Feed-In Tariffs for Wind Energy in Portugal: Current Status and Prospective Future

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Abstract – **The question about how wind energy can be remunerated after the end of feed-in tariff schemes still remains unanswered in Portugal. Presently, the majority of wind energy promoters are connected through a point of common coupling, with a defined capacity attribution. In return, these promoters are rewarded with a premium rate (i.e., a feed-in tariff) for a limited amount of time or energy delivered. Therefore, promoters are foreseeing novel ways to return their investments and maximise their income, assuming feed-in tariff schemes will eventually come to a halt. This paper addresses the current Portuguese regulatory and commercial frameworks, especially the feed-in tariff mechanisms in force for supporting wind energy. The current level of revenues obtained by wind energy promoters in Portugal (provided by the feed-in tariff scheme) is compared with the hypothetical income they could obtain on a market environment. The non-firm access to the distribution networks is presented as a solution for integrating further generation capacity and thus increasing profitability for their promoters.**

Keywords – **Distribution Networks, Distributed Generation, Feed-In Tariffs, Firm Access, Non-Firm Access**

I. Introduction

There is a continuing social, political and economic interest in fostering the integration of renewable and/or efficient generation (e.g., wind energy) capacity in many countries and regions including Europe, for reasons like curbing greenhouse gases emissions and increasing the use of existing native resources for producing electricity [1-3]. Distributed Generation (DG) takes a great part in this effort, due to its lower capital costs in distribution networks, as well as attractive incentive mechanisms [3, 4].

According to the existing commercial framework for wind energy in Portugal, promoters are rewarded with a premium rate (feed-in tariff) for a limited amount of time or energy delivered (whatever comes first). When one of these conditions is reached by a certain power plant, current regulations stress that it should sell its energy in the "free market" from then on [2].

In the "free market", power plants may sell their energy either in a centralised market (e.g., pool-based auctions) or in a decentralised market (by means of bilateral arrangements and contracts). Whatever the case, entering the "free market" might mean slackening the profitability of wind energy (when compared with the income obtained with the feed-in tariff scheme). Thus, promoters are foreseeing novel ways of returning their investments and maximising their income, assuming feed-in tariff schemes will eventually come to a halt.

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In the process of attributing capacity to one point of injection, most network operators observe technical requirements and physical constraints, following a "firm access" approach [5]. If this approach persists, many distribution networks might soon reach their connection capacity limit [6, 7]. The option of network reinforcements is, in most cases, not possible due to technical or licensing difficulties. High costs to the parties interested and procedural delays may be further accompanied by low public tolerance to such developments [8]. This triggers the concern whether further generation capacity can be integrated into distribution networks with increased income for all promoters involved. The "non-firm access" to the networks may be the response to this concern, as it allows the integration of installed capacities, globally, above a certain amount considered "safe" regardless of the network's operating constraints [6, 9, 10]. This form of integration aims to deliver additional amounts of energy and, consequently, raise overall income. Nevertheless, it might imply the use of operation strategies (for instance, power curtailment) to assure feasible and safe network operation [11].

II. Connecting Wind Generation to the Portuguese Distribution Network: Existing Regulatory and Commercial Requirements

Currently in Portugal, the conditions in force for connecting generation into distribution networks (as stated in the recently approved Distribution Grid Code [12]) are the following:

1) Power plants above 6 MWi (installed capacity) should operate with unitary power factor;
2) The voltage magnitude at the busbar of connection should not deviate more than 0.02 p.u. with the connection of a new power plant;
3) The defined line thermal and voltage busbar magnitude limits ([0.9 p.u.; 1.1 p.u.]) must be respected, considering no loads.

As an example, Figure 1 shows a typical Portuguese distribution network feeder with no loads, interconnected with the transmission network. Losses in the distribution network are not considered in this work. Moreover, only the electric energy outputs of the wind generators are considered. The instantaneous power outputs required and their possible impacts in network operation are not regarded.

Let one promoter get access to the distribution network of Figure 1 in busbar *B4* (busbar chosen according to its corporate strategy). According to the grid code regulations (conditions 1. to 3.), the installed capacity attributed to this promoter is P_{B4_inst}=17.45MW. This value is reached as there is a change of

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+0.02 p.u. in the voltage magnitude of the busbar of connection (condition 2. of grid code regulations).

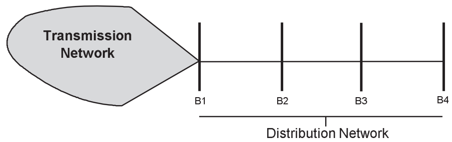

Figure 1. Distribution network feeder, interconnected with the transmission network

Since there is still technical margin for further generation to come into the distribution network (its line thermal and voltage limits have not been reached yet), we assume that a new promoter (independent from the first) manifests its interest in getting connected. Busbar *B2* is selected, again based on the corporate strategy. The installed capacity attributed to this new promoter is P_{B2_inst}= 9.05 MW, limited by the thermal limit of line *B1-B2* ($P_{B1\text{-}B2\_max}$=26.50 MW), the line both promoters now share. Therefore, according to the current grid code regulations, P_{B2_inst} and P_{B4_inst} globally represent the maximum capacity that can be attributed to the distribution network feeder of Figure 1 – firm access to the network.

It is further hypothesised that each promoter installs a wind-based power plant sized exactly as its attributed capacity. From now on, the power plant in busbar *B4* is named P_{G1}, and the one in busbar *B2* is named P_{G2}.

Currently in Portugal, wind-based power plants are not required to bid in the market, since there is a feed-in tariff mechanism supporting them [13]. All their production is bought by the Retailer of Last Resort, under reference tariffs set by the Government [14]. This amount of energy is then regarded as "negative load" by the Retailer of Last Resort, when bidding in the market. In its feed-in tariff regulation, the Government distinguishes generation according to its avoided costs [15]:

$$VRD = \{kh \cdot [PF + PV] + PA \cdot Z\} \cdot k_{CPI} \cdot k_{avl} \ (€) \qquad (1)$$

VRD is the amount received by the renewable/efficient DG power plant (in €). Equation (1) is updated on a monthly basis. *kh* is a modulation factor that alters the remuneration with the time period (peak, full or valley hours) in which energy is produced. *PF* is the fixed part of the remuneration, related with the cost savings resultant of the building of a renewable/efficient generation plant instead of a new generation plant developed by the Public Electric Sector with the same level of guarantee. *PV* is the variable part of the remuneration, related with the remuneration of the energy produced by the renewable/efficient DG power plant. *PA* is the environmental part of the remuneration, which addresses the environmental value provided by the renewable/efficient DG power plant. The environmental part *PA* is multiplied by factor *Z*, that varies with the technology supporting the renewable/efficient DG power plant and its operating regime. *VRD* also depends on the monthly Consumer Price Index (k_{CPI}) and on a coefficient k_{avl}, that corresponds to an estimate of the avoided losses, both in transmission and in distribution, caused by the renewable/efficient DG power plant [15, 16].

III. Application of the Current Regulatory and Commercial Requirements to a Case Study

The available production profile of P_{G1} during a certain day of operation *D* is shown in Figure 2.

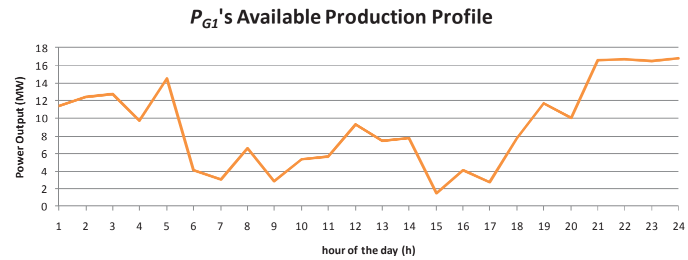

Figure 2. Available production profile of P_{G1} during day *D* (data retrieved from a Portuguese wind-based power plant in 01/02/2005)

Figure 3 presents the available production profile of P_{G2} during the same day of operation *D*.

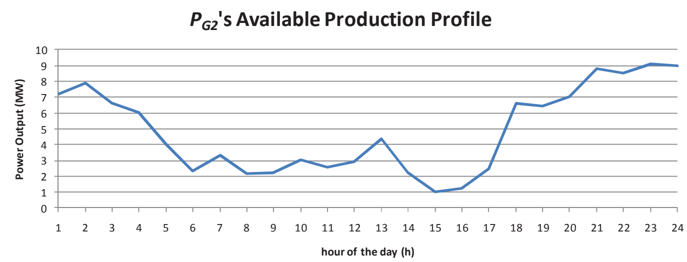

Figure 3. Available production profile of P_{G2} during day *D* (data retrieved from a Portuguese wind-based power plant in 01/02/2005)

A pattern of similarity can be easily observed between the power profiles of P_{G1} (Figure 2) and P_{G2} (Figure 3), which is explained by the physical proximity between the two power plants.

Considering the 2010's average reference tariff, the revenues collected by the DG power plants in the day of operation *D* are presented in Table I. The quantity adopted for describing the value of energy delivered is *€/MWh* (Euro per megawatt hour).

TABLE I. Revenues collected by the power plants P_{G1} and P_{G2}, in the day of operation *D*

	P_{G1}	P_{G2}
Energy produced in day *D* (MWh)	217.25	117.21
2010's Reference Tariff – *VRD* (€/MWh)	76 [*1]	
TOTAL (€) - approximated value	*16511*	*8908*

[*1] Average reference tariff in 2010 for wind-based generators (support scheme valid for 15 years or 33 GWh/MW installed) [2]

A. New Commercial Framework for Wind Energy: the Transition to the Free Market

Provided that either a time or an energy cap limits the feed-in tariff scheme, it is assumed now that all wind-based power plants connected to the distribution network feeder of Figure 1 fall into the "free market". In the absence of any other price reference and assuming that the volume of renewable energy into the grid is low enough to not influence significantly market prices, the price derived from the daily market (centralised market) is the reference for any possible bilateral agreement. All power plants are subject to the same market price (spot price) and its volatility. Also, they are price takers, i.e. they do not set directly the market clearing price. In the Iberian Electricity Market, the market clearing price is unique for both Portugal and Spain (unless in the case of congestion in their interconnections) [14]. Hence, the market price is not differentiated from node to node (no nodal pricing).

The transmission market price profile (spot price) during the day of operation D is shown in Figure 4 and Table II.

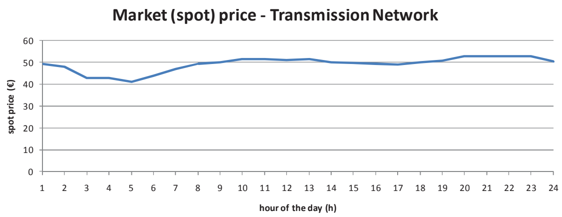

Figure 4. Transmission market price profile (spot price) during day D [*2]

TABLE II. TRANSMISSION MARKET (SPOT) PRICES DURING DAY D [*2]

Period (hour of the day)	Nodal spot price sp (€)	Period (hour of the day)	Nodal spot price sp (€)
1	49.5	**13**	51.62
2	48	**14**	50
3	42.69	**15**	49.7
4	42.69	**16**	49.25
5	40.96	**17**	49
6	43.9	**18**	50.01
7	47.05	**19**	50.69
8	49.25	**20**	53.03
9	50.03	**21**	53.03
10	51.56	**22**	53.02
11	51.53	**23**	53
12	51.01	**24**	50.4

[*2] data of 14/03/2011, obtained from OMEL (Iberian Electric Market Operator) – http://www.mercado.ren.pt/InfOp/MercOmel/Paginas/Precos.aspx

As both power plants have limited ability to follow price signals, their production follows the same available profiles given in Figures 2 and 3. The income obtained by the wind-based power plants in the free market is given in Table III.

TABLE III. INCOME OBTAINED BY P_{G1} AND P_{G2} IN THE FREE MARKET

P_{G1}'s income (€) - approximate value	P_{G2}'s income (€) - approximate value
10754 *(-35 %)*	5802 *(-35 %)*

An obvious consequence of the entrance of these power plants in the "free market", in the conditions stated, is a significant reduction (of approximately 35 %) in their income for selling energy, when compared with the regulated scenario (Table I).

B. Moving from Firm to Non-Firm Access to the Networks to Integrate Further Generation Capacity

The existing grid code regulations do not allow the connection of further generation capacity to the distribution network feeder in Figure 1. Still, a decree published in 2007 states that the size (installed power) of wind-based power plants may increase up to 20% above the capacity already attributed to the respective promoter [17]. However, the capacity already attributed remains unchanged. If the scope of this decree is extended by dropping condition 3 of the grid code regulations (which addresses the thermal and voltage limits of the network), the non-firm access to the distribution networks is allowed. This permits the attribution of further capacity, regardless of the renewable and/or efficient conversion technology involved. To grant equity between existing and forthcoming capacities attributed, it is assumed that the size of each new amount to be attributed should not surpass the latest capacity amount attributed in the former "firm access" regime.

Given this shift in regulations, another independent promoter grants access to the distribution network of Figure 1, concretely in busbar $B3$. According to the revised grid code regulations (without condition 3, but with the capacity cap described in the previous paragraph), the installed capacity attributed to this promoter is P_{B3_inst}= 9.05 MW (see Figure 5).

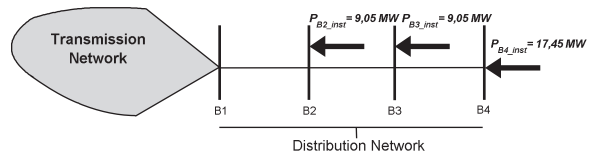

Figure 5. Integration of installed capacity P_{B3_inst} in busbar $B3$ of the distribution network feeder

This new promoter installs, as well, a wind-based power plant (P_{G3}) sized exactly as its capacity attributed.

The sum of the installed capacities of the wind-based power plants (P_{G1_inst}=17.45MW, P_{G2_inst}=9.05MW and P_{G3_inst}=9.05MW) surpasses now the thermal limit of the line they all share, line $B1$-$B2$ ($P_{B1\text{-}B2\_max}$=26.50MW). In order to schedule them again in day D (including now P_{G3}), it is hypothesised that the distribution system operator (DSO) sets a "first come, first serve" logic to rule the access to its assets: power plants are ranked by the order they were connected to the distribution network: $P_{G1} \rightarrow P_{G2} \rightarrow P_{G3}$.

The available production profile of P_{G3} during day D is shown in Figure 6. Following the "first come, first serve" logic, after the setting of P_{G1} and P_{G2}, P_{G3} is determined according to the available production profile of Figure 6.

Figure 7 illustrates the actual production profile of P_{G3}, which is curtailed in some hours due to the thermal limitations of line $B1$-$B2$. The energy not delivered by P_{G3} is definitively lost, since it does not possess any storage capabilities. The loss of energy delivered by P_{G3} is socially and politically undesirable too, due to the efforts being made to tackle climate change and curb greenhouse gases emissions.

Figure 8 presents the level of utilisation of line $B1$-$B2$ after the setting of the DG power plants in day D.

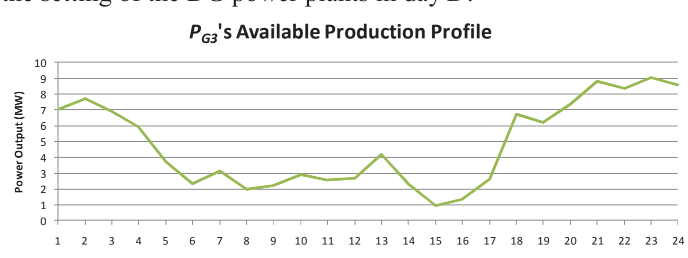

Figure 6. Available production profile of P_{G3} in day D (data retrieved from a Portuguese wind-based power plant in 01/02/2005)

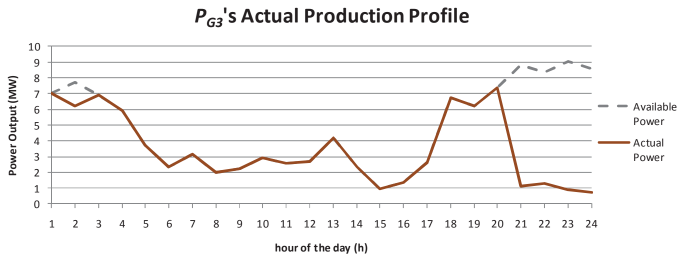

Figure 7. Actual production profile of P_{G3} in day *D*

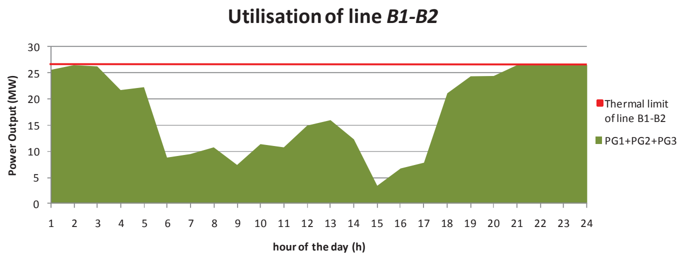

Figure 8. Level of utilisation of line *B1-B2* in day *D*

In Figure 7, the ratio between "Actual Power" and "Available Power" throughout day *D* is 0.72. The income collected by the DG power plants in the free market (with the production profiles of Figures 2, 3 and 7, respectively) in day *D* is illustrated in Table IV.

TABLE IV. INCOME OBTAINED BY THE WIND-BASED POWER PLANTS IN THE FREE MARKET IN DAY *D*

P_{G1}'s income (€) - approximate value	P_{G2}'s income (€) - approximate value	P_{G3}'s income (€) - approximate value
10754	5802	4126

C. Economic Assessment Considering the Regulatory and Commercial Requirements

Let the DG power plants installed by each promoter be regarded as "projects". The Net Present Value of these projects is used to assess the profitability for their promoters, considering the different regulatory and commercial requirements described previously:

- Business-As-Usual Scenario – current regulatory and commercial framework, the regulated scenario;
- Market Scenario – the promoters bid in the free market after the cease of the regulated incentives, but the firm access remains;
- Market & Non-Firm Access Scenario – similar to the Market Scenario, but now the non-firm access to the networks is allowed.

The time span considered for the assessment is 15 years, which corresponds to the maximum amount of time that a wind power plant can benefit from the regulated incentives. The adopted market price is the average market price estimated by the Portuguese Regulator in the Tariff Regulations for the year 2011 – 46.6 €/MWh [18]. The energy produced by each DG power plant is calculated using the *Weibull Distribution*, which works out the number of hours per year that certain wind speeds are likely to be recorded and ultimately obtains, by means of the relevant power curves, the likely total power outputs per year. The data required for these calculations are provided in the Appendix.

The inflation rate is 2.5% and the capital invested is returned at a rate of 9% (i.e., the Weighted Average Cost of Capital, WACC, is 9%). Only Earnings Before Interest and Taxes (EBIT) are taken into account. Therefore, amortisation schedules following loans and income taxes are not considered. The NPVs of the projects at the end of their time span, considering the different scenarios described, are presented in Table V.

TABLE V. NET PRESENT VALUE OF THE PROJECTS AT THE END OF THEIR TIME SPAN

	Project	Business-As-Usual Scenario	Market Scenario	Market & Non-Firm Access Scenario
Net Present Value (M€)	P_{G1}	+ 9.396	- 0.272	- 0.272
	P_{G2}	+ 8.565	+ 3.707	+ 3.707
	P_{G3}	-	-	+ 1.647

In the "Business-As-Usual Scenario", P_{G1} reaches the energy cap for receiving regulated incentives (33 GWh/MW installed) at the 11th year of the project, while P_{G2} reaches it at the 12th year. Beyond this point, both promoters are paid at the market price. The transition to the "Market Scenario" means a significant slackening in the profitability of the promoters: P_{G1} does not even return its capital investment at the end of the 15 years. In the "Market & Non-Firm Access Scenario", P_{G3} is integrated and is able to return its capital investment at the end of the time span. The NPV of P_{G3} is calculated assuming a ratio between "Actual Power" and "Available Power" (throughout the whole time span) equal to the one described in Figure 7 – 0.72.

IV. DISCUSSION

Motivations such as curbing greenhouse gases emissions and increasing the use of existing native resources for producing electricity are leading the continuous interest in integrating renewable and/or efficient generation (such as wind energy) capacity in many countries and regions, such as Europe and Portugal.

Considering feed-in tariff schemes eventually will come to an end, caused either by time/energy caps or any political drivers, wind-based power plants are going to enter into the "free market". Given current legislation, this shift means slackening the profitability of wind-based power plants (when compared with the one obtained with the feed-in tariff scheme), see the example of Table V.

The connection capacity of many distribution networks might reach its limit in the near future, following the current regime of firm access to the networks. The implementation of a regime of non-firm access to the distribution networks permits the integration of further generation capacity. Nevertheless, the utilisation of schemes, such as power curtailment, to guarantee safe network operation limits the amount of energy that can be delivered. Yet, in the case study analysed in this paper, the power plant connected under the non-firm access regime (P_{G3}) proved to be a viable investment for its promoter (see the positive NPV of P_{G3} in Table V).

By inspecting Figure 8, it can be seen that line *B1-B2* still has margin for receiving additional generation in some hours. This suggests that the loss of energy delivered by P_{G3} could have been reduced or even eliminated if some appropriate network operation scheme (e.g., a joint power schedule) had been devised. However, even disregarding potential regulatory barriers for the joint scheduling of separately-owned wind-based power plants, it still seems technically and economically unlikely that P_{G1} and P_{G2} would agree to take part in it. This is because wind-based power plants have limited ability to adjust their production according to corporate objectives, e.g. price signals.

The integration of power plants or energy sources with the ability to follow price signals, together with appropriate incentive mechanisms, may turn the joint operation of DG power plants on a market environment an attractive network operation strategy for all promoters involved, under this regime of non-firm access. The exploitation of the complementarity between intermittent and non-intermittent power plants/energy sources is currently being investigated by the authors. The aim is to allow the delivery of additional amounts of energy and, consequently, increase the profitability for promoters after the end of feed-in tariff schemes.

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APPENDIX

TABLE A-I. TECHNICAL DATA OF THE DISTRIBUTION NETWORK FEEDER

V_{rated} (kV)	15	S_{base} (MVA)	10

Lines (Short-line π Model)	*Resistance (Ω)*	*Reactance (Ω)*	P_{max} *(MW)*
$Z_{B1\text{-}B2}$	0.1	0.4	26.50
$Z_{B2\text{-}B3}$	0.1	0.4	26.50
$Z_{B3\text{-}B4}$	0.1	0.4	26.50

TABLE A-II. *WEIBULL DISTRIBUTION* PARAMETERS

A			*k*
P_{G1}	P_{G2}	P_{G3}	P_{G1},P_{G2},P_{G3}
7.889	7.563	7.780	1.907

Where *A* is the scale parameter and *k* is the shape parameter of the *Weibull Distribution*.

TABLE A-III. POWER CURVE OF P_{G1}, P_{G2} AND P_{G3}

Wind Speed (m/s)	Power output (p.u.)	Wind Speed (m/s)	Power output (p.u.)
0	0	**13**	1
1	0	**14**	1
2	0.0015	**15**	1
3	0.0122	**16**	1
4	0.04	**17**	1
5	0.0849	**18**	1
6	0.1566	**19**	1
7	0.2595	**20**	1
8	0.3976	**21**	1
9	0.5756	**22**	1
10	0.7707	**23**	1
11	0.8829	**24**	1
12	0.9658	**25**	1

TABLE A-IV. ECONOMIC ASSESSMENT DATA

	P_{G1}	P_{G2}	P_{G3}
Capital Investment (M€/MW installed)	1		
Maintenance Costs (M€/year)	0.100	0.050	0.050
Terrain Costs (M€/year)	0.036	0.018	0.018

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