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Mitigation analysis of MV distribution network constraints thanks to a self-consumption policy for photovoltaic distributed units

Valentin Pailloux, Bruno Francois

Univ. Lille, Arts et Metiers Paristech, Centrale Lille, HEI, EA 2697
L2EP, Laboratoire d'Electrotechnique et d'Electronique de Puissance,
F-59000 Lille, France
valentin.pailloux@centrale.centralille.fr, bruno.francois@centralille.fr

Abstract—Self-consumption of homemade electricity from renewable energy is encouraged by the European commission to enforce their penetration in state energy portfolios. By using electrical energy storage systems and demand response, this technique can lower the overall cost of the renewable energy transfer in the electrical system and so increase it. To develop self-consumption efficiently, various energy policies can be imagined to create economic support schemes for motivating consumers to make active decisions in this way and mobilizing financial resources for an energy transition toward more RES in the future. Germany has experimented earlier this policy orientation while France is only beginning to consider self-consumption. The goal of this paper is to compare German and French policies in order to evaluate the benefits of PV production self-consumption. So economic national frameworks are recalled and then a 100kW PV producer is considered. With one-year time data series and an energy model, different operation conditions are simulated and times of return on investment are compared. Then, benefits for the electrical network operation are studied. The benchmark distribution network model from CIGRÉ is used to quantify and compare technical constraint occurrences.

Keywords—*self-consumption; renewable energy integration; electrical constraints; electrical storage; energy management system.*

I. INTRODUCTION

Due to the uprising of distributed renewable sources in the last decade, the model of centralized generation of electricity providing end-consumers by a vertical electricity network is changing. Because most of the wind and solar power plants are connected on the Medium and Low Voltage Networks, the power flow can be sometimes inverted and this will take place more and more often in a near future. Thus Distribution System Operators have to manage and plan differently their networks to incorporate these new technologies and governments have to adapt their legislations.

Most of the time, in France, wind and solar power plants do not exceed the 12MWp legal limit to be connected to the Medium

Voltage distribution network, this allows the producer not to pay the using fees of the very high voltage network.

In Germany onshore wind and PV power plants are generally much more powerful than in France with connected capacities reaching 135MW for wind and 166MWp for PV. Those plants have to be connected directly on the transmission system. It does not preclude a lot of smaller wind and PV power plants to be connected to the distribution system.

In consequence, when a new power plant is connected on a branch of the grid, which is initially sized just to transmit power from upstream to downstream, the line voltage profile can be drastically affected and congestion may occur.

Some basic solutions exist to avoid these problems, like the reinforcement of the network, which is very expensive and requires works, or the forecast of consumption and production profiles. The latter solution is being improved for wind and solar energy, which are much correlated with weather changes. Making the network management automatic, and then smart, is a way to improve its fast and complex operations, many projects are ongoing to digitalize the grid.

Furthermore new methods appeared in the last decade and are seen as solutions of the future – the Power to Gas and Power to Heat consist in converting the extra electrical energy produced in gas, such as hydrogen or methane, or in heat respectively. Some experiments are in progress in Germany (Enertrag – Prenzlau) and in France (GrHyd - Dunkerque) to prove the reliability of these solutions.

Nonetheless the fastest expanding trends to improve the resilience of the energy grid, as from a technological point of view as from a regulation point of view, are energy storage and self-consumption which are linked [1], [2].

While nowadays more than 99% of the stored energy intended to generate electrical power is Pumped Storage Hydropower [3], the price of lithium batteries have been divided by 4 between 2010 and 2017 and this resource is abundant on Earth, besides new

environmentally friendly technologies are appearing as the metal air battery, thus energy storage using batteries is seen to soar in the coming years.

Thus, to address this topic this paper will, firstly, draw the situation in Germany and in France about self-consumption framework. Secondly, a model will be proposed in order to compare several modes of energy management in the fourth chapter. Finally, the fifth part will implement the model within a distribution network model in order to assess if this solution can preclude constraints in the grid.

II. MODELS AND POLICIES

In Germany, a new electricity accounting system was designed and defined by the law in 2018 fostering self-consumption for photovoltaic installations (Fig.1).

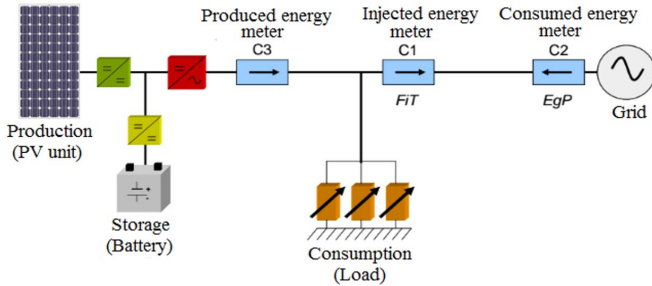


Figure 1. Principle sketch of the German accountability model defined by the law for grid-connected systems.

The German electricity regulation has got 3 tariffs operating: the Electricity grid Price (EgP) is the normal price of electricity that everybody pays when consuming electricity from the grid. The Feed-in Tariff (FiT) is the electricity purchase price for an individual- or utility-scaled electricity generation unit, it concerns only renewable energies. Finally, the Self-consumption Tariff (ScT) is the innovation of the German law, which allows the small producer to earn more money by consuming his home-produced

energy than selling it to the Distribution System Operator (DSO) by giving a price to his self-consumed electricity. Those prices are given values in Table 1 hereunder.

Using the German context and using the notations of Fig.1 the costs and benefits are:

- Cost of grid electricity = $C_2 \times EgP$,
- Gain of self-consumption = $(C_3 - C_1) \times ScT$,
- Gain of electricity injection = $C_1 \times FiT$.

A classic end-consumer with no power generation will pay the full cost of grid electricity at the price EgP . Then if he has got a photovoltaic array then he will have to decide between injecting all his generated energy at the tariff FiT , or self-consuming as much as possible at the Self-consumption Tariff and sell the extra energy at the Feed-in-Tariff.

This choice will rely on the value of EgP , FiT and ScT , it becomes more interesting to self-consume if ScT is greater than the difference between FiT and EgP , on the contrary case it is profitable to inject all the produced energy.

Historically, France has always fostered the injection of all the generated power to the grid, with a high FiT compared to the EgP (14c€/kWh in this study), and no ScT . The French FiT is defined quarterly since and has been launched seriously in 2007, when it took the value 55c€/kWh for rooftop solar PV projects of any power, and 30c€/kWh for ground-mounted applications. Since the moratorium of 2011, more categories have been created to implement various tariffs: ground-mounted applications and rooftops according to the installed peak power and the integration on the roof. The FiT is decreasing quarterly by about 2% for small rooftop integrated solar PV projects, and by about 1% for other applications.

III. CASE STUDY – AN INDEPENDENT POWER PRODUCER

TABLE I. FEED-IN-TARIFFS IN FRANCE AND IN GERMANY (2016)

	France				
System	<i>Full rooftop integration</i>	<i>Simplified rooftop integration</i>		<i>Ground mounted</i>	
Power up to (kWp)	9	36	100		
FiT (c€/kWh)	23,54	12,39	11,77	8.40	
	Germany				
System	<i>Rooftop mounted</i>				<i>Ground mounted</i>
Power up to (kWp)	30 kWp	100 kWp	1,000 kWp	>1,000 kWp	
FiT (c€/kWh)	24.43	23.23	21.98	18.33	18.76

In order to compare both German and French systems, an installation with a 100kW peak load is considered and associated with a 100kWp photovoltaic array and a 100kWh battery. Both German and French pricings are then applied on the simulation.

For the battery, a yield of 90% and a depth of discharge of 80% were taken into account, so the final storage capacity is 80kWh. None power limit was set up in the model, but equivalent commercial batteries can reach 50kW, and in the simulations even under the strongest demand of power from the battery, most of the time the called power remains low at about 20kW, so this assumption won't alter significantly the results.

Such a system would be equivalent to a farm provided with 100kWp peak of electric machines or devices, with about 900m² of well-oriented barn's rooftop to install a 100kWp photovoltaic array and an extra 4m² place for a system of batteries of 100kWh.

As an input of the model, two profiles have been used for the consumption of the load and the production of the photovoltaic array. They give values every 10 minutes over one year, as we can see them on the first and the second graphs of fig. 2.

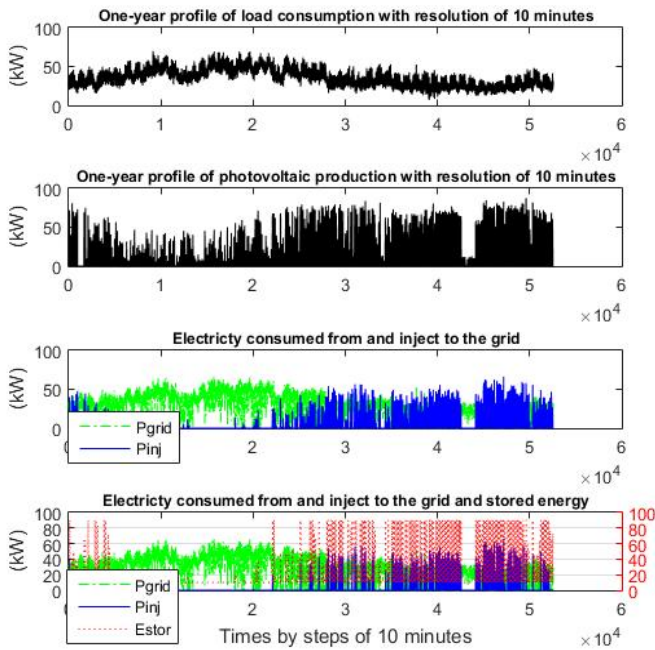


Figure 2. (1) Load profile (2) pv generation profile (3) self-consumption profiles without and (4) with a battery.

With these two profiles, various energy management strategies are possible.

In MODE1, all the power consumed by the load is taken from the grid (tariff: EgP), and no PV system is considered.

In MODE2, as in MODE1, the consumed power is taken from the grid (EgP) and the PV production is taken into account and is injected to the grid (FiT).

In MODE3, as much as possible, the PV production is self-consumed (ScT) and the missing power to supply the load is taken from the grid (EgP). The extra produced PV power is injected to the grid (FiT).

Furthermore, it is possible to self-consume more energy produced by the PV system by storing it in a battery to mitigate the effect of intermittency of solar power. Hence, in MODE4, the extra produced PV power is stored in the battery (instead of injecting the extra produced PV power in MODE3) and, only when the latter is full, the home-produced power is injected to the grid. Then, when the PV production is no enough, the required power can be taken from the storage device. Only when the latter is empty, the load is supplied by the grid. MODE3 and MODE4 can be observed on the third and the fourth graphs of fig. 2.

Visually it is easy to differentiate the seasons on the consumption and production profiles: consumption is higher and production is lower in winter, and the opposite situation happens at the summer period. In consequence, with MODE3 and MODE4, more power is taken from the grid (P_{grid}) during winter. Reversely, during the summer period, more power is injected to the grid (P_{inj}) and at the same time more energy is stored in the battery in MODE4 ($Estor$ corresponding to the right y-axis).

Between time steps 4,104 and 5,105 on the x-axis, a drop takes place in the PV production profile because of a fault or a maintenance operation on the PV system.

Comparing the graphs of self-consumption without (MODE3) and with the battery (MODE4), the system with the battery stores a non-negligible amount of energy and inject less power to the grid than the system without the battery. This means that the storage capacity helps to self-consume more self-generated power from the PV panels and, by consequence, helps to consume less power from the grid, then the autonomy of the producer is increased.

IV. COMPARISON OF ENERGY MANAGEMENT STRATEGIES

The amount of energy consumed from the grid, as well as the amount of self-consumed energy and the energy injected into the grid are computed. Thanks to the price of the 3 types of energy (EgP , ScT and FiT), it is possible to calculate the annual cost of electricity, as we know.

Fig. 3 shows the costs of various modes of energy management for the configuration described previously (charge 100kW, PV 100kW, Battery 100kWh), then costs are compared between the French system and the German system.

V. IMPACT OF ENERGY MANagements ON GRID CONSTRAINTS

The presented self-consumption model is integrated into the model of a distribution system in order to emphasize any variation in the probability of constraints rate. For this, a benchmark distribution network model provided by the CIGRÉ has been used (Fig. 4).

In a previous paper [4], the renewable energy integration capacity was computed by a deterministic method – setting the consumption profile at 20% of its real peak power in a bus, and while the production peak power was raised stepwise, a load flow was run until the first constraint appeared in the system. The algorithm was stopped and the peak power of PV production was defined as the maximum power of PV installations to be integrated at the bus thereof.

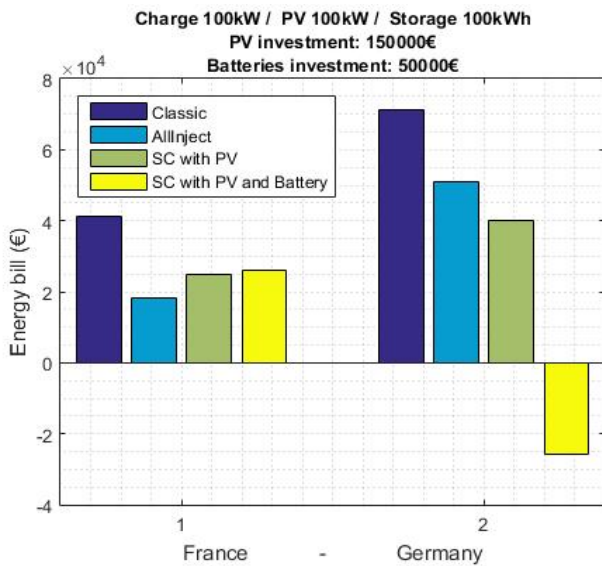


Figure 3. Annual cost of energy in France and in Germany for a given configuration and various energy management modes.

The four bars for France and for Germany on fig.3 correspond to MODE1 to MODE4 as described in the case study, that is to say :

- MODE1 – no PV array or battery considered;
- MODE2 – a PV array injecting all its generated power into the grid;
- MODE3 – the power from the PV array is self-consumed as much as possible by the load, before injecting the rest into the grid;
- MODE4 – same as MODE3 with a battery to increase the rate of self-consumed energy.

A benchmarking made in early 2017 gives a coarse approximation of the investment costs for the system: 1,500€/kWp for PV panels and 500€/kWh for connected batteries including the installation of the equipment. Let's notice that China produces more than two-thirds of the world's PV panels and their price has fallen more than 80% since 2008.

With the cost of the initial investment in such a system, it is possible to compute the Time of Return on Investment (*TRoI*) of the system. The *TRoI* is defined as the time when the gains generated by the system will fully compensate the initial investment.

The *TRoI* within the French framework is 9 years without battery (MODE3) and 12.9 years with a battery (MODE4). As for within the German framework the *TRoI* will be 4.8 years without battery and 1.9 years with battery.

This indicator shows clearly that the German policy is more favourable to self-consumption than the French system. Besides the bar chart shows that the gains are greater in France when all the generated electricity is injected into the grid.

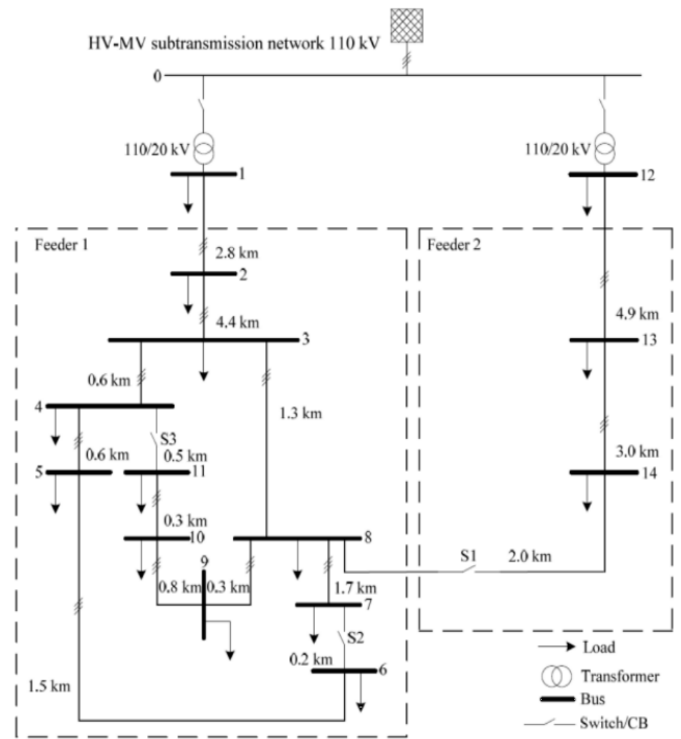


Figure 4. cigre medium voltage network.

The constraints can have two origins: overvoltage in a bus or congestion in a line [5]. Once the maximum integration capacity of the bus was calculated, this capacity was set at 200% and the consumption profile was given its normal peak power of 100%. Then a probabilistic approach using the Monte Carlo method enables the calculation of the probability of constraint in the bus with such a configuration [6]. This method was used for each one of the 16 buses of the CIGRÉ grid and highlighted the bus 6 as the

most vulnerable to constraints [1]. Initially bus 6 was provided with a load of power 380kW and 100kVAR. The maximal integration capacity of renewables was calculated to be 5.8MWp. The following calculation will take 11.6MWp as installed PV power. So, previous self-consumption models and strategies have been integrated into the network model at the critical bus 6.

Then the load-flow is run for each of the 52650 “10-minute time steps” of the annual profiles, and, each time, a constraint is detected the probability of constraints rises. As seen in the table 2, the probability of overvoltage in the bus and of congestion in the lines decreases when the capacity of the battery is rising.

For a configuration without battery (MODE1-2-3), whichever the management of the power (self-consumption or total injection) the probability of constraints will remain the same because the power is conservative within the bus.

However a battery can absorb and release a certain amount of power, and it does it naturally at the most critical moment in the self-consumption mode (MODE4), that is to say when generation is greater than consumption. That is the moment when a constraint can occur.

Table 2 shows the probability of constraints rates in the bus 6 for overvoltage constraints, and in the surrounding lines for congestion constraints. Greater is the battery capacity, lower is the probability of constraints rate. This means that the battery, integrated to the self-consumption system of an Independent Power Producer (IPP) connected to this bus and running for the IPP’s interest, helps to mitigate the constraints in the distribution network.

TABLE II. PROBABILITY OF CONSTRAINTS IN SELF-CONSUMPTION MODE

Probability of constraints			
Battery capacity	0kWh	100kWh	200kWh
Bus 6	0	0	0
Line1-2	0.251	0.223	0.158
Line2-3	0.303	0.270	0.179
Line3-4	0.392	0.346	0.221
Line4-5	0.411	0.362	0.226
Line5-6	0.432	0.377	0.234

VI. CONCLUSION

Self-consumption of renewable energy is a new tendency which can be incentivized with the Self-consumption Tariff (ScT). In France it has always been more interesting to inject all the generated power into the grid, a legal framework for self-consumption was only defined in August 2016.

As seen in this study a self-consumption system including a storage device such a battery can increase the self-production rate and, at the same time, diminish the probability of constraints in the distribution network.

This study showed that implementing a storage device associated with a PV installation connected to the grid helps to decrease the probability of constraints thereof. Here the Energy Management System (EMS) was running into the mode "peak shaving" which consists in absorbing the extra generated power from the PV array.

However other modes exist and can be even more efficient to mitigate grid constraints. As example, nowadays in some places where an overproduction of distributed energy sources is poised to create some constraints into the grid, the grid operator decides to curtail the production of some units. Hence, the producers have to support substantial financial losses [5]. With an electrical storage system and an adapted self-consumption framework, the EMS could decide to work at the advantage of the consumer most of the time and be controlled at the advantage of the grid operator when the forecasted probability of constraints is at its highest point. It could be possible to pay the owner of the storage device for this service.

Self-consumption will grow in the coming years [7] in developed country and in emerging countries, which are struggling grid failures. Nonetheless, new issues may arise with the rise of self-consumption. As example, in current distribution network tariff, if the grid is less used, all taxes could be transferred on other consumers and so discriminations between grid-connected customers are created.

Further studies can be driven on an economic comparison of the cost of necessary reinforcements in the network with the storage solution. If the storage gives flexibilities to the DSO, all technico-economic analysis must be revisited as shown in [10].

Extension to LV network are interesting because greatest connection of facilities with PV self-consumption are expected in the short term. Moreover, as the grid structure is radial, it could be even more questionable that storage can be a way of solving congestion or overvoltage situations less expensive than the reinforcement measures to be adopted in LV networks.

Anyway, economic interest is not the only motivation for citizens. There are many other ways of estimating the benefits derived from the installation of these self-consumption facilities, (reduction of losses - for the appropriate levels of penetration and if there are any, CO2 reductions, by replacing the marginal technologies of the market, ...). In this way, the social and environmental benefits would be valued (global) and not the individual ones (TRoI).

REFERENCES

- [1] B. Dehler, D. Keles, T. Telsnig, B. Fleischer, M. Baumann, D. Fraboulet, A. Faure, W. Fichtner, "Self-consumption of electricity from renewable sources", June 2015, RREB6, INSIGHT_E project, European Commission under the 7th Framework Program for Research and Technological Development, <http://www.insightenergy.org/>
- [2] C. Mateo, R. Cossent, T. Gomez, G. Pretticco, P. Frías, G. Fulli, A. Meletiou, F. Postigo, "Impact of solar PV self-consumption policies on distribution networks and regulatory implications", December 2018, Solar Energy, 176, pp. 62-72.

- [3] International Energy Agency, "Technology Roadmap Energy Storage", Box4: Energy storage technology description, p. 20, 2014.
- [4] M.T. Do, A. Bruyere, B. Francois, "Sensitivity analysis of the CIGRE distribution network benchmark according to the large scale connection of renewable energy generators", IEEE Powertech Conference, June 18-22, 2017, Manchester, UK.
- [5] M.T. Do, B. Francois, "Probabilistic approach to evaluate the cost and constraints of the renewable production curtailment in MV network", IFAC 2017 World Congress, 2017, July 9-14, Toulouse, France.
- [6] V. Klonari, "Probabilistic Analysis of Low Voltage Distribution Networks with Distributed Generation", 2016, PhD thesis, University of Mons, Belgium.
- [7] G. Masson, J. Ignacio Briano, M. J. Baez, « Review and analysis of PV self-consumption policies », Report IEA-PVPS T1-28, 2016.
- [8] J. Garcia-Villalobos, P. Eguia, E. Torres, A. Etxegarai, « Evaluating the impact of geographic distribution of photovoltaic self-consumption on energy losses », IEEE Powertech Conference, June 18-22, 2017, Manchester, UK.
- [9] S. Wang, "Optimal Allocation of Energy Storage System for Fluctuation Mitigation in Active Distribution System", IEEE Powertech Conference, June 18-22, 2017, Manchester, UK.
- [10] A. Chagnard, B. Francois, "Technical and Economic analysis of a Regulatory Call for PV Plants with Energy Storage in French Islands", International Conference on renewable Energies and Power Quality, ICREPQ'19, Tenerife (Spain, 10-12 April 2019 ISSN 2173-038 X, No17 .