Empowering the existing hybrid plant in
San Cristóbal
(Galápagos Islands, Ecuador)

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Objective

The purpose of this report is to briefly analyze all possible solutions to reduce the fuel dependency for San Cristóbal island electricity production and wind power curtailment.

Introduction

A preliminary analysis was done to verify the consistency of information and possibilities to store excess energy from wind turbines. As a result of this analysis, it was found that a complete integration of diesel units on the power control is recommended to avoid excessive wind power curtailment (33% today) and thus diesel consumption. There are mainly three months in which a lot of wind energy now is lost and could be utilized.

Model

The model used for the system simulation is depicted in Figures 1-6. It consists basically of three blocks.

A block is used to calculate the wind power based on wind speeds, another is used for the BESS representation (including the batteries model and the charger model) and the last one to calculate the diesel generation based on the existing PV, wind and stored energy on batteries.

The necessary data to run the model are the wind speeds, the PV profile and the load profile. For San Cristóbal, these data were provided for an entire year, with a sampling of 10 minutes.

The model for calculating the wind power is the simplest one and only calculates the wind power based on the wind speed data.

The model for the BESS, as already mentioned, consists of two blocks. The model of batteries is based on information of EGP projects and basically estimates the state of charge of one battery by integration of the current, that is calculated taking in mind the internal resistance and voltage reduction because of the variation of the state of charge.

The batteries chosen for the simulation are of 38 Ah, about 620 V and 24 kWh (Sodium Nickel Technology). This is only for simulation needs, a detailed analysis of the best technology for the case should be performed before detail design.

The charger control is very simple and only identifies the time window to load or unload the batteries. This decision is based in the state of charge and the desired moment of the day to perform the discharge.

For this work, it has been assumed that the state of charge is varying between 20% and 95 % to ensure the lifetime of the batteries.

The same block considers an efficiency for load/unload of 80% (entire cycle).

Finally, the block to estimate the diesel consumption assumes a minimum diesel generation (in our case, 200 kW), and calculates the necessary diesel generation to ensure a good frequency control.

The inertia of each diesel generation unit was assumed the same. The inertia of PV, wind and BESS is null.

In this study, the hypothesis is to operate as a minimum only one diesel generator, at its technical minimum of 30% of nominal power Pn (200 kW), in order to reduce fuel consumption and to not have engine mechanical problems due to low power (<30% Pn). The grid voltage and frequency reference can be operated also from BESS inverters, but we decided to always maintain working one diesel generator to be a back-up for grid voltage and frequency reference.

The same block estimates the necessary number of diesel generator units and varies the inertia accordingly.

Results

A complete analysis month by month was realized, considering the number of batteries varying between 0 and 20,000. The case with 20,000 batteries is only theoretical and illustrates what happens if infinite storage capacity is present.

Figura 7 shows the results of the analysis for September, which is the month with higher wind power surplus. This figure clearly shows that for infinite storage capacity, the curtailment is null, because all the energy is stored for the following months. Thus, the diesel consumption remains the same than without BESS.

To minimize the diesel consumption, a total of 5,000 batteries is necessary (about 120 MWh). This value is clearly unacceptable from an economical point of view.

From the same figure, it appears more convenient to generate with diesel about 250 MWh and only between 50 and 100 batteries would be necessary as shown in the same figure (1,2-2,4 MWh).

Moreover, Figura 8 shows the situation in April, with a low wind power generation. In this case the storage would be practically useless.

The results show that a very few amount of energy could be stored, and that even in this case, between 50 and 100 batteries would be the best solution (1,2-2,4 MWh in total) even if the use of these batteries would be limited for a short period of the year.

After the sizing of the BESS nominal power, in order to maximize the storage usage during the year, a new PV capacity could be added.

The following cases are analyzed:
- PV of 1.0 MW of ac nominal power;
- PV of 1.0 MW of ac nominal power, plus daily BESS discharge during night;
- PV of 1.5 MW of ac nominal power, plus daily BESS discharge during night;
- PV of 2.0 MW of ac nominal power, plus daily BESS discharge during night;
- PV of 2.5 MW of ac nominal power, plus daily BESS discharge during night.

The results are summarized in Tables I and II, considering different BESS energy installations (0 and 1 MWh).

As base case we consider only diesel generation without BESS and without additional PV plant.

Each table shows the energy generated by Diesel units compared with base case.

From these tables it can be shown that no big differences could be expected due to BESS nor due to its strategy of discharge, in the sense that with current fuel cost and CAPEX assumption the installation of the BESS is beneficial but not economically convenient.

On the other hand, bigger energy savings could be expected when adding a PV plant, with or without BESS. This option seems economically convenient and in particular the 1 MW option without BESS seems the optimal one to be implemented as for today.

A further cost reduction of storage systems that is behind the corner could make convenient in medium term (2-3 years from now) also the installation of 1-2 MWh of BESS.

The analysis has been performed considering initially for a period of 10 years, with an annual interest rate of 5%, because 10 year is the expected lifetime for BESS batteries. In case of PV plant without BESS the optimization comes considering the lifetime of 25 years as commonly used for this technology.

Next steps

The next step to improve this analysis could be considering the indirect costs/year for maintenance (ordinary and extraordinary) of diesel unit, for pollution, for noise.

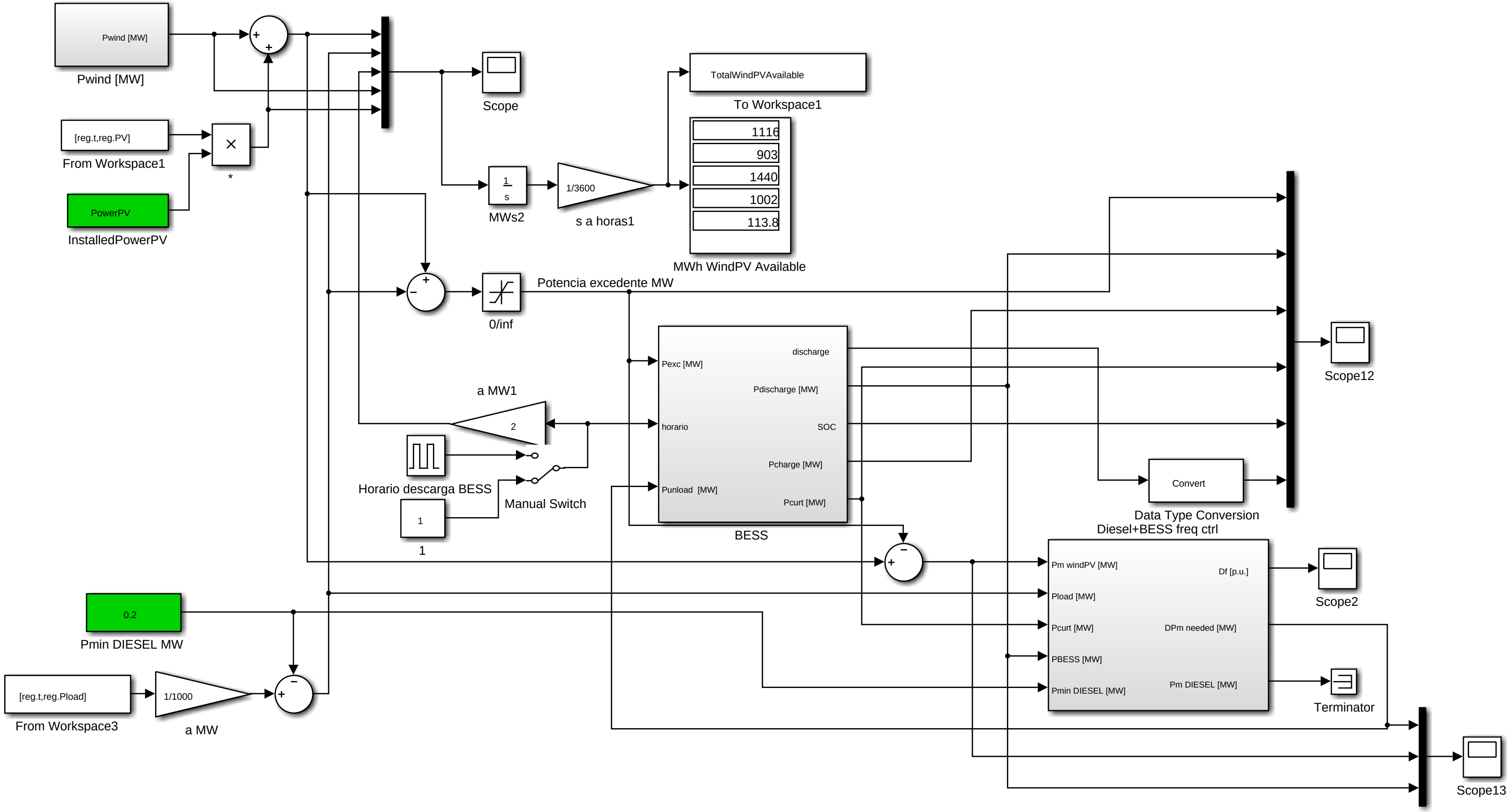

Figura 1. Complete Model.

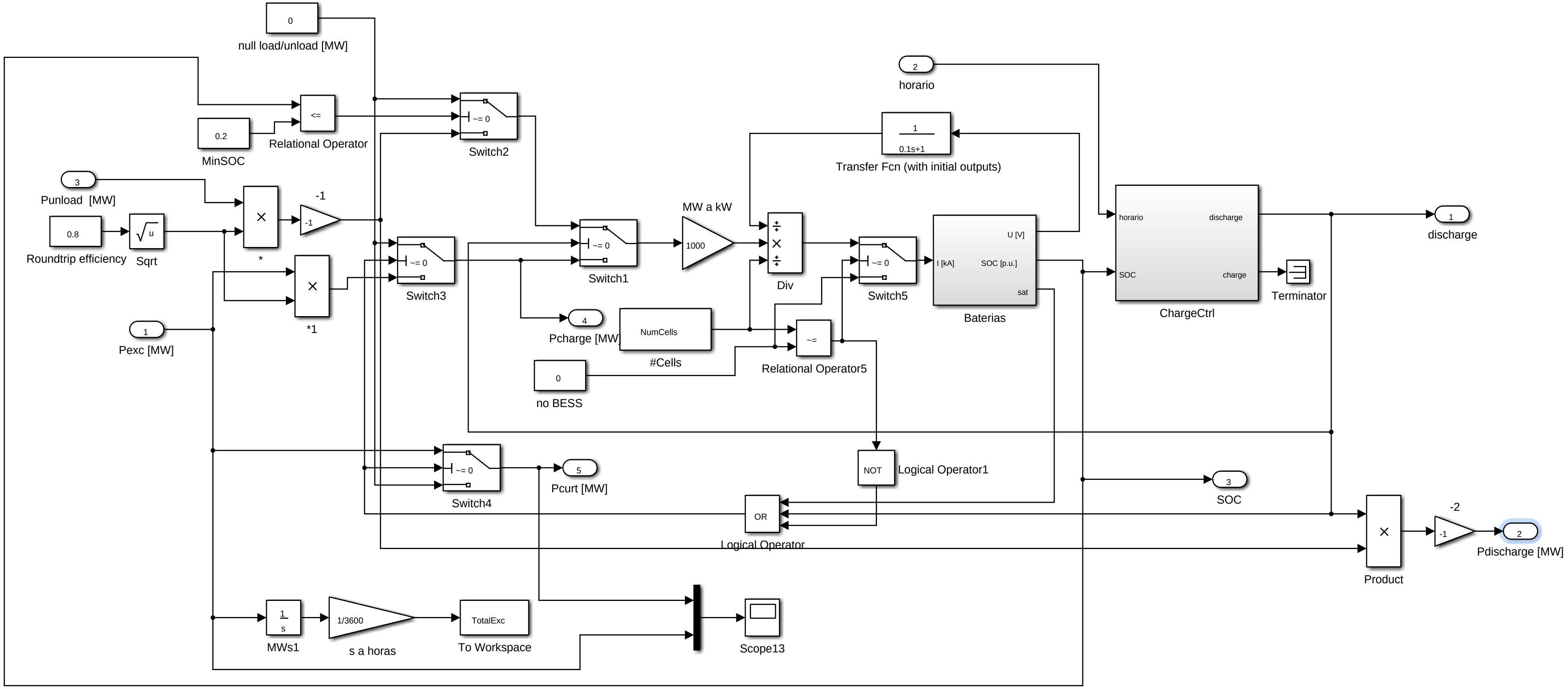

Figura 2. BESS Model.

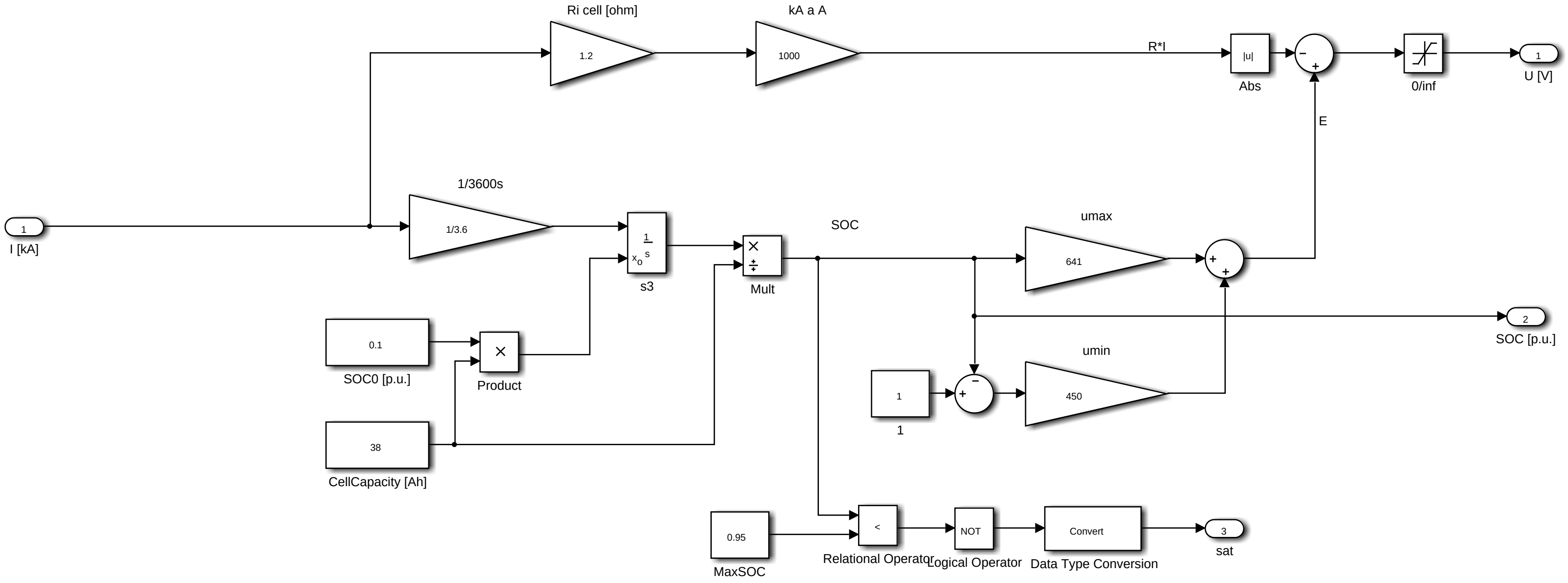

Figura 3. Batteries model.

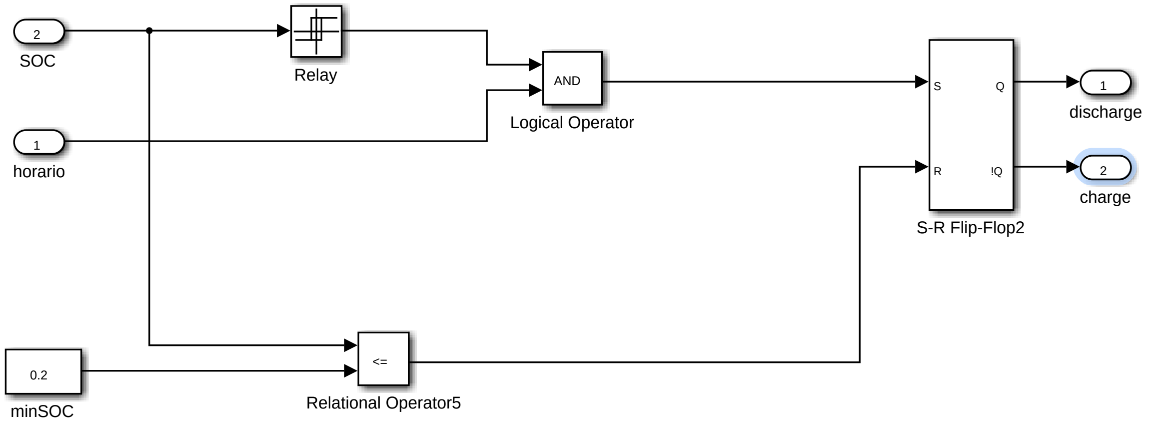

Figura 4. Batteries charger model.

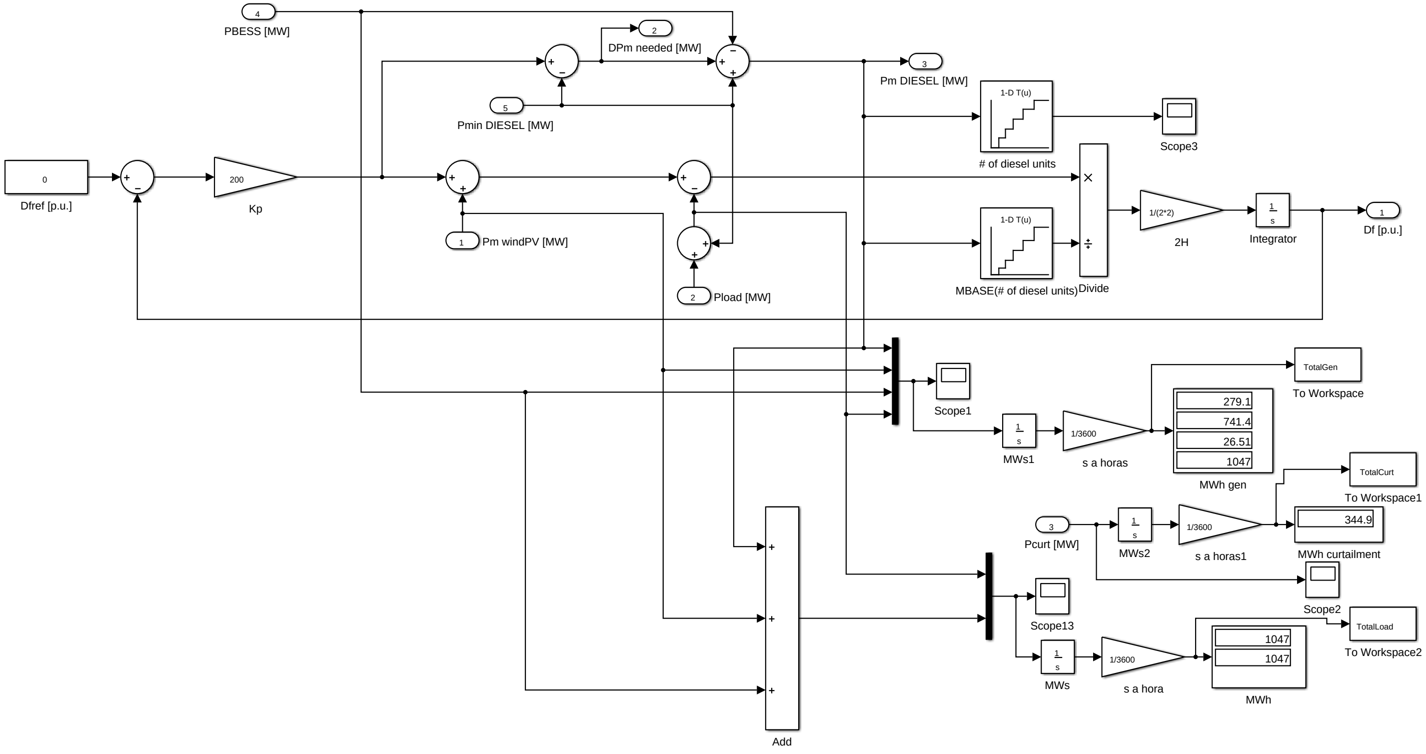

Figura 5. Control of frequency and calculation of diesel generation model.

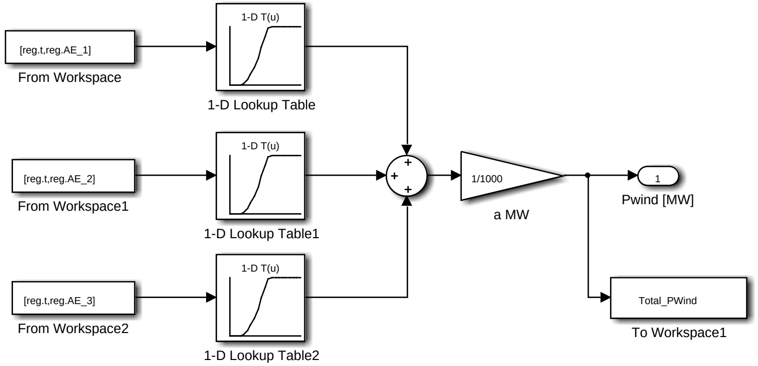

Figura 6. Wind power model.

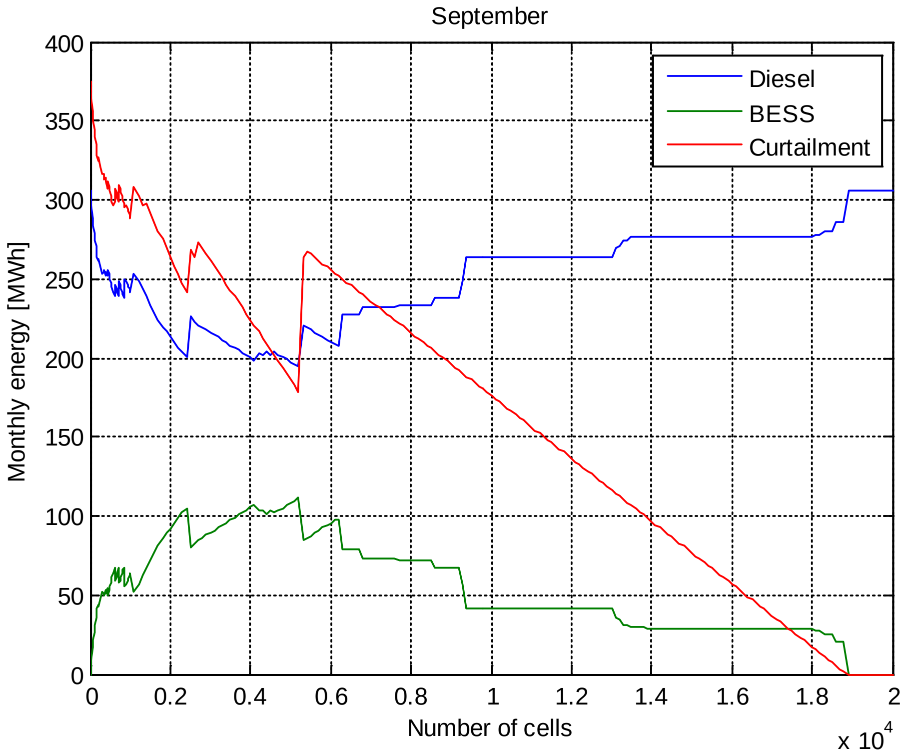

Figura 7. September simulation.

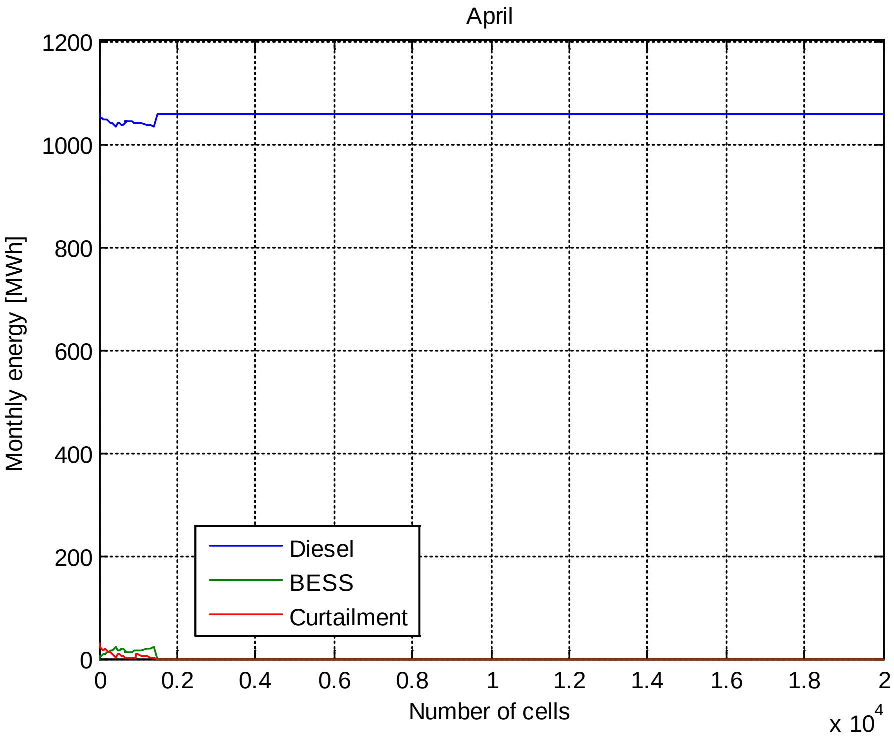

Figura 8. April simulation.

Table I: with 1MWh BESS

Input data		
Years	10	
interest rate	0.05	
Cost of fuel	0.3	u$s/litro
Specific consumption	250	litros/MWh
Specific cost	75	u$s/MWh
PV installation cost	1.5	MUSD/MW
BESS installation cost	0.4	MUSD/MWh
BESS size	1	MWh

Results

Annual energy generated with Diesel gensets, minimum 1 unit at 30% [MWh]. BN: BESS discharge at night.

	Without PV	PV 1MW	PV 1MW BN	PV 1.5MW BN	PV 2MW BN	PV 2.5MW BN
Total	9408.03	7740.33	7743.84	7145.92	6718.27	6462.02

Difference of energy generated with Diesel compared with present case without PV + BESS [MWh]

	Without PV	PV 1MW	PV 1MW BN	PV 1.5MW BN	PV 2MW BN	PV 2.5MW BN
Total	0	1667.7	1664.19	2262.11	2689.76	2946.01

Difference of present value of Diesel compared with present case without PV + BESS [u$s*1e6]

	Without PV	PV 1MW	PV 1MW BN	PV 1.5MW BN	PV 2MW BN	PV 2.5MW BN
Total	0.00000	0.96582	0.96378	1.31006	1.55772	1.70612

	Without PV	PV 1MW	PV 1MW BN	PV 1.5MW BN	PV 2MW BN	PV 2.5MW BN
PV MW	0	1	1	1.5	2	2.5
PV MUSD	0	1.5	1.5	2.25	3	3.75
BESS MWh	1	1	1	1	1	1
BESS MUSD	0.4	0.4	0.4	0.4	0.4	0.4
PV+BESS MUSD	0.4	1.9	1.9	2.65	3.4	4.15
DIESEL - (PV+BESS)	-0.40000	-0.93418	-0.93622	-1.33994	-1.84228	-2.44388

The results in the Tables I show that the investment is not fully repaid by the diesel savings .

Table II: without BESS

Input data					
Years	25				
interest rate	5.00%				
Cost of fuel	0.3	u$s/lit			
Specific consumption	250	lit/MWh			
Specific cost	75	u$s/MWh			
PV installation cost	1.5	MUSD/MW			
BESS size	0	(0 MWh)			
Results					
Annual energy generated with Diesel gensets, minimum 1 unit at 30% [MWh]					
	Without PV	PV 1MW	PV 1.5MW	PV 2MW	PV 2.5MW
Total	9525.39	7891.51	7320.37	6921.79	6693.25
Difference of energy generated with Diesel compared with present case without PV [MWh]					
	Without PV	PV 1MW	PV 1.5MW	PV 2MW	PV 2.5MW
Total	0	1633.88	2205.02	2603.6	2832.14
Difference of present value of Diesel compared with present case without PV [u$s*1e6]					
	Without PV	PV 1MW	PV 1.5MW	PV 2MW	PV 2.5MW
Total	0.00000	1.72709	2.33081	2.75212	2.99370
Costs					
	Without PV	PV 1MW	PV 1.5MW	PV 2MW	PV 2.5MW
PV MW	0	1	1.5	2	2.5
PV MUSD	0	1.5	2.25	3	3.75
DIESEL-(PV)	**0.00000**	**0.22709**	**0.08081**	**-0.24788**	**-0.75630**

Table II shows that the diesel savings could pay the investment and give revenues for PV plant of 1MW and 1.5 MW. The optimum size is **1 MW**.

Galapagos San Cristóbal Island Wind Project – RWE system analysis

Introduction

As part of the GALAPAGOS SAN CRISTÓBAL ISLAND WIND PROJECT, RWE has analyzed the existing power system on San Cristóbal Island. The aim of this analysis is to identify further development of renewable energy potential. A summary of these results has been included in the project report. This extended version describes the used system model, further results, and underlying technical and financial assumptions.

Modell description

RWE's system analysis results are based on a linear energy system optimization tool. The tool considers energy demand on an hourly basis (8760h per year). The energy demand is preset; as is the availability of renewable energy sources per installed unit of capacity, i.e. solar PV and wind energy. While satisfying the energy demand and considering renewable energy availability as well as additional technical restrictions (e.g. efficiencies), the optimization tool derives the cost optimal system configuration for this environment. Considered costs include (annualized) investment costs, (fix) operating costs as well as fuel costs.

The used linear model is displayed in Figure 1.

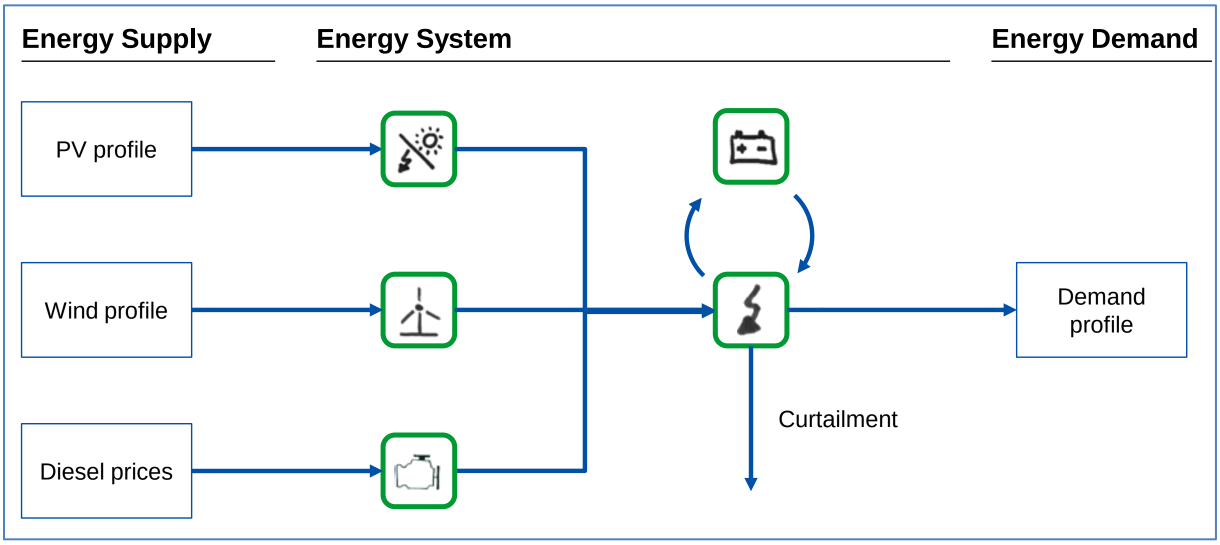

Figure 1 - Linear energy system optimization model for San Cristóbal

The energy demand for San Cristóbal Island is determined in the demand profile. For every hour of the year, the drain of electricity is set. For renewable energy sources (wind, solar PV), the hourly power production is set by a generation profile. This profile scales with the installed capacity. Curtailment of electricity is modelled via a separate potential energy sink.

Analyses are undertaken to understand system implications of various options to increase the share of renewable electricity on San Cristóbal Island. The following system changes are analyzed:

1. Full automation of wind-diesel-dispatch (via adapted wind generation profiles)
2. Addition of new wind turbines, solar PV and/or storage; the amount of additional capacity is determined by the optimization tool.
3. In addition, the minimum penetration rates for renewable energies is set to 70% and 90% respectively to understand the impact on system configuration and costs of such highly renewable based energy systems.

The linear modelling approach improves solvability of the optimization problem; however as a useful model always simplifies the real behavior of technologies, this model assumes stable efficiency factors independent from the load factor (no consideration of part load inefficiencies) as well as it disregards minimal part load of e.g. diesel engines.

Results

The results are based on actual and simulated production data from San Cristóbal Island from September 2014 to August 2015.

The automation of wind-diesel-dispatch shows a significant increase in wind energy supply – along with a decrease in diesel engine operating hours and diesel costs. The renewable energy penetration is increased from <25% to approximately 35% by dispatch alone, without any additional capacities added to the grid.

Scenario	Demand [MWh_{el}/a]	Curtailment [MWh_{el}/a]	Wind supply [MWh_{el}/a]	Diesel supply [MWh_{el}/a]	Diesel costs [USD/a]
Status Quo	16,410	2,430	3,710	12,700	904.840
Full automation	16,410	430	5,710	10,700	761.940

Table 1 - Results status quo vs. full automation of wind-diesel-dispatch

All following calculations assume full automation of dispatch decisions. Depending on the underlying diesel prices, the addition of wind, solar PV, and/or storage capacities varies, as the diesel price has a major influence on their profitability. At low prices for diesel of 0.92 USD/gal further investments in renewable generation capacity cannot be justified. However, with increasing prices for diesel (e.g. 1.40 USD/gal) the installation of additional wind generation capacity will decrease the total electricity generation costs and likewise increase the penetration of renewable energies. With further incline of diesel prices, also solar PV and storage play a role in a cost effective energy supply system.

Scenario	Wind [kW]	PV [kWp]	Storage [kWh]	Diesel use [gal/a]	Savings [USD/a]	Share of RES
0.92 USD/gal				984,915	0	35%
1.40 USD/gal	524			757,190	13,800	40%
2.00 USD/gal	910	1,425	390	614,610	102,400	52%
3.00 USD/gal	1,510	2,840	2420	481,760	390,000	62%

Table 2 - Additional renewable generation capacity, total diesel use, yearly savings, and RES penetration compared to full automation scenario

Given Ecuador's overall nation-wide 90% renewable target, higher shares of renewable energy are possible within a reasonable investment range. However, due to the absence of hydro power on San Cristóbal Island, compliance with the overall target remains challenging.

Scenario	Wind [kW]	PV [kWp]	Storage [kWh]	Total investment [Mio. USD]	Diesel use [gal/a]	Add. costs [USD/a]
50% RES	840	1200	230	2.83	636,280	-
70% RES	1,680	4,510	6,550	11.70	381,770	17,000
90% RES	0	23,870	41,900	55.50	127,260	2,340,000

Table 3 - Installed capacities, total investment, diesel use and additional costs (at 2.00 USD/gal) for high shares of renewable energies

Assumptions

Technology	Wind	Photovoltaics	Battery storage
CAPEX (USD/kW(h))	1,100	1,500	470
OPEX (% of CAPEX)	2%	2%	1%
Lifetime (years)	25	25	20

Additional inverter replacements after half of the lifetime for photovoltaics and wind.

Interest rate: 1,5 %