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Title: Simulation and optimization of control strategies for renewable energy low power systems

Authors: URBANO-ARCILA, Paola Andrea, LASTRES-DANGUILLECOURT, Orlando, HERNÁNDEZ-GALVEZ, Geovanni e IBÁÑEZ-DUHARTE, Guillermo Rogelio

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ECORFAN-México, S.C.
143 – 50 Itzopan Street
La Florida, Ecatepec Municipality
Mexico State, 55120 Zipcode
Phone: +52 1 55 6159 2296
Skype: ecorfan-mexico.s.c.
E-mail: contacto@ecorfan.org
Facebook: ECORFAN-México S. C.
Twitter: @EcorfanC

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Introduction

Control Strategy: Or **dispatch strategy**, is a set of rules governing how the system charges the battery bank on a hybrid renewable energy system (HRES). [1]

Renewable energy system: Set of equipments and devices which generates electric power to supply a determinated electric load, transforming the energy from renewable sources.

- -Very Low power : <1 to 10 kW
- -Low power: 10 to 100 kW
- -Medium power : 100 kW to 1 MW
- -High power: 1 MW to 10 MW
- -Very High power: 10 MW and more[2]

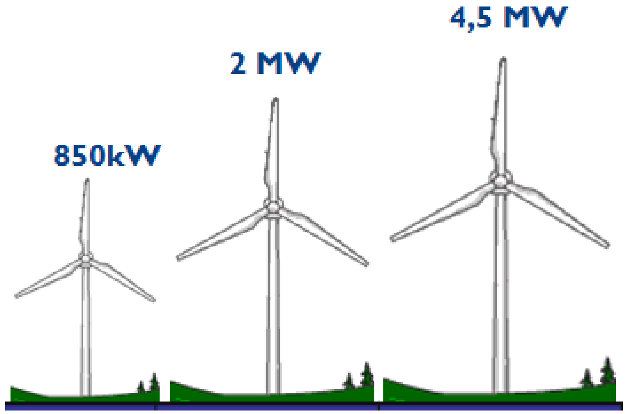


Fig. 1a Wind turbines power[2].

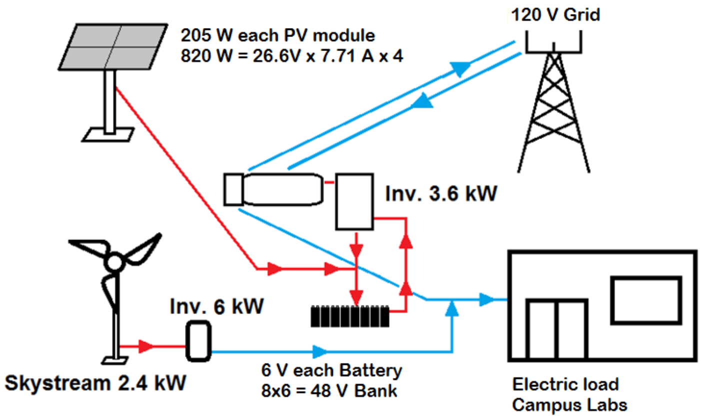


Fig. 1b Wind turbines power.

An energy system that uses more than one energy source is called a **hybrid system** (Wind /PV).[3]

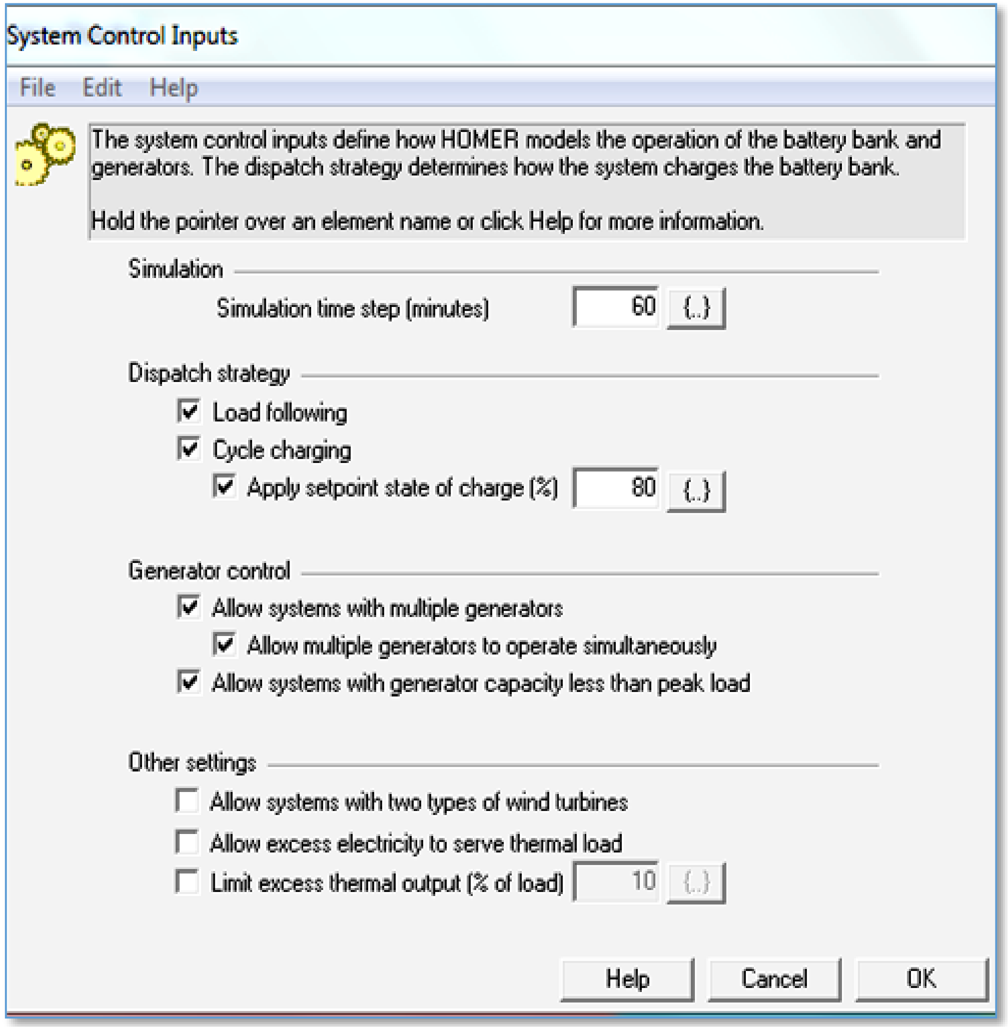
[1] Lambert T., Micropower system modeling with *HOMER. 2006*
[2] Álvarez C., Manuales de energías renovables –Energía Eólica. 2006
[3] Olatomiwa L., Energy management strategies in hybrid renewable energy systems: A review. 2016

Control strategies for energy dispatch - HOMER

Load Following (LF): Generation technologies produces only enough power to serve the load, and does not charge the battery bank. [1]

Cycle Charge (CC): Generation technologies operates, at its maximum rated capacity (to fulfill the demand requirements) and charges the battery bank with the excess. [1]

Allows to stablish a *Setpoint* SP(0 - 100%), in a way that if batteries are under this SP-***SOC*** (State of charge) and the generator has been working during the last hour, the generator will charge the battery bank to achieve a SOC equal to the *Setpoint*. Fig. 3 shows the window displayed by *HOMER* to select the control strategy and to set the SOC if needed. [5]



The system control inputs define how HOMER models the operation of the battery bank and generators. The dispatch strategy determines how the system charges the battery bank.

Hold the pointer over an element name or click Help for more information.

Simulation

Simulation time step (minutes) 60

Dispatch strategy

☑ Load following

☑ Cycle charging

☑ Apply setpoint state of charge (%) 80

Generator control

☑ Allow systems with multiple generators

☑ Allow multiple generators to operate simultaneously

☑ Allow systems with generator capacity less than peak load

Other settings

☐ Allow systems with two types of wind turbines

☐ Allow excess electricity to serve thermal load

☐ Limit excess thermal output (% of load) 10

Fig.3. *HOMER* window to entry the control strategy settings [5]

[5] Hernández G..Dimensionado de sistemas integrados de energía Eólica/Hidrógeno/Celdas de Combustibles . 2011.

Inverter controller modes

-DROP/USE

-HBX

-GRID USE

- AGS

-FLOAT MODE

Manufacturers

Outback MATE2

Xantrex XW Series

Trace SW Series II

GRID USE: Allows programing the times the FX system connects to an AC input source and enables the **USE** mode. The time and date must be accurately programmed for Grid-Use mode to function properly. Is programmed separately for weekday and weekend connect times.

AGS: Starts the generator anytime one or more of the Gen Start conditions are true and will stop the generator only when all of the conditions are false except during a programmed *Quiet Time* (normally at night when a noisy generator would be disturbing).

FLOAT MODE: When a charge controller finishes a bulk charge and moves into float charge, the MATE directs any other charge controllers into a float charge as well. [6]

DROP: Disconnects the AC input source but will allow it to be reconnected if the “low battery cut-off set point” occurs or the Inverter controller (FX) is overloaded.

USE: Enables the FX to connect to an AC input source.

HBX (High battery transfer): Allows control over the use of grid-supplied power, based on user determined battery voltages and times SPs. A user can maximize renewable energy power through careful HBX usage.

- Is used with grid-connected FX that have utility power as their AC input.
- Applications that have enough renewable energy power production to meet the needs of the loads most of the time.
- Allows the FX to connect to an AC source if the battery voltage has fallen below the SP for a time.

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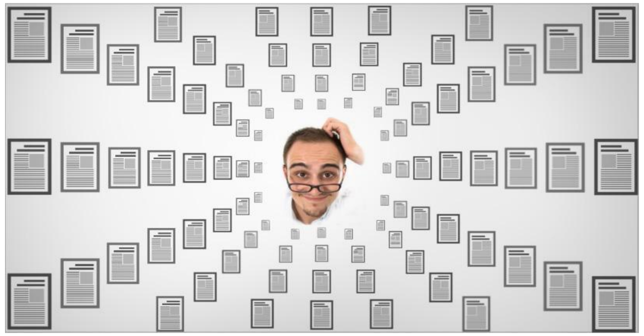
[6] Outback User´s Manual. 2008.

Related works



Mera (2006): Design of a Wind/ PV hybrid system to light and pumping water on a remote area in Ecuator. [7]

Lastres (2007): Detailed study of a stand alone wind power system with hydrogen storage for a Cuban mountain town. This study allowed to have an actual vision of the economic and technical perspective for its application in similar conditions, in the developing countries. [8]

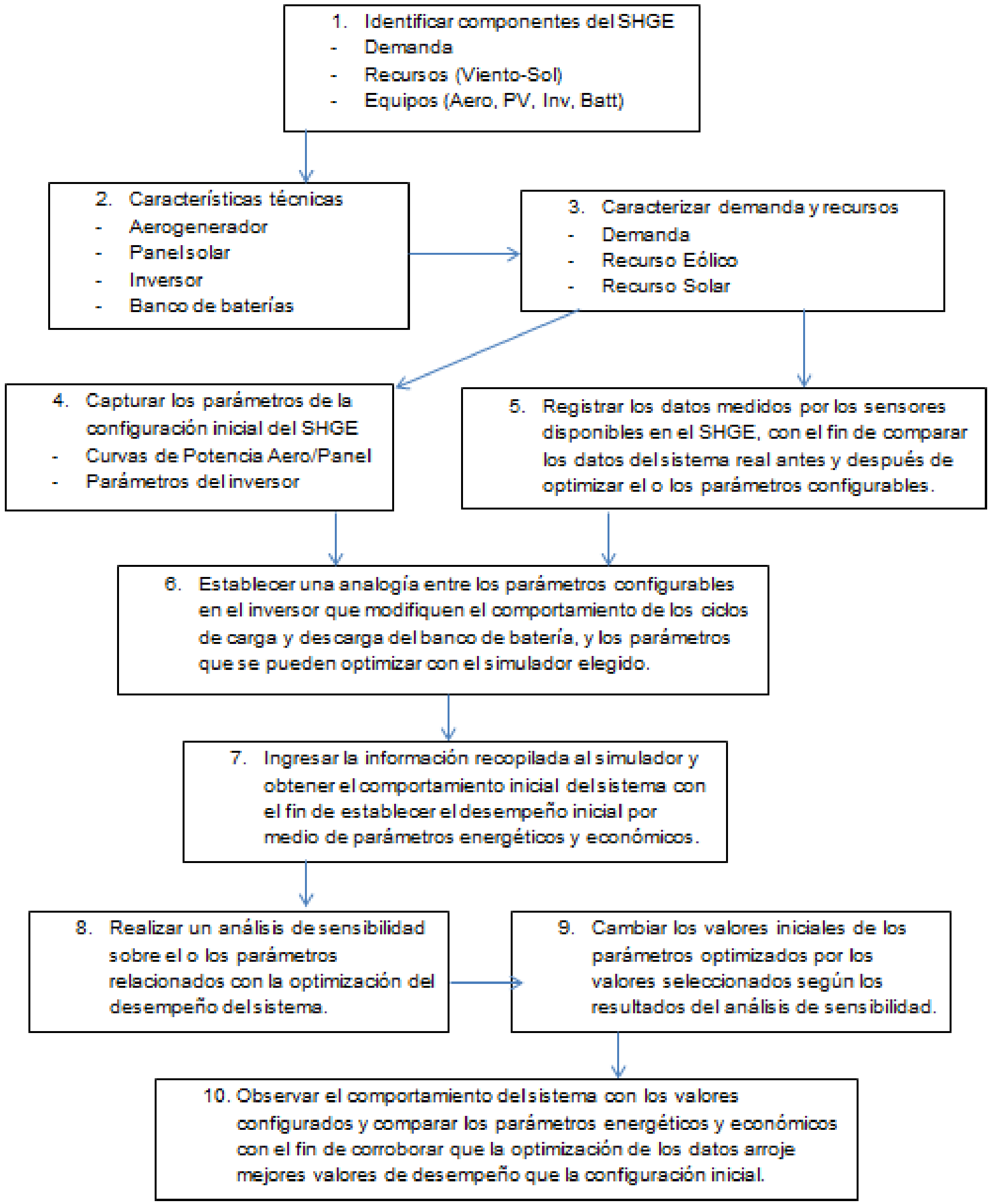
Dufo-López (2007): Developed a methodology and software (HOGA) to design and optimize hybrid renewable energy systems taking as a variable the control strategy, using genetics algorithms (MODM). [9]

Hernández (2011): Design of integrated systems of Wind/Hydrogen/fuel cell energy systems. Taking, among the many variables and design restrictions, the environmental component to evaluate the best system configuration applying Multi-criteria analysis methodologies (MCDM) to achieve the objectives.

Olatomiwa (2016): Review for different configurations of standalone and grid-connected hybrid systems to ensure and finally conclude, that the energy management strategy that works well and can be adopted for certain renewable energy system may not be the best for other configurations.[3]

[7] Mera, J. G., Estudio de Sistemas híbridos (Eólico-Solar) de Energía para Iluminación y Bombeo. 2006
[8] Lastres O., Simulación de sistemas eólicos autónomos con almacenamiento de hidrógeno. 2007
[9] Dufo-López, R., Dimensionado y Control Óptimos de Sistemas Híbridos Aplicando Algoritmos Evolutivos. 2007

Methodology and equipment



1. Identificar componentes del SHGE
   - Demanda
   - Recursos (Viento-Sol)
   - Equipos (Aero, PV, Inv, Batt)

2. Características técnicas
   - Aerogenerador
   - Panel solar
   - Inversor
   - Banco de baterías

3. Caracterizar demanda y recursos
   - Demanda
   - Recurso Eólico
   - Recurso Solar

4. Capturar los parámetros de la configuración inicial del SHGE
   - Curvas de Potencia Aero/Panel
   - Parámetros del inversor

5. Registrar los datos medidos por los sensores disponibles en el SHGE, con el fin de comparar los datos del sistema real antes y después de optimizar el o los parámetros configurables.

6. Establecer una analogía entre los parámetros configurables en el inversor que modifiquen el comportamiento de los ciclos de carga y descarga del banco de batería, y los parámetros que se pueden optimizar con el simulador elegido.

7. Ingresar la información recopilada al simulador y obtener el comportamiento inicial del sistema con el fin de establecer el desempeño inicial por medio de parámetros energéticos y económicos.

8. Realizar un análisis de sensibilidad sobre el o los parámetros relacionados con la optimización del desempeño del sistema.

9. Cambiar los valores iniciales de los parámetros optimizados por los valores seleccionados según los resultados del análisis de sensibilidad.

10. Observar el comportamiento del sistema con los valores configurados y comparar los parámetros energéticos y económicos con el fin de corroborar que la optimización de los datos arroje mejores valores de desempeño que la configuración inicial.

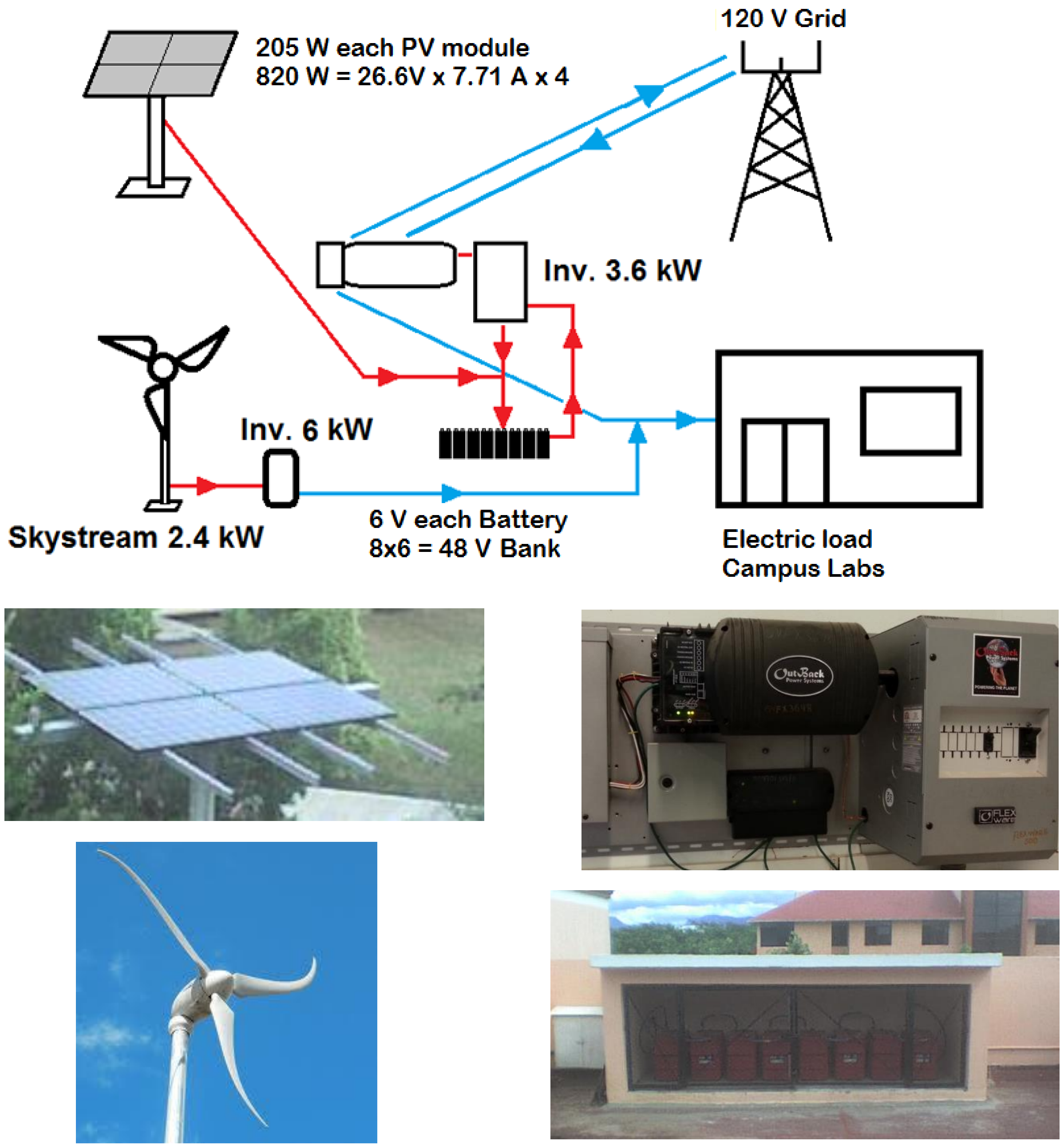


Fig. 4 Installed Hybrid System UNISTMO.

Methodology and equipment

The MATE controller allows the configuration of different parameters that are not in itself strategies of control and dispatch of energy. However, "the user can maximize the use of renewable energy and minimize supply from the grid through the careful use of parameters and modes of operation“.

Fig. 5 UNISTMO Controller panel.

Fig. 6 Human Machine Interfase (HMI) MATE UNISTMO. [4]

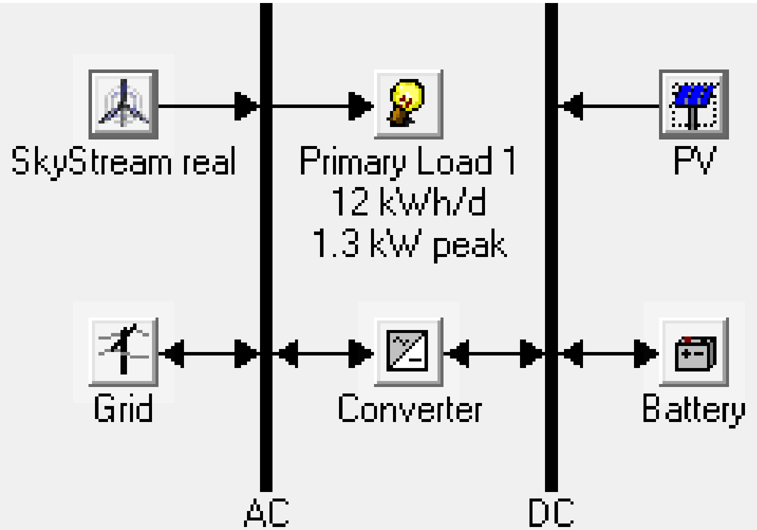


Fig. 7 Hybrid energy system in the UNISTMO.

Configuration Before

It is necessary to make an analogy between the charge voltage of the batteries and the SOC of the batteries, since the simulator only uses the parameter SOC and the configuration of the inverter only allows the voltage parameter of load. Most recent inverter models allows to configure either the load voltage or the SOC.

	PARAMETER	V	SOC%
1	ABSORB SP FX/CHAR	57.6	100.00328
2	ABSORB VOLTAGE CC/GHGR	57.6	100.00328
3	FLOAT SP FX/CHAR	53.2	**71.79796**
4	**FLOAT VOLTAGE CC/CHGR**	54.4	79.49032
5	SELL RE-VOLTS	52	64.1056
6	**REFLOAT FX/CHR**	50	51.285
7	**LOW BATTERY CUT-IN**	50	51.285
8	**LOW BATTERY CUT-OUT**	42	0.0026
9	HBXDGSP	39	-19.2283
10	HBXUGSP	36	-38.4592
12	DROP/USE/HBX MODE	USE	Float

Control Strategies Analogy

Load following/ DROP Mode

When it comes into operation the backup system (Network) covers the energy demand. Do not charge the battery bank unless the voltage is lower than the lower limit of protection or low voltage cut out.

Cycle of Charge /USE Mode

The backup system (Network) operates to meet the demand that is not reached to cover with the energy from the renewable sources and in addition, it charges the batteries until its SOC SP or Flotation voltage.

Results

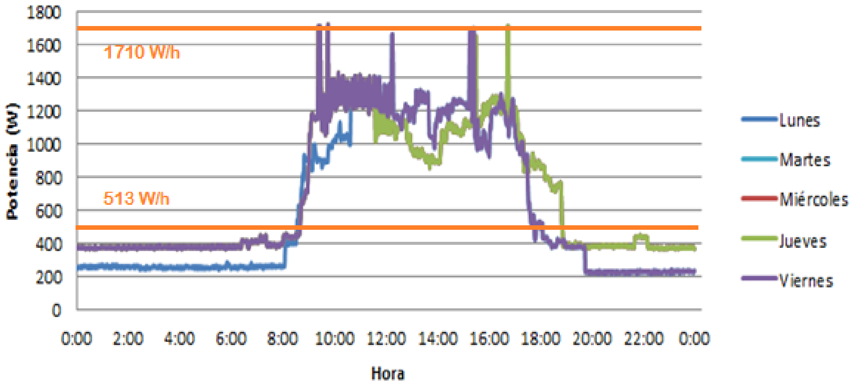


Fig. 8 Electrical load on a weekday.

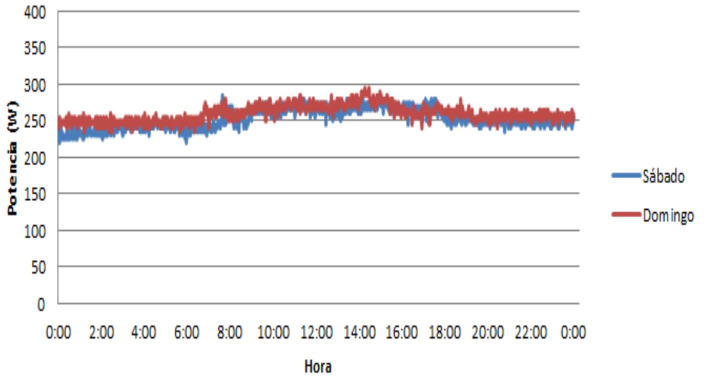


Fig. 9 Electrical load on a weekend.

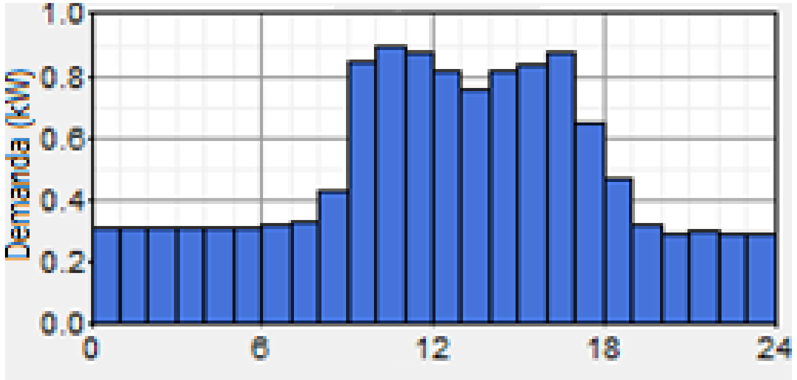


Fig. 10a Daily load. UNISTMO Solar and W energy labs.

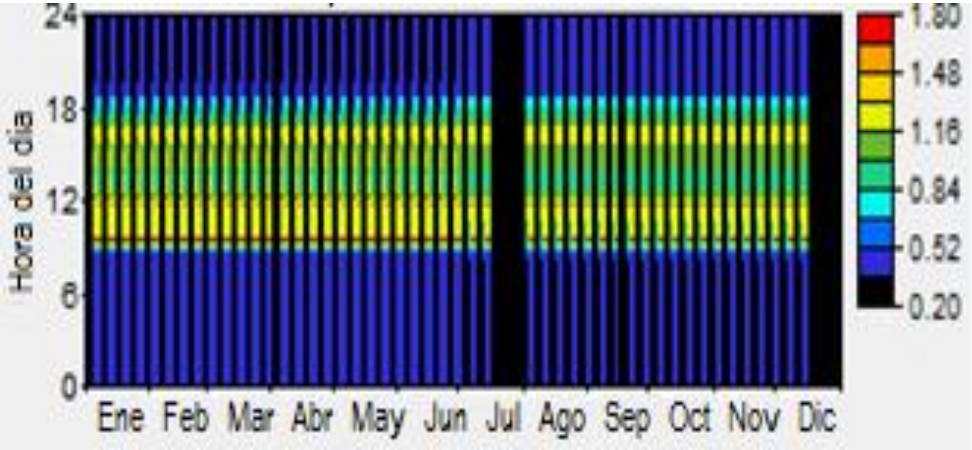


Fig. 10b Annual load. UNISTMO Solar and W energy labs.

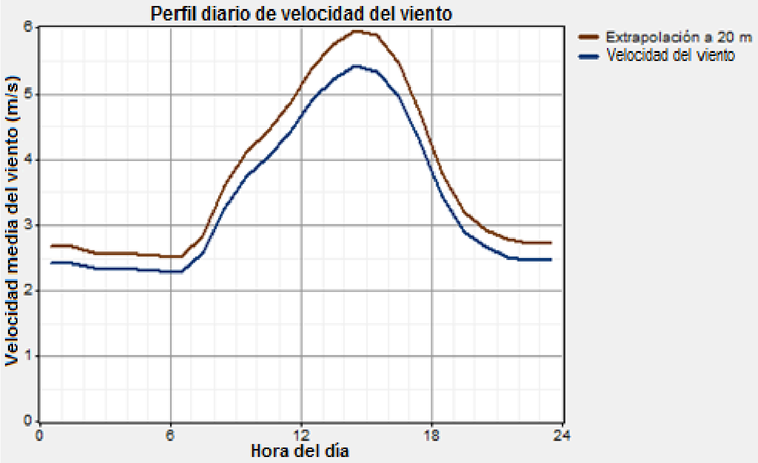
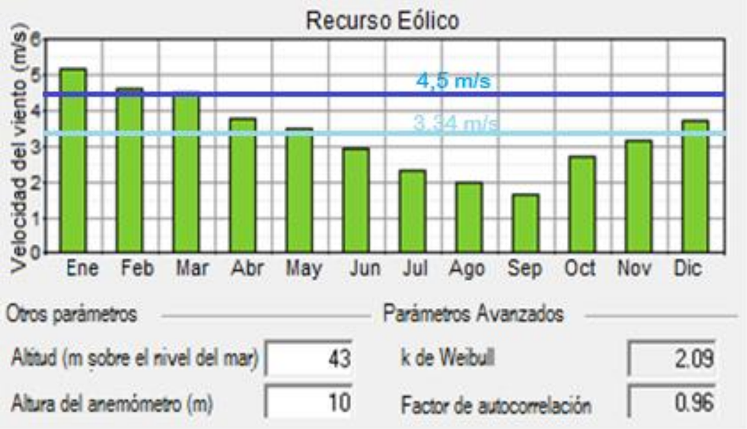


Fig. 11 Wind speed daily profile.



Otros parámetros

Altitud (m sobre el nivel del mar) 43

Altura del anemómetro (m) 10

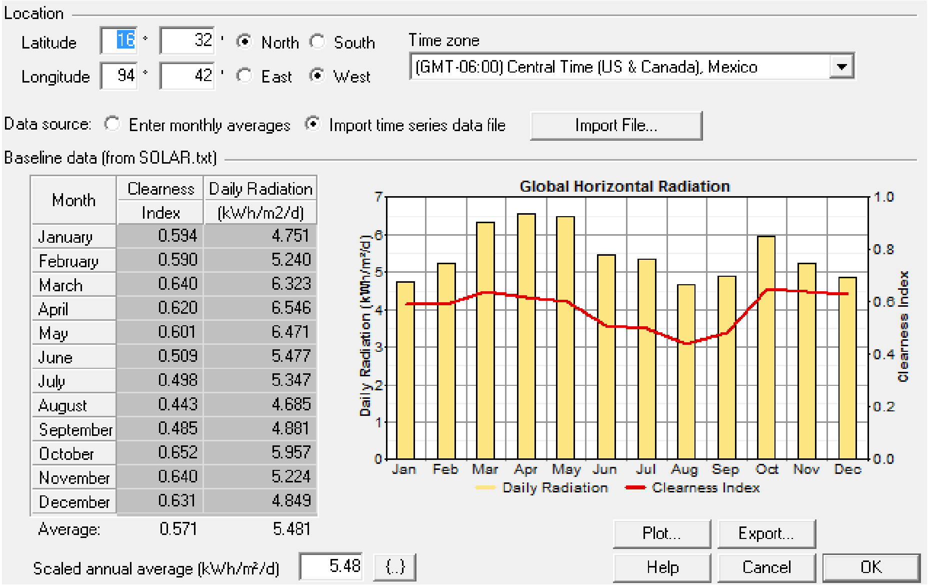
Parámetros Avanzados

k de Weibull 2.09

Factor de autocorrelación 0.96

Fig. 12 Wind resource UNISTMO.

Simulation Outputs



Location

Latitude 16 ° 32 ' ● North ○ South

Longitude 94 ° 42 ' ○ East ● West

Time zone: (GMT-06:00) Central Time (US & Canada), Mexico

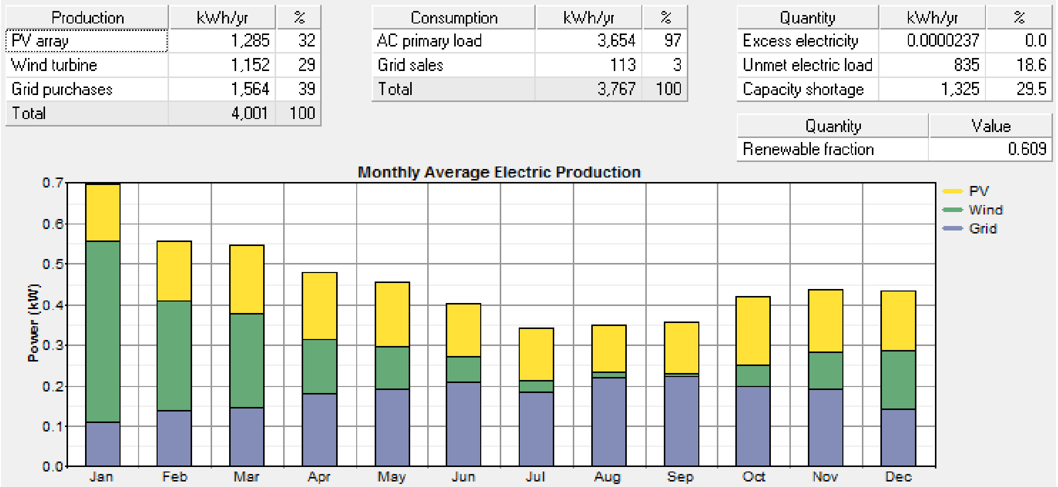
Data source: ○ Enter monthly averages ● Import time series data file

Baseline data (from SOLAR.txt)

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.594	4.751
February	0.590	5.240
March	0.640	6.323
April	0.620	6.546
May	0.601	6.471
June	0.509	5.477
July	0.498	5.347
August	0.443	4.685
September	0.485	4.881
October	0.652	5.957
November	0.640	5.224
December	0.631	4.849
Average:	0.571	5.481

Scaled annual average (kWh/m²/d) 5.48

Fig. 13 Solar Resource UNISTMO.



Production	kWh/yr	%
PV array	1,285	32
Wind turbine	1,152	29
Grid purchases	1,564	39
Total	4,001	100

Consumption	kWh/yr	%
AC primary load	3,654	97
Grid sales	113	3
Total	3,767	100

Quantity	kWh/yr	%
Excess electricity	0.0000237	0.0
Unmet electric load	835	18.6
Capacity shortage	1,325	29.5

Quantity	Value
Renewable fraction	0.609

Fig. 14 System annual performance.

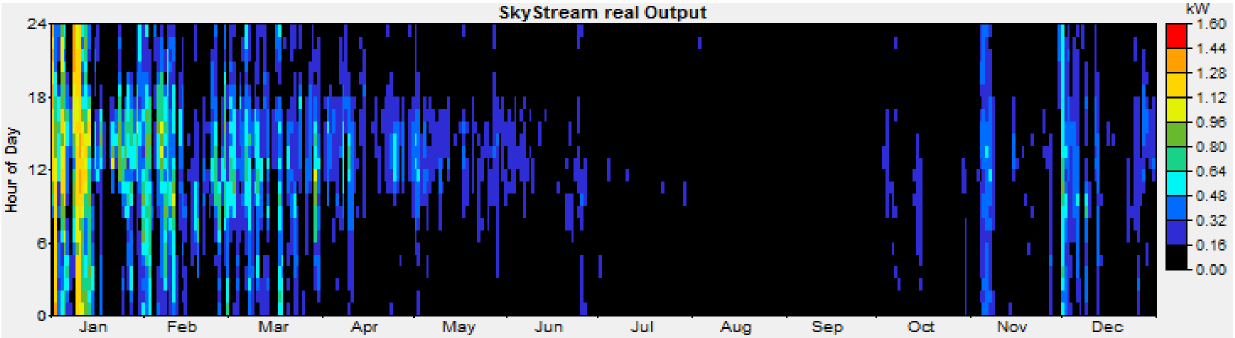


Fig. 15 Wind turbine annual performance.

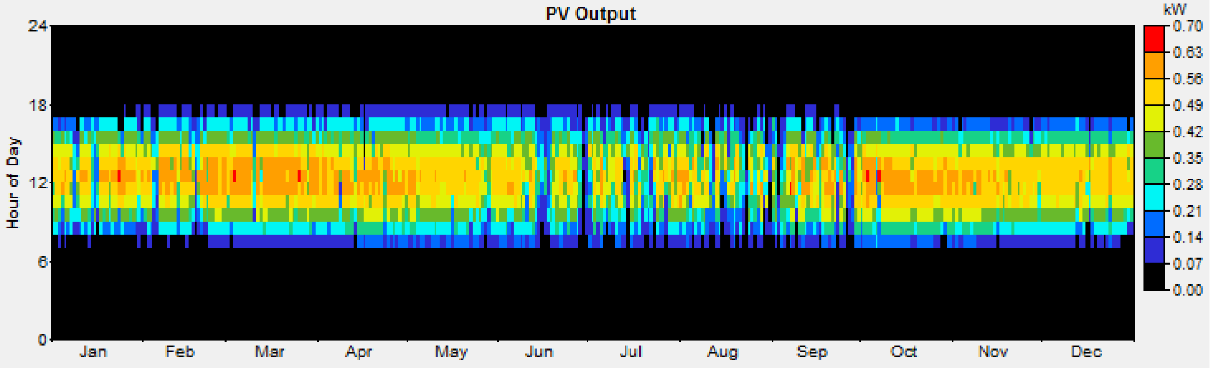


Fig. 16 Solar panel annual performance.

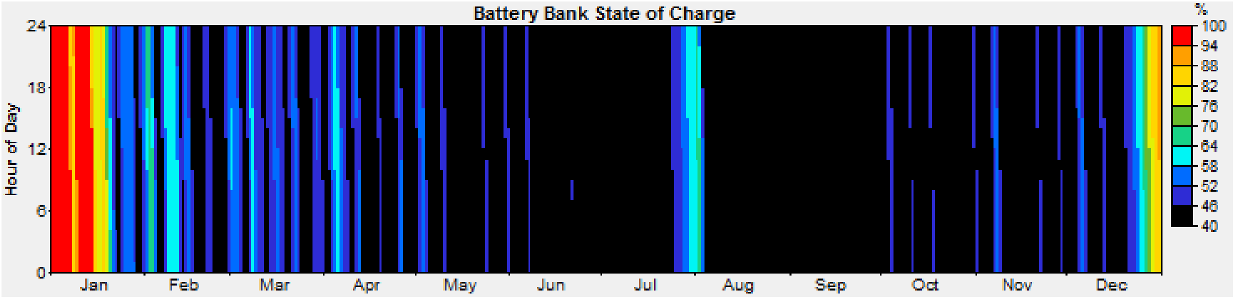
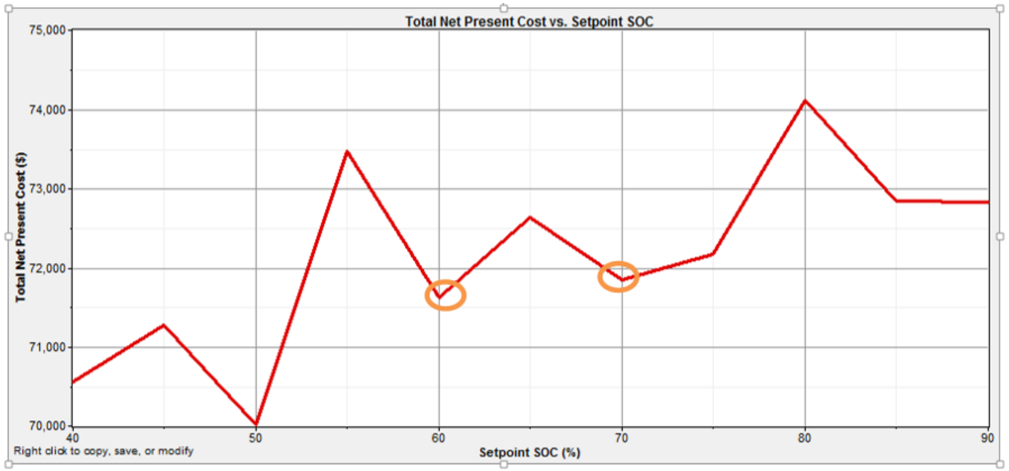


Fig. 17 Battery bank annual performance.

Sensitivity Analysis On SOC SP



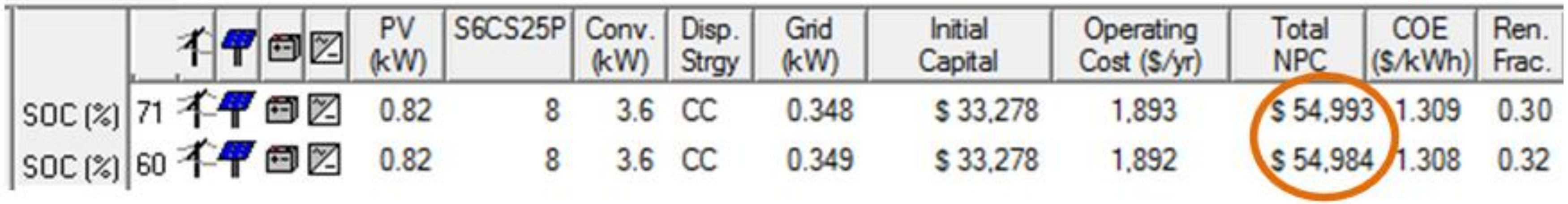
The 50% SP SOC yields better economic results, lower NPC. It is not taken since it is not convenient to have the battery with a low charge. The SOC of 60% with NPC of less than 70% and a similar value for the operating costs of the backup system is chosen.

.

Sensitivity Analysis on Control Strategies

PV (kW)	Gen1 (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)	Batt. Lf. (yr)
0.82	3	8	3.6	CC	$ 33,286	4,173	$ 81,150	1.576	0.13	0.00	2,935	3,161	12.0
0.82	3	8	3.6	LF	$ 33,286	5,653	$ 98,124	1.906	0.21	0.00	2,514	5,397	12.0
0.82	3		3.6	CC	$ 28,286	8,165	$ 121,943	2.369	0.14	0.00	4,054	8,679	
0.82	3		3.6	LF	$ 28,286	8,165	$ 121,943	2.369	0.14	0.00	4,054	8,679	

Annual cost of operation, NPC and COE are smaller with the CC strategy. The fraction of renewable energy is with the LF strategy.

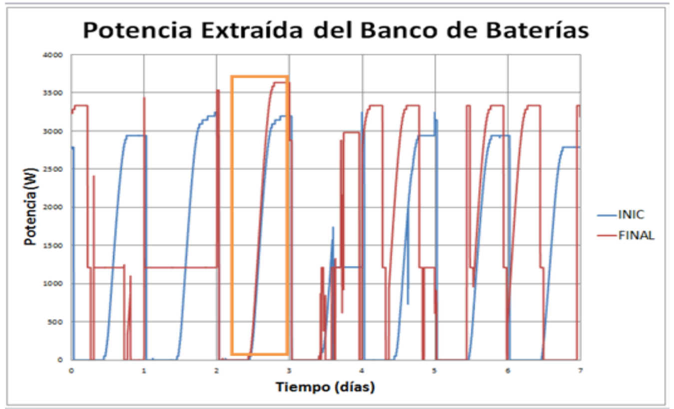


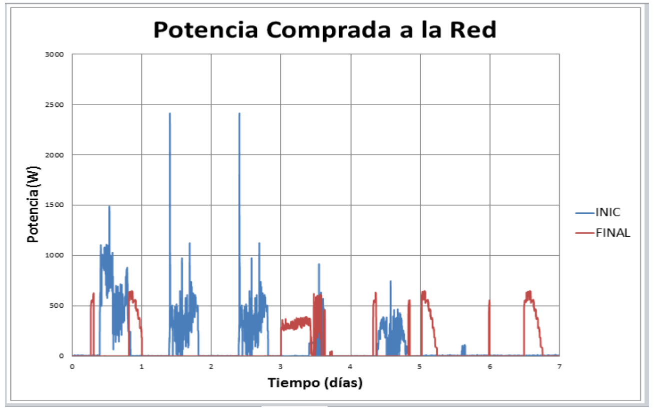
		PV (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
SOC (%)	71	0.82	8	3.6	CC	0.348	$ 33,278	1,893	$ 54,993	1.309	0.30
SOC (%)	60	0.82	8	3.6	CC	0.349	$ 33,278	1,892	$ 54,984	1.308	0.32

Initial: SOC% of 71% and CC strategy. Final: SOC% of 60% and CC strategy. Better energy performance since the NPC is lower.

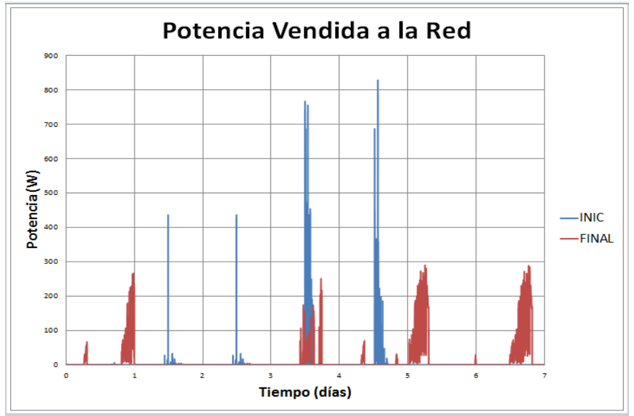
Results on the Real Hybrid System

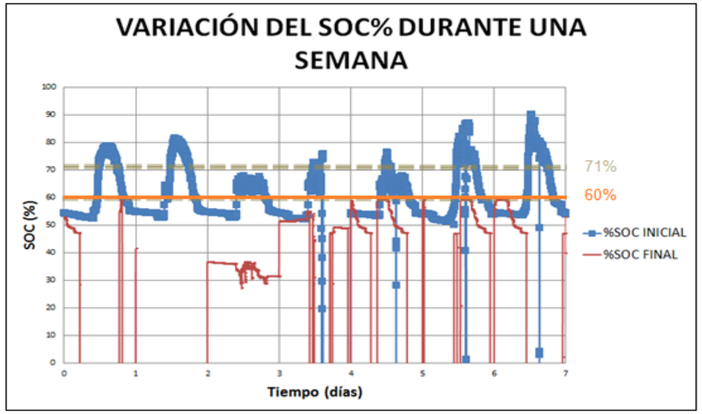
Finally, both options were inactivated, leaving the system with the floating mode OFF and the DROP network operation mode, with a Vfloat SP of 51.4 V, equivalent to 60% of the SOC. This in order to have the system operating in this way similar to an isolated system without connection to the electrical network, where the backup power source is the mains.





Feature	Unit	Before	After	% Change
ACO	USD/AÑO	1.893	1.892	0.05
NPC	USD	54,993	54,982	0.02
COE	USD/kWh	1,309	1,308	0.08
Frac. Ren.	%	30	32	-6.67
EABB	kWh/d	8.427	8.541	-1.35
EC	kWh/d	9.408	0.023	99.76
EV	kWh/d	25.899	0	100.00





Conclusions

- The methodology developed is based on the HRES operational analysis, the energy performance analysis and the optimization of economic variables, using a logical algorithm that seeks to minimize the cost of the produced energy, varying control parameters such as the state Charge of the batteries and the strategies of control and dispatch of energy.
- Applying the methodology, it was possible to establish that an adequate energy management, for the hybrid study system, is the strategy of the battery charge cycle, SP SOC of 60%, equal to 51.4 V and is configured in the parameter of float voltage.
- It was possible to reduce energy purchased from the grid to 0.023% of the initial energy, reducing the energy consumption costs to meet demand that is not covered by renewable energy.
- It is advisable to keep the voltage of the battery bank high as this is protected from deep discharges that accelerate its deterioration. Application of the methodology determined that the SP of the SOC should be increased 10%, in this way the system has better protection against an eventual deep or excessive discharge.
- HRES must have a study and optimization process for a better energy use of resources. Each system is different according to its components, type of energy demand and the available resources.
- Performance obtained by simulation is: Annual operating cost was reduced by 0.05%, the total net present cost was reduced by 0.02%, the cost of energy production was reduced by 0.08%, and the fraction of renewable energy Increased from 30 to 32%.

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