JOURNAL OF SUSTAINABLE ENERGY VOL. 4, NO. 2, JUNE, 2013

AVAILABILITY MODELING AND SIMULATION OF THE HYBRID POWER GENERATION SYSTEMS

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Abstract - The paper aims to present a model of availability analysis for hybrid systems by using adequate simulation software and adapting classical computation models of power systems main reliability and availability indicators. As simulation software we used HOMER program and for indicators calculus the reliability diagrams method. We obtained hybrid power system different configuration availability data. The last part of the analysis the conclusions are presented.

Keywords: hybrid power system, dispatch strategy, states of the system, availability, simulation.

1. INTRODUCTION

Diesel power systems problem in supplying the isolated electricity consumers (in terms of negative impact on environment, fuel price etc.) led to the search for new solutions. The most obvious was the use of renewable resources (RR) in combination with existing Diesel groups [1], thus resulting hybrid power systems (HPS). These systems utilize two energy sources: a principal one, usually solar and/or wind and a secondary one consist in Diesel groups on various fuels (Diesel, GPL, biodiesel etc.). Because of the intermittent and unpredictable characteristics of the RR the HPS require a storage subsystem. In fig. 1 we present the main components of a HPS.

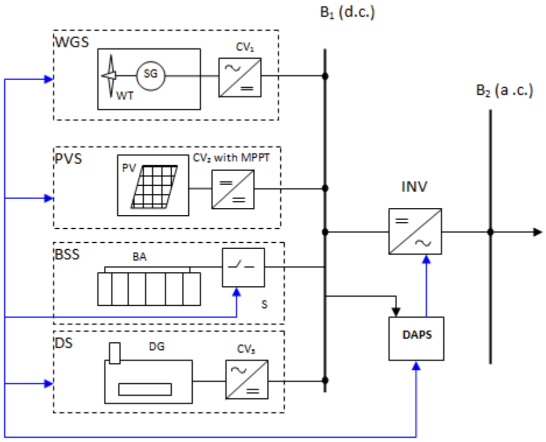


Fig. 1. Representation of HPS subsystems

The significance of the fig. 1 elements is presented in table 1:

Table 1. Significance of the elements from fig.1

Acronym	Subsystem
WGS	Wind generation subsystem
PVS	Photovoltaic subsystem
BSS	Battery storage subsystem
DS	Diesel subsystem
WT	Wind turbine
SG	Synchronous generator
CV	Converter
PV	Photovoltaic array
MPPT	Maximum power point tracker
DG	Diesel group
INV	Inverter
DAPS	Driving, automation and protection subsystem (system controller included)
B_i	Bus "i"
S	Switching subsystem
IC	Insulated potential consumer

A classic HPS dispatch strategy consists in [2]:

- For daylight and available RR the load will be cover from PVS/WGS;
- For night or RR not available, BSS will cover the load;
- For night or day without RR or BA (battery discharged) the load will be covered by DG, simultaneously the BA will be recharged.

The hart of any HPS without witch it could not operate is the controller. This unit is equipped with microchip and appropriate software so as to perform the following functions within HPS:

- Monitoring and controlling the state of the entire HPS;
- Prioritizing power generation and load cover from HPS sources according to preset priorities;
- Monitoring and controlling the BA state of charge;
- Starting / stopping the DG when necessary.

Such a degree of automation was necessary because the consumers which are supplied with power from these systems are insulated and often far from national electric grids.

This automation degree made the uses of HPS to expand to the following application: telecommunication and weather stations, national parks, island and rural electrification [3, 4, 5].

2. THE HPS STATES

To analyze the power and reliability performance of HPS it is essential to define the states of the system and to assess its existence probability [6, 7].

In fig. 2 we present the states graph of the HPS from fig. 1, emphasizing their states and realistic transition between them. Theoretically, there are possible other transition modes too, but in practice it is found that these are not confirmed during exploitation of power elements within HPS [6, 7, 8].

The marked states significance from fig.2 is described in table 2:

Table 2. States significance of HPS

State name	Number of state	State description
NO	(1)	Normal operation
WT	(2)	Waiting
CR	(3)	Critical (exposed)
FT	(4)	Fault (irreversible, CM needed)
CM	(5)	Corrective maintenance
PM	(6)	Preventive maintenance
PPM	(7)	Programmed preventive maintenance
SPMO	(8)	Specific preventive maintenance

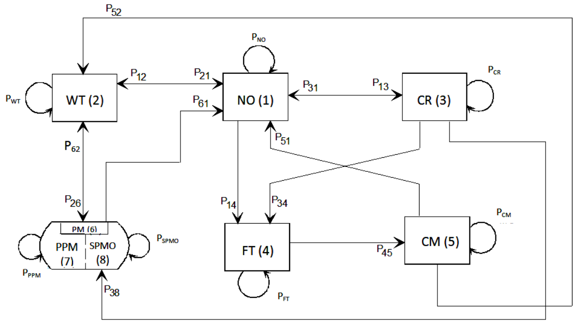


Fig. 2. States graph of HPS using as indices the state probabilities (Pi) and transitions (Pij)

HPS is in NO state, if there are simultaneously satisfied the following conditions:

- The condition to start is satisfied (event E_1);
- Power systems within HPS are in operation (event E_2);
- Elements within DAPS are operational and didn't actioned tempestuous (false controls), (event E_3);
- IC takes the produced power (event E_4).

Therefore we can write the probability of the NO state as:

$$P_F = P_{E1}\, P_{E2}\, P_{E3}\, P_{E4} \qquad (1)$$

Where: P_i = probability to achieve the event E_i , i =1 to 4

For the HPS exemplified in fig.1 we can write:

$$P_{E2} = \mathrm{Prob}\,[(\mathrm{WGS} \cup \mathrm{PVS} \cup \mathrm{BSS} \cup \mathrm{DS}) \cap \cap \mathrm{B1} \cap \mathrm{B2} \cap \mathrm{INV}] \qquad (2)$$

The WT state of HPS power elements (PE) can be caused by the downtime of the IC or, as the case:

- ♦ For WTS and PVS - if the RR are unavailable;
- ♦ For DS – if the power required by IC is assured from RS or BSS;
- ♦ for BSS – if the power required by IC is assured from RS or DS;

If all PE of the HPS are in WT state, then the HPS is in WT state.

The CR state of the PE can occur during HPS operation due to exceeding the limits of the normal working parameters, until the DAPS elements acting (during the time delay period). Therefore this state is of short duration. If the PE working parameters remain at normal values, then PE passes from CR state to NO state.

If the PE working parameters do not return to the normal values, then it is possible two states:

- ➢ DAPS elements acts and HPS passes in SMPO state;
- ➢ PE overload and fail, HPS passes in FT sate.

The FT state is obvious the most undesirable, because it implies higher risks, economic consequence and by case, social consequence.

Transition in FT state can be produce in the following ways:

- From NO state by (sudden) catastrophic failure of the PE;
- By parametric failure of PE cumulated with DAPS elements operating refuse;
- By natural catastrophic events (flooding, hurricanes, heavy snowfalls), but according to reliability theory these are not count in reliability calculus of HPS.

If all power sources of HPS or only one of DAPS elements, or B1, B2, INV are in failure state, then HPS is in failure state.

MC state is a consequence of the FT state. After identifying the fault element, establishing the causes of fault and remedies, the subsystems /equipment are passed in MC state. The probability of existence of this state is practically equal to probability of fault state:

$$P_{MC} = P_5 = P_{FT} \qquad (3)$$

After CM work is done, equipments of PE are passed in:

- ➢ NO state - if the conditions to start and power deliver are fulfilled;
- ➢ WT state – if either one of the bonds with neighboring systems is not available or for the WT states PE are in the states evoked above.

The transition from PM state can be done in two ways:

- ➢ Following a predetermined program, based on operating period, thus performed the PPM actions. Transitions in PPM state is made from WT state, i.e. in the period in which are not satisfied PE external operating conditions or the HPS functions can be assured by other PE from HPS structure;
- ➢ Following state degradation of some equipment, which is notified by the DAPS and recorded in CR state. In this case equipments are subjected to SMPO actions.

After PM working is done the PE is passed in one of the NO or WT states as needed.

3. AVAILABILITY INDICATORS OF HPS

At the HPS level it is crucial the "energy availability" indicator which is directly mirrors in HPS energy, economic and social efficiency. In terms of operational behavior, HPS and PE of its structure are characterized by the following [6]: time characteristic quantities, power and safety characteristic quantities and availability characteristic quantities.

For a HPS the availability characteristic quantities can be described as follows:

Time availability (A_T): PE or HPS capacity to respond to a request.

$$A_T = \frac{T_F + T_{AS}^{V}}{T_A} = \frac{T_A - T_D - T_{MP} - T_{AS}^{LR}}{T_A} \tag{4}$$

Where:

T_F = Total operating time (the sum of NO and CR states operating time);
T_{AS}^{v} = Desired waiting time;
T_A = Analyses time;
T_D = Total fault time (power reduced to zero);
T_{MP} = PM time;
T_{AS}^{LR} = Waiting time due to RR unavailability.

The A_T indicator reflects only the HPS capacity to respond in time to a request, without reference to power level delivered.

Power availability (A_P): the HPS capacity to deliver o request a certain level of power. It is equal to power safety.

$$A_P = \frac{P_F}{P_F + \Delta P_D} = \frac{P_N - \Delta P_D}{P_N} = R_P \tag{5}$$

Where:

P_F = Produced power;
ΔP_D = Forced partial or deliberate reduction of power;
P_N = Rated power.

Energy availability (A_P): HPS capacity to deliver a certain amount of energy in a T_A period.

$$A_W = A_P \cdot A_T = \frac{P_F}{P_F + \Delta P_D} \cdot \frac{T_F + T_{AS}^{V}}{T_A} = \frac{P_F \cdot T_F + P_F \cdot T_{AS}^{V}}{P_N \cdot T_A} = \frac{W_F + \Delta W_{AS}^{V}}{W_N} \tag{6}$$

Where:

W_N = Nominal energy (maximum) which might produce in case of uninterruptible operating of the HPS at P_N and on T_A duration;

W_N = Energy delivered at P_N in T_A time;

ΔW_{AS}^{V} = Energy available in some PE in T_{AS}^{V} period;

The A_W indicator can be expressed as:

$$A_W = \frac{P_N - \Delta P_D}{P_N} \cdot \frac{T_A - T_D - T_{MP} - T_{AS}^{LR}}{T_A} \tag{7}$$

Than we obtain:

$$A_W = \frac{P_N \cdot T_A - P_N \cdot T_D - P_N \cdot T_{MP} - P_N \cdot T_{AS}^{LR} - \Delta P_D \cdot T_F - \Delta P_D \cdot T_{AS}^{V}}{P_N \cdot T_A} \tag{8}$$

Or it can be written as:

$$A_W = \frac{W_N - \Delta W_{ID} - \Delta W_{IMP} - \Delta W_{IAS}^{LR} - \Delta W_{IR} - \Delta W_{IAS}^{V}}{W_N} \tag{9}$$

or:

$$A_W = 1 - \frac{\Delta W_{ID}}{W_N} - \frac{\Delta W_{IMP}}{W_N} - \frac{\Delta W_{IAS}^{LR}}{W_N} - \frac{\Delta W_{IR}}{W_N} - \frac{\Delta W_{IAS}^{V}}{W_N} \tag{10}$$

Respectively:

$$A_W = 1 - I_{WD} - I_{WMP} - I_{WAS}^{LR} - I_{WR} - I_{WAS}^{V} = 1 - I_W \tag{11}$$

Where:

ΔW_{ID} = Energy unavailable due to faults, on T_D interval;
ΔW_{IMP} = Energy unavailable due to PM actions, on T_{MP} interval;
ΔW_{IR} = Energy unavailable due to forced reduce of power, on T_F interval;
ΔW_{IAS}^{V} = Energy unavailable due to malfunction in waiting period T_{AS}^{LR};
I_W = Energy unavailability due to above five causes

These quantities can be emphasis in the P-t diagram as shown in fig. 3.

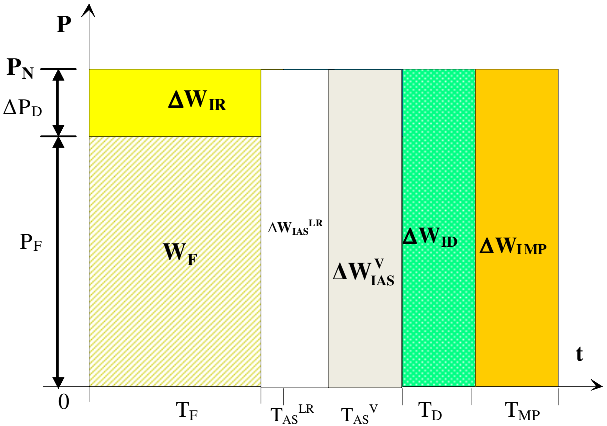


Fig. 3. P-t diagram of HPS

3. POWER AND ENERGY SIMULATION OF A HYBRID POWER SYSTEM

A) Characteristic quantities for HPS:

The simulation will be made on a specific case described in [2]: a hamlet of five cottages in a remote insulated area of Bihor country, Borod – Auşeu area. The renewable resource considered is solar and wind. Daily solar irradiance is 3,36 kW/m^2/day and annual average of the wind speed at 20m above ground is between 3,6 m/s and 5,4 m/s. On we consider also the a.c bus of 48 V, total a.c. power needed 2314 W and the DG working on GPL.

The simulation program used is HOMER, a computer model developed by NREL (U.S. National Renewable Energy Laboratory), to assist in design of micropower systems. It can also simulate its physical behavior and compare many different design options based on their technical and economic merit [9].

HPS configuration is with a.c. and d.c. bus as shown in fig. 4.

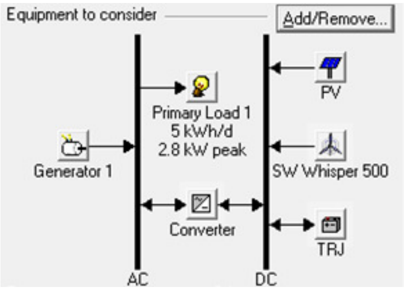
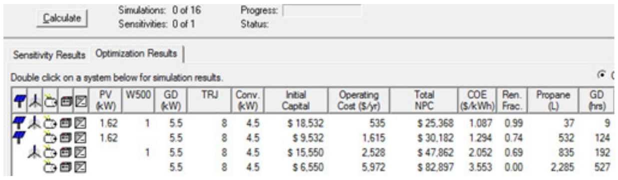


Fig. 4 : Screen capture with HPS configuration in HOMER

The main simulation screen is presented in fig.5 and it shows three feasible hybrid configurations. The first row, solar-wind-Diesel hybrid power system (SWD-HPS) have the lowest net present cost, followed by solar-Diesel (SD -HPS) and wind-Diesel (WD-HPS).



Simulations: 0 of 16
Sensitivities: 0 of 1
Progress:
Status:

Double click on a system below for simulation results.

	PV (kW)	W500	GD (kW)	TRJ	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Propane (L)	GD (hrs)
	1.62	1	5.5	8	4.5	$ 18,532	535	$ 25,368	1.087	0.99	37	9
	1.62		5.5	8	4.5	$ 9,532	1,615	$ 30,182	1.294	0.74	532	124
		1	5.5	8	4.5	$ 15,550	2,528	$ 47,862	2.052	0.69	835	192
			5.5	8	4.5	$ 6,550	5,972	$ 82,897	3.553	0.00	2,285	527

Fig. 5 : Screen capture with HPS optimization results in HOMER

Further we select each configuration and by selecting each subsystem of the chosen configuration we obtained its operational behavior, fig. 6 ÷ 8. Data of interest we have circled with red border and have been noted as:

- Rated capacity (P_N);
- Total production (W_F);
- Total operating hours (T_F)

a) Case of SWD-HPS:

PVS:

Quantity	Value	Units
Rated capacity	1.62	kW
Mean output	0.21	kW
Mean output	5.12	kWh/d
Capacity factor	13.2	%
Total production	1,867	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	1.68	kW
PV penetration	102	%
Hours of operation	4,386	hr/yr
Levelized cost	0.142	$/kWh

WGS:

Quantity	Value	Units
Total rated capacity	3.00	kW
Mean output	0.26	kW
Capacity factor	8.64	%
Total production	2,271	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	3.23	kW
Wind penetration	124	%
Hours of operation	4,557	hr/yr

BSS:

Quantity	Value	Units
Nominal capacity	14.4	kWh
Usable nominal capacity	8.64	kWh
Autonomy	41.5	hr

Quantity	Value	Units
Energy in	1,019	kWh/yr
Energy out	816	kWh/yr
Storage depletion	0	kWh/yr

DS:

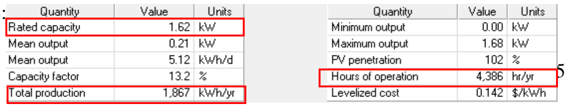
Quantity	Value	Units
Hours of operation	9	hr/yr

Quantity	Value	Units
Electrical production	43.5	kWh/yr

Fig. 6 : Elements characterizing the SWD-HPS functioning behavior

b) Case of SD-HPS:

PVS:



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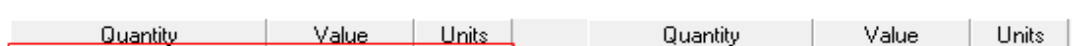


Quantity	Value	Units

Quantity	Value	Units

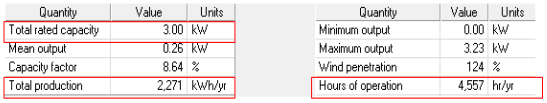
BSS:

DS:

Fig. 7 : Elements characterizing the SD-HPS functioning behavior

a) Case of WD-HPS:

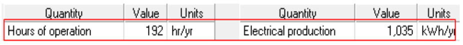
WGS:



Quantity	Value	Units
Total rated capacity	3.00	kW
Mean output	0.26	kW
Capacity factor	8.64	%
Total production	2,271	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	3.23	kW
Wind penetration	124	%
Hours of operation	4,557	hr/yr

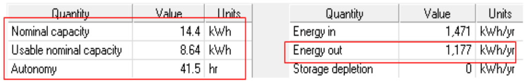
DS:



Quantity	Value	Units
Hours of operation	192	hr/yr

Quantity	Value	Units
Electrical production	1,035	kWh/yr

BSS:



Quantity	Value	Units
Nominal capacity	14.4	kWh
Usable nominal capacity	8.64	kWh
Autonomy	41.5	hr

Quantity	Value	Units
Energy in	1,471	kWh/yr
Energy out	1,177	kWh/yr
Storage depletion	0	kWh/yr

Fig. 8 : Elements characterizing the WD-HPS functioning behavior

Because we are interested in the power in use (P_F) this must be calculated for each HPS subsystem using the data from fig. 6 ÷ 8.

The BA power in function (P_F) and nominal power (P_N) can be calculated by following these steps:

1) From simulation data of fig. 6 ÷ 8 we obtain:
   - Nominal BA capacity: C_N = 14,4, kWh;
   - Usable BA nominal capacity: C_{NU} = 8,64 kWh;
   - Autonomy: AUT = 41,5 h.
2) We calculate than:
   - BA nominal power: $P_N = C_N/AUT$ = 348 W;
   - BA power in function: $P_F = C_{NU}/AUT$ = 208 W;
3) Total operating time of BA:
   - Power supplied by BA on a discharge cycle: $E_{Pc} = P_F \cdot AUT = 208 \cdot 41{,}5 = 8632W$;
   - Total number of discharge cycle: $N_{Cd} = W_F / E_{Pc}$
   - BA total operating hours: $T_{FBA} = N_{Cd} \cdot D_{Cd}$.

We consider the duration of a operating cycle is equal to BA autonomy: D_{Cd} = AUT.

The final results are presented in table 3 ÷ 5.

Table 3. The results for SWD-HPS

	W_F [KWh/y]	T_f : [h/ay]	P_F = [W]	P_N [W]
FVS	1867	4386	425	1620
WGS	2271	4557	498	3000
BSS	816	3901	208	348
DS	43,5	9	4833	5500
TOTAL	4997,5	8760	5964	10108

Table 4. The results for SD-HPS

	W_F [KWh/y]	T_f : [h/ay]	P_F = [W]	P_N [W]
FVS	1867	4386	425	1620
BSS	1246	5976	208	348
DS	656	124	5290	5500
TOTAL	3769	8760	5923	7108

Table 5. The results for WD-HPS

	W_F [KWh/an]	T_f ÷ [h/an]	P_F = [W]	P_N [W]
WGS	2271	4557	498	3000
BSS	1177	5644	208	348
DS	1035	192	5390	5500
TOTAL	4483	8760	6096	8848

B) Availability indicators of the HPS:

- Power availability of the HPS is calculated as: $A_{Phps} = P_F / P_N$;
- Energy availability is calculated as: $A_{Whps} = A_{Phps} \cdot A_{Thps.}$

Where time availability ($A_{Thps.}$) can be calculated using different method, in this paper we applied reliability equivalent diagrams method (RED).

For the system of fig. 4 we consider that the DG can both to supply the loads and to charge the battery as shown in fig.8. The reserve (RZ) of HPS is the Diesel subsystem (DS).

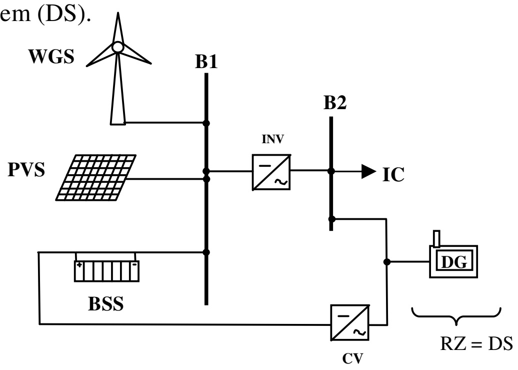


Fig. 8 The HPS configuration

The RED for the configuration from fig.8 taking into account the following:

- During the day PVS is in parallel with WGS forming the PVW subsystem. PVW subsystem is in parallel with BSS forming RR subsystem. RR subsystem is in series with INV forming renewable source subsystem (RS), fig.9;
- During the night the PVS is unavailable, so that the RED is remain only with WGS and BSS, fig.10. This configuration is the same with WD-HPS;
- The equivalent fundamental reliability indicators for the HPS are considered of a series system fig. 11;
- We consider that the HPS element are characterized by exponential law, knowing λ and μ the RED can be calculated with the known formula [6]:

$$\begin{cases} \lambda_S = \sum_{i=1}^{n} \lambda_i ;\ \mu_S = \dfrac{\lambda_S}{\sum_{i=1}^{n} \dfrac{\lambda_i}{\mu_i}} - \textit{for series elements} \\ \lambda_S = \dfrac{\lambda_1 \cdot \lambda_2 \cdot (\mu_1 + \mu_2)}{\lambda_1 \cdot \mu_2 + \lambda_2 \cdot \mu_1 + \mu_1 \cdot \mu_2} ;\ \mu_S = \mu_1 + \mu_2 - \textit{for paralel elements} \end{cases} \quad (12)$$

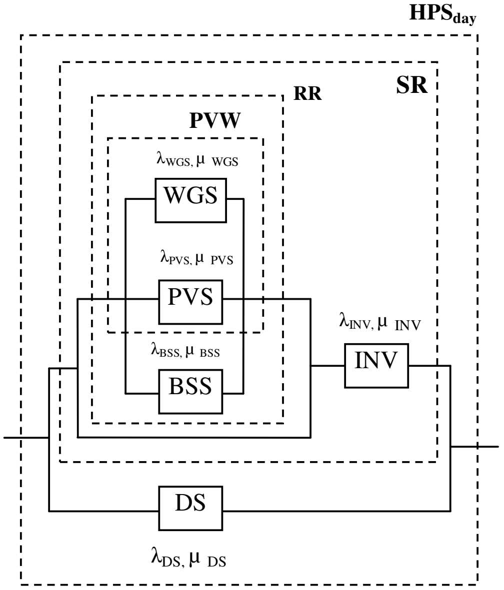


Fig. 9 RED for day configuration

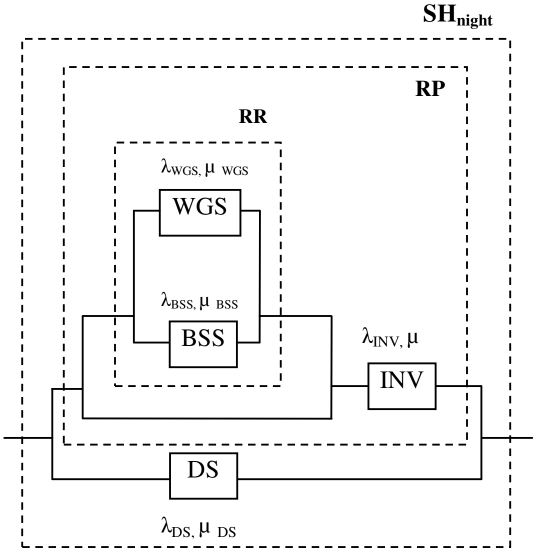


Fig. 10 RED for night configuration

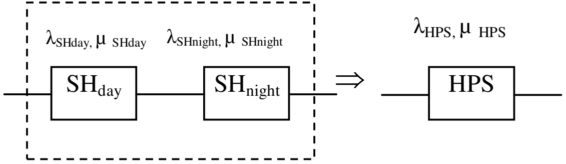


Fig. 11 RED for HPS

The MTBF and MTM values of each subsystem can be found in [10, 11, 12, 13, 14, 15, 16] and are presented in table 6. We can calculate λ and μ for each HPS subsystem, the results being presented in table 7.

Table 6. MTBF and MTM values for HPS subsystems

	PVS	INV	BSS	DS	WGS
MTBF	10 [y]	1,5 [y]	5 [y]	1000 [h]	2400 [h]
MTM	40 [day]	40 [day]	40 [day]	60 [day]	60 [day]

Table 7. The λ and μ values for each HPS subsystem

Subsystem	λ_i [$\times10^{-4}$ h^{-1}]	μ_i [$\times10^{-4}$ h^{-1}]
WGS	4,166	6,944
PVS	0,114	10,416
BSS	0,232	10,416
DS	10	6,944
INV	0,76	10,416

With the values from table 6 and 7 and the RED from fig. 9 ÷ 11 we can calculate λ and μ of the HPS with the formula:

$$MTBF_{hps} = \frac{1}{\lambda_{hps}}$$

$$MTM_{hps} = \frac{1}{\mu_{hps}} \qquad (13)$$

The results are presented in table 8 and 9.

Table 8. Values of λ and μ of the HPS day and night

HPS	λ_{HPSday} [h^{-1}]	μ_{HPSday} [h^{-1}]	$\lambda_{HPSnight}$ [h^{-1}]	$\mu_{HPSnight}$ [h^{-1}]
WSD	$7,276\cdot10^{-5}$	$1,738\cdot10^{-3}$	$8,378\cdot10^{-5}$	$1,806\cdot10^{-3}$
SD	$7,295\cdot10^{-5}$	$1,739\cdot10^{-3}$	$9,391\cdot10^{-5}$	$1,736\cdot10^{-3}$
WD	$8,378\cdot10^{-5}$	$1,806\cdot10^{-3}$	$8,378\cdot10^{-5}$	$1,806\cdot10^{-3}$

Table 9. Results for different HPS

HPS	λ_{HPS} [h^{-1}]	μ_{HPS} [h^{-1}]	$MTBF_{HpS}$ [h/year]	MTM_{HPS} [h/year]
WSD	$5,572\cdot10^{-4}$	$1,282\cdot10^{-3}$	6388	563,691
SD	$1,669\cdot10^{-4}$	$1,737\cdot10^{-3}$	5993	575,551
WD	$8,378\cdot10^{-5}$	$1,806\cdot10^{-3}$	1194	553,574

HPS and time availability we calculated using the results from table 8 and with (14):

$$A_{Thps} = \frac{MTBF_{hps}}{MTBF_{hps} + MTM_{hps}} \qquad (14)$$

Final results of the availability indicators of the HPS are presented in table 10.

Table 10. Availability calculated for different HPS

Availability HPS type	A_{Phps}	A_{Thps}	A_{Whps}
	[%]	[%]	[%]
SWD-HPS	59	91	53
SD-HPS	74	91	67
WD-HPS	68	95	69

5. CONCLUSION

Power availability of the SD-HPS is about 70% followed by WD-HPS of above 60% and SWD-HPS with above 50%.

The higher is the DG installed capacity the greater energy availability of WD-HPS will be, in this case the power in function has values close to nominal power.

From table 10 it shows that SWD-HPS has the lowest energy availability. This is because the total nominal power of the system is higher while power in function remains at low value (leading to report decrease of the two values). Also why using a greater DG installed power leads to diminishing the energy availability for the same supplied energy.

Availability modeling of a HPS can be done since the design phase, taking into account the following issues:

- ✓ Grounding the HPS configuration and its dispatch strategy;
- ✓ Identifying possible HPS states in which the system can evolved, specifying their significance and transition modes between them;
- ✓ Simulation of the HPS functioning behavior with adequate software. Usually not all the data can be obtained from the simulation but it can be calculated using RED method and knowing the λ and μ values for each HPS subsystem;
- ✓ HPS can be in different configurations, availability of the systems can be obtained for all of them;
- ✓ The WSD-HPS having different configuration for day and night because of unavailability of PVS during daylight, this mirrored in total availability of the system.

REFERENCES

[1]. Singh V. – *Blending wind and solar into the diesel generator market*, REPP No. 12, 2001

[2]. Bunda Ș., Bendea G., Secui C. : *Influence factors on cost in designing of the hybrid power system*, Journal of Sustainable Energy, No.3, Vol. 3, September 2012

[3]. *** - www.northernpower.com - *Northern's Telepower System Powers Remote Satellite Earth Station in Antarctica* – Project Brief

[4]. *** - *Renewable Energy at Channel Islands National Park* – Case Study by National Renewable Energy Laboratory, November 1997

[5]. *** - www.northernpower.com - *Northern Provides Power for Brasilian Community* - Project Brief

[6]. Felea I. - *Ingineria fiabilităii în electroenergetică*, EDP. Bucuresti, 1996

[7]. Felea I., Meianu D., Barla E., Bunda Ș. - *Modelling the provisional reliability of small scale hydroelectric plants by reporting of its states*, Anal of DAAAM for 2009 and Proceedings of the 20th International DAAAM Symposium , ISBN 978-901509-70-4 and ISSN 1726-9679

[8]. Ulleberg O., Morner S.O. – TRNSYS simulation models for solar-hydrogen system, IEEE Transactions on Energy Conversion, Nov. 2002, Vol 27, no. 3

[9].*** - http://homerenergy.com/documents/ /Micropower System Modeling With HOMER.pdf

[10]. Mishra P.M., Joshi J.C. – *Reliability estimation for components of photovoltaic systems*, Centre of Energy Studies, New Delhi, 1995

[11]. http://www.renewableenergyworld.com/rea/partner/ first-conferences/news/article/2011/05/why-pv-

balance-of-systems-is-important-in-2011
[12]. http://www.xantrex.com
[13]. Alexander B. Maish et all. – *Photovoltaic System Reliability*, 6th IEEE Photovoltaic Specialists Conference, 1997, Anahaim, California
[14]. Aleksander Preglej et all. – *Impact of inverter configuration on PV system reliability and energy production*, Georgia Institute of Technology, Atlanta
[15]. *** - http://reliawiki.com/index.php/Introduction_to_Repairable_Systems#Availability –WT availability
[16] http://www.dieselgeneratorcn.com/program01.html