“THERMAL WIND SOLAR POWER PLANT as a SOLUTION of the ENERGY SECURITY SUPPLY PROBLEM on ISLANDS”

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Abstract

The study presents possible innovative solutions for the problem of intermittency and new ways to increase the penetration of the wind energy and other renewable energy sources (RES) on small electrical grids.

The solution is a new concept of power plant, a thermal wind solar power plant (TWSPP): the wind energy converters are interconnected with two heat-pump systems, one of the heat-pump system extracts heat from an insulated compartment (the cold source); and another heat-pump system transfers heat from the soil, the thermal energy of the oceans, or the thermal energy of the groundwater to the hot source of the plant. This setup works as a conventional power plant. The main items of the power station are: heat pumps, heat - exchangers, condenser systems, turbo – generator, and the auxiliary systems.

The TWSPP works 24 h per day, with stable voltage, and frequency, and constant power output, under a mature energy control system.

Key words: Heat pumps, TWSPP, wind energy, energy security, intermittency/power quality, energy storage

I. Introduction

Cape Verde is a ten-island archipelago (4,033 km^2), located about 400 miles off the West Africa coast. Nine islands are inhabited, with a population of 434,000 people (based on the 2000 census).

This developing country with lack of natural resources such as water, forests and oil, has a considerable potential in wind and solar energies, which could be a good basis for the country’s economical and technological development.

Cape Verde should orient its scientific and technological policies in close relationship with the educational and cultural systems to the following areas:

- Production and development of energy based on an energy and environmental strategy;

- Production and development of potable water in conformity with the national water management policy;

- Technological and industrial development strictly following an integrated policy for energy and environment;

- Development of “knowledge-policy” and “learning policy” which will enable the country to acquire and develop scientific information and know-how.

This study is our contribution for the implementation of a new energy policy for Cape Verde islands.

II.1 Energy and Wind Energy on the Cape Verde islands:

The national consumption of primary energy in Cape Verde (oil and fire wood) was 130,000 toe (ton of oil equivalent) in 1999. The energy sector is largely dependent on imported oil products; the imports represent 101,637 toe meaning that about 78% of the total energy consumption in 1999.

The wood demand (fire wood, charcoal, and biomass) represented about 21% (from 26% in 1995) of the total final energy in 1999, because of a substitution of this fuel by butane gas in the last two decades (butane demand increased from 1,700 tons in 1983 to about 10,000 tons in 2002).

The share of the wind energy in the national energy balance was less than 3% in 1995, and decreased to about 1% of the total final energy consumption in 1999, due to the fact that the last wind parks were installed in November 1994. New investment on wind energy is planned for the period 2006/2007, increasing the installed power to a triple factor on Cape Verde islands.

National energy supply system future development will face two potential trends with strong environmental impacts:

- First, Cape Verde will be confronted with an increasing local and global pollution on the inland market from the higher demand of fossil fuels, mainly in the transport, power and water (by desalination processes) production sectors; and,
- Second, there will be a higher pressure on the scarce natural resources, such as forests, because the lack of supply capacity on fuel wood.

It should be added that urban zones, mainly in the Praia city, the capital on Santiago island, are replacing their water sources from wells and galleries located on the surround rural zones, to allocate this water to the rural populations. This is achieved by supplying desalinated water to urban populations. For this reason, ELECTRA, the power and water utility in Cape Verde, since 1994, started also producing water by desalination processes in Praia on Santiago island. After heavy investments in 2002 on reverses osmosis plants, the groundwater represents now, less than 30% of the total water consumption of the main city - Praia.

Energy and water demand is also expected to sharply increase because of growing tourism activity, which is becoming a strong part of economic growth in the country.

The islands present a very good potential in RES, mainly in wind and solar energies. However, there are some technical problems to integrate these sources in the energy conventional system. For instance, the wind energy is variable and intermittent with its direction and intensity. Besides these factors there are also the seasonal fluctuations of the wind. This form of energy is also not directly storable as the hydro energy. These facts imply that the wind energy shall be transformed in mechanical or electrical energy for practical uses.

The energy quality of the electrical energy (voltage and frequency) and the minimum running load of the diesel engines of the grid-connected conventional power stations are two main constrains in trying to increase the level of wind energy penetration on the small electrical grid systems, supplied by diesel engines, as the existent ones on Cape Verde islands.

The main electrical grids on the three islands: Santiago serving the town of Praia with more than 30 MW (and 3 x 300 kW – Step 1 wind farm since 1994), S.Vicente serving Mindelo and the island with more than 23 MW (and 3 x 300 kW – Step 1 wind farm since 1994), and Sal serving this island with more than 11 MW (and 2 x 300 kW – Step 1 wind farm since 1994), are mainly supplied by diesel generators. The demand growth of electrical energy increased of about 8 -15% annually in recent years on these three main islands.

ELECTRA the Power and Water Company, with the supports of GEF-financing (climate Change Operational Program # 6 aimed at promoting the adoption of renewable energy by removing barriers and reducing implementation costs), the World Bank and the Government of Cape Verde, are proposed to expand the existing capacity wind farms to the following size:

Praia – 4,8 MW
Mindelo – 1,8 MW
Sal - 1,2 MW

The expansion of wind farms will provide the country with an environmentally friendly energy resource of a total of 7,8 MW, an estimated investment of about 12 million EURO.

However, these wind farms as intermittent generators, are only considered in the economical analysis as fuel savers. “It is assumed in the analysis that diesel capacity to cover the maximum demand (plus a safety demand) must be maintained to keep loss of load probability at acceptable levels since that will be the *de facto* situation. As a result, capacity value of wind farms must be ignored.” [1]
The guaranteed power capacity of the new wind farms will be considered 0 (zero).

This project that we call Step 2, will result in one of the highest penetration levels, over 30% on the Sal Island, for wind energy projects in the world.
The penetration limit is another barrier for wide spread use of renewable energy technologies such as wind energy, because of concerns about potential voltage and frequency fluctuations arising from swings in the power output from an intermittent generating resource. The studies of system stability for the Cape Verde island grids indicate that some curtailment could be necessary in the first few years of operation on the Sal Island due to these effects.

A third restriction that can also be *a real limit of wind energy penetration in small grids is the low load operation of the diesel engines.* The manufacture of the new diesel engines states, "An unrestricted low load operation is permitted with diesel oil. Bellow 25% rated output heavy fuel operation is neither efficient nor economical". [2]

II.2 Refrigeration and Heat Pumps

"…the transfer of energy is more efficient than the conversion of its form."
Phillip G. Lebel[1][3]

"Heat pumps! This concept has a fascination for engineers and scientists as something magic, especially at times of crisis, since it appears that we can get heat free of charge and with more than 100 per cent in the transformation of mechanical or electrical energy to heat of high temperature. However, quite often the great economic advantage of this after all might not be so impressive – since just as the heat pump principle is a strict application of thermodynamics its application in the real life must be seen as a techno-economical problem." [4]

Prof. Eric G. Granryd (Royal Institute of Technology- Sweden) translation in 1992 of Prof. Matts Backstrom statement in paper published in 1940 – "Wood firing, Electric Heating or Electrically Operated Heat Pumps?". [5]

A device that removes a quantity of heat $q_{(rem)}$ from a low-temperature reservoir (T_2 temperature of the cold region), and rejects a greater amount of heat $q_{(rej)}$ to a high-temperature reservoir (T1 temperature of hot region), by the use of mechanical work w(in), from an external source is a Refrigerator, and the Coefficient of Performance (COP) is:

$$\mathbf{COP = q_{(rem)}/w_{(in)} = q_{(rem)}/(q_{(rej)} - q_{(rem)})}$$

$$\mathbf{COP^* = T_2/(T_1 - T_2)}$$

* Carnot refrigeration Coefficient of performance

When, we are interested in the heat-rejected $q_{(rej)}$, to the high-temperature region we can call the same device a Heat-pump.

The heat rejected $q_{(rej)}$, is equal to the heat removed $q_{(rem)}$, plus the work input $w_{(in)}$:

$$\mathbf{q_{(rej)} = q_{(rem)} + w_{(in)}}$$

$$q_{(rej)} / w_{(in)} = q_{(rem)} / w_{(in)} + 1$$

(COP) Carnot Heat-Pump = COP* + 1

Carnot heat pump Coefficient of performance

If the COP* = 5, the COP Carnot Heat-Pump will be 5+1 = 6

$$\mathbf{COP\ Carnot\ Heat\text{-}pump = T_1/(T_1 - T_2)}$$

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[1] *Energy Economics and Technology – 1982, Phillip LeBel speaking about "Heat-Pumps".*

The weak point of the Heat Pump is that: if the T_2 decrease at same T_1, the COP will decrease in higher percentage, and we will need a higher work input $w_{(in)}$, for the same $q_{(rej)}$.

For that reason in the winter it is difficult to use the outside air in the North region. It is preferable to use the earth (underground temperature of the soil) or some water source, as low-temperature reservoir.
The real performances of the heat pumps in actual use, never achieve the performance suggested by the Carnot cycle. However, the heat-pump performance has been in a process of improvement, and the heat pump may be a better solution for some industrial sectors, that require either heating $Q_{(rej)}$ or cooling $Q_{(rem)}$. [6]

The refrigeration systems and the heat pumps are units that transfer energy. They are both characterized, by a COP – coefficient of performance = $q_{(rem)}$ or $q_{(rej)}/w_{(in)}$ greater than 1 (one).

Although, some limitations in compression technology and T_2 limitations (large temperature differences between T_1 and T_2) for the heat-pumps, the future will play in favor of these systems.

With the real COP of the heat-pumps greater than 3,5 and with better improvement in the near future, the heat-pumps will reduce the use of energy input $\mathbf{w_{(in)}}$, will decrease pollution and open new possibilities to use this technology in connection with the wind and solar energies.

II.3 Thermal Wind Solar Power Plant (TWSPP)

As we stated before, the wind energy is variable and intermittent with instant variable direction and intensity. Beside these factors there are the seasonal fluctuations of the wind.

This form of energy is also not directly storable as the hydro energy. These facts imply that the wind energy shall be transformed in mechanical or electrical energy for practical uses.

The energy quality of the electrical energy (the voltage, frequency and flicker) that limit the degree of wind energy penetration on the electrical grids, and the minimum running load of the diesel engines (about 25 % of the capacity of each genset) (note: CAT inform) in the conventional power stations connected to the grid, are the two main constrains in the tentative to increase the level of wind energy penetration on the small electrical grid systems, supplied by diesel engines, as the existent systems on Cape Verde islands.

The study presents a possible innovative solution for this problem of intermittence of the wind energy and other RES. A new conception of power plant, a thermal wind solar power plant (TWSPP) is proposed: the wind energy is connected to two heat-pump systems:

- one of the heat-pump system extracts heat from an isolated compartment (the cold source of the TWSPP); and
- the second heat-pump system transfers heat from the soil, the thermal energy of the oceans, or the thermal energy of an underground water source (the hot source of the TWSPP system).

This new type of power station works as a conventional power station: the energy inputs are:

- the wind energy cooling system as the cold source;
- The soil thermal energy or the thermal water sources existent on Santo Antão island, is transferred to the hot source of the power station.

The main component parts of this power station are:
- the heat pumps;
- the heat - exchangers,
- the condenser system,
- a turbo – generator, and
- auxiliary systems.

The TWSPP works 24 h per day, with stable voltage, and frequency, and constant power output, under a mature technological energy control system. The storage capacities of the hot and cold sources (infinite capacity of energy from the hot source and limited storage capacity, but renewable cooling capacity from the cold source) are the other important advantages of this type of TWSPP.

The TWSPP will control the variation of the power input of the RES (wind and solar energies), the operation of the power system, and the power quality of the energy output, increasing consequently the level of penetration of the RES on the limited electrical grid systems of the Cape Verde islands.

This power station works, under a mature technological energy control system, as a conventional power plant and the energy inputs are the wind energy cooling system (the cold source – that could be negative temperatures, lower than -10º C), the thermal energy of the soil (about 23º C), the thermal energy of the oceans (about 24º C), or the thermal water sources as the existent on Santo Antão island (about 37º C on the surface and about 78º C at the geothermal reservoir of Lajedos - the hot source of the system. [7]

The storage capacities of the hot and cold sources, the infinite energy capacity of the hot sources and the renewable cooling capacity of the cold source, are the other important advantages of this type of power station.

The system will be based on the Rankine cycle using an organic fluid as Freon or isobutane refrigerant fluids.

The system can be used for generation of electricity, distillation or desalination of sea water.

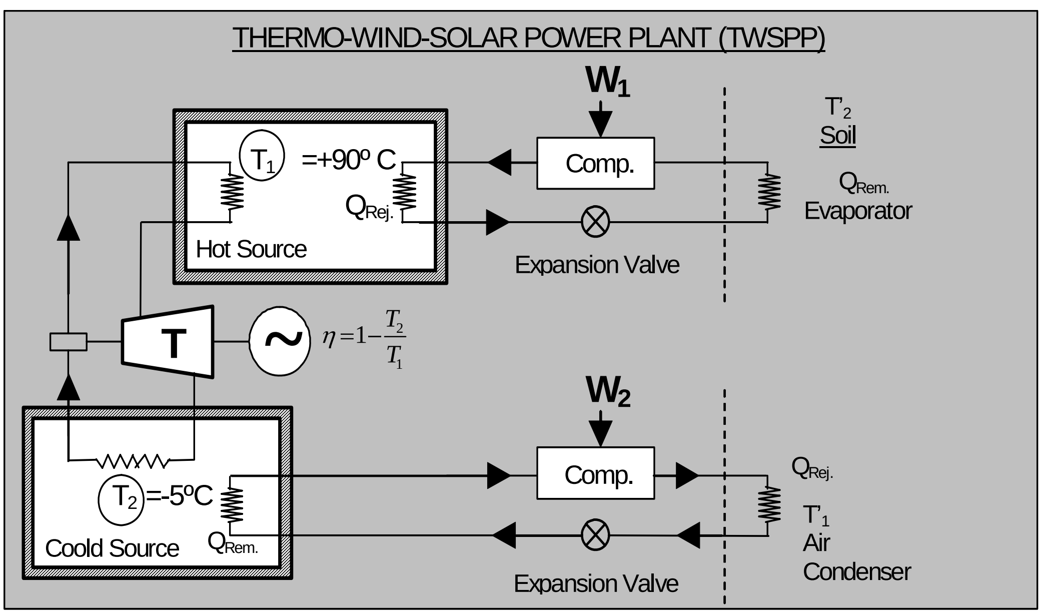
A binary system type geothermal conversion system could cost about $1,500 USD/kW, installed for wellhead temperature of 100ºC and based on a condensation temperature of 50ºC. [8] Based on actual cost of the house heat pumps of less than $3,000/kW, a TWSPP could cost about US $3,000/kW installed.

The US Federal Energy Management Program states the following Example for Renewable Costs [9]:

Table 1

Technology	Cents/kwh	$/kw	Note:
Geothermal Heat Pump	35 – 62% cost savings	$2,200 - $3,000	House heat pumps
Wind On-Site – 20 kW	8 – 12	1,500 – 2,500	
Wind On-Site – 500 kW	4 – 5	800 - 1,200	
Wind Power Purchase	1.2 – 2.6 (premium)	NA	
Solar-Photovoltaics			
2 kW system	18 – 36	6,500 – 13,000	
20 kW system	8 – 12	5,300 – 7,500	
Solar – Hot water		($50 – 80/sf)	Sf (square feet)
Biomass power	6 -20	1,700	

Fig.1



III – Conclusion

Although, some limitations in compression technology and constraints to obtain large temperature differences between T_1 and T_2 of the heat-pumps, the future will play in favor of these systems.

With the TWSPP we will control the variation of the power input of the RES (wind and solar energies), the operation of the power system, and the power quality of the energy output, increasing consequently the level of penetration of the RES on the limited electrical grid systems of Cape Verde and other islands.

The TWSPP can be used for generation of electricity, distillation or desalination of sea water.

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