Wind Power in Greece – Current Situation, Future Developments and Prospects

J. Kabouris and N. Hatziargyriou

***Abstract*—** This paper describes the current status of wind power in wind Greece focusing on the future developments and prospects. The exploitation of the verified wind potential of the country faces significant difficulties (public acceptance licensing, environmental, financing etc) resulting in considerable delays. Most of the applications for new wind farm installations refer to three specific areas of high wind potential in the Greek mainland. Due to the geographical distribution and the size of wind farms (10 to 40 MW installed capacity), wind integration in these areas will be highly concentrated and the wind farms will be connected mainly to the high voltage network. Since the areas of interest are connected to the bulk transmission system through weak transmission corridors there are specific plans for reinforcing the network in order to alleviate constraints and accommodate future wind farms. The expected impact of the large wind penetration will impact significantly on the ESI and the new challenges arise are also reported.

***Index Terms*—Wind power penetration, security assessment, transmission reinforcement**

I. Introduction

The Electricity Supply Industry (ESI) in Greece serves the electricity needs of the mainland and numerous isolated islands. As shown in the map of Fig. 1, significant wind potential exists in the Aegean islands, Crete and the east part of continental Greece (Evia island, South-east Peloponnese and Thrace) due to the high winds predominant in the N-NE direction, mainly influencing the Aegean sea. Mean annual wind speeds in many sites of these areas are very favorable for exploitation (7-11 m/sec).

The development of RES has been among the current energy policy lines for Greece during the last 10 years. One major goal for the country is the compliance with the Kyoto protocol commitments to reduce Greenhouse gases between 1990 and the compliance period 2008-2012; based on a fair distribution of responsibilities adopted by the European Union (EU) Council of Ministers, Greece's commitment is to restrict in 2010 the emissions to the +25% level in comparison to 1990 [1]. This target is expected to be achieved through the large penetration of RES and the increase of the share of natural gas against fossil fuels. Concerning RES-electricity, an ambitious target has been set by the European Council [2] for Greece, aiming at 20.1% RES contribution to electricity supply by 2010, including large Hydros. Among available RES technologies, wind power is expected to contribute the largest part.

Liberalization of the electricity markets [3] foresees the opening of the generation sector to private investors and the establishment of competition among generators. Although RES are excluded from competition, the challenge for large-scale exploitation of wind energy should be considered under the new competitive environment. Since RES are, in most of the cases, not yet economically competitive to the conventional thermal generation, they are promoted through various motivations which include satisfactory fixed feed-in tariffs correlated with the retail kWh prices (70% of the retail consumer price for the mainland and 90% for the isolated systems of the islands), guaranteed access to the grid, long-term contracts (10 years), subsidies on capital investment (up to 50%), tax exceptions etc [4]. The cost for the connection to the grid or any "shallow" reinforcements required in the transmission network is carried by the IPPs by 50%. Additionally, for every IPP applying for the development of a wind farm, the respective transmission capacity within the grid is reserved on a first-come first-served (FCFS) basis. RES units are not required to pay any Transmission or Distribution Use of System fees.

These policies have been proven quite efficient constituting a major breakthrough in wind energy development. As a result, applications for more than 14,500 MW of wind farms (WFs) have been filed to the Regulatory Authority for Energy (RAE). Despite the strong interest by private investors however, the wind power installed capacity in the country does not exceed 500 MW. The main barriers for the deployment of wind power are the strong public opposition to wind turbines, and the complicated administrative procedures for WFs licensing. Political interventions are expected soon to overcome these problems. From the technical point of view, wind power integration into electricity grids is restricted mainly by the limited transmission capacity in the mainland and the penetration limitations in the islands. This paper presents the current and foreseen developments in the area of wind energy in Greece, the impact of large-scale wind integration to the ESI and the technical problems under the view of large penetration. Mainland and isolated island systems are reported separately due to the differences in the system structure and market organization.

II. Mainland Interconnected System

2.1. Brief System Description

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The Hellenic interconnected system serves the needs of the mainland and some interconnected islands. The gross electricity demand during 2004 was about 51.7 TWh. The mean annual increase rate of energy demand is about 4% during last decade.

The transmission system under the responsibility of the Hellenic Transmission System Operator - HTSO serves the mainland of Greece and some interconnected islands. It consists of 400 and 150-kV networks. The system is interconnected to the Balkan countries (Albania, Bulgaria, and FYROM) via three 400-kV tie lines of total Available Transfer Capacity of 600 MW and to Italy via an asynchronous 400-kV AC-DC-AC link with a transfer capacity of 500 MW.

The demand is served mainly by thermal power plants and large hydros of total installed capacity in the order of 10,100 MW. The main production center is in North-west Greece in the vicinity of a lignite rich area. Significant hydro production exists in the North and Northwest of the country, while another lignite production is available in the Southern peninsula of Peloponnese. There are also WFs of total nominal capacity ~415 MW, installed at the island of Evia and Thrace (about 200 MW in each region), while another ~65 MW are under construction. These WFs are equipped mainly with stall controlled WTGs and they contributed at about 1.5 % of the electricity needs during 2004. Table I summarizes installed capacity figures and the energy balance for the year 2004.

TABLE I
INSTALLED CAPACITY OF THE MAINLAND GENERATION SYSTEM

Type	Net Capacity (MW)	Annual production (2004) (GWh)	Contribution (%)
Thermal	7045	43216	83.56
Lignite fired	*4795*	*32491*	*62.82*
Oil fired	*718*	*2687*	*5.20*
Gas fired	*1532*	*8038*	*15.54*
Large Hydros	3060	4927	9.52
With Lake	*2445*	*3827*	*7.41*
Pump-storage	*615*	*1100*	*2.13*
Renewables	450	758	1.47
Wind	*415*	*735*	*1.42*
Small hydro	*35*	*22*	*0.05*
Net Imports		2821	5.45

Nevertheless, there are a lot of prospects for exploitation of the wind potential. More specifically, a large number of applications have been submitted to the Regulatory Authority for Energy (RAE) accounting more than 12,500 MW nominal capacity in the mainland. More than half of the applications refer to the windy areas of Evia, Southeastern Peloponnese and Thrace (encircled in Fig. 1). Until July 2004, authorities had issued licenses for 395 WFs of total capacity 3421 MW.

In windy areas there is a lack of transmission infrastructure to transfer future WFs generation to the bulk transmission system. HTSO has specific plans [5] to reinforce the congested corridors. Nevertheless, HTSO has provided access to the grid to more than 1850 MW of WFs and about 200 MW of other RES projects. Due to the geographical distribution and their size (15 to 45 MW installed capacity) most of these WFs will be connected to the high voltage network through 30 to 40 new HV/MV substations. WFs of nominal capacity up to 5 MW may be connected to the local distribution networks.

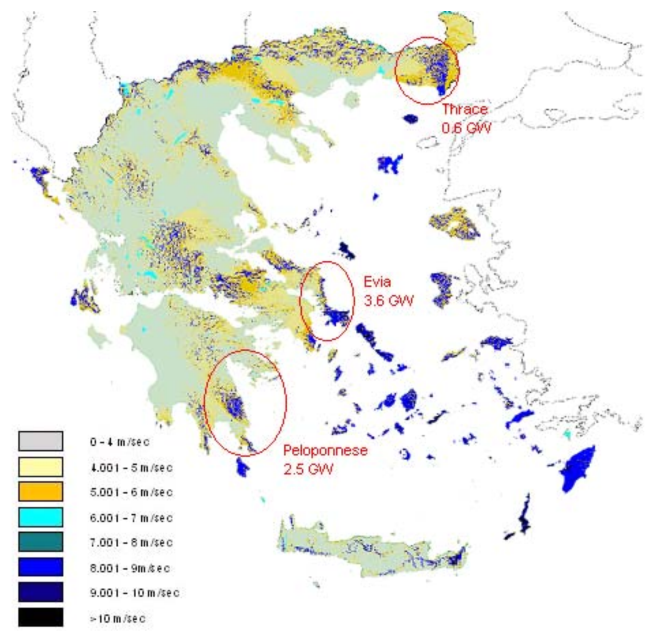

Fig. 1. Wind Potential and geographical distribution of applications for wind farms

The electricity market is organized on a "pool" type; thermal producers are remunerated at System Marginal Price (SMP); SMP is calculated on an hourly basis and represents the price of the marginal generator to meet the load. RES energy is bought by HTSO at a fixed price (currently 68.42 €/MWh) related to the retail electricity price. Since SMP is much lower than RES fixed tariff, the excess cost is distributed to all consumers as an "uplift" cost.

2.2. Planned Transmission Reinforcements

Due to the limited transmission capacity in windy areas, HTSO has carried out specific plans for HV network reinforcements to accommodate future wind farms. Also, a major project to interconnect the north Cycladic islands is under development. These interventions (included in the "5-year statement") will drastically increase the network potential towards large wind power penetration, as reported next. It should be underlined that transmission projects face long delays in Greece due to the time consuming licensing procedures and the strong public opposition.

Evia: This area has a large verified wind potential especially in the south. Currently, about 200MW of wind farms have been installed along a radial OHL connected to 4 new s/s. The applications in the area exceed 3.5 GW. Evia is connected to the mainland through 2 submarine cables and one OHL operating at 150 kV. The limited transmission capacity to the mainland is a major barrier for wind exploitation. The planned network reinforcements include (see Fig. 2):

- A new connection of south Evia to the mainland through two new submarine cables (20 km each).
- The upgrade of the existing 150kV single-circuit OHL to a double-circuit one.

- The erection of 11 new s/s at the south part to accommodate future wind farms
- The construction of OHL on the island (total length about 80 km)

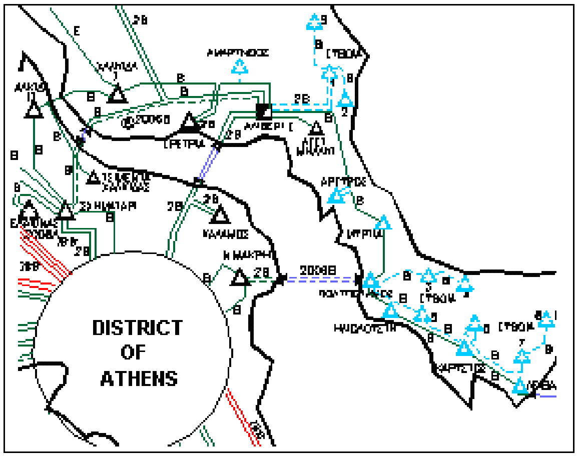

Fig 2. Existing and planned transmission network in Evia

These projects have already been licensed (except small parts) and are expected to be committed during 2006-2007. These interventions will increase the network capability by about 500MW and will also serve the future interconnection of the Cycladic islands.

SE Peloponnese: Southeast Peloponnese is also a region of high wind potential, especially the south part that is currently served by a radial 150kV transmission line. No wind farms exist in the area, but the applications exceed 2,5 GW. The capability of the existing network to absorb wind power is about 80 MW. The planned network reinforcements include (see Fig. 3):

- The construction of a new 150 kV double-circuit OHL (ASTROS-MOLAI - length about 80 km)
- The upgrade of an existing 150kV single-circuit OHL to a double-circuit one.

The former project is under construction and it will be committed by June 2006, while the latter is expected to be committed by 2008. Furthermore, a new 150kV double-circuit OHL to the south has been planned for 2010.

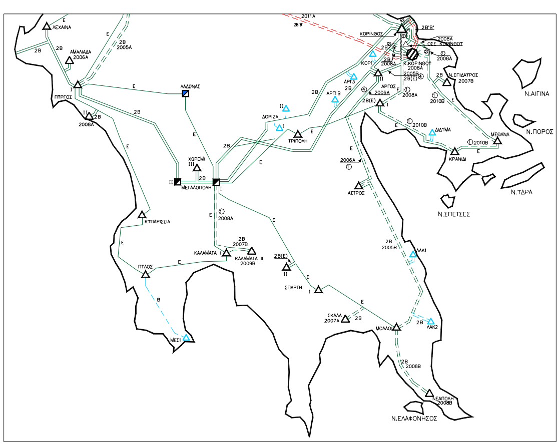

Fig 3. Planned reinforcements in Peloponnese

Thrace: The area of Thrace has a satisfactory wind potential, but also -and more important- enjoys the public acceptance of WFs. Currently, the area is fed by a 150kV system and there are 200MW of wind farms installed in the area through 4 new s/s. Although the total network capacity is in the order of 100 MW, a special control scheme, reported in the next section, has been applied to allow a higher penetration. In order to increase the wind penetration in the area and to facilitate the future connection of the Greek system to Turkey, major transmission projects have been planned in the area which foresee the construction of a new double-circuit 400 kV OHL from the Thessaloniki area to the Turkish border and an EHV s/s at Thrace (see Fig. 4). These projects will allow the absorption of excess wind capacity of at least 500MW. Said projects are under licensing procedure and they are expected to be realized by 2008.

Cycladic Interconnection: Recently, a major project has been adopted that foresees the interconnection of the northern Cycladic islands (namely Andros, Tinos, Myconos, Syros, Paros and Naxos) to the mainland. These islands are currently fed by autonomous systems of high fuel cost and limited wind power penetration. The connection will be performed through Evia through an existing 150 kV cable and the Lavrion (in Attica region) through AC or DC link. I is expected that the project will be realised by 2010-2012 and it will allow the installation of 150-200MW of WFs in these islands.

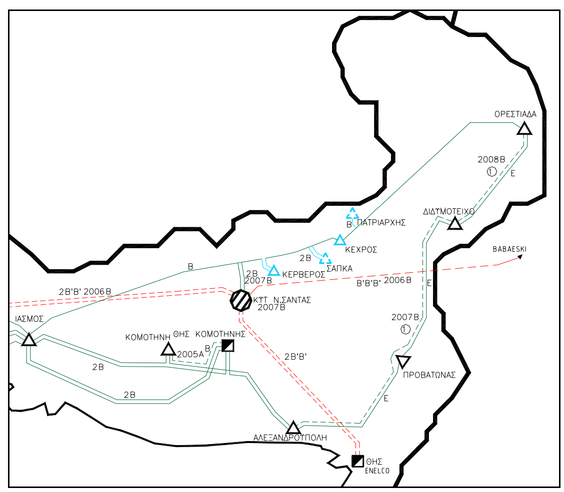

Fig 4. Planned reinforcements in Thrace

2.3. *Special Control Scheme for Thrace*

In Greece, the Hellenic Transmission System Operator (HTSO) has adopted a special operational practice in order to increase the wind power penetration into the windy area of Thrace in the North East part of Greece. The main concept is the introduction of "interruptible contracts" and the continuous monitoring and control of the power flow through the congested corridors by issuing a setpoint to each Wind Farm (WF) to reduce its production, whenever system security is endangered. This practice implies both regulatory and technical amendments [10].

Figure 5 depicts the transmission system in the region. The existing generation comprises a combined cycle thermal plant (natural gas fired) at KOMOTINI. The maximum capacity of this plant is 480 MW while its technical minimum is 280 MW. The region of Thrace is connected to the transmission system through four overhead transmission lines through the boundary bus of IASMOS; the thermal limit of each line is in the order of 170 MVA during summer and 200 MVA during winter. The wind penetration is limited by the available transfer capacity (ATC) from Thrace to the system; static security is the limiting factor. The KOMOTINI power plant is usually bidding successfully in the power market and therefore Thrace is usually an exporting area. Moreover, for large portions of time, it is a "must-run" unit since it is necessary to provide local voltage support. Under these conditions, the possibility of adjusting local thermal power generation, in order to increase wind penetration is not considered, because of the impact this would have on the electricity market (increased uplift costs). Furthermore, the KOMOTINI power plant contributes to the Automatic Generation Control and the provision of this ancillary service is sometimes very important for the quality of the entire system operation.

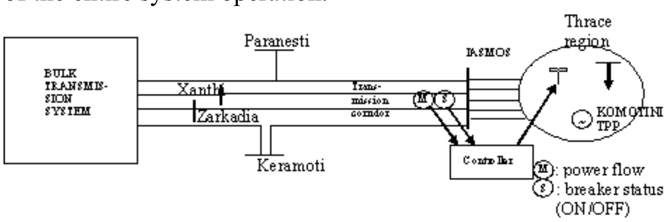

Figure 5. Schematic diagram of system configuration

HTSO should guarantee the absorption of all the power produced by the WFs installed in the country. According to the existing planning practices, the maximum wind power penetration in the area should not exceed 100MW. The application of "interruptible contracts" allowed HTSO to double this limit without compromising system security, or IPPs economic feasibility. From the regulation point of view, the new practice of "interruptible contracts" required the issue of a new Ministerial Decree in 2003 which allows HTSO to violate the "priority in dispatch" rule for RES by curtailing power output of WFs, when necessary; it also sets the mutual obligations between the HTSO and IPPs.

The control is based on the continuous measurement of the total power flow from Thrace to the bulk transmission system through the corridor. The control concept is applied according to the following rule: "the power flow through the interconnecting lines is not allowed to exceed a predefined security limit". This limit is calculated with respect to the N-1 security criterion according to the Grid Code regulations. If this limit is violated, the controller sends setpoints to the WFs with interruptible contracts to reduce their production and consequently the power flow through the congested corridor by the necessary amount. These setpoints represent the upper limit of the power output by each WF that can be securely injected to the grid. The necessary power reduction is to be shared by all WFs with interruptible contracts.

The control scheme [8] is implemented using an autonomous system comprised of Programmable Logic Controllers (PLCs) communicating to each other through two different and independent telecommunication lines. Two independent PLCs (main and backup) are installed at the boundary substation to monitor the operating status and the power flow through the interconnection lines and implement exactly the same algorithm. One PLC is installed at each substation where WFs with interruptible contracts are connected, in order to provide the necessary interface to the WF supervising control system. In each WF the respective PLC collects real time data, transmits the limiting setpoints (if any) to the WF supervising control system and communicates with the PLCs installed at the boundary substation. In addition to the above described autonomous control system, the supervision and control of the WFs by the Energy Control Center is always enabled via the existing Remote Terminal Units (RTUs).

The operation of the control system will be necessarily monitored by the Control Center through the SCADA for security and settlement purposes. Whenever a WF does not comply for reduction according to the setpoint issued by the control system, the dispatchers are alerted and they should communicate (through the telephone) with the authorized WF personnel to execute manually the command. In cases of emergency the WFs, which did not comply with the commands will be disconnected from the grid using the remote control facilities of the SCADA.

In all cases the control system operation and the WF response is recorded in the EMS databases for settlement purposes. The WFs that did not comply with the reduction commands are penalized and furthermore, the power injected to the grid above the issued setpoints is not remunerated. Also, the curtailed energy by each WF is recorded since it must not exceed the 30% of WFs annual potential according to the Ministerial Decree.

2.4. Impact on ESI

The economic impact of the large scale wind penetration on ESI is a crucial issue; large RES penetration will impact on emissions, energy balances and generation mix, electricity economics, electricity markets, etc. A major issue is that it will change the generation mix against conventional thermal generation (mainly the load following generators) and it will reduce proportionally their market share. This impact seems to be significant for the new natural gas combined cycle generators in most of the cases. In this sense, it seems that the targets for market opening and large-scale wind penetration may conflict each other. This section presents results from preliminary studies [11] for the assessment of the impact of the high wind penetration on:

- Emissions reduction and contribution to environmental targets
- Security and diversity of supply (capacity credits)
- Cost of electricity, energy balances and generation mix

- Repercussions to the electricity markets and specifically on the new combined cycle generators

The study covers the period 2005-2015. An average annual energy demand rate of 2.9% for the period 2005-2010 and 1.5% for the period 2010-2015 was considered. According to the Strategic Planning [6], it has been considered that new thermal units are introduced to the system as follows:

- 2 peak units of 125 MW in the year 2005
- one combined cycle unit of 400 MW each year of the period 2005-2012, and one in the year 2015

Regarding the evolution of WFs, two main scenarios (shown in Fig. 6) have been examined. The basic scenario is a moderate one, representing the "business as usual" case. It is based on realistic estimations concerning the anticipated penetration of wind projects in the interconnected system resulting from the progress of licensing procedures and considering network limitations. The optimistic scenario is more environmental oriented, aiming to the achievement of the Kyoto goal. Such a scenario has been provided by RAE in the framework of Strategic Planning [6]. Additionally to each wind penetration scenario, a small penetration of other RES (mainly small hydros) has been considered (Fig. 6).

In order to assess the impact of each scenario, results are compared to a hypothetical case where no RES production is available (namely "No RES scenario").

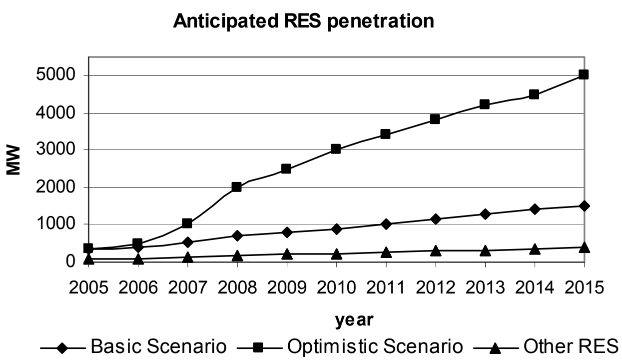

Fig. 6. Anticipated RES penetration scenarios

Historical data regarding the operation of existing wind parks, correlated with typical wind velocity time series, are processed in order to obtain typical wind production time series for each region within each scenario. Operation of wind projects is simulated by adjusting the load demand time series with the resulting wind production ones. Based on the statistics of previous years, large Hydros have been considered to contribute about 3000-3200 GWh annually.

Figure 7 depicts the expected evolution of the energy balance for each scenario. It seems that it is hard to achieve the EC target (20.1% of the total electricity by 2010 should be produced by renewables, including large hydros), though the optimistic scenario comes very close. For the basic scenario (which seems to be the most realistic) renewables contribute only 10.7%, while the respective contribution for the optimistic scenario is 19.8%.

Figure 8 depicts the evolution of CO_2 emissions for each scenario. Only the optimistic scenario leads to the achievement of the set target, but in the year 2015; for the year 2010, the optimistic scenario leads to a reduction of CO_2 emissions by 4.6 Mton compared to the 'No RES scenario'.

Figure 9 illustrates the variation of the country's dependency on imported fuels (natural gas and oil). It is clearly seen that the country's dependency on imported fuels can be decreased only if the optimistic scenario is realized.

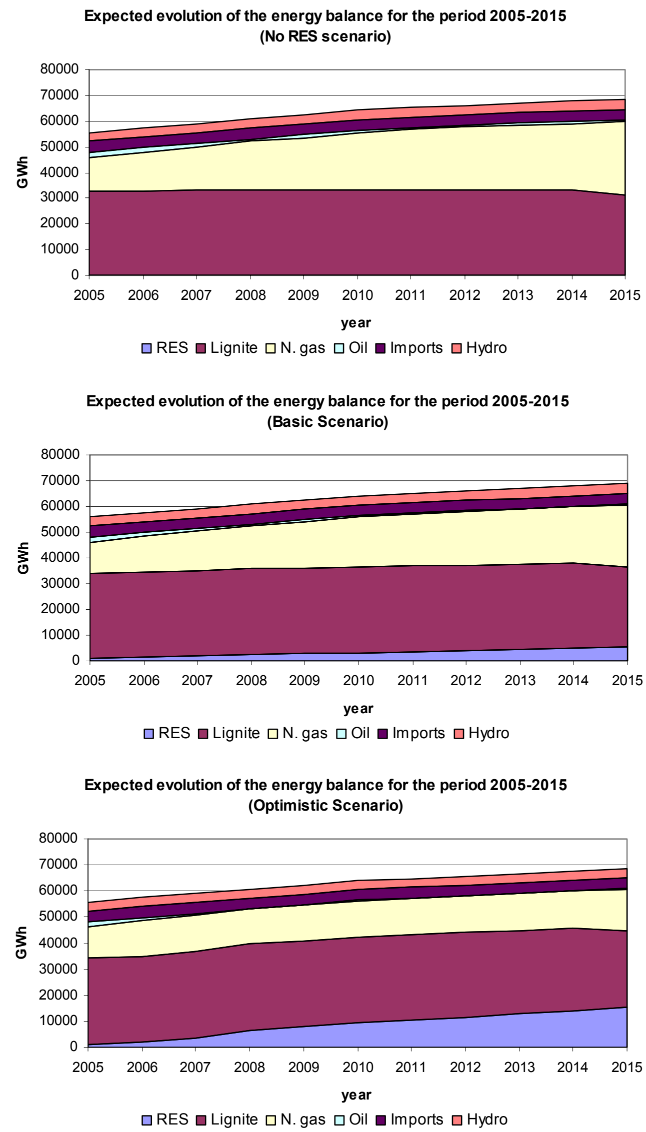

Fig. 7. Anticipated evolution of the energy balance for each scenario

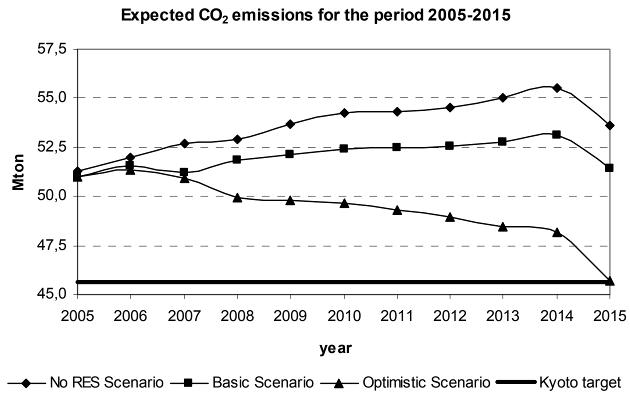

Fig. 8. Expected CO_2 emissions for each scenario

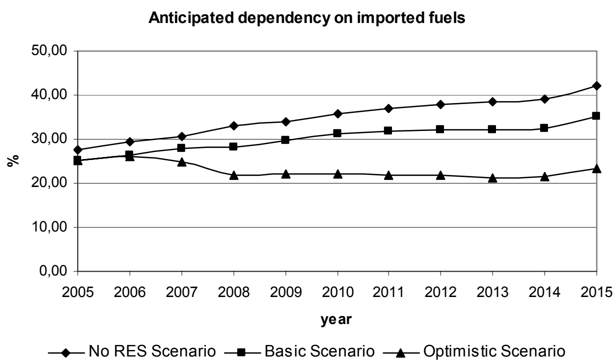

Fig. 9. Anticipated dependency on imported fuels for each scenario

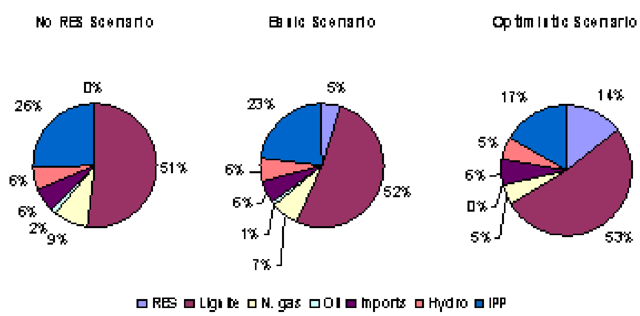

Fig. 11. Market share of thermal IPPs for each scenario (year 2010)

Fig. 10 presents the estimated cost components of electricity (i.e. the expected production cost, the remuneration of RES production, the cost of expected CO_2 emissions and the cost of the expected unserved energy) for the year 2010 as percentages compared to the 'No RES scenario'. RES production is priced at 69 €/MWh. The cost of emissions has been considered to be equal to the penalty set if the expected emitted quantities exceed the adopted limit (40 €/Mton). It should be noted that the penalty for emissions exceeding the Kyoto targets is expected to increase to 100 €/Mton by 2008. Finally, the cost of the expected unserved energy is assessed to be 2000€/MWh. For the basic scenario the total cost is reduced by 5.9%, while for the optimistic scenario the total cost increases by 6.9%. Figure 11 shows the market share that the thermal IPPs hold in the year 2010 for each scenario. A drastic reduction in the expected market share of new generators is observed due to the large-scale wind penetration. It seems that there is a conflict between the efforts to attract investments in thermal units and RES simultaneously.

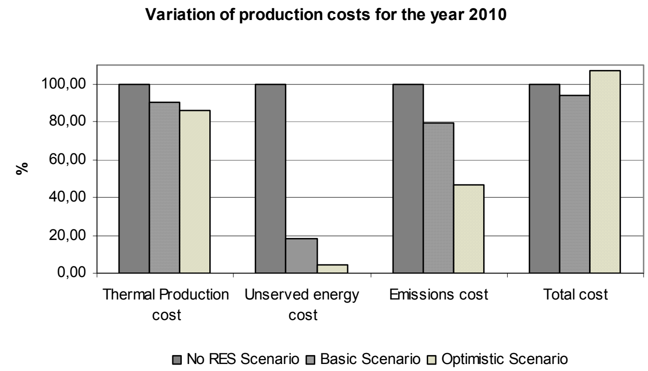

Fig. 10. Expected electricity cost for each scenario

2.5. Future Challenges

From a technical point of view the large scale wind integration raises a variety of technical problems and challenges which can be classified to the following:

1. Long-term Planning and transmission investment plans

Due to the uncertainties in the location of future WFs the transmission expansion planning is a crucial issue. Lack of infrastructure may lead to further delays. On the other side, stranded investments should be avoided. Also, the optimization of connection interfaces is a crucial issue.

2. Power System Performance

A number of actions concerning the every day generation should be revised. The most critical issue is the load-frequency control, which is based on the monitoring of the Area Control Error through the interconnections. Because of the stochastic aspect of wind power and due to the spatial concentration of the wind parks improved prognosis methods and tools must be applied based on meteorological predictions [7]. Only WFs equipped with WTGs using power electronic interface can contribute to frequency regulation.

Robustness against voltage variations: Since future WFs are expected to be concentrated in specific areas, the fault ride-through capability is a crucial issue in order to avoid simultaneously the loss of all WFs in these areas due to short circuits

Voltage regulation: WFs using induction generators without any power electronic interface to the system can not ensure satisfactory performances, as far as primary regulations (voltage as well as frequency) are concerned, particularly when there is no wind. Concerning voltage control or VAR control (reactive power), WFs using conventional alternator type generators and generators using power electronic interface can provide good performances and hold a variable unit power factor. System Voltage stability does not seem to be affected by the large wind penetration [9].

Dynamic Performance: The assess of system dynamic performance following contingencies is under study in order to estimate the restrictions imposed to wind penetration level. Detailed dynamic models for each WTG type should be adopted. On-line Dynamic Security Assessment seems to be the best solution.

3. EMS functions

Large wind penetration implies the need to revise and/or upgrade specific EMS functions such as Load Forecast, Unit Commitment, Primary and Secondary Control, Security Analysis, Training and Emergency Control.

The most critical issue is the primary and secondary frequency control since it will remain difficult to forecast the power gradients arising in the wind power production within a quarter of an hour. The HTSO carries studies to define the ways these power gradients are compensated for via the secondary control, either by central production facilities or by cross-border exchanges. This gives rise to a number of important questions, for instance: Who will be establishing and financing data acquisition and remote control facilities as such? Who will be paying for the lost production? Who will be refunding the loss if the production margin is lowered before a particular time of operation – resulting in the wind turbine owner being unable to deliver the production offered to the exchange? How will the priority between several wind farms be administered – whose production is going to be restricted?

4. WF monitoring and control

There will be a need for continuous monitoring and control of at least large WFs for security purposes. The spatial distribution of WFs will require severe interventions and expansion of the existing SCADA and telecommunications. These interventions require high costs since there is not telecommunication infrastructure in windy areas. The distribution of these costs is an open issue.

5. Market Organization

Considerable regulatory interventions are required in the Grid Code for the issues mentioned above. These regulations and rules are under investigation by HTSO in coordination with the RAE. Also, it can be stated that, to comply with the E.U. treaty rules, new support schemes for RES must be in order to introduce competition (and such achieving the resulting benefits). Also, some problems concerning organisation issues encountered so far must be resolved (acceleration of licensing procedures, monitoring of progress for the licensing projects, etc.). These schemes must be examined in the view of efficiency, compatibility with E.U. rules, and simplicity in the regulations level.

III. Islands

In the following, an overview of the current wind power status in Greece is provided for the sake of completeness.

In Greece there are about 35 autonomous power systems, most of them in the range of few MW, supplying the load demand of small islands in the Aegean Sea. The generation units of these systems are usually oil-fired (burning diesel or mazout oil) resulting in high production cost. In most of these islands a high wind potential has been verified presenting strong correlation with the peak loads (especially during summer time). Besides, these systems exhibit some special characteristics associated with generation, transmission and load profiles. Usually there is only one power plant, while the produced energy is transmitted to the consumers through medium voltage radial networks. The load factor of these systems is usually very low (0.25-0.4) due to high peaks of short duration occurring during summer (high tourist season) and low valleys during the rest of the year. The low load factor requires increased generation capacity and consequently high investment costs. The penetration of wind power into exploitation of the high wind potential of these islands faces severe technical limitations due to the low loads and technical minimums of existing diesel generators. As a result a small number of WFs of capacity up to few MWs (totally ~35 MW) has been installed on these islands; this capacity cannot be significantly increased due to technical penetration limits. Also, the limited size of WFs is not economically attractive for private investors, although they enjoy a very attractive feed-in tariff (84,58 €/MWh). The future interconnection of some islands to the mainland is expected to increase significantly the wind exploitation (see sec. 2.2).

Crete

Crete is the largest isolated power system in Greece with the highest rate of increase nation-wide in energy and power demand (about 8%). In 2004 the peak load was about 530 MW and the annual demand 2540 GWh. The load curve is characterized by large daily and seasonal variations (summer and evening peaks). The conventional generation system consists of three thermal power plants of total installed capacity of 690 MW in three power plants Chania, Linoperamata and Atherinolakos. 25 thermal units of various types are installed, i.e. steam turbines, gas turbines, combined cycle units and diesel units. Being an isolated system, there is no real market operating, instead a "Single Buyer" organization is operated by the Public Power Corporation (PPC) of Greece. Currently, there are 14 WFs in operation comprising 160 WTs with a total capacity of 87 MWs. It is expected that during 2006 the WFs installed capacity will reach ~105 MW. This high wind power activity has been encouraged by the very favorable wind conditions prevailing in the island, public acceptance, the attractive policies and the satisfactory fixed feed-in tariffs (84.58 €/MWh. Moreover, Crete is characterized by a well structured Transmission grid, consisting of 150 kV OHL, and a good online monitoring system. Under this regime, Crete is a system of very high wind penetration. Contribution of WFs reached ~10 % of total energy demand during 2004.

Considering that the low load in Crete is little above 100 MWs, this increased wind power activity may lead operation of the system with high wind power penetration, especially during off-peak hours, e.g. in 2000 the hourly wind penetration has reached about 40% [12-13]. In order to operate an isolated system under such high RES penetration conditions, it is very desirable to have advanced EMS functions, in order to advice operators of possible actions. MORE CARE is adaptable, advanced control software that can achieve optimal utilisation of renewable energy sources in medium and large size isolated systems, that has been developed within EU research projects [15, 16] and has been installed in the EMS system of Crete. A number of modules based on Artificial Intelligence and conventional methods have been developed and incorporated in the MORE CARE software, in order to provide short-term (up to 8 hours ahead) and long-term (48 hours ahead) Load and Wind Forecasts and Unit Commitment and Economic Dispatch functions modules. In this way, the operator is given advice on the possible switching on/off of the units and their production set-points, in order to minimise the operational cost satisfying operational constraints. In addition, Dynamic Security Assessment functions provide on-line monitoring of the system in the event of pre-specified disturbances and detect insecure dispatching recommendations to the operator in preventive mode [16, 17]. MORE CARE has been interfaced to the on-line SCADA Data Base and is installed in the Control Center of Crete, since July 2002. The evaluation of this installation has shown satisfactory forecasting results, clear economic gains provided by the economic dispatch advice, timely and accurate assessment of dynamic security [18].

IV. Conclusions

This paper presents the current and foreseen developments in wind energy in Greece, the impact of large-scale wind integration to the Energy Supply Industry and the technical problems under the view of large penetration. Current solutions and requirements in order to operate the system under high wind power penetration are briefly outlined.

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References

[1] "Energy for the future: Renewable sources of Energy", White paper for a community strategy and Action Plan, COM(97) final, OJ C210, 6.7.1998
[2] EC Directive 2003/54 (26.06.03)
[3] Directive 2001/77/EC for the promotion in internal market of the RES Electricity, 2001
[4] J.Kabouris, K. Perrakis, "Wind Energy in Greece", Renewable Energy, Vol .21, pp417-432, November-December 2000.
[5] J. Kabouris, A. Koronides, G. N. Manos, A. Papaioannou, "Development of Network Infrastructure for Bulk Wind Power Injection in Greece", Proceedings of the EWEA Special Conference "Wind Power for the 21th Century", Kassel, Germany, 25-27 September 2000.
[6] Regulatory Authority for Energy (RAE) of Greece, 'Long-Term energy policy for Greece, 2001-2010', January 2003.
[7] D. A. Bechrakis, J. P. Deane, E. J. McKeogh, "Wind resource assessment of an area using short term data correlated to a long term data set", Solar Energy Vol. 76, No 6, pp. 725-732, 2004.
[8] "Application of Interruptible Contracts to Increase Wind Power Penetration in Congested Areas", J. Kabouris, C. D. Vournas, IEEE Transactions on Power Systems, Vol. 19, No 3, p.p. 1642-1649, August 2004.
[9] J. Kabouris, D. Michos, "Special Control Scheme Implementation to Increase Wind Power Penetration in Weak Areas of the Hellenic Interconnected System", 2005 CIGRE Symposium on Power Systems with Dispersed Generation, Athens 17-20 April 2005.
[10] C. D. Vournas, G. A. Manos, E. G. Potamianakis, J. Kabouris, "Voltage Security Assessment of Greek Interconnected Power System with Large Wind Penetration", European Wind Energy Association Conference, Copenhagen, Denmark, 2-6 July, 2000.
[11] J. Kabouris, N. Zouros, P. Nikolopoulos, E. Contaxi, "Analysis of the Introduction of Large Scale Wind Energy into the Greek Electricity System", PowerTech 2005 Conference, St Petersburg, June 2005.
[12] "Status Of Distributed Generation In The Greek Islands", N. Hatziargyriou, A. Tsikalakis, A. Androutsos, IEEE, PES GM06, Montreal
[13] John Stefanakis, "CRETE: An ideal Case Study for Increased Wind Power Penetration in Medium Sized Autonomous Power Systems", IEEE Winter Meeting 2002, Proc., pp329-334
[14] "MORE CARE Overview", N. Hatziargyriou, et al. Proceedings of the IEEE/IEE MedPower2002 Conference, Athens, Greece, 4-6 November 2002.
[15] "MORE CARE" Final Report, NTUA, April 2003
[16] "Artificial Intelligence Techniques applied to Dynamic Security Assessment of Isolated Systems with High Wind Power Penetration", N. Hatziargyriou, J.A. Pecas Lopes, J. Stefanakis, E. Karapidakis, M.H. Vasconcelos, A. Gigantidou, 2000 Session of CIGRE, Paris, August 2000.
[17] "On-Line Preventive Dynamic Security of Isolated Power Systems Using Decision Trees", E. Karapidakis, N. Hatziargyriou, IEEE Trans. on Power Systems, May 2002, Vol. 17, Nr. 2, pp. 297-305
[18] "Security and Economic Impacts of High Wind Power Penetration in Island Systems", N. Hatziargyriou, D. Georgiadis, A. Tsikalakis, A. Dimeas, J. Stefanakis, A. Gigantidou, E. Thalassinakis, 2004 Session of CIGRE, Paris, August 2004.

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