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FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS UNIVERSIDAD DE CHILE

Vancouver 2010 Symposium on Microgrids

Status of Microgrid R&D in Chile

CE-FCFM

Centro de Energía

Facultad de Ciencias Físicas y Matemáticas

Universidad de Chile

July 2010

Agenda

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- ***Background and introduction***
- *Huatacondo project*
- *Further developments*
- *Conclusions*

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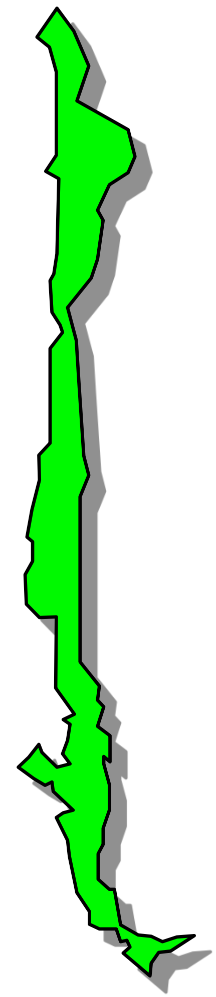
Integration of Renewable Energy Technology

Big potential !

- Mini hydro, sun, wind, geothermal, biomass, ocean.
- Investment uncertainty.
- New estimation techniques.

Renewable Energy	SIC Installed Capacity [MW]	Potential [MW]
Hydro	117	20.392
Geothermal	0	16.000
Wind	118	40.000
Biomass	191	13.675
Solar	0	100.000
Total	**426**	**190.067**

Source: PRIEN, U Chile
U. T. Federico Santa María



Background & Introduction

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Background & Introduction

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CE-FCFM recognizes as objective **Smart-Grids systems** focused in Virtual Power Plants and Distributed Generation (DG units such as: Micro-Hydro, Solar, Wind and Geothermal at low temperature). Planning and regulatory developments applied to (DG) and Renewable Energies integration.

In this context, for the short and medium term studies, **the optimization problem is essentially stochastic**, due to the various **uncertainties in production and consumption of powe**r.

The **unit commitment** has to be taken into account. The introduction of microgeneration units make possible **to homogenize microgenerators into agregated macro generators.**

Agenda

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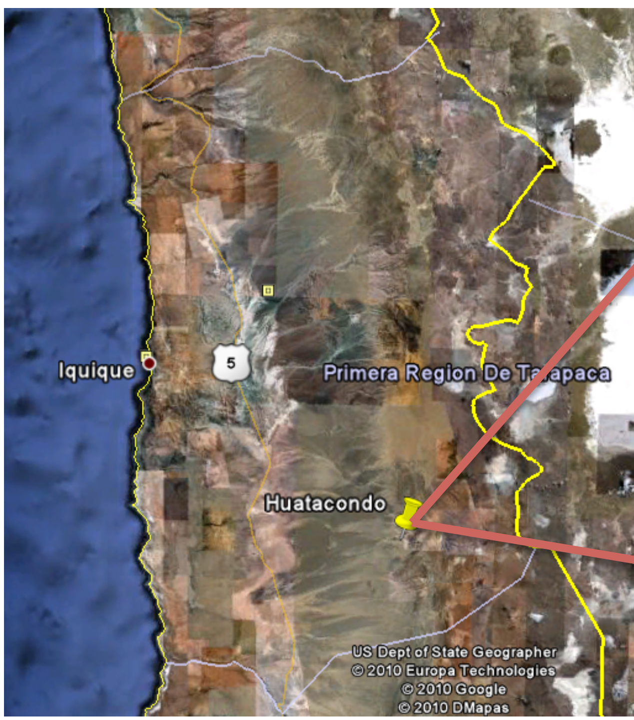
Huatacondo project

Village location



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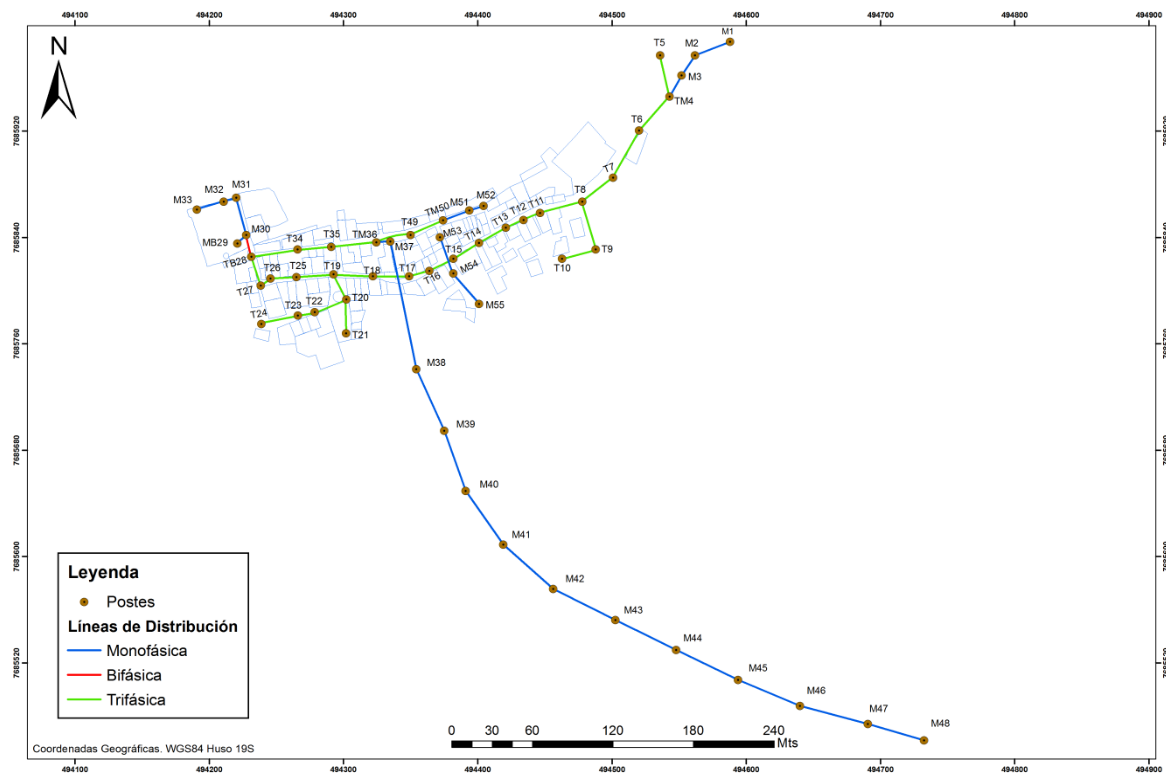
Grid status:

It is isolated from the interconnected system and supplied only during 10 hours a day by a diesel generator.



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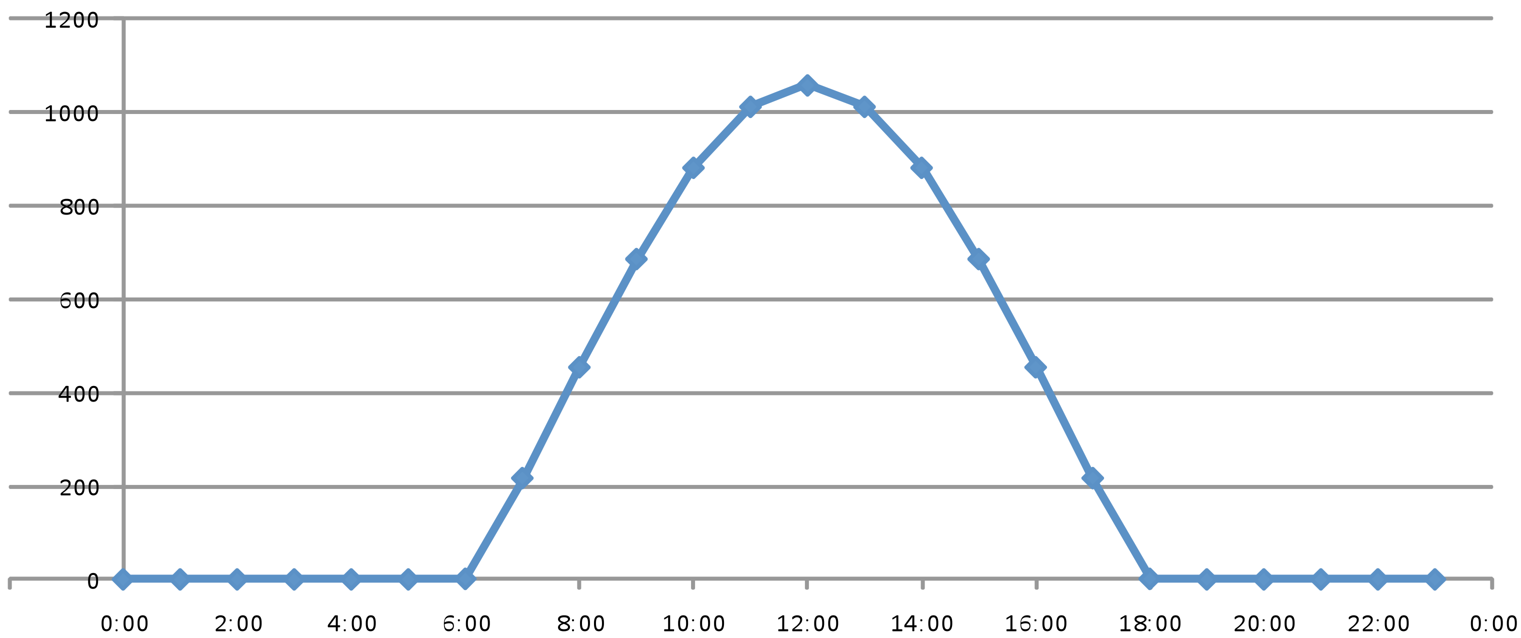
Energy sources potential – Solar energy



	In 1 m^2
kWh/year	2898
kWh/day(average)	7.9

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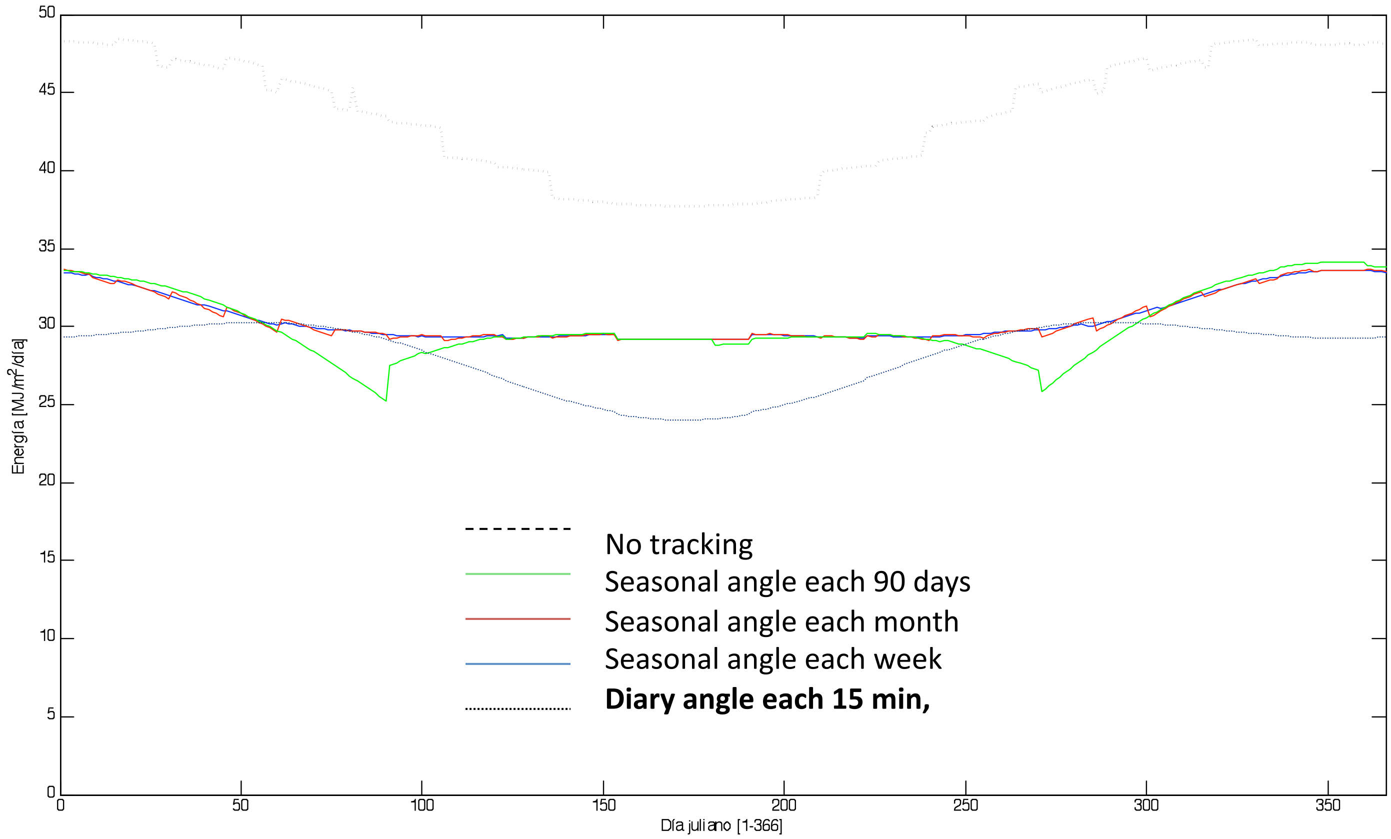
Energy sources potential – Solar energy



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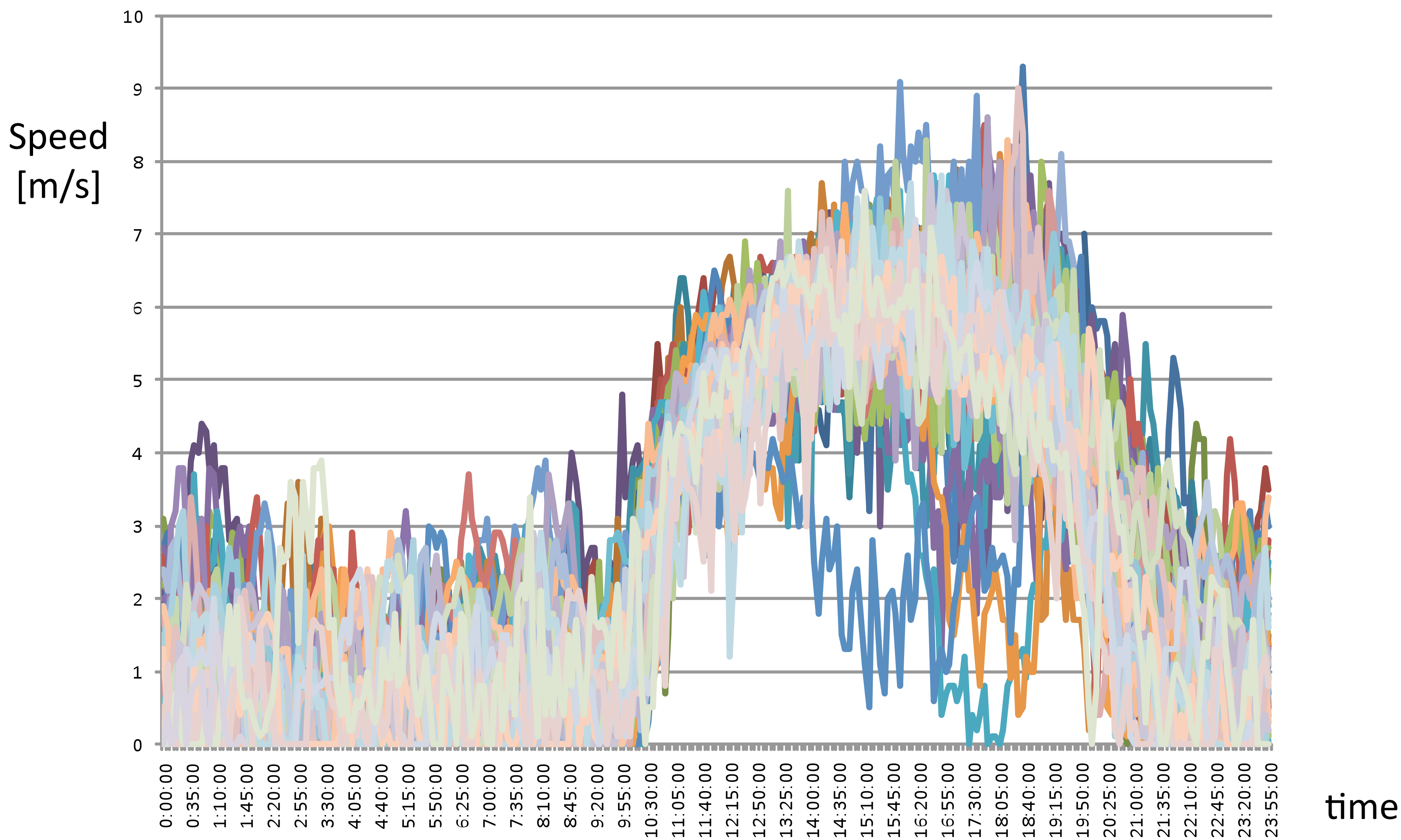
Energy sources potential – Wind energy



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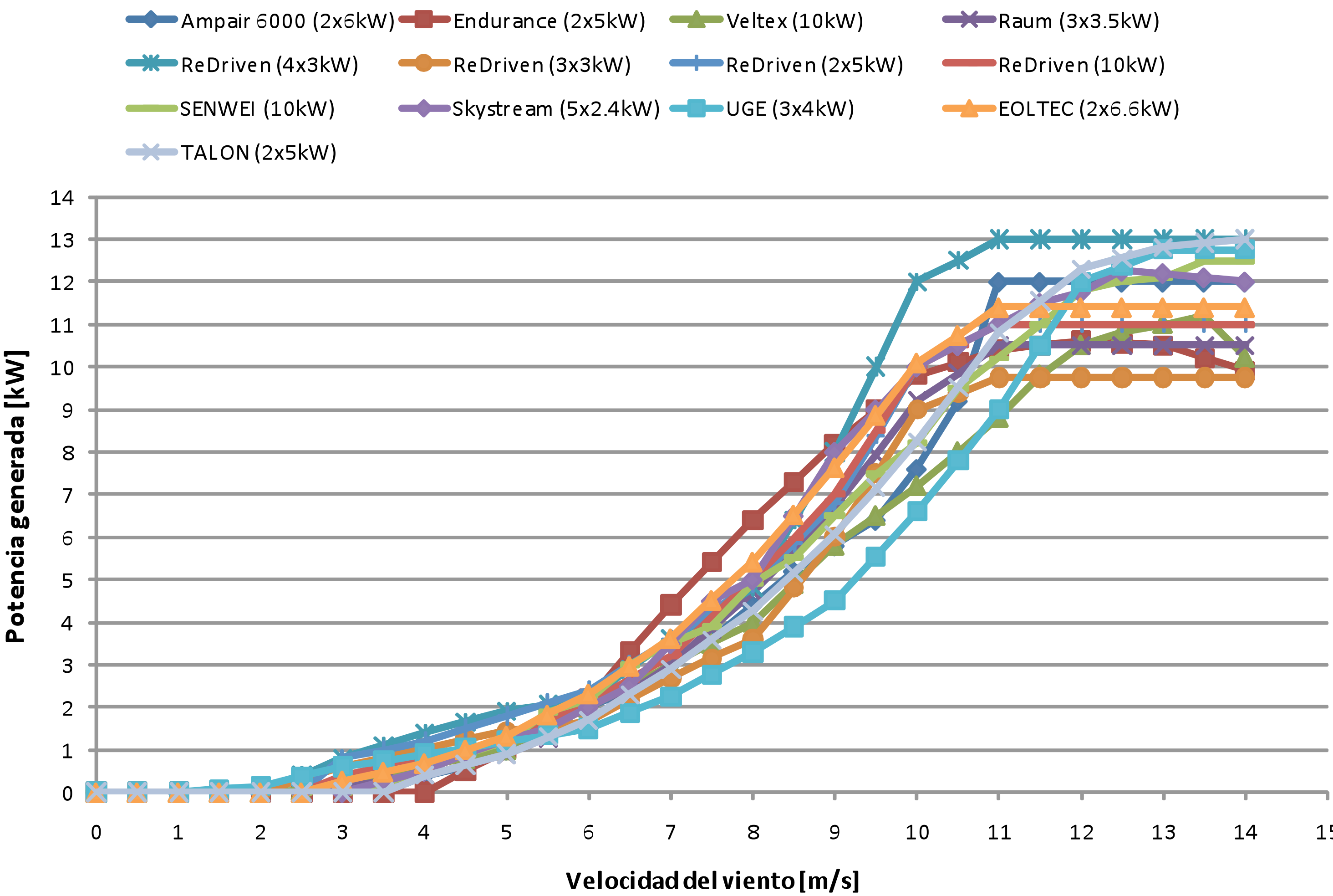
Energy sources potential – Wind energy



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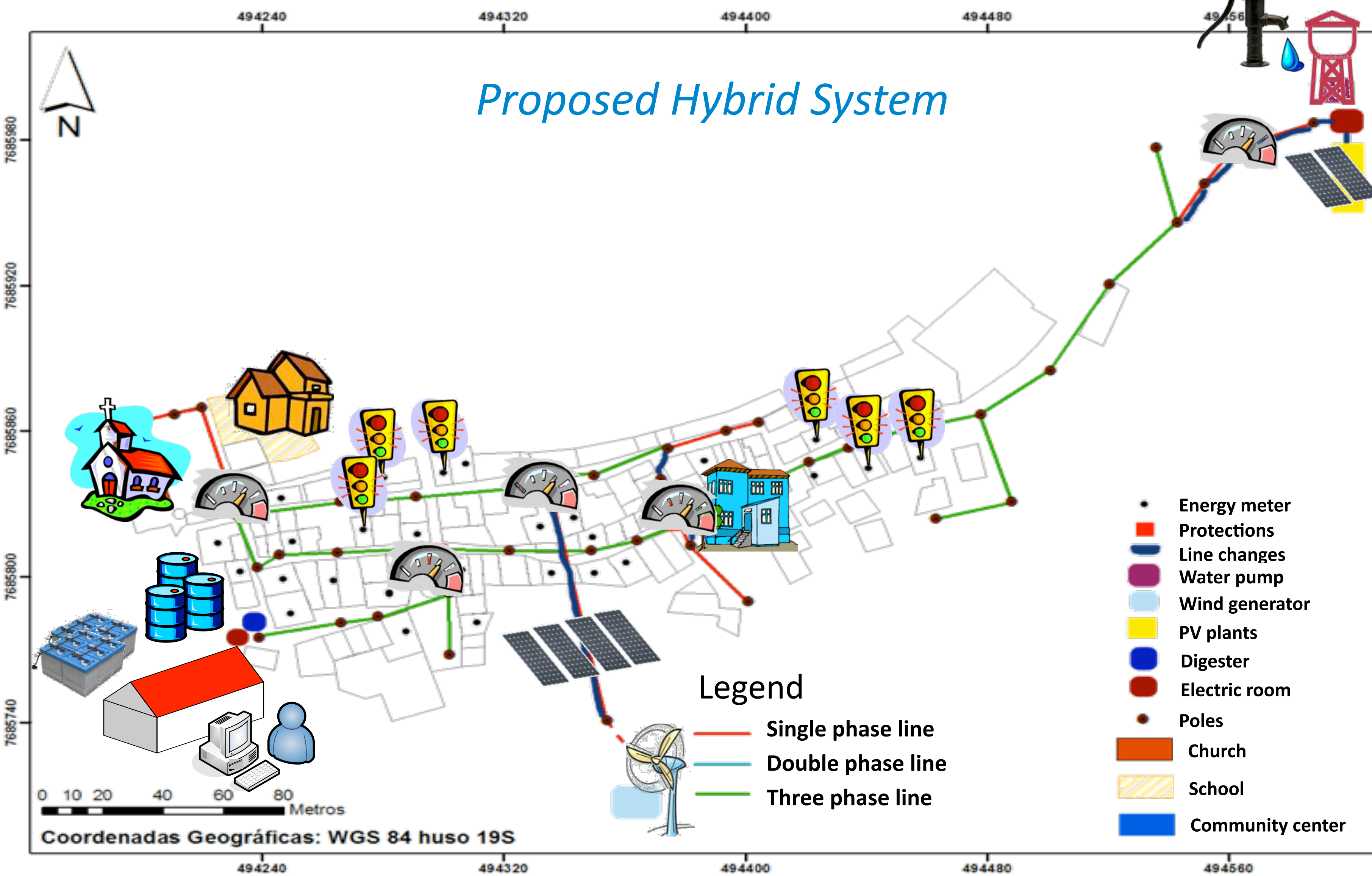

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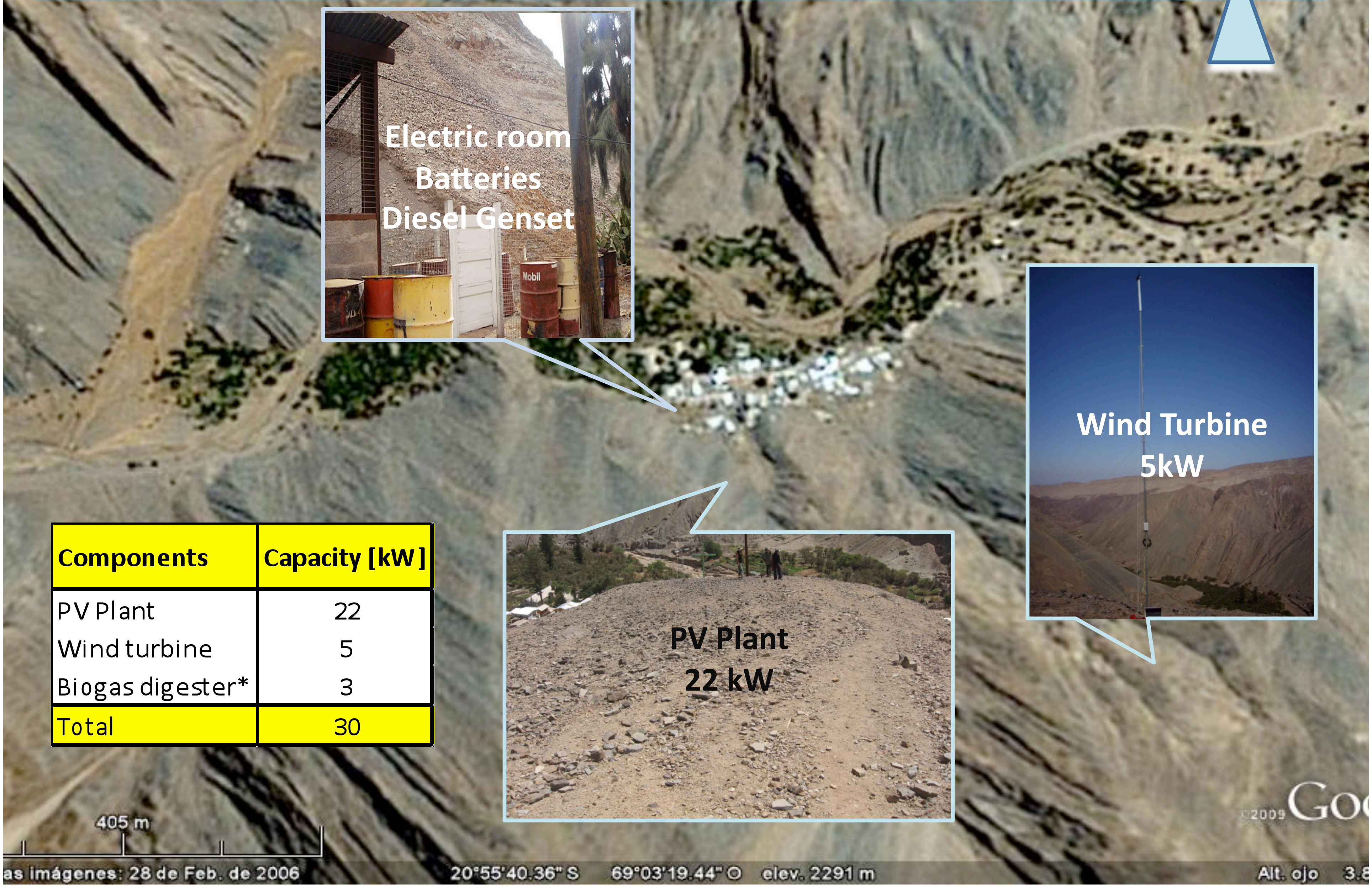

Components	Capacity [kW]
PV Plant	22
Wind turbine	5
Biogas digester*	3
Total	30

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Proposed Hybrid System

•It takes advantage of the distributed renewable resources in the area providing a 24 hours service.

•Since the village experienced problems with the water supply system, a management solution should also be included in the system.

•A demand side option to compensate the generation fluctuations due to the renewable sources is considered.

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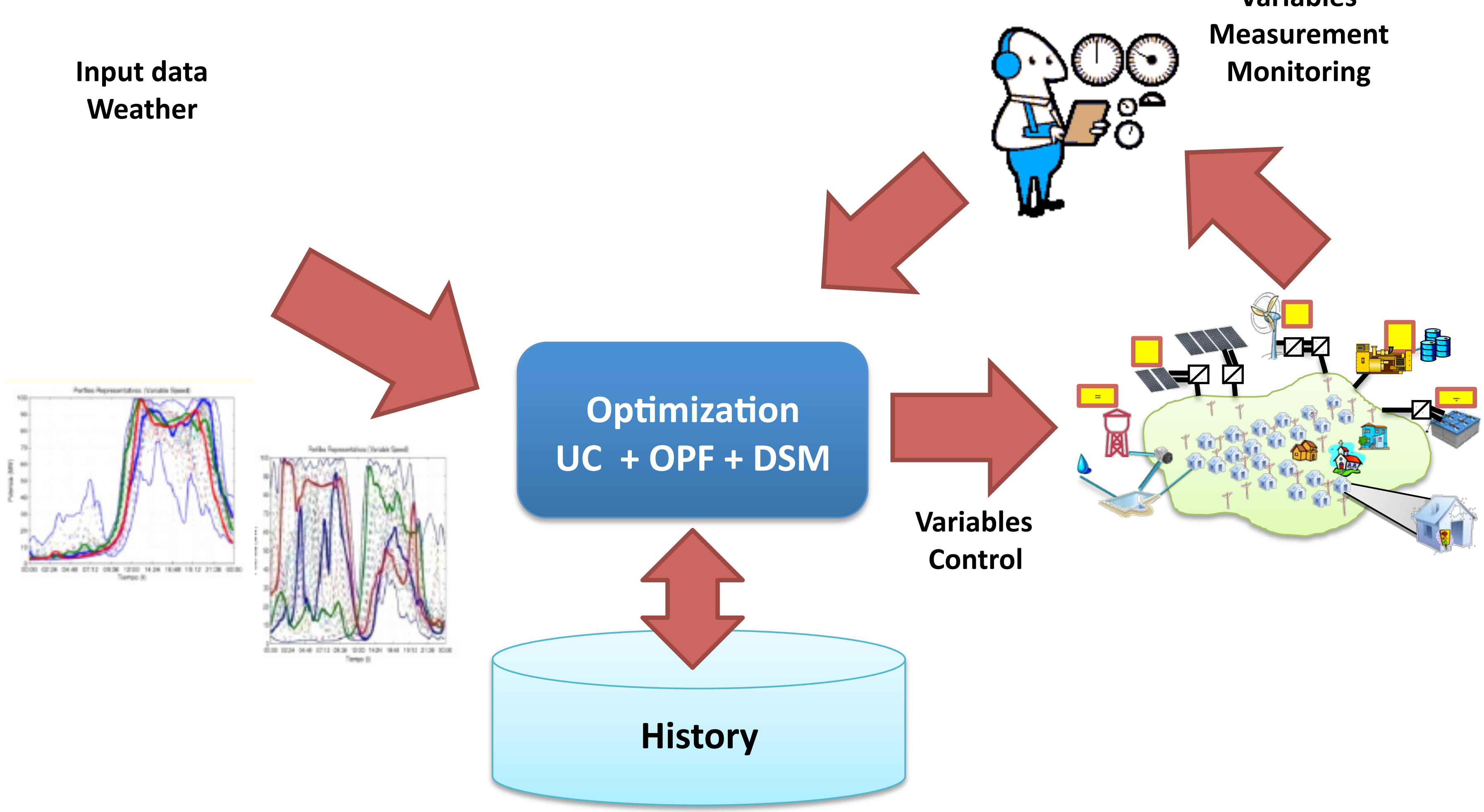
Proposed Energy Management System (EMS)



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Proposed EMS - Predictive Control Strategy

Objective function	$$\min_{U=\left[u(t)^T,\ldots,u(t+N_u-1)^T\right]^T} J = \sum_{i=1}^{\ell} \lambda_i J_i(x_t, U)$$
Unit modeling	$$x(t+k) = \sum_{i=1}^{s} f_i\left(x(t+k-1), u(t+k-1)\right)\delta_i\left(t+k-1\right)$$ $$k = 1,\ldots,N_y$$ $$x(t) = x_t$$
Constraints	$$c_1(x(t+k-1), u(t+k-1)) \le 0, \quad k = 1,\ldots,N_y$$ $$c_2(x(t+k-1), u(t+k-1)) = 0, \quad k = 1,\ldots,N_y$$

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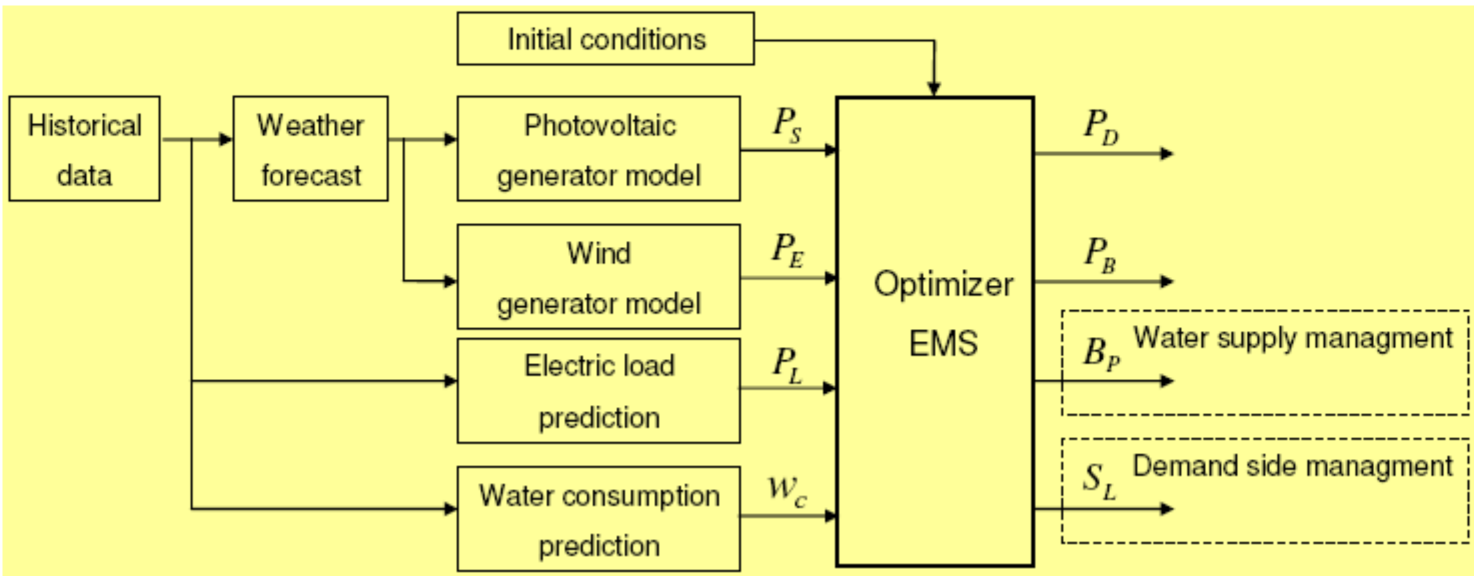
Proposed EMS - Predictive Control Strategy



References for the diesel power (P_D), *the battery power* (P_B), *the signals* for the water supply system (B_P), *and the signals for consumers* (S_L).

Predicted solar power (P_S), *wind power* (P_E), *load profile* (P_L) *and water* consumption (w_c).

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Proposed EMS - Modeling of renewable generation units.

- *Photovoltaic panels:*

$$P_S(t+k) = \eta_S A_S R_S(t+k)$$

- *Wind generator:*

$$P_E(t+k) = f\left(v_E(t+k)\right) = \frac{\rho}{2} c_p\left(\lambda, \beta\right) A_E v_E^3(t+k)$$

For forecasting irradiance R_s and wind speed v_E we consider a Global Forecast System (GFS) for the bounded conditions of a Weather Research and Forecast (WRF) model.

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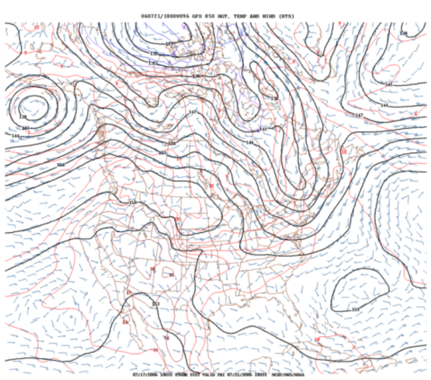
Proposed EMS - Weather forecast.

•GFS is a global numerical weather prediction computer model that runs two times a day and produces forecasts up to 16 days in advance, but with decreasing spatial and temporal resolution over time.

•WRF has a comprehensive description of the atmospheric physics that includes cloud parameterization, land surface models, atmosphere ocean coupling, and broad radiation models. The spatial resolution with mesoscale models can go up to 30 seconds of a degree (less than 1 km2).



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Proposed EMS - Modeling of conventional generators.

- *Diesel generator:*
  - *Operational costs. A non-convex cost function is approximated by piecewise linear segments:*

$$C(t+k) = C_c \sum_{v=1}^{n_v} \left(\alpha_v P_v(t+k) + \beta_v B_v(t+k) \right)$$

$$P_D(t+k) = \sum_{v=1}^{n_v} P_v(t+k)$$

  - *Tank volume*

$$V_D(t+k) = V_D(t+k-1) - \sum_{v=1}^{n_v} \left(\alpha_v P_v(t+k) - \beta_v B_v(t+k) \right)$$

  - *Start-up costs*

$$C_s(t+k) \geq C_D(B_g(t+k) - B_g(t+k-1))$$

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Proposed EMS - Modeling of conventional generators.

- *Battery bank:*
  - *Energy dynamic*

$$E(t+k) = E(t+k-1) - \delta_t P_B(t+k)$$

  - *Inverter model*

$$P_I(t+k) = \begin{cases} \eta_{Id} P_B(t+k) - P_{I0} & P_B(t+k) \geq 0 \\ \dfrac{P_B(t+k)}{\eta_{Ic}} - P_{I0} & P_B(t+k) < 0 \end{cases}$$

battery injects power to the hybrid grid ($P_B(t+k) \geq 0$)

battery charging mode ($P_B(t+k) < 0$)

$P_B(t)$ is the battery current power
$P_{I0}(t)$ is the own consumption of the inverter

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Proposed EMS - Water supply system.

- Water tank volume:

$$V_T(t+k) = V_T(t+k-1) + \delta_t w_f(t+k) - \delta_t w_c(t+k) + V_{Tf}(t+k)$$

water inflow — water consumption — unserved water consumption

$$w_f(t+k) = \kappa_T \eta_P P_P(t+k) = \kappa_T \eta_P \overline{P_P} B_P(t+k)$$

P_p is the pump water
B_p represents the on-off of the pump

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Proposed EMS - Demand Side Management.

•It is supposed that online signals can be sent to consumers in order to modify their temporal consumption pattern, leaving daily energy constant.

Load: $$\tilde{P}_L(t+k) = S_L(t+k)P_L(t+k)$$

$$S_{Lmin}(t) \leq S_L(t) \leq S_{Lmax}(t)$$

S_L is the shifting factor of the electric demand

P_L is the expected load.

•It is assumed that expected energy consumption remains constant for the whole optimization period:

$$\sum_{t=T_1}^{T_2} \tilde{P}_L(t+k) = \sum_{t=T_1}^{T_2} P_L(t+k)$$

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Proposed EMS - Constraints.

- Power balance for the hybrid grid

Diesel power *Battery power* unserved power

$$P_D(t+k) + P_I(t+k) + P_{NS}(t+k)$$

$$=$$

$$\tilde{P}_L(t+k) + P_P(t+k) - P_{Lost}(t+k) - P_S(t+k) - P_E(t+k)$$

Expected load *Pump power* unused power from the energy sources (storage was not possible) *solar power* *wind power*

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Proposed EMS – Objective Function.

- The optimization problem for EMS that minimizes the operational costs of the hybrid grid is formulated as:

$$J = C_c \delta_t \sum_{k=1}^{T} C(t+k) + \sum_{k=1}^{T} C_s(t+k) + C_{NS} \delta_t \sum_{k=1}^{T} P_{NS}(t+k) + C_{Tf} \sum_{k=1}^{T} V_{Tf}(t+k)$$

diesel costs

start-up diesel costs

Penalization of the unsupplied energy

Penalization of the unserved water supply

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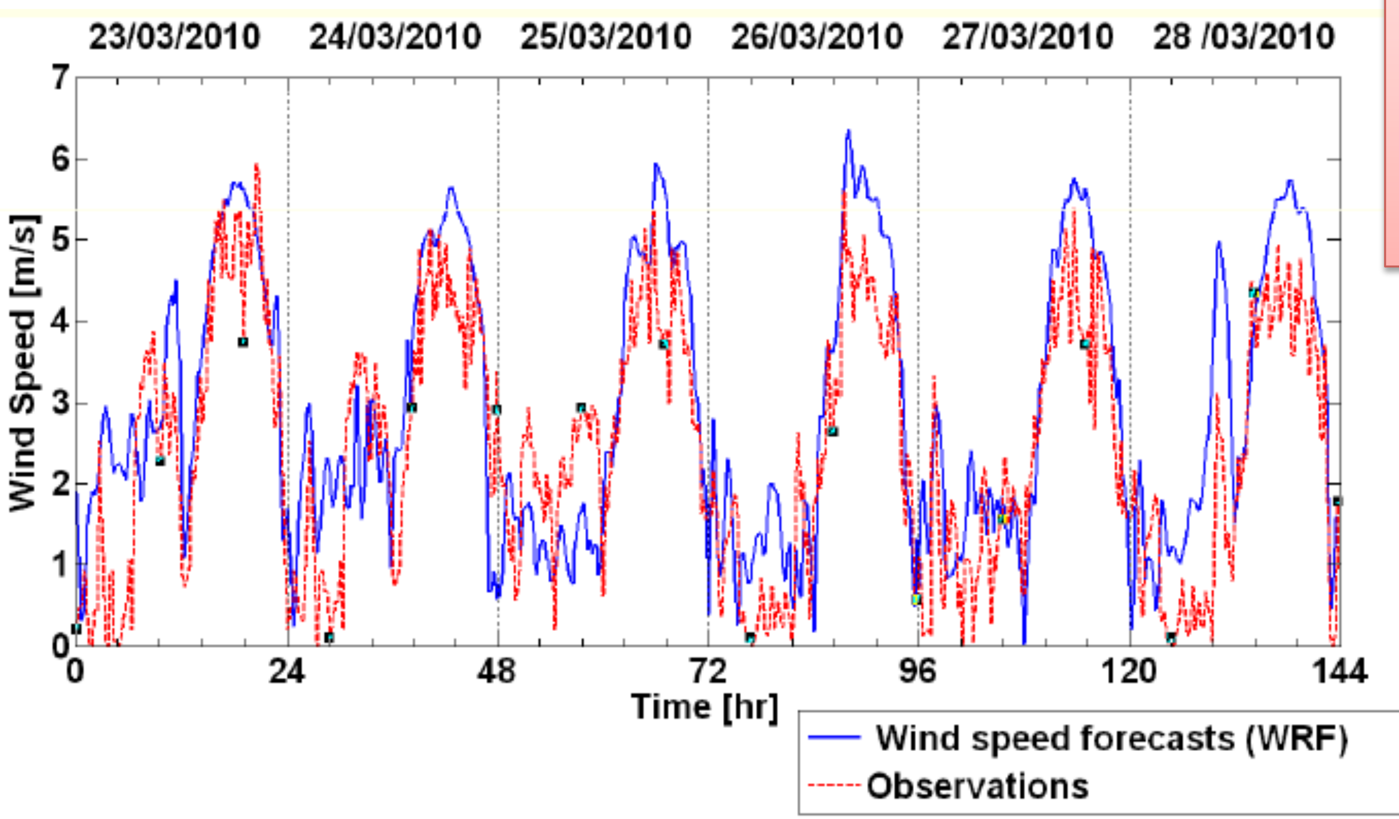
Proposed EMS – Results.

- Wind forecasting results



Irradiance and wind speed for Huatacondo are predicted using the WRF-GFS models.

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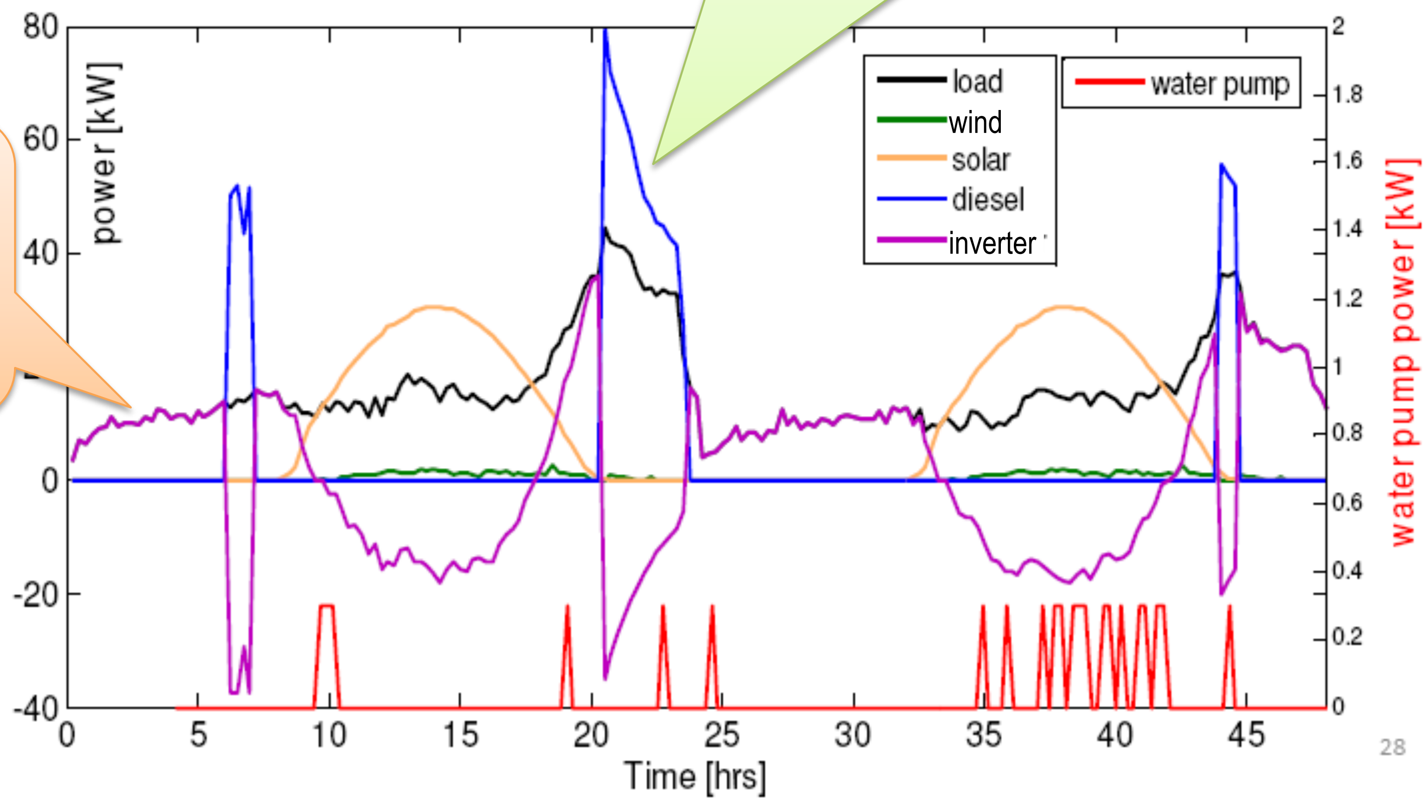
Proposed EMS – Results.

Optimization results are obtained for a forecast horizon of 48 hours considering a sampling time of 15 minutes

Load and water consumptions are forecasted using historical patterns of the location



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Proposed EMS – Results.

Case I. A typical demand and an irradiance profile for summer season.

SLmin	SLmax	Start-up cost $	Operation cost $	Total cost $	Saving %
1.00	1.00	3,000	28,949.2	31,949.2	0.00
0.99	1.01	3,000	28,870.2	31,870.2	0.25
0.95	1.05	3,000	28,571.6	31,571.6	1.18
0.90	1.10	3,000	28,285.8	31,285.8	2.08
0.85	1.15	3,000	28,170.4	31,170.4	2.44
0.80	1.20	3,000	27,971.4	30,971.4	3.06

Cost savings when the consumers shift their loads.

Small savings can be explained due to the abundant renewable resources able to cover almost the load. Therefore, the use of the diesel generator is limited and the battery bank storages the renewable energy surplus.

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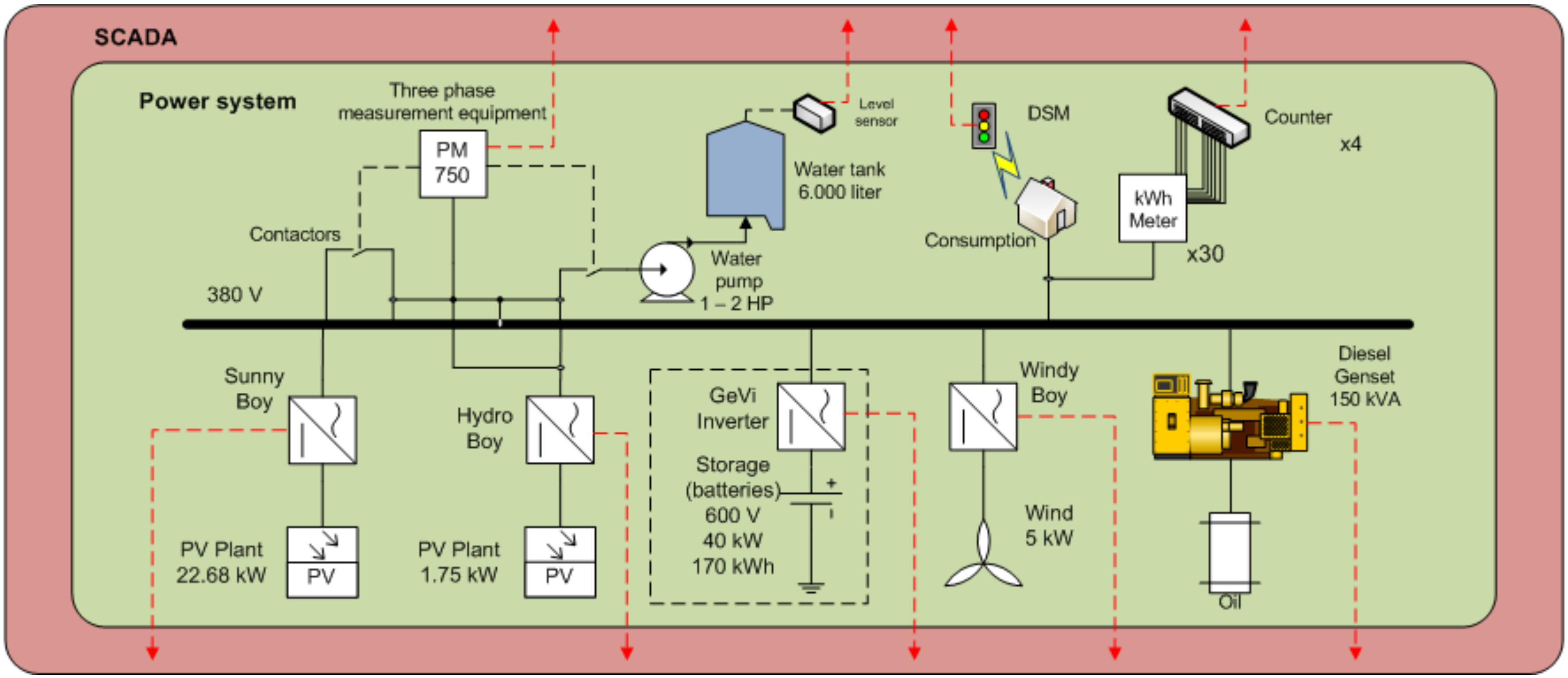
Current activities – Power system schematic



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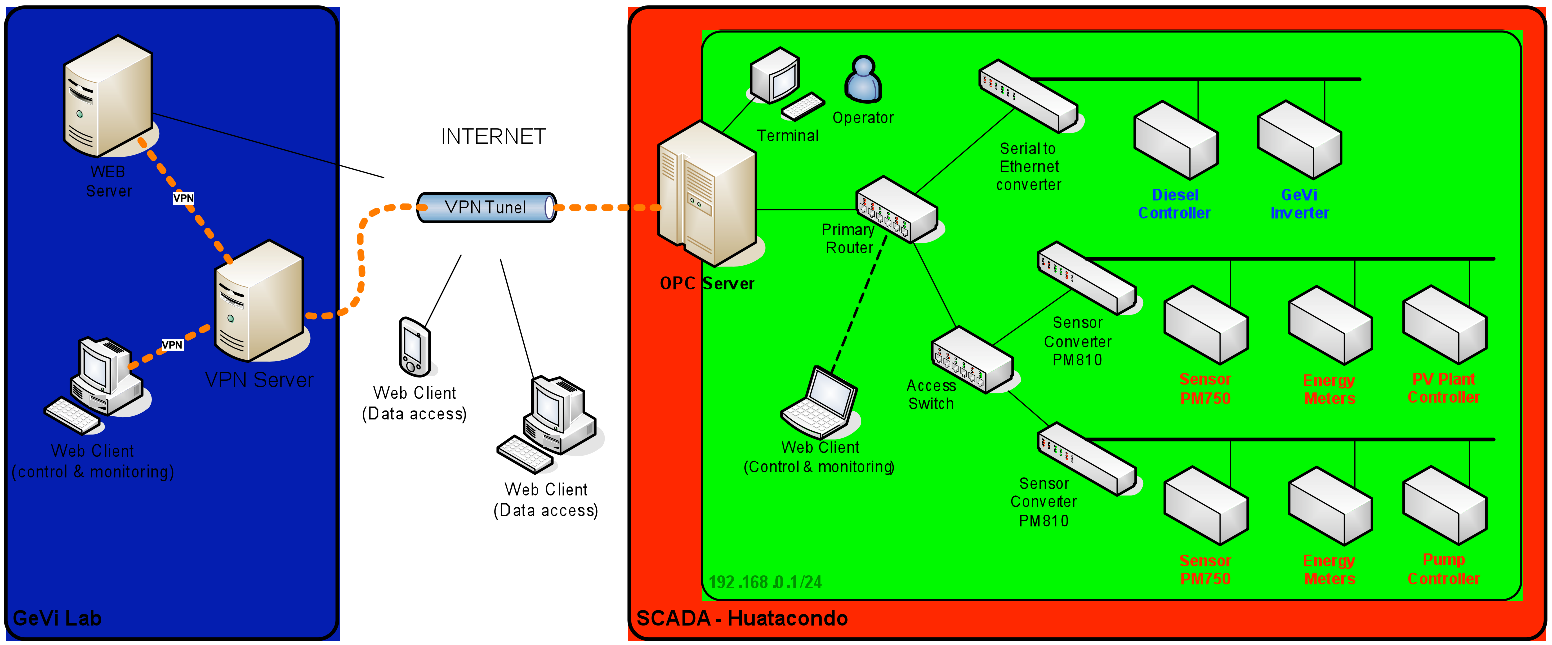
Current activities – SCADA system schematic



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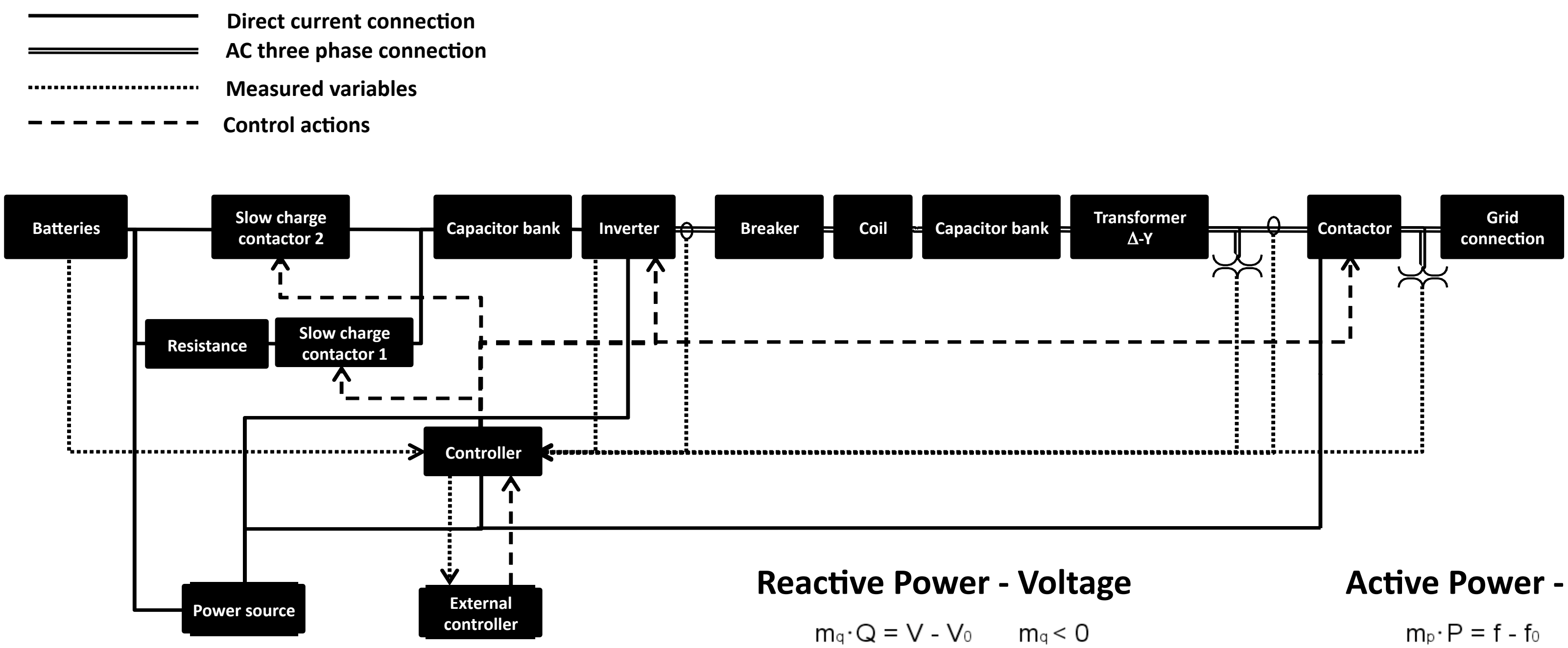
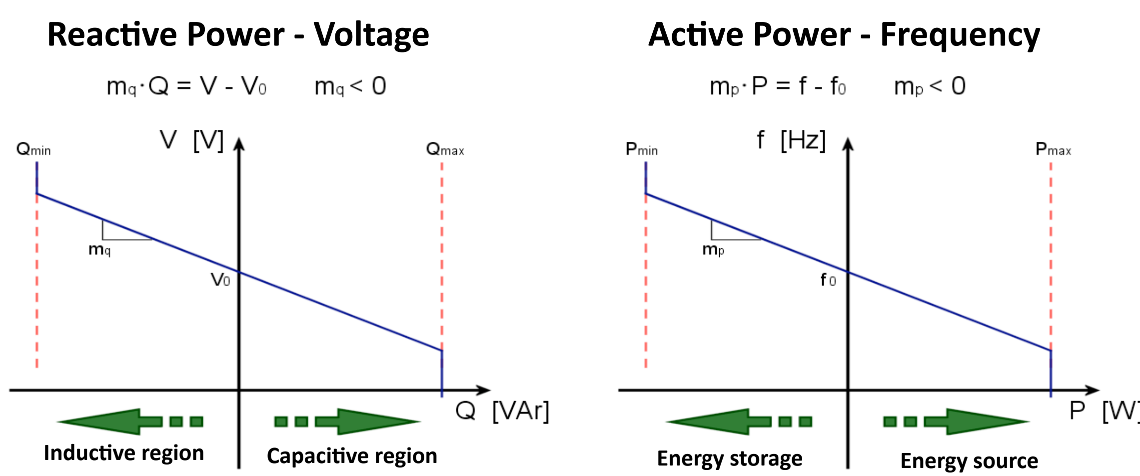
Current activities – GeVi inverter





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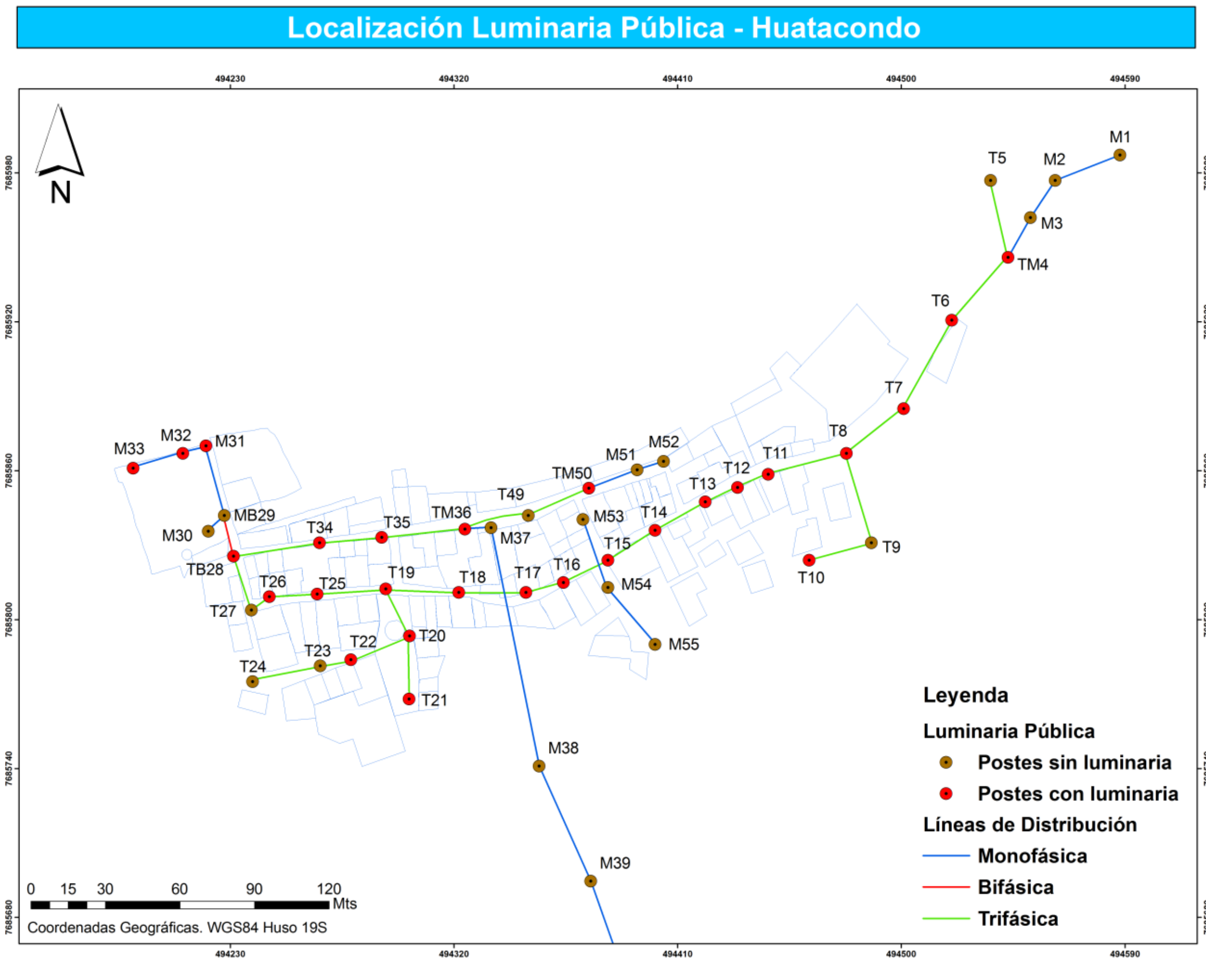
Current activities - Network improvement



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Current activities - Network improvement

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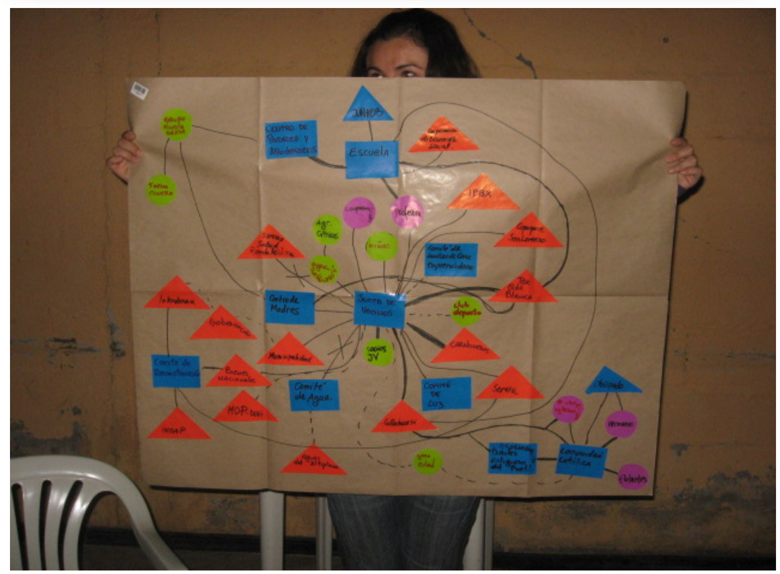
Community work



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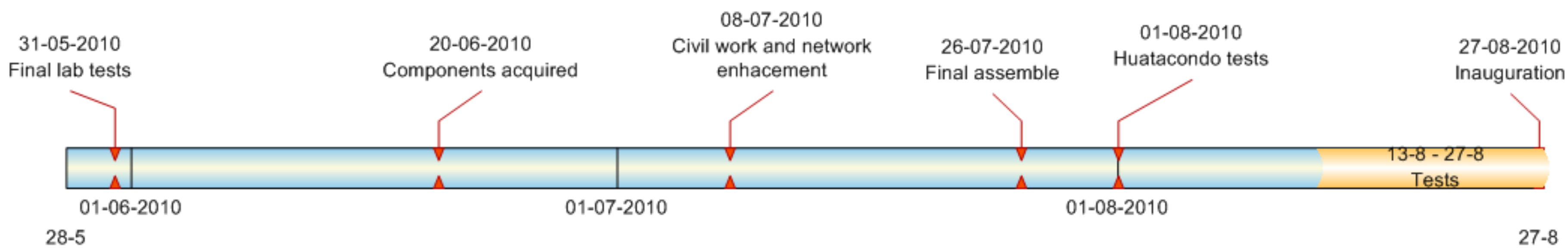
Time line



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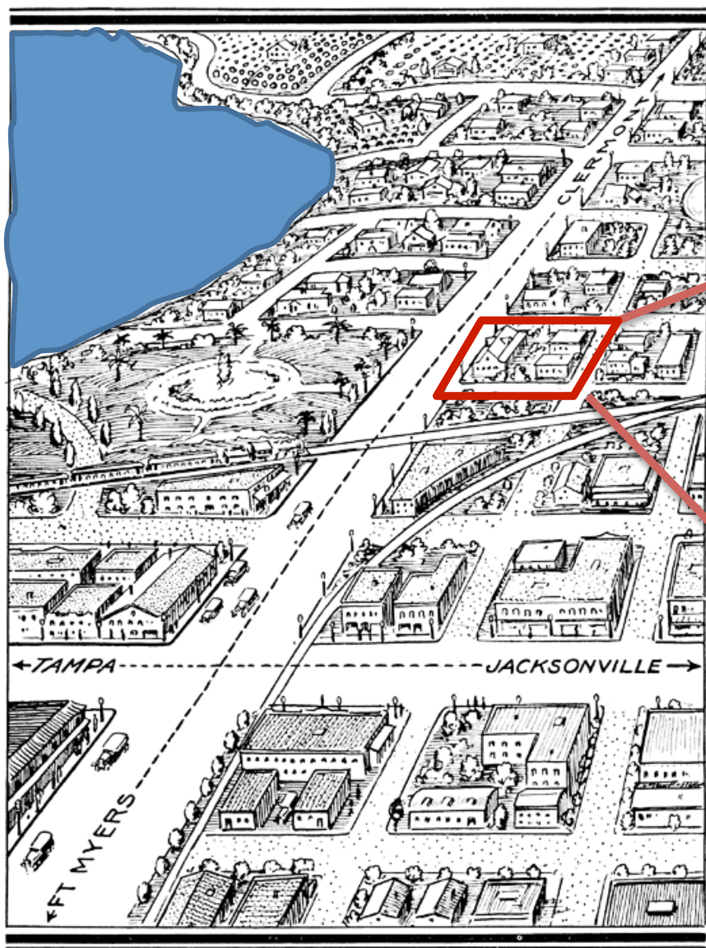
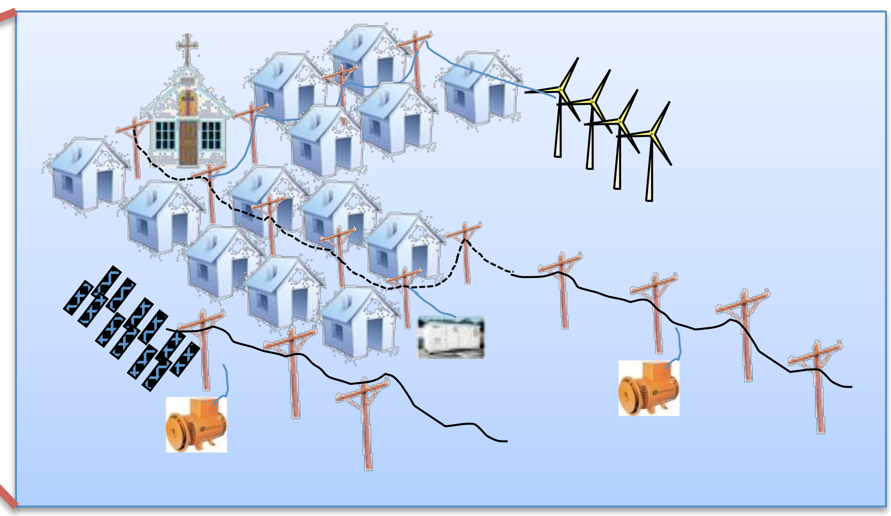
Emergency micro-grids

To have in different cities of the country micro-grids that support efficiently under emergency situations.





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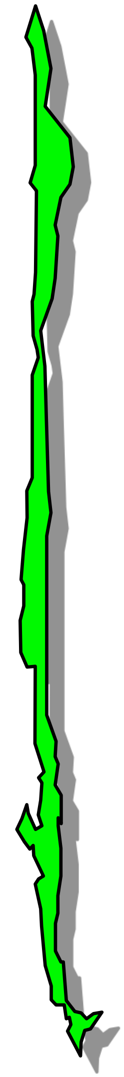
Sustainable squares

Public places → sustainability → education



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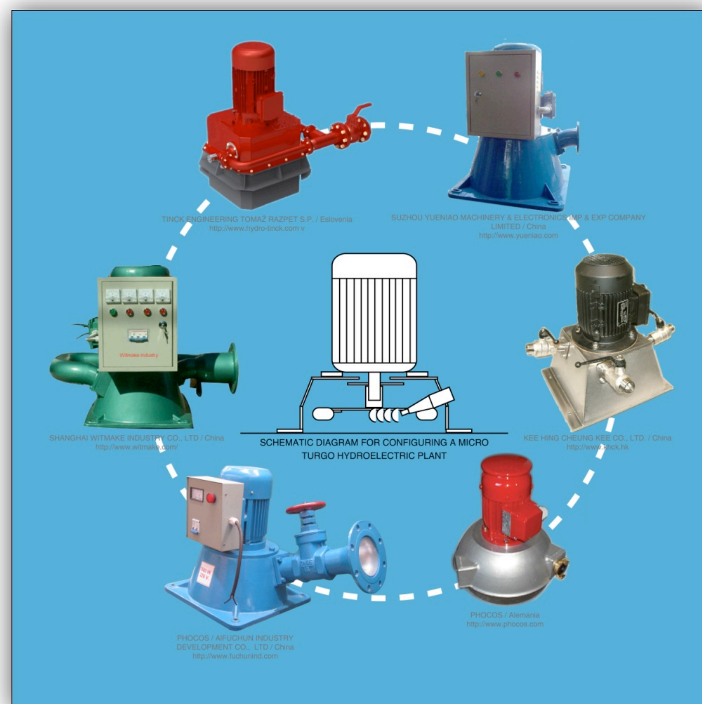
Micro-Hydro Plug&Play



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Conclusions

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•The EMS provides the on-line set-points for generation units while minimizing the operational cost and considering the forecast of renewable resources, load, and water consumptions.

• The results of the EMS showed that the power balance in the hybrid grid is fulfilled for all study cases, showing the economic benefit of a coordinated online dispatch.

•Huatacondo project may become the first micro-grid development at country level. There is a high potential of duplicate the project in other isolated communities.

•Further activities are focused on imporvements on micro grids, and other application such as: sustainable squares and emergy micro grids.

•Advances on micro generation units are under development → micro hydro plug & play.