INCREASED WIND ENERGY EXPLOITATION VIA INTERCONNECTION OF AEGEAN ISLANDS TO THE MAINLAND GRID

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ABSTRACT

In this paper the interconnection of Aegean Sea islands to the mainland grid of Greece is evaluated, as an alternative to their current autonomous operation, fed by local oil-fired power stations. Interconnection of the islands increases substantially the potential for exploitation of their favourable wind resources. The paper presents results of a preliminary feasibility analysis, which evaluates alternative interconnection technologies and calculates the fundamental economics of each solution over a 25-year evaluation period.

INTRODUCTION

Generation of electricity in islands is generally made by autonomous power stations, using expensive oil-based fuel products. Consequently, their interconnection to larger power systems, such as the mainland grid, via submarine cables, presents a particular economic interest. Actually, all large Ionian Sea islands and more than 40 other islands in Greece have already been interconnected to the mainland grid or to each other, forming pools of islands, via HV (150 kV) or MV (20 kV) submarine cables. Interconnections offer the additional opportunity for better exploitation of the favourable wind potential existing in most of the islands.

In the last years a considerable progress has been made in the technology of HV submarine transmission technology. The levels of transmitted power and the permissible lengths were considerably increased, so that larger islands or island groups can now be interconnected to the mainland, [3,4]. A first application of these new possibilities has been explored in [1,2], for the case of the Cycladic islands.

In this paper results are presented from a preliminary feasibility study for the interconnection of all Aegean islands to the mainland grid and the full exploitation of their significant wind energy potential. The base case for economic comparisons is the current autonomous operation status of the islands.

TECHNOLOGICAL PROGRESS

AC technologies

Compared to the land cables, the use of XLPE insulation in HV submarine cables is restricted, due to the difficulty to construct long one-piece cable lengths and the ensuing need for multiple flexible factory joints, [3]. Single-core submarine XLPE cables have been the usual choice, but it appears that the three-core design with water impervious barriers (sheaths) on each core nowadays becomes the preferred solution, [4].

The progress in Static VAR Compensators (SVC) considerably extends the reactive power and voltage control possibilities offered by traditional mechanically switched shunt reactors and capacitors. On the other hand, due to the lower dielectric constant, the XLPE insulation of the submarine cables presents lower charging currents per unit length than the earlier used paper/oil insulation materials. In [4] it is stated that the length of a 150 kV, 3x1x1000 mm^2 XLPE submarine cable line, if properly compensated, can exceed 200 km, transmitting 200 MW, but such installations have not been realized yet.

DC technology

HVDC transmission technology has been applied for many decades now for the interconnection of strong AC power systems, using Line Commutated Converters (LCCs). Recent progress in high power Voltage Source Converter (VSC) technology has enabled the development of HVDC systems for feeding isolated AC networks, without the need for installing sources of commutating capacity at the remote network [3]. Extruded HVDC cables with polymeric insulation are now used in VSC-based schemes, instead of mass impregnated cables.

In DC transmission systems the length and power may be higher than in AC systems, while increased voltage control capabilities are available. Single-core DC cables are also much simpler and lighter than the corresponding AC. Thus, DC transmission becomes more cost effective for long distances.

METHODOLOGY OF ANALYSIS

Outline of the methodology

When studying the interconnection of an island, local conventional generation may be entirely removed, or it may continue operating in parallel to the interconnection. In both cases, the main steps of the analysis are the following:

1) Considering the forecasted load demand of the island over the whole evaluation period (in this study 2010-2035), the interconnection distances and sea depths involved, and taking into account the capabilities of available technologies, alternative interconnection scenarios are formulated.

2) The required development of local thermal power stations is determined both for autonomous operation and interconnection to the mainland system. Wind power development scenarios are also adopted.

3) For the selected scenarios, load flow studies are performed, including local wind and conventional power stations and taking into account extreme loading conditions over the evaluation period, to assess the the technical feasibility of each solution and to determine the required voltage control equipment.

4) The total cost is estimated for each interconnection scenario, as well as for autonomous operation. This includes all investment and operational expenses over the evaluation period, expressed in present worth with a suitable discount rate (6% in this study).

Logistic Modeling

The purpose of the logistic modeling is to evaluate the energy production and therefore the associated operating costs for all power stations (local, mainland system and wind) involved in each scenario. A probabilistic methodology has been adopted (instead of time-domain simulation, using suitable time series), which is applied for each year of the evaluation period, using the following main input data:

- Annual load duration curve
- Interconnection capacity
- Thermal power station unit data (types, capacities, fixed and variable operating costs)
- Fixed and variable costs for the mainland system
- Investment costs for all equipment.
- Wind power station capacities and average annual wind speeds on the island (fixed tariffs are assumed for the produced wind energy).

In the general case, the local load demand of the island is covered by three possible sources, in this order of preference: (a) Wind power, (b) Mainland system via the interconnection and (c) Local thermal power stations.

In the absence of wind power, determining the contribution of each source is straightforward, given the load duration curve. Otherwise, the wind statistics are involved, along with the curtailments in wind power, due to technical constraints introduced by the conventional units and the interconnection, as explained below.

For a given load level, P_L, of an interconnected island, the maximum wind power, P_{Wmax}, that can be absorbed, is given by:

$$P_{Wmax}= P_L+P_{In}-P_{Cmin} \qquad (1)$$

where P_{In} is the interconnection capacity and P_{Cmin} is the lower output limit of the conventional (thermal) units. When $P_L \leq P_{In}$, no conventional units are in operation and therefore $P_{Cmin}=0$ in eq. (1). If $P_L>P_{In}$, then local thermal units are dispatched, to cater for a possible loss of wind power, whose capacity is at least

$$P_{Cn}= P_L - P_{In} \qquad (2)$$

These units must operate above a minimum output level:

$$P_{Cmin}=c\, P_{Cn} \qquad (3)$$

where factor c reflects the inherent technical minimum of a unit and its limited capability of undertaking sudden output changes, because of wind power variations. Eqs. (1)-(3) lead to the wind power absorption limit:

$$P_{W\max} = (1-c)P_L + (1+c)P_{In} \qquad (4)$$

$P_{W\max}$ is a function of the island load level, for a given interconnection capacity. Hence, for a specific prevailing wind speed V, the actual wind power delivered to the grid, after curtailment, will be:

$$P_W(V, P_L) = \min\{P(V), P_{W\max}(P_L)\} \qquad (5)$$

where $P(V)$ denotes the wind power station aggregate power curve.

For the calculated wind power output of eq. (5), the interconnection and conventional station contributions are then given by:

$$P_C = \max\{cP_{Cn}, (P_L - P_W) - P_{In}\} \qquad (6)$$

$$P_I = P_L - P_W - P_C \qquad (7)$$

Eqs. (6),(7) express the fact that the interconnection is the source of preference for covering the remainder of the load demand, without however underloading the operating conventional units below P_{Cmin}.

Based on the above reasoning, it is then possible to calculate annual energy contributions of all sources, given the load statistics (duration curve) and wind characteristics (annual average speed, leading to a Rayleigh distribution) of the island, which are treated as statistically independent random variables. For instance, using discrete probability distributions $H(V_i)$ for the wind and $F(P_{Lj})$ for the load, the expected annual wind energy production will be:

$$E_W = 8760 \sum_{i=1}^{N_V} \sum_{j=1}^{N_L} H(V_i) \cdot F(P_{Lj}) \cdot P_W(V_i, P_{Lj}) \qquad (8)$$

Similar relations are applicable for the other sources. In the case of autonomous island operation, a similar approach is followed to derive the energy production of wind farms and the conventional power station.

APPLICATION RESULTS

The examined interconnections of Aegean islands have been grouped as shown in Fig. 1:

(1) Cycladic islands
(2) North Aegean islands
(3) Crete
(4) Dodecanese islands

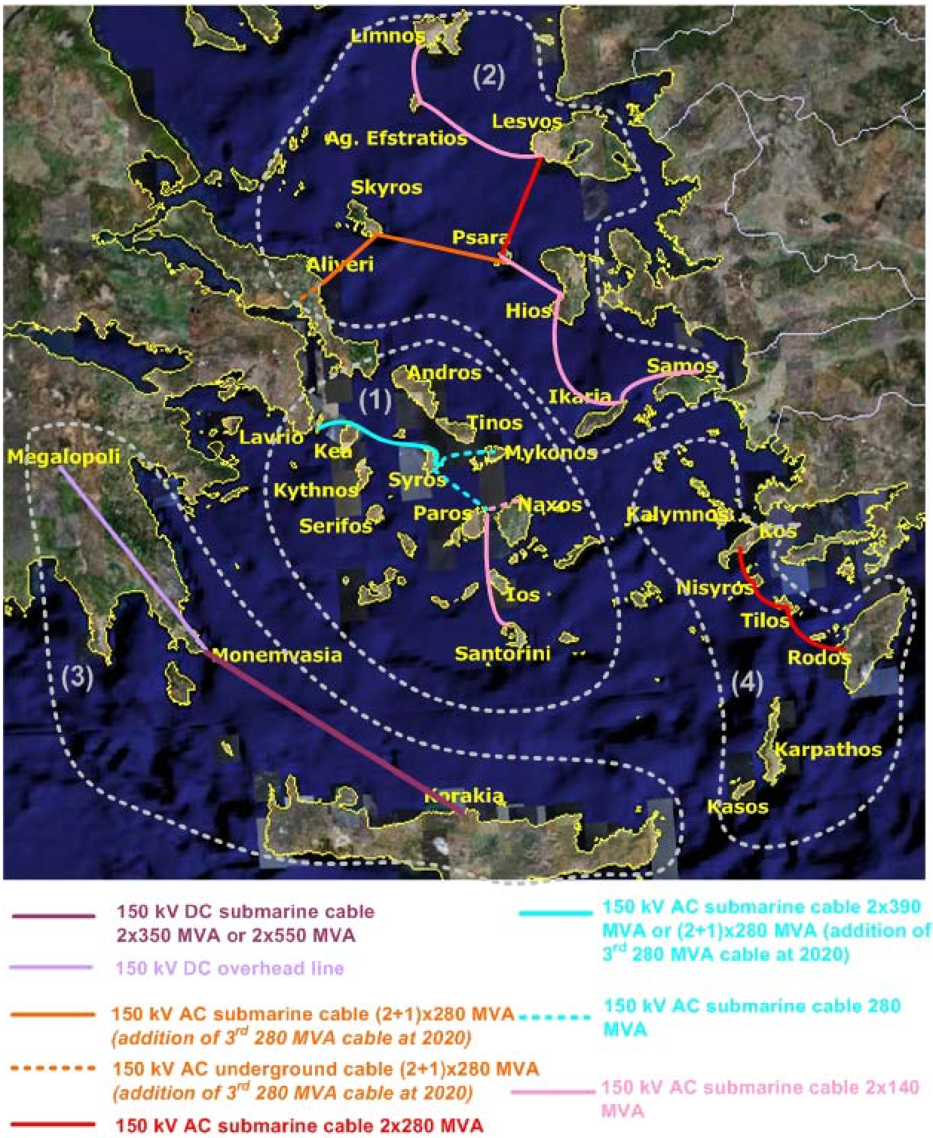

Fig.1. Aegean island interconnections to the mainland grid.

Interconnections among these groups can also be considered. Interconnection (1) is currently at the stage of engineering design, while the other three are the subject of the preliminary study presented in this paper. For space limitation reasons, only results for interconnections (2) and (3) will be presented in the following.

North Aegean islands

The connection point to the mainland power system is the 400/150kV substation of the Aliveri power station. Three transmission technology scenarios were studied:

- AC connection, with intermediate substations on Skyros and Psara islands, to reduce cable lengths
- DC connection, both to Hios and Lesvos,
- DC connection to Hios and then AC to Lesvos.

For the extensions to Ikaria-Samos from Hios and to Lemnos from Lesvos, AC technology is foreseen, because of the relatively small demands.

To ensure "N-1" reliability of supply, the installation of two three-core AC cables or two independent DC circuits is foreseen, each sized for the full transfer capacity. Thus, local power plants can be removed from the islands.

The installed wind power on each island is restricted to 25% of the maximum annual demand, for autonomous operation. For interconnected conditions it is increased at least to 100% of the load demand.

The main results of the economic evaluation are shown in Table 1. It is observed that interconnection of Hios-Lesvos and Ikaria-Samos is clearly justified, unlike Lemnos. Interconnecting all four islands appears to be the preferable solution, since it presents the lowest mean energy production cost (€/MWh, equal to the ratio of discounted total expenses to the discounted total energy). The contribution of wind power to the supply of the local demand is shown in Table 2, both for autonomous and interconnected operation, expressed in (%) of the total energy demand over the whole evaluation period (2010-2035). Although the wind power penetration is the same in both island groups, the wind energy penetration is higher in Hios-Lesvos, due to the different load characteristics (increased load factor).

Interconnection of Crete

Crete is interconnected to the 400/150kV substation of the Megalopolis thermal power station, on the centre of Peloponnese. The landing point of the sub-sea line on Crete is at the Korakia power station, avoiding the construction of new overhead HV lines on the island, as shown in Fig 1. For Crete, only HVDC technology is considered, due to the large distance and load (713 MW in 2010). Further, because of the uncertainties and difficulties in the construction of the sub-sea interconnection (250 km length, 1000 m maximum depth), it is considered that the development of local power stations on the island will continue as currently planned, at least for the first 10-15 years. Hence, a relatively small interconnection capacity is selected, of 2x350 MW in two independent circuits, ensuring a transmission capacity of 350 MW under N-1 fault conditions. At this capacity, the interconnection will always serve the base island load, as well as a significant part of the medium-range demand of the island. Higher load levels will be covered by the local power stations, which will operate in parallel to the interconnection. The installed wind power on the island is subject to restrictions due to the capacity of the interconnection, as discussed in a previous section.

Table 1: North Aegean island interconnection economics

Island system	Peak Load 2010 (MW)	Total 25-year cost in M€ and (mean cost in €/MWh)	
		Intercon'ed	Autonomous
Hios-Lesvos	137	1.635 (130)	2.109 (160)
Ikaria-Samos	56	667 (147)	826 (162)
Lemnos	17	243 (183)	217 (165)
All islands (except Lemnos)	193	2.293 (131)	2.753 (162)

Table 2: Contribution of Local Power Stations (LPS) or System and Wind Stations to the local energy demand

Island system	Autonomous		Interconnected	
	Wind	LPS	Wind	System
Hios-Lesvos	11	89	54	46
Ikaria-Samos	11	89	46	54

Table 3. Crete interconnection economics

	LPS Fuel	Total cost (ME)	(%)
Autonomous operation	Oil	11.729	100
	LNG	10.200	87
Interconnection to mainland grid	Oil	9.395	80
	LNG	9.389	80

The local conventional power stations in Crete currently comprise only oil-fired units (steam, diesel, combined cycle and gas turbines), but the use of LNG is under consideration. For this reason, four alternative scenarios have been considered, as indicated in Table 3. It is observed that the interconnection of the island is always preferable, regardless of the introduction of LNG, which is critical only in the case of autonomous operation.

The contribution of wind energy is 13% in the case of autonomous operation and increases to 24% in case of interconnection. Higher wind energy penetrations can be obtained by the increase of the interconnection capacity.

CONCLUSIONS

Results have been presented from a preliminary feasibility study, which indicate that the interconnection of the North Aegean islands and Crete to the mainland grid of Greece presents considerable economic interest. The increase in the exploitation of the available wind potential on the islands contributes to this effect. Further investigation of the technical issues involved is necessary to proceed with such projects.

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