [2]

- load management to ensure that power is efficiently used;
- management of individual power sources and energy storage, combined with an integrated decision – strategy tree regarding proper configuration of energy system at any given value of input and output;
- operator notification on any warning or alarm conditions that might occur or have occurred;
- performance data logging in order to facilitate troubleshooting and maintenance of equipment and network.

Fundamentally, however, the most critical task of the system is to provide good frequency and voltage regulation. Unless the system can provide good power quality, as measured primarily by frequency and voltage stability, operating it is not viable.

When a change of system state occurs that calls for a modification of the control modes and configuration of one or more devices, it is important that the mode changes occur seamlessly, without causing discontinuities in power flow, which would be manifested as frequency or voltage transients on the power lines, in the case of electrical energy, or interrupting activity and discomfort in the case of thermal energy. [3]

Being a large scale hybrid power system a distributed AC-bus architecture is suitable. For thermal power distribution a classical local heat production solution is chosen.

The basic task of any AC power system is to maintain well-regulated voltage and frequency on the AC bus, despite changes in the load and in the unregulated generating sources. Regulating frequency is essentially a matter of maintaining an instantaneous balance of real power kW in the system at all times, while voltage regulation involves maintaining an instantaneous balance of reactive power kVAr at all times, two functions sometimes referred to as “grid forming”.

The power converter interface to the energy storage must be designed to operate in a way that is compatible with the wind turbine and photovoltaic array requirements.

The auxiliary component of the system, next to the synchronous generators, responsible for delivering reactive power so as to maintain the AC bus voltage are the 4-quadrant inverters of the individual energy sources, inverters that have to operate synchronously together or with the Diesel generator.

In the situation of AC generator shutdown, frequency control is performed by energy storage coupled with power converters, (battery/inverter system). [2]

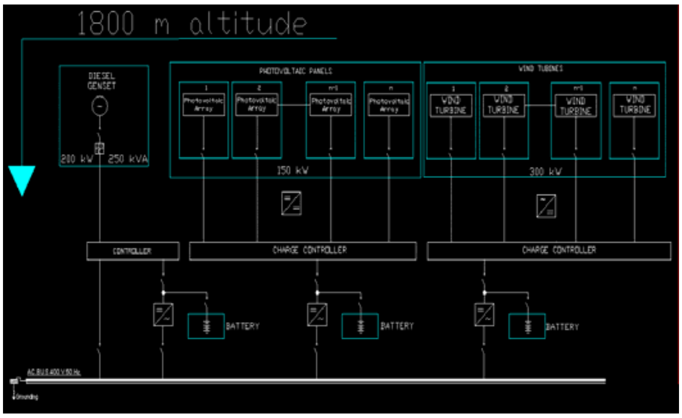

Fig. 3 1800 m altitude network diagram

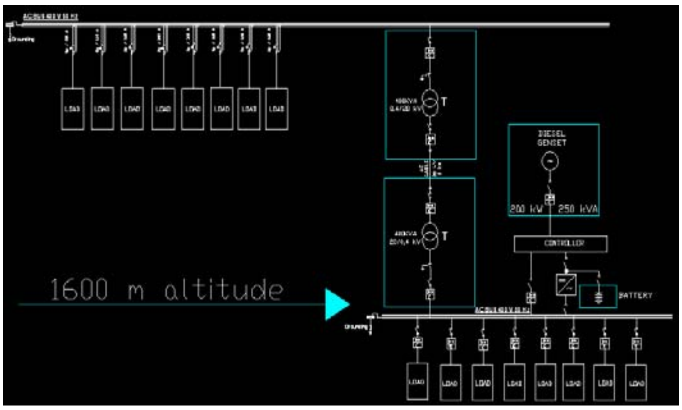

Fig. 4 1800 loads and 1600 m network diagram and loads

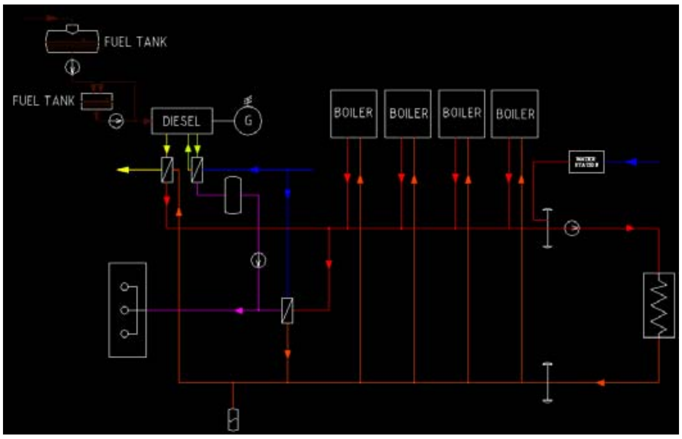

Fig. 5 Thermal diagram – 1800 m altitude (for 1600 m altitude there are only 3 boilers)

III. System Architecture – Delivering Uninterrupted Power

The architecture for the electrical system, selected to meet these objectives, is shown in simplified form, in Figs. 3 and 4. The architecture for the thermal system, chosen to satisfy thermal load, secondary to the electrical load, is presented in Fig. 5.

A. Frequency Regulation

At any given moment, if more power is at the input of the system than at its output, the difference will be stored as an increase in kinetic energy of the rotating machines within the power system that happen to be running at that specific time.

This relationship of power imbalance to frequency change only applies when the hybrid power system frequency is determined by the rotational speed of one or both synchronous generators operating at that time in the system. If the hybrid system is governed by a voltage source inverter, the frequency is set by a crystal oscillator and does not vary.

However, a similar situation exists in that any power imbalance then typically shows up as an increase or decrease in voltage on the AC and/or DC side of the inverter. The problem then becomes one of voltage control rather than frequency control. [4]

B. Voltage Regulation

Regulating the AC voltage of the power system is a problem of maintaining a balance between the source and sinks of reactive power in the system.

If the reactive power sources, the synchronous generator or the 4-quadrant inverters of the individual energy sources, are unable to deliver the reactive power demanded by the sinks, the bus voltage will fall such that the balance is maintained. With reactive power, the issue is not so much ensuring that equilibrium is maintained (which is automatic), but that the balance occurs at the desired voltage level (400 V).

C. Wind Source

10 kW wind turbines are preferred as equipment for generating energy from wind power. The advantage of this selection is the size and mass, acceptable for transportation and assembly at such location. The wind turbines will be equipped with permanent magnet synchronous generators, which represent the best solution in this case.

D. Solar Source

Photovoltaic panels having installed power of 150 kW, will consist of 1,000 photovoltaic modules each 150 W.

E. Energy Distribution

Between the two consumption areas will an energy distribution path will exist, which will ensure the supply of electricity to loads existing at 1600 m altitude, from wind and photovoltaic sources.

To minimize losses for the distribution, a 20 kV underground power line will connect the two areas. The normal power flow is from 1800 m altitude to 1600 m altitude, but in case of un – meet load in the 1800 m area, the Diesel generator from 1600 m area can supply it.

IV. Decision Algorithm – The Milestone of Hybrid Power Systems

The power flow management algorithm is presented in Fig. 6 for electrical power and Fig. 7 for thermal power.

In comparison with conventional power systems, where short-term load variations are typically small and the main power source is dispatchable on demand, high penetration power systems are challenging to implement.

The wind and solar power input of the system is stochastic in nature and highly variable. There is also the fact that on small isolated power grids, single loads tend to represent a larger percentage of the total load, being a big problem to be dwelt with.

For example, starting a small induction motor or a significantly large number of lamps at the same time could have a major impact on the system. The variability in the wind and solar energy and the variability in the load combine to yield rapid and high amplitude fluctuations in the net load, which is the difference between the primary load and the instantaneous power output of the system. The net load represents the power that must be supplied by the diesel generator and/or energy storage, or if it is negative, must be dispatched from the system. [3]

Low system inertia is another factor that contributes to the challenge of providing best frequency regulation. The rotating mass contained in a typical isolated hybrid system is significantly smaller than that of a large utility-scale power system. Whereas the time constant in a utility system for the frequency to respond to a change in load is measured in seconds or even minutes, it is measured in tenths of a second for the hybrid system. The actual control loops used to control power flow must provide very fast response. Due to the requirements for speed and automatic control mode switching, AC-based hybrid systems require active computer control to provide stable operation and good power quality. [4]

Because of the considerable impact of individual component characteristics on overall system operation, it is preferred that the design of control algorithms for hybrid power systems meets the specific conditions of the particular power system architecture.

In the preliminary stages of a hybrid power system project the beneficiary has very detailed questions about how to achieve the most efficient production and on–site management. Thus, the simulation tools can be helpful, offering the ability to create customized solutions for each specific request.

Hybrid power systems are characterized by a standard configuration, depending on the scale of the system and variables like the nature of consumers, the level of security in case of damage and last, but not the least, how the output power is used. The complexity of options makes almost impossible the implementation of solutions tested in any other isolated system. Simulation software and particularly simulation algorithms are indispensable tools for planning and constructing functional systems. Simulation is also imperative when choosing power electronics and energy storage equipment.

The assumptions considered for the simulation model presented in this paper are:

- reactive power is provided by the power electronics, multiple 4-quadrant inverters, if Diesel generators are off and by the Diesel generators alone or synchronizing with the inverter if needed;
- efficiency of boilers 85%, Electrical efficiency of Diesel 35%;
- minimum load of Diesel 50%, minimum load of boilers 20%;
- the temperature of combustion gas from diesel engines is a constant 495 [° C]

The final result of the simulation program will consist of a hourly system configuration for heat and electricity supply.

Notations used:

- S1-Source 1, wind power (including battery storage–B.A);
- S2-Source 2, photovoltaic (including source storage–B.A);
- S3-Source 3, Cogeneration (1600 m and 1800 m) (including battery storage – B.A);
- S4-Source 4,B1, B2, B3, B4, boilers (1600 m and 1800 m);

Formulae used in the simulation include the following:

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot S \cdot v^3 \quad (1)$$

Where: P_{wind} represents the available wind power , ρ the air density,v wind speed,S the total area covered by the the turbine blades.

$$P_{turbine} = \frac{1}{2} \cdot C_P \rho \cdot S \cdot v^3 \quad (2)$$

Where: $P_{turbine}$ represents the mechanical power ouput of the turbine and C_P represents the turbines performence coefficient;

$$P_{output} = P_{turbine} \cdot \eta_{EG} \quad (3)$$

Where: P_{output} represents the electrical output of the generator and η_{EG} represents the generator efficency.

$$P_{i.s} = S_c \cdot I_{gl} \tag{4}$$

Where: $P_{i.s}$ represent the solar incident power on the surface of the photovoltaic, S_c photovoltaic module area; I_{gl} intensity of global solar incident radiation on the surface of the module area;

$$P_e = P_{\max} \cdot C_p \cdot \frac{I_{gl}}{I_{gl.STC}} \cdot \left[1 + \alpha_T \cdot \left(T_C - T_{C.STC}\right)\right] \tag{5}$$

Where: P_e represents the DC ouput power of the photovoltaic array, P_{max} DC maxim ouput power of the photovoltaic array – standard conditions; c_p loss coefficient, $I_{gl.STC}$ intensity of global solar incident radiation on the surface of the module area, standard conditions,

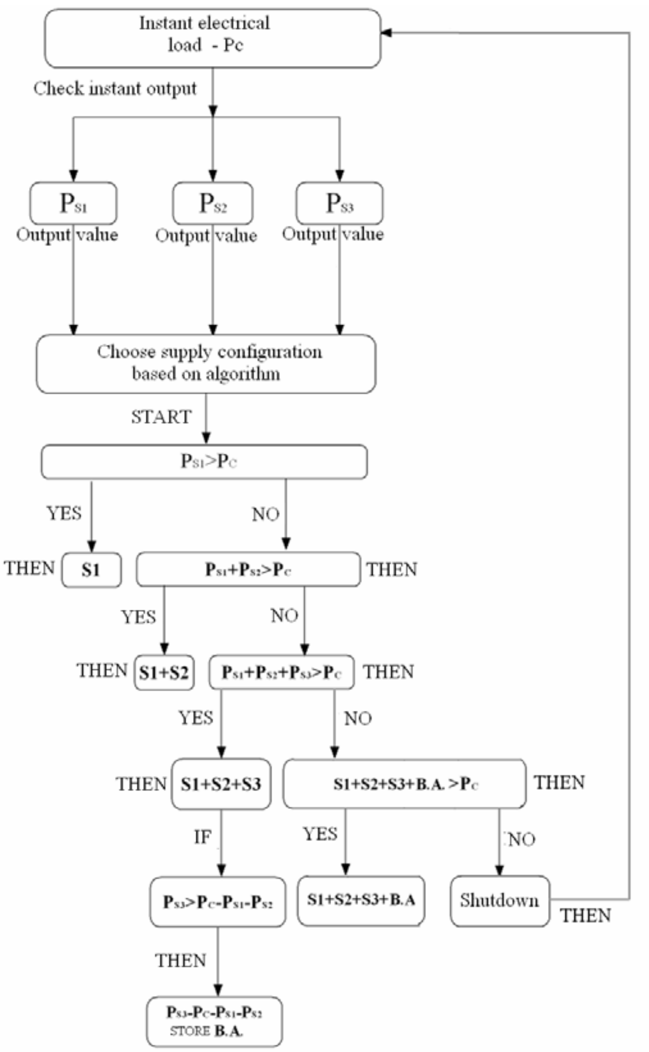

Fig. 6 Power flow management algorithm, electrical.

α_T the change rate of power with the cell temperature, T_C photovoltaic cell temperature in operating conditions, $T_{C.STC}$ photovoltaic cell temperature in operating conditions – standard condition.

V. Hybrid System Simulation – The Answer to Give

In Tables I ÷ VI simulation results of the hybrid power system are presented. The period of the simulation is one year. The simulation was modeled after the functioning algorithm presented in Fig. 6 and 7, partially using Homer simulation results:

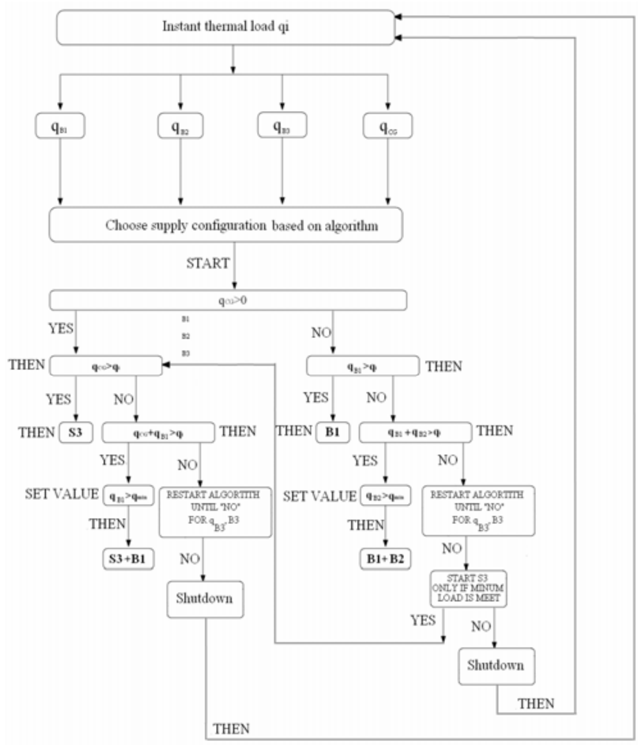

Fig. 7 Power flow management algorithm, thermal

TABLE I
Wind Energy – S_1

P_{med}	[kW]	120.0
P_{max}	[kW]	251.4
E_P	[MWh]	1051.0

TABLE II
Solar Energy – S_2

Output	P_{med}	[kW]	27.9
	P_{max}	[kW]	197.7
	E_P	[MWh]	244.1
Delivered to load	P_{med}	[kW]	25.1
	P_{max}	[kW]	150.0
	E_P	[MWh]	219.5

TABLE III
Wind and Solar Output

P_{med}	[kW]	145.09
P_{max}	[kW]	401.45
E_P	[MWh]	1271

TABLE IV
Boilers – 1600 m Altitude

q_{med}	35.0	[kWt]
q_{max}	241.2	[kWt]
Q_{an}	306.8	[MWht]
B	360.9	[MWh]

TABLE V
BOILERS – 1800 M ALTITUDE

q_{med}	55.3	[kWt]
q_{max}	333.9	[kWt]
Q_{an}	484.9	[MWht]
B	570.4	[MWh]
B_{fuel}	166215.9	[kg/yr]

TABLE VI
BOILERS – 1600 M AND 1800 M ALTITUDE

Q_{an}	791.6	[MWht]
B	931.4	[MWh]
B_{fuel}	269555.0	[kg/yr]

TABLE IV
DIESEL COGENERATION UNITS – 1600 M AND 1800 M ALTITUDE

Electrical			
Output used	P_{med}	36.4	[kW]
	P_{max}	171.6	[kW]
	E_P	637.0	[MWh]
Output	P_{med}	90.0	[kW]
	P_{max}	171.6	[kW]
	E_P	1577.0	[MWh]
Output stored	P_{med}	53.7	[kW]
	P_{max}	139.9	[kW]
	E_P	940.0	[MWh]
Thermal			
Output	q_{med}	121.4	[kW_t]
	q_{max}	231.4	[kW_t]
	Q_{an}	2126.4	[MWht]
Output used	q_{med}	63.6	[kW_t]
	q_{max}	188.8	[kW_t]
	Q_{year}	1268.8	[MWht]
Output not used	Q_{year}	857.6	[MWht]
Annual energy consumtion			
	B	4505.5	[MWh]
	B_{fuel}	381055.1	[kg/year]

VI. CONCLUSION

The study presented in the paper provided the customized solutions for a unique hybrid power system, with clearly specified performance requests.

Some of the specific objectives that guided the development of the system are as follows:

- To maximize the potential fuel savings and to reduce diesel maintenance expenses, the system should allow the diesel generators to be shut down as much of the time as possible. This objective requires the system to include a small amount of high power density energy storage.
- To further maximize the return on investment, the system needs to ensure that 100% of the wind turbines' energy output serves a productive load. In other words, wind power in excess of what was needed to meet the primary demand must be diverted to another application having economic value.

The project is important and necessary because:

- energy production units use only renewable energy as primary fuel;
- cogeneration is an important part of the project;
- it has a positive impact on the environment;
- it leads to the development and growth of regional touristic potential;

We appreciate that the system is technically reliable, since all of the important requirements were meet.

Regarding the cost hybrid power systems, it is misleading to think of the non-generation hybrid system equipments (controllers, power converters, energy storage) as nothing more than auxiliary. These components typically represent 25%-50% of the equipment cost [3], not including the cost of the Diesel location and distribution system.

From an economic point of view, the indicators are relatively high because the technology is still very new, at least on the Romanian market, and therefore expensive.

Economic assessment should consider the following aspects:

- Life expectancy is satisfactory;
- Depreciation of investment;
- Benefits;
- Cost of installation.

Also by comparing this energy investment with other similar energy investment in more developed countries, the following conclusions occur:

- costs of installation and operation are high;
- although the figure seems high, it is noted that the investment would be pay-back in about 7 ÷ 10 years, a very reasonable value for energy;
- investing in technology for energy generation based on renewable sources is technically and economically cost-effective when using a hybrid solution.

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