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Estimating the Wind Energy Rejection by the Crete Island Electrical Network during the Next Decade

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Abstract: Most Aegean Sea islands, including Crete, are characterized by a considerable annual increase of the electrical power demand exceeding the 5% in annual basis. Wind generated electricity appears to be an economically viable solution, as the area has excellent wind potential. However, in most islands there is no remarkable wind energy addition during the last years. One sound explanation of this unexpected situation is the incapability of the existing weak autonomous electrical networks to continuously absorb the variable wind energy production, in an attempt to protect the local grid stability from production fluctuations resulting from the stochastic wind speed behavior. The present paper is based on a minimum wind energy rejection calculation model, already successfully validated versus detailed historical data, in order to estimate the expected wind energy rejection in the near future. Special attention is paid to simulate realistically the near future situation of the Crete island electricity generation system. The results obtained should be taken seriously into consideration by local authorities and private investors, in order to face the urgent electrification problem of the Crete island without further jeopardizing the local environment from the heavy polluting thermal power stations.

Key-Words: Wind Energy; Autonomous Electrical Network; Numerical Algorithm; Increased Wind Power Penetration; Wind Energy Rejection

1 Introduction

In most Greek islands there is no remarkable wind energy addition during the last five years, despite their excellent wind potential and their pressing need for new electrical power to meet the explosive electricity demand.

One sound explanation of this unexpected for the common sense situation [1] is the incapability of the existing weak autonomous electrical networks to absorb continuously the wind energy production, in order to protect the local grid stability from production fluctuations resulting from the stochastic wind speed behavior. Thus, the instantaneous wind power contribution to the total autonomous electrical system load demand is strictly bounded, so as to give the opportunity to the existing thermal power units to replace any unexpected wind production loss in case that the wind speed is suddenly zeroed [2,3].

The direct outcome of this situation is the stagnation of almost all the planned new wind power investments in Greek islands, despite the urgent need of new electricity generation. A pronounced up to date answer to this problem is the installation of new thermal power units, utilizing imported oil and contributing in the deterioration of the environment [4,5]. However, local communities are strongly opposed to the creation of new heavy polluting thermal power stations in their location, canceling or delaying most of the State plans [6,7].

One of the most typical cases is the island of Crete. Crete, being the biggest Greek island, possesses the strongest autonomous electrical network of the country [8]. However, the previous year peak load demand was 543MW, while for the 2005 the corresponding peak electrical load exceeds the 570MW. Taking into consideration that the real maximum power of the existing thermal power units for summer operation is hardly 650MW, one can easily conclude that extended black outs would be possible in the island without the contribution of the existing wind parks (rated power 90MW).

In this context, in work published by the authors [9] a remarkable energy rejection was encountered for 2001 and 2002, even in this relatively large island electricity generation system (EGS). This negative situation worries the existing wind park owners (due to their profit reduction) and leads to serious skepticism all the new investors of the sector. As a result, no remarkable wind power addition is officially reported during the last three years, despite the formerly expressed strong interest for 200MW new wind power installations [10].

The present paper is based on a minimum wind energy rejection calculation model, already successfully tested versus detailed historical data, in order to estimate the expected wind energy rejection in the near future. Special attention is paid to simulate realistically the near future situation of the local electricity generation system (EGS). On top of that, the impact of all possible changes on the expected evolution for the most important parameters can be also included, using a parametrical sensitivity analysis. Such parameters are the numerical value concerning the maximum wind energy penetration limit in relation to the instantaneous load demand, the new-erected wind park penetration rate and the electricity consumption annual escalation rate.

2 The Crete Island Electricity Generation System

The electricity generation system (EGS) of Crete island is currently based on 26 thermal power units with total official capacity of 742.9MW, 16 wind parks of various size with rated power equal to 90MW, two small hydro plants of 2x300kW and a tiny private photovoltaic power station of 170kW.

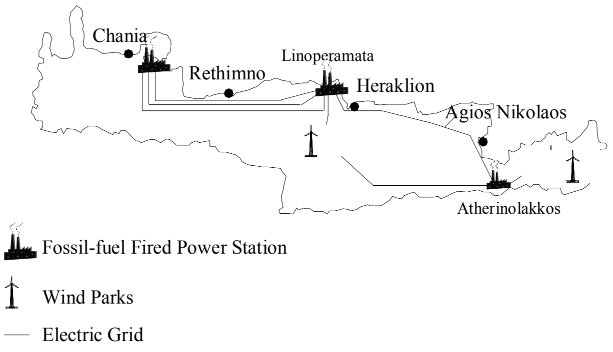

Fig. 1. Existing wind farms and fossil-fuel fired power stations location in Crete

More precisely, Crete island electricity generation system is based on several oil-fired thermal power units located either near Chania (west of Crete) or at Linoperamata (location outside of Heraklion), see figure (1). Recently, two internal combustion engines (2x51MW) started their operation in the new Atherinolakkos power station. In fact, the real power of the system is 693MW for winter and 652MW for summer operation. Additionally, the Greek Regulatory Authority of Energy (RAE) called recently for tenders in order to build a new thermal power station (TPS) of approximately 220MW near the city of Rethimno [10]. The whole procedure is about to start and the authors anticipate the operation of Rethimno TPS not earlier than 2008. Taking into consideration the touristic character of the island and the overall economic development, serious power insufficiency problems appear, especially during the summer, leading to expensive solutions for coping with the peak power load, mainly due to the overuse of the gas turbine generators.

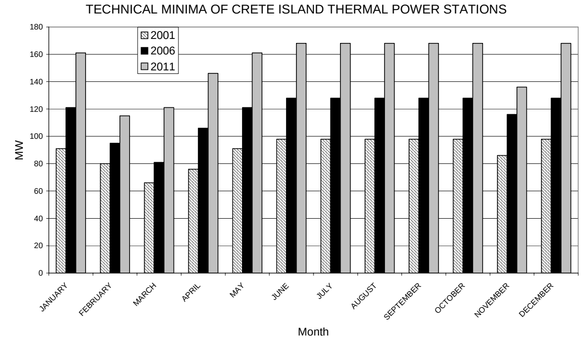

Fig. 2. Technical minima of the local system

On the other hand, the current technical minima of the base units of local EGS vary between 70MW (during winter maintenance period) and 100MW during summer. Bear in mind that the minimum output of the system is higher than these values, depending of the month of the year, figure (2). Since the technical minima of the system affect strongly the wind energy penetration in the system, we present in figure (2) the expected monthly variation of the system technical minima for the next decade. According to the information gathered, the technical minima of the system should increase by 40MW after the incorporation of Atherinolakkos TPS, while an additional increase (≈50MW) is forecasted due to the Rethimno power station operation.

Due to the excellent wind potential and the acceptable infrastructure of the island, many investors are interested to create new wind parks in the area. More precisely, a remarkable wind park installation activity has started since 1992, leading by 2004 to the existence of sixteen (16) wind power stations of rated power 90MW (end of 2004). More specifically (Table I), four of the island wind farms belong to local electricity utility (PPC), two wind parks belong to local municipalities and the rest installations (representing almost the 87% of the island capacity) were erected by private investors. Up to now the centre of wind energy production is the East part of the island (Lasithi prefecture), although recently significant investment interest is expressed for the other parts of the island. According to the available information, ten new wind parks are planned for the near future (realization time up to 2008) pushing the total wind power of the area above 120MW.

Table 1. Existing wind parks in Crete island (2004)

	Location	Prefecture	Owner	Start Up Time	Rated Power (MW)
1	Toplou	L	PPC	1993	5.10
2	Toplou	L	PPC	1993	1.00
3	Toplou	L	PPC	1995	0.50
4	Mare	L	Municip.	1993	0.5
5	Xirolimni	L	PPC	2000	10.20
6	Mitato	L	Private	1998	10.20
7	Chandras	L	Private	1999	9.90
8	Meg. Vrisi	H	Private	1999	4.95
9	Achladia	L	Private	1999	10.00
10	Anemoessa	L	Private	1999	5.00
11	Krya	L	Private	1999	10.00
12	Plativolo	L	Municip.	2000	2.50
13	Vrouchas	L	Private	2003	7.65
14	Xirolimni	L	Private	2004	3.0
15	Plativolo	L	Private	2004	3.0
16	Krousona	H	Private	2004	5.95

(L) for Lasithi and (H) for Heraklion prefecture

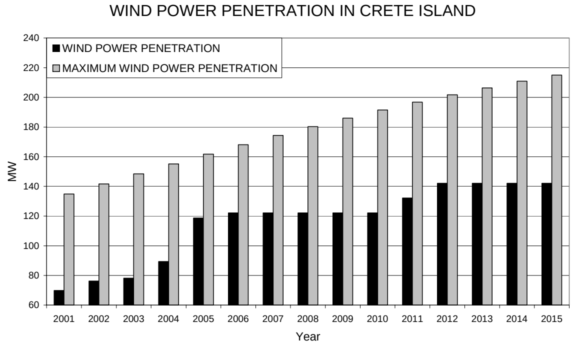

Fig. 3. Expected wind power time evolution

For the entirety of these new wind parks, a substantial subsidy (approximately 30% to 40% of the initial capital to be invested) has been approved [11] either via the National Competitiveness Program (Ministry of Development) or via the National Development Law 3299/04 (Ministry of Economy). It is important to mention that the new scheduled wind parks financial budget is almost 40,000,000Euro, while 15,000,000Euro is approximately the corresponding Greek State subsidy. In figure (3) one may examine the forecasted wind energy penetration in the local electrical grid in comparison with the maximum permitted value. According to the existing data, the maximum wind power penetration is realized during 2006, while in the next years no new wind power addition is expected without remarkable energy storage systems' creation [12,13].

The same time that no additional power is built, in the Crete island a significant electricity demand increase is encountered approaching the 7%, figure (4). On top of this, during summer the peak load increase exceeds the 7%, questioning strongly the reliability of the local EGS. However, this situation is going to get much more difficult in the near future.

Thus, based on the existing long-term historical data, the local network manager (PPC) expects an almost 6% mean annual electricity demand amplification during the next ten years, predicting the corresponding annual electricity generation to 4170GWh by 2012 [14]. A similar attitude is forecasted for the annual peak load demand, thus the expected value for 2012 is 885MW.

A more optimistic approach is presented by a NTUA research team [15], according to which up to 2005 the annual electricity consumption increase is 5.5%, dropping to 3% for the 2006-2015 period. Thus, according to this analysis in 2012 the annual electricity demand of Crete island should be 3230GWh, while the corresponding peak load value should not exceed the 709MW.

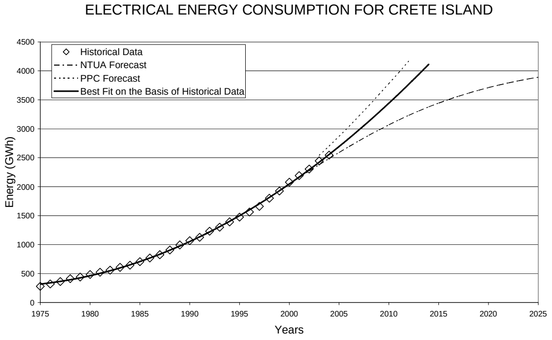

Fig.4. Electrical energy demand time evolution

In any case, both studies mentioned -as well as the estimations by the authors- clearly underline the serious peak power demand fulfilment problem by the year 2007, even if the Atherinolakkos TPS starts its full operation according to the official plan.

3 Brief Presentation of the Algorithm Used

In recently published work by the authors [11] a reliable algorithm (WINDENEREJ) was invented in order to estimate realistically the wind energy rejections in the Crete island. The computational results of this algorithm were fairly well compared with the historical data provided by the local wind parks owners as well as by the local electricity utility (PPC). This successfully tested method is going to be exploited in order to forecast the expected wind energy rejections by the local EGS in course of time. More specifically, for the application of this algorithm the following information is needed:

i. *The instantaneous electrical load demand of the system*, i.e. "$N_D(t)$". For the estimation of the load demand for the next few years (2005+x, x=1 to 10) we use the corresponding time-series of the previous six years and an annual escalation rate coefficient "ξ_x", thus one may write:

$$N_{2005+x} = \left(\sum_{i=1}^{6} \alpha_i(t) \cdot N_{2005+x-i}(t) \right) \cdot \xi_x(t) \qquad (1)$$

It is important to note that the sum of weight factors appearing in equation (1) "α_i" is equal to one, i.e.:

$$\sum_{i=1}^{6} a_i = 1 \qquad (2)$$

and the corresponding historical data take into consideration the specific day of each week. For this purpose, analytical weekly load distributions are created after the analysis of the local EGS data, for each month of the year on a hourly basis [16]. Finally, the numerical value of "ξ_x" (being one of the most important parameters of the problem) results from the analysis of section 2, see also figure (4), taking into consideration that several "$\xi(t)$" distributions may be used.

ii. *The technical minima of the local EGS,* i.e. "$N_{min}(t)$". The specific numerical value of "$N_{min}(t)$" is up to now empirically estimated, resulting by the existing thermal power units operational characteristics and the corresponding maintenance and renovation plan applied by PPC. A reasonable time distribution of the system technical minima is presented in figure (2), force majeur excluded.

iii. *The upper wind energy participation limit in the instantaneous electrical power demand*, i.e. "λ". This value is empirically estimated by the local utility to avoid undesirable local network operation due to the variable production of the system wind parks. Generally speaking, this value is set arbitrarily less or equal to 30%. A systematic parametrical analysis concerning the impact of the exact numerical value of "λ" on the wind energy rejection is necessary to improve the results reliability.

Thus, using the proposed algorithm and the above described data, the maximum grid absorbed wind energy "$N_w^*(t)$" in course of time can be estimated as:

$$\begin{array}{lll} a. & N_w^*(t) = 0 & If \quad N_D(t) \le N_{\min}(t) \\ b. & N_w^*(t) = N_D(t) - N_{\min}(t) & If \quad N_{\min}(t) \le N_D(t) \le (1+\lambda(t)) \cdot N_{\min}(t) \\ c. & N_w^*(t) \le \lambda \cdot N_D(t) & If \quad N_D(t) \ge (1+\lambda(t)) \cdot N_{\min}(t) \end{array} \qquad (3)$$

- ➢ In the first case (a) there is no wind energy absorption "$N_w^*(t)$" by the local network, hence all the wind energy production is rejected.
- ➢ In case (b) the wind energy is entering the grid by priority, since the local TPS operate above their technical minima.
- ➢ In the last case the wind energy penetration is bounded by the upper wind energy participation limit "$\lambda(t)$" and the instantaneous load demand of the consumption.

Having estimated the maximum wind energy penetration in the local EGS, one may calculate first the maximum wind power contribution "N_{wi}^*" concerning a specific wind park "i" as:

$$N_{w_i}^* = \phi_i \cdot \left(N_w^*(t) - N_{w_1}(t) - N_{w_2}(t) - N_{w_3}(t) - N_{w_4}(t) \right) \qquad (4)$$

and subsequently the corresponding maximum wind energy absorbance "E^*" for a selected time period (e.g. one month), i.e.:

$$E_i^*(t_o, t_o + \delta t) = \phi_i \cdot \int_{t_o}^{t_o+\delta t} N_w^* dt - \phi_i \cdot \left(CF_1 \cdot N_1^* + CF_2 \cdot N_2^* + CF_3 \cdot N_3^* + CF_4 \cdot N_4^* \right) \qquad (5)$$

where "φ_i" is the rated power contribution "N_i^*" of the specific wind park "i" in total nominal installed power of the local EGS, thus:

$$\phi_i = \frac{N_i^*}{\sum_{i=5}^{i=16} N_i^* + \sum_{j=1}^{j=j_{\max}(t)} N_j^*(t)} \qquad (6)$$

where the first term of the denominator of equation (6) is the existing wind power of the island and the second term describes the new wind parks planned to be in operation for the specific time period under investigation, see also Table 1. For the application of equations (4) and (5) one should take also into account that the wind parks (1 to 4 of Table 1) being in operation before the law 2244/94 are not obliged to any production rejection except the one imposed by the system technical minima. Finally, in the present approach the assumption (used also by the local EGS operator) that the wind energy rejections of the system are distributed according to the existing wind park nominal power is adopted.

In case that the wind energy production "$N_{wi}(t)$" of a specific wind park "i" is assumed known, one may also estimate the minimum resulting wind energy rejection as:

$$\Delta E_i^{\min}(t_o, t_o+\delta t) = \int_{t_o}^{t_o+\delta t} \max\left\{\left[N_{w_i}(t) - N_{w_i}^{*}\right],\ 0\right\}\cdot dt \qquad (7)$$

Additional wind energy rejection "δN_o" is possible for every wind park "i" due to the EGS subsystems (associated with it) problems or technical transportation peculiarities (like voltage and frequency instability, load asymmetry, excess reactive power demand, etc.).

For the accurate prediction of the wind energy rejection one should also forecast the instantaneous energy generation of each park or equivalently the instantaneous wind speed and density of each wind turbine at hub height, along with its technical availability and the official power curve provided by the manufacturer. Such an enormous volume of information is not easily obtained, especially when future values are needed.

According to equation (7) one may estimate the corresponding wind energy rejections of a specific wind park for a given time period (e.g. a month or a year). In this context, the expected wind energy rejection depends on:

✓ The productivity of the examined wind park

✓ The productivity of the old wind parks of the island (i.e. i=1 to 4)

✓ The installed wind power of the local EGS, see equation (6)

✓ The random wind energy rejections (δN_o)

✓ The maximum wind power absorption by the local electrical network, equation (3).

4 Application Results

The proposed analysis is to be applied for three selected wind parks (lines 9-11 of Table 1) of total rated power of 25MW, representing the 28% of the currently "in operation" wind power, i.e. φ=0.28. The applied analysis has a time horizon up to 2015, since during this period the wind turbines of the installations fulfill 15 years of service life. On top of this, further forecasting the local EGS characteristics is not very reliable.

Hence, the main target of the present application is to estimate the 15-years long maximum wind energy absorption (or minimum wind energy rejection) for the specific wind parks, taking into consideration the available information about the local EGS parameters.

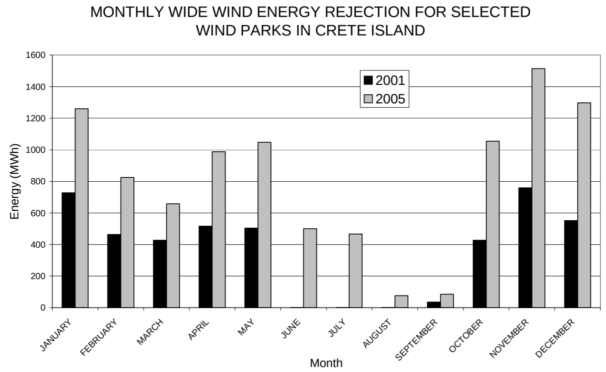

Fig. 5. Comparison of monthly-wide wind energy rejection for selected wind parks (2001-2005)

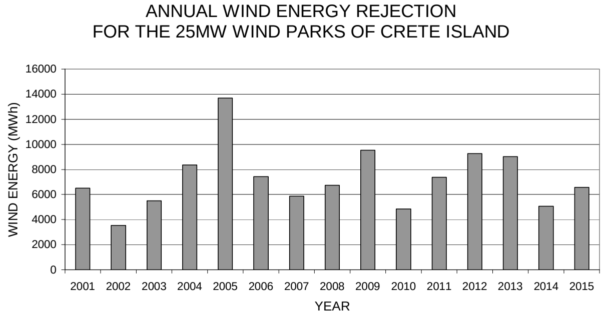

Fig. 6. Time-evolution of annual wind energy rejection for selected wind parks (2001-2015)

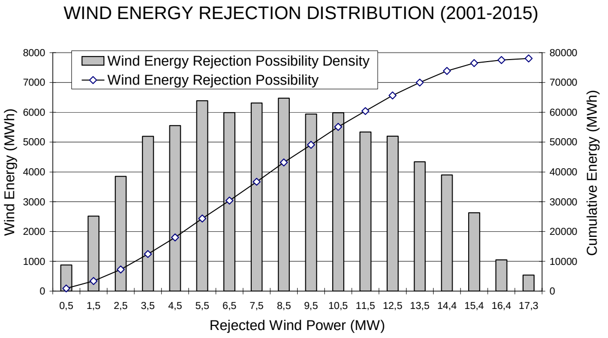

Fig. 7. Wind energy rejection distribution vs. aborted wind power for the 2001-2015 period

Applying the above analysis, the hourly distribution of the wind-farms energy rejection may be estimated for every year. For example, in figure (5) we compare the monthly wind energy rejection for the wind-farms under investigation for 2001 and 2005. These wind-farms employ pitch-controlled and variable-speed machines, allowing optimum collaboration with the local electrical network, hence additional rejection is possible for wind parks using stall control and constant speed machines. Accordingly, in figure (6) one may observe the annual energy cut-outs imposed by the local EGS operator for the time period examined. The average annual wind energy rejection is approximately 8GWh/y.

Finally, figure (7) presents the wind energy rejection distribution for the period 2001-2015, as a function of the instantaneous wind power aborted for the specific wind energy installations under investigation (rated power 25MW); lines 9-11 of Table 1. Result of this figure is that 76% of the potential wind energy is rejected when the set level of wind power rejection is less or equal to 12MW. Finally, for the three wind parks examined, the expected wind energy rejection approaches the 8,000MWh/y at minimum, being almost 10% of their annual wind energy production. This situation will deteriorate as additional wind power enters the local electrical system.

5 Conclusion

An integrated numerical algorithm, able to estimate the maximum wind energy penetration in a given autonomous electrical network is developed. More precisely, the proposed calculation method estimates the maximum wind energy contribution on the basis of the information provided by the system operator, concerning the corresponding load demand and the operational status of the existing thermal power stations. For the prediction of the minimum wind energy rejection one takes into consideration, besides the operational characteristics of the local system, the island wind parks energy production without energy rejection.

The calculation results can be characterized as reliable, since they are based on detailed and long-term data and measurements and describe fairly well the existing official wind energy rejection in the previous years. In this context, the results obtained should seriously be taken into consideration by local authorities and private investors, in order to face the urgent electrification problem of the Crete island and maximize the wind energy sector investors benefit, without further jeopardizing the local environment from the heavy polluting thermal power stations.

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