A New Model of Generation with Self-Consumption in Portugal (November 2015)

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Abstract— The RES policies for support of electricity generation allow the promotion and penetration of green energy but sometimes with high costs. The self-consumption models, off-grid, grid connected with or without injection, and net-metering appear to incentive DG based in RES and with lower costs for the electric system.

The viability of these self-consumption models depend on the generation and consumption profiles for each consumer type. Using the typical profiles for consumption and photovoltaic generation published by the Portuguese energy services regulator, the profiles for four typical days of the year are selected for working days and weekends, and for the commercial or small industry sector, and residential. Using a Matlab® developed software to analyze these profiles in order to identify the restrictions that will lead to an optimal adjustment between the generation and consumption profiles.

Some of the choices for adjustment of the generation appear to be inappropriate when considered independently and others improved the investment return rate.

Although the policies that are implemented in Portugal nowadays allow the compensations of a considerable part of the electric bill for each consumer with resource to photovoltaic technology, the model that allows the most profit is net-metering which still does not have a legal framework.

Index Terms — Distributed power generation, Self-Consumption, Net-metering, Generation profiles, Consumption Profiles, Photovoltaic systems.

I. INTRODUCTION

RES based electricity generation has been increasing in worldwide consumption however, only 21.2% of the global consumption in 2012 is form renewable sources [1]. In Portugal the high penetration of RES led to the possibility of energy export [2] and the goal for 2020 is that 59% of electricity generation form RES [3].

The incentive policies in Portugal that promote the RES are essentially based in feed-in tariffs and they have been reducing in the past years mainly due to the rapid photovoltaic evolution. This costs reduction and the increase of the final price of electricity for the consumer brings new opportunities for distributed generation policies such as self-consumption or net-metering. In order to evaluate the existing policies for producer-consumer and how they adapt to commercial or small industry, and residential consumers it was required to perceive how the consumption and generation profiles may adapt to each other.

In the second chapter the different incentive policies for distributed generation based in RES, specifically, those for self-consumption are identified, and also the existing regulation in Portugal.

The third chapter aims to analyze the data form consumers and generators and us creating the respective profiles These profiles are adapted to an average consumer and generator thus giving the average profile for each sector in study, commercial, or small industry, or residential.

The fourth chapter addresses the developed software to aid in the analysis of the profiles calculating the daily and yearly energy balances, based on the results an attempt is made to achieve optimal design for the adjustment of generation to the consumption profiles in each of the studied schemes, and financial analysis is then developed to confirm the hypothesis and the adaptation of the schemes.

A. Abbreviations and Acronyms

DG – Decentralized Generation
BTN – Normal Low Voltage, supplies in low voltage with contracted power below 41.4 kVA.
BTE – Special Low Voltage, supplies in low voltage with contracted power above 41.4 kW.
ERSE – Entidade Reguladora dos Serviços Energéticos (Portuguese energy sector regulator).

Net-metering – A system that accounts for the surplus of the instantaneous consumption of the generated electricity and gives a credit for each kWh delivered to the grid, the credits can later be used by the consumer in a way that the grid is perceived as an ideal storage solution.

RES – Renewable energy sources.

Prosumer – The consumer who also generates electricity with equivalent capacity to his consumption for instantaneous consumption, that may or may not receive a value for the non-consumed energy delivered to the grid.

II. SELF-CONSUMPTION AND SUPPORT SCHEMES

The power sources generally used in decentralized generation are solar, wind and hydro [4]. In some cases energy storage is necessary given the characteristics of renewable energies [5].

A. Incentives schemes and self-consumption

Support schemes for RES are diversified and of specific nature according to their purpose, generally can be classified as feed-in tariff (FIT) and premium (FIP), tenders, quota

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obligations, Tradable Green Certificates, (TGC), Contracts for Difference (CfD), and direct investment support, tax reduction and exemption and other fiscal measures [6][7]. As for the self-consumption and net-metering schemes they are more adapted for DG.

In FIT the generator receives a payment for each electricity unit generated independently of the market price [7][8]. The price is fixed during the whole of the guarantee period and might be differentiated by technology or generated energy steps, usually limited to an amount of yearly energy or for the whole of the guarantee period [6] that usually is up to 15 or 20 years [7]. In FIP the generators trade the electricity directly in the market and receive an additional payment on top of the market price, usually combined with an upper and lower limit [7][9].

In CfD the government sets a strike price for the energy in the long term, if the market price is below that value the generators receive the difference in the form of a FIP, if the market price is above the strike price the generators pay the government the difference [9][10].

The tender scheme is a form to avoid overcosts since the investors have to compete for the support. The regulator entity or the government announces the opening of a tender to install a certain capacity or technology and the investors bids the price for the electricity, the lowest bid wins [7]. The tenders are not by themselves an incentive policy however they are used to determine the level of incentive of other policies such as FIT [9][10].

The quota system and TGC are based in the concept of classification of the electricity according to its origin. The electricity is sold in market and the generators may sell a certificate that represents an amount of renewable energy [7]. The sale of these certificates assures an additional payment to the market price [7]. In addition, the quota obligation of RES in the generation mix either for consumers, traders, or generators is complementary and used as an incentive to the TGC. Sanctions are enforced if the quota obligations are not met [7].

The incentive in fiscal grants may be in the form of direct subsidization of projects, loans with reduced interests, tax deductions or the combination of several of these measures [6][9].

The self-consumption and metering schemes promote the consumption of the generated electricity in DG near the consumption over the payment of tariffs for grid injection. There can be direct incentives with a prize for self-consumed electricity or indirect if the FIT is lower than the price of electricity for the final consumer [11].

In Portugal the self-consumption policy allows the generation without using the grid however there is the possibility of selling the electricity surplus to the grid at the price of 90% of the monthly average market price [12].

As for net-metering the electricity surplus is injected in the grid and accounted in credits that may be used in a large period of time (on or two years) using the grid as a long term storage [11]. Net-metering may be perceived as the aggregation of the schemes for direct self-consumption and FIT [13].

B. Regulation in Portugal

Until 2015 the legal framework for DG was divided in two programs based in FIT, microgeneration with the total of 26,193 installations with the combined capacity of 94 MW and minigeneration with 1,398 installations with the total of 65 MW [4]. In these regimes the solar photovoltaic source represents more than 99% of all the RES [4].

The Decree-Law 153/2014, of 20th of October enforced the new framework for DG which in similar to the previous programs and for self-consumption allowing the installation of renewable and non-renewable sources and enforced simplified licensing procedures.

The DG program consists in the installation of RES generation up to 250 kW in an existing consumer installation, and the energy delivered to the grid is limited to twice as much as the annual consumption.

The self-consumption regime promotes the adequacy of the self-consumption unit to the energy demand thus minimizing the injection of energy in grid however, any surplus of electricity can be sold to the last resource supplier or in the free market. As for the installed capacity it is limited to twice as much as the connected power which, in turn, is limited to the contracted power of the consumer installation.

This regime also considers a mechanism that provides compensation of the economic and general interest costs (CIEG) for the electric system when the combined installed power in self-consumption reaches at least 1% for the total generation installed power.

III. DATA ANALYSIS

The profiles were created from the initial profiles published by ERSE and adapted to the average consumers and average microgeneration and minigeneration. The analysis is based in the yearly energy balances and in four typical days that represent the yearly consumption of working days, weekends, for winter and summer.

The initial profiles applicable to final consumers in medium voltage, BTE, three profiles for BTN (class A, B, and C), public lighting, and photovoltaic generation for DG, as well as the grid losses and the reference load diagram, were approved for the year of 2015 by ERSE.

The final profiles are obtained using the data for the number of consumers and consumption for each voltage level or consumption class, and for generation and number of generators in Portuguese DG regimes. So, the working profiles are the average instantaneous power for each consumer or generator.

A. Identifying Consumers and Consumption

Portuguese electrical energy consumption increased gradually up to 2010 with 48,949 GWh, and has been dropping since reaching 46,245 GWh in 2013 [4]. This consumption is distributed by the regulated and free market that in 2014 represented near 10% and 90% of the all the consumption, respectively.

BTN classes are differentiated by contracted power and yearly consumption: Class A above 13.8 kVA, class B up to 13.8 kVA and above 7,140 kWh, and class C is below 13.8 kVA.
and up to 7,140 kWh. Each class can be associated with a specific segment, residential, commercial or industrial based on the consumption profile. Fig. 1 suggests a commercial or industrial consumption segment for BTE with the peak consumptions during the middle of the morning and the afternoon.

And the BTN C profile in Fig. 2 is more related with residential segment due to the location of the peak consumptions later in the day.

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The BTE and BTN C profiles will be the basis of the study as representatives of the referred consumption segments.

### B. Daily profiles for consumption and generation

To identify the behavior of consumers and of photovoltaic generation, typical consumption days were selected representing consumption in winter and summer, during workdays (typically a Wednesday) and weekends:

- 14th of January – winter workday (Wednesday)
- 17th and 18th of January – winter weekend
- 1st of July – summer workday (Wednesday)
- 4th and 5th of July – summer weekend

Each class of consumption in BTN is composed by different types of consumers but it is related to tariff profiles (ERSE, 2014) and with this it is possible to reach the distribution of consumption and consumers for each class as TABLE I.

<table>
<thead>
<tr>
<th>Tariff Class</th>
<th>Consumption (MWh)</th>
<th>Number of Consumers</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTE</td>
<td>3,335,421</td>
<td>33,739</td>
</tr>
<tr>
<td>BTN A</td>
<td>4,982,764</td>
<td>1,658,029</td>
</tr>
<tr>
<td>BTN B</td>
<td>610,757</td>
<td>203,231</td>
</tr>
<tr>
<td>BTN C</td>
<td>12,530,544</td>
<td>4,169,575</td>
</tr>
<tr>
<td>Total</td>
<td>21,459,486</td>
<td>6,064,575</td>
</tr>
</tbody>
</table>

The initial profiles are normalized, that is, the sum of all values for a given year is 1,000, and are discriminated in periods of 15 minutes with the total of 35,040 samples for each profile. With this data the final consumption profiles are calculated with the average power of the average consumer.

Similarly to the calculation of the consumption profiles the same method may be applied to the generation profiles for microgeneration and minigeneration using the annual generation and number of generators for each regime as shown in TABLE II.

<table>
<thead>
<tr>
<th>Type</th>
<th>Number of Generators</th>
<th>Installed Capacity (kW)</th>
<th>Generation (MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microgeneration</td>
<td>26,193</td>
<td>100,109</td>
<td>148,994</td>
</tr>
<tr>
<td>Minigeneration</td>
<td>1,398</td>
<td>64,846</td>
<td>85,813</td>
</tr>
<tr>
<td>Total</td>
<td>27,591</td>
<td>164,955</td>
<td>234,807</td>
</tr>
</tbody>
</table>

The result is the final profiles for consumption and generation in BTE and minigeneration are calculated. As an example Fig. 3 shows the winter profiles and Fig. 4 summer profiles for BTE.

Fig. 3 Final consumption and generation profiles for BTE and minigeneration, typical weekday during winter. (a) consumption (red); (b) generation (blue);

Fig. 4 Final consumption and generation profiles for BTE and minigeneration, typical weekday during summer. (a) consumption (red); (b) generation (blue);

The final profiles for BTN C and microgeneration are also presented as an example, in Fig. 3 shows the winter profiles and Fig. 6 summer profiles.
IV. TECHNICAL AND ECONOMIC ANALYSIS

Here is addressed the developed software, the case studies are approached and the adjustment models are developed to take into account in the dimensioning of the generation. Finally an economic evaluation is made to confirm the viability of the proposed adjustments.

A. Developed application

A software was developed in Matlab® that reads an Excel® file (*.csv) with the information of a consumption and a generation profile. The structure of this file has to be with 5 columns with date (DD-MM-YYYY), weekday, hour for each 15 minutes sample (HH:MM), the instantaneous power of consumption (kW) and the instantaneous power of generation (kW), and the first row has the headers for each column (e.g. Date, Day, Hour, Consumption BTN C (kW), Microgeneration (kW)). The software builds the graphs with the consumption and generation profiles allowing to show the daily profiles of the four typical days, or weeks that concern the typical days (14th to 20th of January; 1st to 7th of July) as shown in Fig. 7.

B. Case studies

The models for DG for RES based in consumer-generator policies that are covered are the off-grid self-consumption, self-consumption with or without surplus injection in the grid, already allowed in the Portuguese legal framework, and net-metering that is still not allowed nowadays.

For the off-grid scenario the chosen consumption profile is the BTN C for the residential sector, with a generation profile of microgeneration (up to 5.75 kW), the typical daily generation is about 10.5 kWh in the winter and 7.5 kWh during the summer days, as shown in the weekly profiles of Fig. 8 and Fig. 9 for winter and summer, respectively.

It is also possible to present the same profiles and identify the energy that is delivered by the grid, the self-consumed, the surplus, and the stored energy that is used in case, only for the models with storage or net-metering. In addition, the daily or yearly balances of energy are calculated for each of the four time periods of peak, half peak, super off-peak, and normal off-peak. These energy balances consider the consumption, generation, self-consumption, the surplus, the grid supply’s (given by generation less self-consumption), stored energy that is actually used in a different period, the net grid supply’s without discounted of the energy value that comes from storage or net-metering, and the energy that is still in storage or in credit for net-metering.

Fig. 5 Final consumption and generation profiles for BTN C and microgeneration, typical weekday during winter. (a) consumption (green); (b) generation (blue);

Fig. 6 Final consumption and generation profiles for BTN C and microgeneration, typical weekday during summer. (a) consumption (green); (b) generation (blue);

Fig. 7 Final profile for BTE and minigeneration, for a typical winter week. (a) consumption (red); (b) generation (blue);

Fig. 8 Typical profile for BTN C and microgeneration, in a winter week. (a) consumption profile (yellow); (b) self-consumption (orange); (c) energy form storage (grey); (d) surplus (green)
Fig. 9 Typical profile for BTN C and microgeneration, in a summer week. (a) consumption profile (yellow); (b) self-consumption (orange); (c) energy form storage (grey); (d) surplus (green)

Fig. 8 shows that in the winter the generated electricity is not enough so satisfy the daily consumption, but in the summer profile in Fig. 9 the main characteristic is that the surplus is clearly higher than the demand needs.

In an off-grid situation the following assumptions are made:
- All of the consumed electricity is from self-consumption and from the stored energy;
- The storage should be enough to ensure the daily demand given the daily surplus;
- By “storage” it is understood as the accounting of the total surplus, not taking into account the limitations of capacity and efficiency;
- The PV power plant should be sized in to assure that the generation is enough for the annual and daily demand.

The daily demand in this situation excluding self-consumption is about 7 kWh during the winter and 3 kWh during the summer. So, the storage should be enough for the daily 7 kWh.

The worst situation of not enough generation occurs during the winter weekend where the consumption is about 137.81% of the generation. This hypothesis has to be validated in an economic analysis.

In the case scenario where a consumer installation is grid connected, with a BTN C profile, but the generation does not provide energy into the grid, the following assumptions are considered:
- The generation should be consumed instantly minimizing surplus;
- The power plant should be dimensioned in a way that the generation peaks match the minimal demand in that period;

For this scenario the during the summer days and in an annual balance the generation is excessive. Looking at the profiles and the peak values in the most restrictive situation the generation peak is 2.34 kW with a consumption in the same instant of 0.33 kW. This occurs in a summer workday.

The hypothesis to adjust the generation and consumer profiles is the reduction of installed capacity in 85.89%.

For the self-consumption scenario with grid injection it is taken in consideration two situations: BTN C consumer profile and microgeneration profile; and BTE and minigeneration profiles. In these scenarios it is taken in consideration the following:
- There is no storage and the surplus is sold to the grid;
- The annual generation should be equivalent to the yearly demand;

The dimensioning should be more sensible to the quantity of surplus since the value of this electricity is much lower comparing to the self-consumed electricity value [12].

For BTN C in a first approach there are two possibilities for reduction of the generation: the generation peak in the day with less generation should match the consumption peak in that day; the generation the peak of generation of the day with less generation should match the consumption in that instant. These two hypothesis imply the reduction of generation in 41.21% and in 64.56% respectively. The economic evaluation should clarify which one, if any, shows the better results.

As for BTE, the generation profiles for winter and summer are shown in Fig. 10 and Fig. 11, respectively.

As for BTE, the generation profiles for winter and summer are shown in Fig. 10 and Fig. 11, respectively.

Fig. 10 Typical profile for BTE and minigeneration, in a winter week. (a) consumption profile (yellow); (b) self-consumption (orange); (c) energy form storage (grey); (d) surplus (green)

Fig. 11 Typical profile for BTE and minigeneration, in a summer week. (a) consumption profile (yellow); (b) self-consumption (orange); (c) energy form storage (grey); (d) surplus (green)

Once again, the first approach should be the increase of generation based in two adjustments: the generation peak of the day with less generation should be less or equal than the consumption peak in that day; the generation peak of the day with less generation should match the consumption in that instant. These two adjustments imply an increase in the generation of 65.86% and or reduce the generation in 55.52%.

For the net-metering scenario also, the BTN C profiles and BTE are studied assuming that:
- All the surplus is accounted in credits and should be valued in periods that the consumption is higher than the generation;
- The generation dimensioning should consider the annual generation and consumption equilibrium as the main adjustment factor.

In BTN C, the adjustment of the yearly generation, implies a reduction of 47.17% of the generation.

For BTE since the annual consumption represents 161.05% of the generation this should be the adjustment to make.
The viability of these hypothesis can only be confirmed in the economic evaluation, however, the hypothesis that consider the increase of generation above 100% of the contracted power cannot be considered due to legal restrictions [12].

C. Energy Value

The self-consumption models in study do not have direct incentives for deployment, however the energy value is the avoided costs of not acquiring electricity from the supplier.

Since there is still a transition from the regulated market, ERSE still publishes transitory pricings for final clients in BTE and BTN tariffs for energy and contracted power [14].

The contracted power for the case studies should be equal or superior to the consumption peaks, about 21 kW and 0.7 kW for BTE and BTN C, respectively. However the generation has to comply with the existing regulation [12], namely the connection capacity of the generation has to be less ore equal to the contracted power. For BTE the selected contracted power is 46 kW (the same as the generation capacity) and in BTN C is 4.6 kVA (as the available contracted power above the generation capacity).

The surplus of electricity supplied to the grid in the situation of self-consumption with grid injection is paid at 90% of the average market price for the Portuguese pole that is 49.9 €/MWh for 2015 (from January to August) (REN Mercados, 2015). This value is higher than the average for 2014 that stayed in 41.9 €/MWh.

As for network tariffs, these are not considered since the legal framework exempts the special regime generators of this payment.

D. Results

The economic assessment is done based in the typical profiles, considering a hurdle rate of 4%, and calculating the value-added tax (VAT) at 15 and 20 years, the internal rate of return (IRR) in the 15th year, and the investment return period.

The off-grid generation required the existence of storage with capacity for 7 kWh per day and the value of the investment revenue has to be enough to acquire these equipments. So, for this model there was no optimal solution since none was viable in the 20 year period considered for the economic evaluation. In order to assure enough generation for the required consumption, the base profiles case study could be considered but with huge restrictions in the expected consumption (about 70% during winter days and 40% during summer days).

In the self-consumption without grid injection the test was that in the day with more surplus the consumption was the higher value at that moment. This was validated with a 5 year return period however, this hypothesis only means a reduction of more or less 26% in the grid supply.

Generally, for self-consumption with grid injection the adjustments that had the most viable economic solution were the ones with the lower installed capacity. In the residential sector the adjustment with the lowest generation showed viability with a return period of 13.4 years and reduced about 40% the grid imports. In the commercial sector the base profiles case was the only viable one allowing the return of the investment in less than 11 years with a 50% reduction on the grid imports.

The net-metering adjustment for BTN C showed a significant improvement in the investment return period, comparing to the base profiles case the return period lowered from 19 years to 10 years. For BTE the base case showed a return period in 9 years where almost 90% of the energy bought from the supplier was reduced.

V. Conclusions

It is important refer that the adjustments made to the self-consumption models, in net-metering the grid imports reduction is about 90% in the adjusted cases, while self-consumption with grid injection allows energy savings about 50% and without grid injection the imports are reduced in 26%.

In conclusion, the legal possibility of using net-metering could be viable since it allows a maximum valorization of the surplus. It could be a way to promote RES and mitigate common problems associated to the intermittence of RES.

REFERENCES