ASSESSING THE PERFORMANCES OF A PV- HYBRID SYSTEM USING COMBINED DISPATCH STRATEGY

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Abstract - The purpose of this paper is to analyze the behavior of a hybrid electricity generation system when the Energy Management Unit is programmed to operate in combined dispatch strategy mode. A dedicated mathematical model was used to size the Hybrid Power System components, these being used as input data for the HOMER Pro simulation program. By running this software, the operating characteristics of the hybrid system in two dispatch strategy modes were obtained and compared, an optimization of the combined dispatch mode was performed and, at the end, the conclusions were presented.
Keywords: hybrid power systems, combined dispatch strategy, cost of decision, state of charge

1. INTRODUCTION

In the last decade, there has been a significant increase in the number of hybrid power systems (HPS) used both for electrification of isolated consumers located away from electricity networks and for the implementation of distributed generation systems in different areas of power systems.

Regardless of how it is used, the end consumer requires HPS to meet the following requirements:

- To be able to operate autonomously, without the intervention of the human factor;
- To provide quality electricity without interruptions;
- To cover at any time the required load, regardless of the external factors that could influence the operation of the electricity generation subsystems.

In order to meet these conditions, it is necessary an optimal design of these systems both from the point of view of its components sizing and from the point of view of the energy management strategy within them.

From the point of view of sizing HPS components, there are two possibilities: either use dedicated mathematical models, or use dedicated sizing and simulation software.

From the point of view of energy management, HPS are provided with Energy Management Unit (EMU) based on microcomputer and appropriate software. An example of HPS based on solar resource is shown in Fig 1.

Due to the EMU capabilities, these subsystems can be programmed to direct electricity flows within HPS in different ways, as follows:

- Load following (LF), which involves the continuous operation of the DG, mainly in partial loads;
- Cycle charging (CC), when DG operates only when BA needs to be charged;
- Combined dispatch (CD) which, as the name suggests, is a combination of the two energy strategies mentioned above.

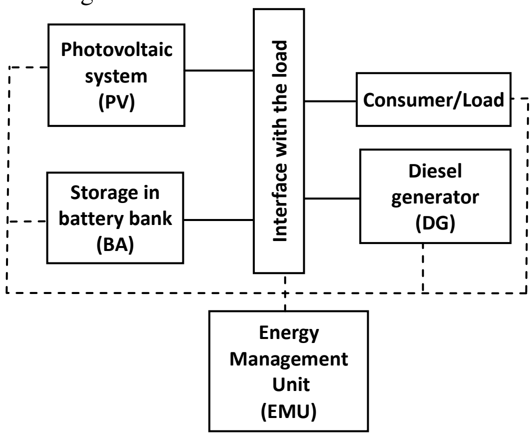

Fig. 1. Block diagram of PV-based HPS

Selecting an appropriate dispatch strategy of the EMU is essential because it contributes directly to:

- Prioritizing of electricity generation within HPS;
- Controlling the energy flows between HPS subsystems;
- Minimizing the cost of electricity produced by the HPS;
- Ensuring continuity in the supply of electricity to the consumer;
- Protecting the HPS subsystem from the damage produced by overloads.

2. THE COMBINED DISPATCH STRATEGY

In the case of the CD strategy, occurs the problem of the decision to load BA depending on the required net load, this being considered as the difference between the load demand and the output power from renewable sources [1].

Because predicting the required net load at a given time is difficult, the value of the current net load is taken into account as a proxy for the future net load thus: if the net load is high, the controller uses LF strategy mode, and if the net load is low it switches to CC strategy mode.

In this way the flow of electricity produced from PV, BA and DG is optimized based on three cost decisions, as seen in the Fig. 2.

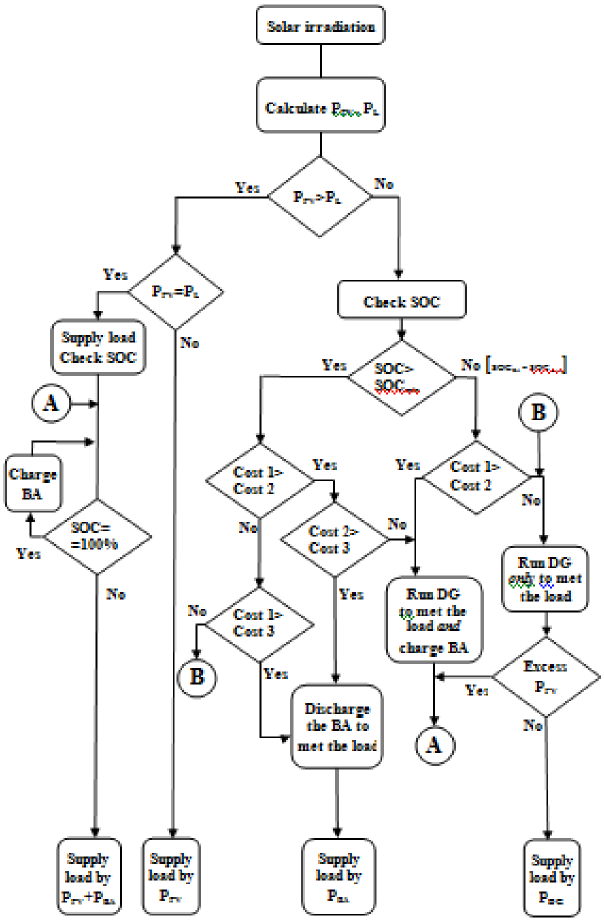

Fig. 2. CD strategy flowchart [1]

Cost 1 represents the first decision which concerns whether the DG should start only to cover the load, without charging the BA.

Cost 2 represents the second decision which concerns whether the DG should start both to cover the load and to charge the BA from the excess power produced.

Cost 3 represents the third decision wich refers to the fact that the DG does not start at all, the load being covered only by discharging the BA.

As shown in Fig.6, the start of DG in the case of CD strategy depends on the BA state of charge (SOC), as follows:

- If SOC = SOC_{min}, the controller gives the start command of DG only if from the comparison cost 1 and cost 2 it results that it is cheaper to cover the load without charging the BA;
- If SOC > SOC_{min}, the start-up of the DG depends on the result of the comparison of three decisional variants: cost 1 with cost 2, cost 2 with cost 3 and cost 1 with cost 3. Following this analysis, depending on the resulted minimum cost, it is decided whether the load will be covered only from BA or from both DG and BA.

3. THE HPS CASE STUDY

For the study purpose it is considered an isolated consumer whose load must be covered by a hybrid solar Diesel system with the storage of electrical energy in accumulator batteries.

3.1. The studied location

This consumer is located in Borod area, Bihor County - Romania, the data of the solar resource for the GPS coordinates of the place being obtained from the NASA website, the HOMER Pro simulation program providing both global horizontal solar irradiation and scaled annual average for this resource, Fig. 3.

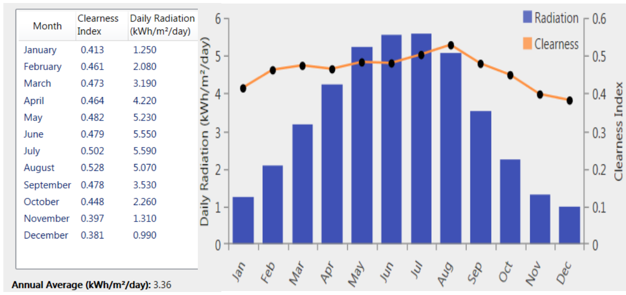

Fig. 3. Solar resource characteristic on site [2]

3.2. The system load data

We consider the following home appliances within isolated consumer, their technical characteristics being presented in Table 1.

Table 1. Characteristics of the load [2]

Load description	QTY		Load Current [A]		Load Voltage [V]		AC Load Power [W]
Lightning – LED 9W	5	x	0,041	x	220	=	45
Refrigerator	1	x	0,8	x	220	=	176
Hydrophore	1	x	3	x	220	=	660
Washing machine	1	x	6	x	220	=	1320
Tv	1	x	0,4	x	220	=	88
Radio	1	x	0,113	x	220	=	25
Total AC power (W)							2314

The HOMER Pro software also allows simulating the consumer load curve, Fig. 4 showing the daily, seasonal and yearly profile of the load [1].

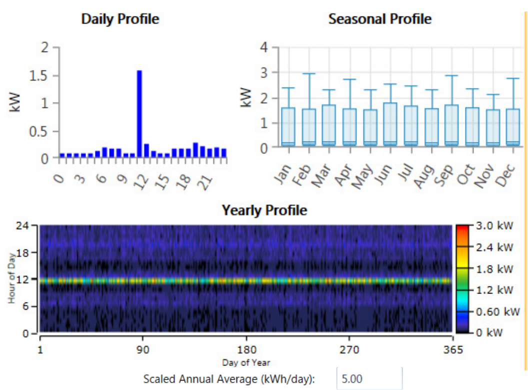

Fig. 4. The load profile of the remote consumer

3.3. The system configuration

The main subsystems of HPS were introduced in HOMER Pro, opting for a scheme with a 230V ac bus bar and a 48V DC bus bar, Fig 5.

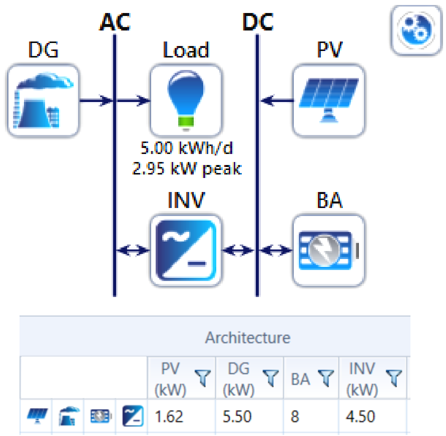

Fig. 5. Solar-Diesel HPS with battery bank

Following the sizing calculations of these subsystems utilizing a dedicated mathematical model in [3], it resulted:

- A photovoltaic system with a total installed power of 1.62 kW;
- A bidirectional pure sin wave inverter of 4,5 kW;
- A battery bank of 8 units, 170Ah capacity each;
- A Diesel group of 5,5kW on GPL with electronic auto start capability, as shown in Table 2.

Table 2. Characteristics of the main components of the SDHPS

PV system [4]	
Manufacturer	*Suntec*
Nominal power [W]	*270*
Nominal voltage [V]	*24*
Current nominal [Ahp]	*7,71*
Open circuit voltage [V]	*24,6*
Short-circuit current [A]	*8,2*
Derating factor [%]	*80*
Tracking	*fixed*
Capital cost [$]	*2982*
Cost of replacement [$]	*2982*
Operation &maintenance cost [$/year]	*10*
Lifetime [years]	*20*
Battery bank [5]	
Manufacturer	*Trojan*
Model	*SSIG 12 170*
Type	*Deep cycle*
Nominal voltage [V]	*12*
Nominal capacity [Ah]	*170*
Capital cost [$]	*1700*
Cost of replacement [$]	*1700*
Operation &maintenance cost [$/year]	*5*
DIESEL group [6]	
Manufacturer	*Honda*
Electronic auto-start	*yes*
Fuel	*GPL*
Nominal power [kW]	*5,5*
Fuel consumption [l/h]	*4,27*
Capital cost [$]	*2250*
Cost of replacement [$]	*2250*
Operation &maintenance cost [$/op.h]	*0,05*
Lifetime [h]	*15000*
INVERTER [7]	
Manufacturer	*Xantrex*
Model	*Pure wave*
Nominal power [W]	*4500*
Nominal ac voltage [V]	*220*
Nominal dc voltage [V]	*48*
Capital cost [$]	*2700*
Cost of replacement [$]	*2700*
Lifetime [years]	*15*
Operation &maintenance cost [$/year]	*22*
MICROGRID CONTROLLER [HOMER Pro]	
Capital cost [$]	*900*
Cost of replacement [$]	*900*
Operation &maintenance cost [$/year]	*10*

4. SIMULATION RESULTS

Given that the main objective of the HOMER Pro software is to reduce the costs for the designed HPS so that the load on the isolated consumer is covered, the economic results are presented first in this section, followed by the technical data and an environmental assessment.

4.1. Economical results

With the technical data of the isolated consumer receivers and with the solar resources data on-site, we simulated the HPS operational behavior in the HOMER Pro program with the dispatch of the EMU system set on CD strategy mode.

At this moment, the differences between the two dispatch strategies of EMU (CC and CD) presented interest due to the fact that in [2] it was demonstrated that for this system the CC strategy is the most valid option compared to LF strategy. The results are summarized in Fig. 6.

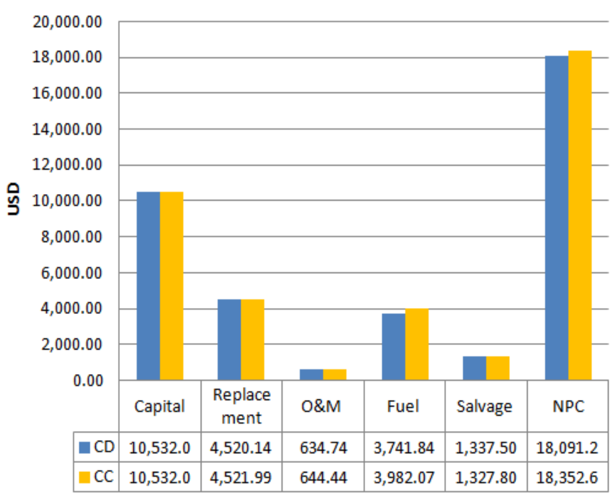

Fig. 6. Cost summary for SDHPS under the two dispatch strategies (CD and CC)

Fig. 6. shows the reason why HOMER Pro chose as valid the CD strategy: although the criterion for the optimal system is that of the NPC, it is observed that all the costs involved in operating and maintaining HPS are lower in the case of CD strategy than in the case of CC strategy for the same capital of 10,532$.

4.2. Technical results

From the point of view of electricity production, the CD strategy is slightly superior to CC in terms of solar resource, so that renewable faction is 64.7% in the case of CD compared to 62.5% in the case of CC, as shown in Table 3. Also, excess electricity in the case of CD is only 101 kWh/year, compared to 143 kWh/ year for DC, but in both dispatch strategies we do not have unmet electric load which proves a correct sizing of the HPS. This is due to the superior strategy in the case of the CD strategy compared to the CC strategy, the photovoltaic panels producing more electricity in the first case. This results in a lower number of hours of DG operation, which operate only 25.7% of the time in CD strategy.

Table 3. Comparative for electrical production indicators of CD and CC strategy

Electrical Production	CD strategy		CC strategy	
	kWh/year	%	kWh/year	%
PV	1,857	74.3	1,857	73.1
DG	644	25.7	684	26.9
Excess	101	4.02	143	5.64
Renewable faction	-	64.7	-	62.5
Max. renewable Penetration	-	8.23	-	8,236
Unmet electric load	0	0	0	0

The operational behavior of HPS backup and storage subsystems highlights the fact that although in CD strategy the DG starts number is higher than CC strategy, 82 starts/yr compare to 60 starts/yr, the number of DG operating hours is lower than in the case of CC strategy as shown in Table 4. Also the fuel consumption decreases, 362 L compared to 385 L, with an average of 0.9 l/day as against to 1,05 l/day.

Table 4. Comparative for operational behavior of Diesel group under CD and CC strategy

DG	CD	CC	[units]
Hours of Operation	222	237	hrs/yr
Number of Starts	82	60	starts/yr
Operational Life	113	105	yr
Capacity Factor	1.34	1.42	%
Fixed Generation Cost	0.525	0.525	US$/hr
Electrical Production	644	684	kWh/yr
Mean Electrical Output	2.9	2.89	kW
Minimum Electrical Output	1.65	1.65	kW
Maximum Electrical Output	4.1	5.5	kW
Fuel Consumption	362	385	l
Avg fuel per day	0.991	1.05	l/day
Avg fuel per hour	0.041	0.044	l/hour
Mean Electrical Efficiency	27.1	27.1	%

It is noteworthy that for the same components of HPS, the storage subsystem behaves almost the same in both cases of EMU dispatch strategy, having the same autonomy of 54,2 h which proves the correct design for this component (which was assumed by 48 h), Table 5.

Table 5. Comparative for operational behavior of storage subsystem under the two dispatch strategies

BA	CD	CC	[units]
Autonomy	54.2	54.2	hr
Lifetime Throughput	9,600	9,600	kWh
Expected Life	6.96	6.96	yr
Energy In	1,531	1,532	kWh/yr
Energy Out	1,233	1,235	kWh/yr
Storage Depletion	9.35	9.91	kWh/yr
Losses	307	307	kWh/yr
Annual Throughput	1,379	1,380	kWh/yr

Due to better Diesel generator performances, the emissions of the internal combustion engine within the DG are lower in case of CD strategy than in CC strategy, especially CO_2, with 545 kg/yr against 580 kg/yr as shown in Table 6.

Table 6. Emissions of the DG under the two dispatch strategies

Emissions	CD	CC	[units]
Carbon Dioxide	545	580	kg/yr
Carbon Monoxide	5.91	6.29	kg/yr
Unburned Hydrocarbons	0.261	0.277	kg/yr
Particulate Matter	0.0355	0.0377	kg/yr
Sulfur Dioxide	1.19	1.27	kg/yr
Nitrogen Oxides	5.56	5.91	kg/yr

5. OPTIMIZATION RESULTS

By running the simulation of the HPS operational behavior in HOMER Pro, the viability of the CD strategy was proved, DG being the subsystem that is most influenced by the EMU dispatch strategy. Thus it follows that an optimization of DG could be done only in the sense of reducing the installed power. Thus, the power of DG was introduced in the simulation software, as a sensitive value, considering that the minimum value for which the generator must have to cover the load required by the consumer is 2314 W.

As expected, the capital cost decreased due to the lower cost for the lower installed power of the DG, and although O&M increased slightly, all other economic indicators declined, including the most important NPC, Fig. 7. The capital and replacement costs decrease due to the lower cost of the DG.

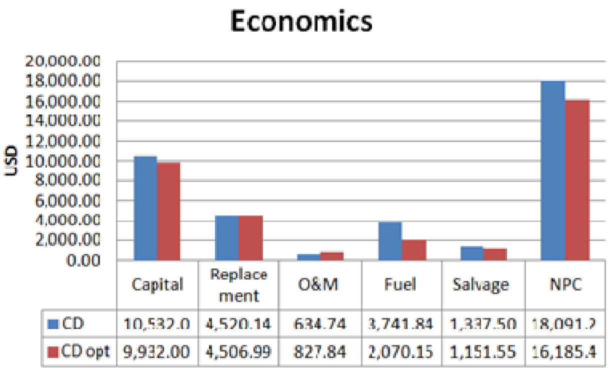

Fig. 7. Cost summary of the CD strategy optimized with lower DG installed power

The O&M increased due to the increase of the DG number of hours of operation, from 222 h/year to 263 h/year in the case of the optimized variant, Fig. 8.

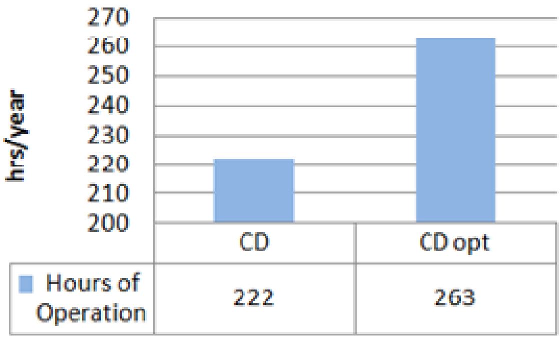

Fig. 8. The increase in hour of operation for the optimized CD strategy

However, due to the lower rated power, DG consumed less fuel for a longer number of operating hours, Fig. 9.

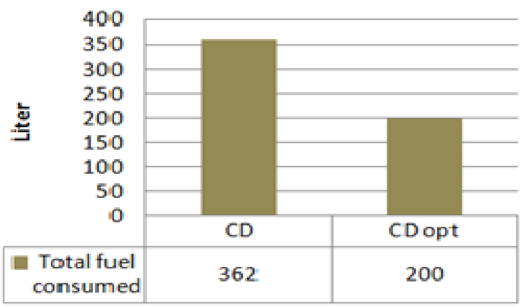

Fig. 9. The decrease in total fuel consumed per year

It should be noted that the average daily consumption has almost halved, from 0.991 l/day to 0.548 l/day, Fig. 10.

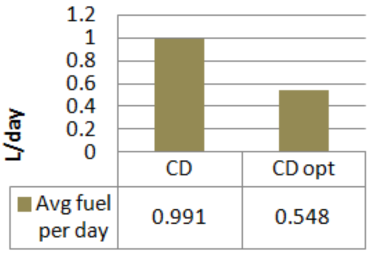

Fig. 10. The decrease in average fuel consumption

An important consequence of the reduction of the DG installed power within HPS has resulted in the improvement of its electrical efficiency, Fig. 11.

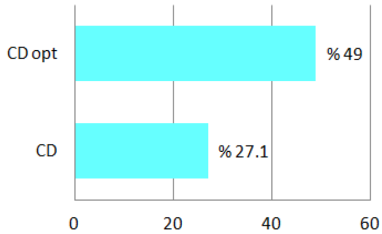

Fig. 11. DG average electrical efficiency of the optimized CD variant

From the impact on the environmental point of view, in case of optimized CD strategy a decrease in CO_2 emissions by 244 kg/year was obtained, which makes that even only in this aspect the optimization is worth it, the results being summarized in Table 7.

Table 7. Emissions of the DG of the two CD strategy variants, normal and optimized

Emisions	CD	CD opt	[units]
Carbon Dioxide	545	301	kg/yr
Carbon Monoxide	5.91	3.3	kg/yr
Unburned Hydrocarbons	0.261	0.144	kg/yr
Particulate Matter	0.0355	0.02	kg/yr
Sulfur Dioxide	1.19	0.658	kg/yr
Nitrogen Oxides	5.56	3.1	kg/yr

5. CONCLUSIONS

The CD strategy is preferable to CC strategy due to the more economical costs of dispatch decision at every time step, this eventually leading to smaller net present costs for the same invested capital.

The energy produced under CD strategy is better, PV subsystem producing more electricity annually with lower excess electricity than in the case of CC strategy.

DG behaves better under CD strategy than under CC strategy, which translates into a reduction both in annual operating hours and in total fuel consumption. One of the immediate consequences of this is the reduction of greenhouse gas emissions from the engine within the DG.

From the detailed analysis of the data obtained by running the HOMER Pro simulation program, it can be seen that the CD strategy gives only slightly better results than the CC strategy. This is because the sizing of HPS components was done separately, using an adapted mathematical model from the technical literature [3]. If the choice and sizing of the components is left to the discretion of the simulation software, the results may be different, as found in [8]. In our case, the HOMER Pro software worked with the inputs given by us and was able to choose the optimal version with these data.

Thus, the only solution for further optimization of HPS performance remained by reducing the power installed in the DG, this being the most influenced component by EMU dispatch strategy. This power reduction was made taking into account the minimum power required by the consumer. As a consequence, it has reduced by almost half the fuel consumption and harmful emissions due to the operation of DG, registering however a slight increase in the number of operating hours, but also an improvement in DG average electrical efficiency.

CD strategy has the following advantages due to combining the two dispatch strategies, CC and LF:

- During periods of low loads, when a low charging power is needed, the use of DG for battery charging is avoided by running in CC mode, thus reducing the number of operating hours, fuel consumption and harmful emissions;
- During periods of high loads, DG is used continuously by operating in LF mode, which is the most appropriate mode for such a load behavior.

CD dispatch strategy can be further optimized only in the sense of reducing the installed power of the Diesel engine. It must be considered that the power reduction of the DG is limited by the required consumer maximum load. As a result of this power reduction, fuel consumption and emissions are reduced, improving DG's energy efficiency.

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