Influence of network constraints and product split on the possible revenue of distributed generators providing ancillary services

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Abstract

The total required ancillary services power will increase due to the decrease of the number of traditional generating units and rise of renewable energy resources (RES). New ancillary services providers will be necessary. Thus, RES could cover these new ancillary services needs. This study is focused on the PV system capability on 18 kV network to export ancillary services to transmission level. Three different commercial behaviours, product splits, with different power share in energy and balancing market are defined. In order to evaluate the proposed product splits their revenue is calculated. Past energy tariffs and market prices as well as ancillary services market prices are used. Based on past data on secondary and tertiary control powers, a scenario based on ancillary services market prices implementation is evaluated. Two options are considered: in option 1, the product split at maximum product price and product (secondary or tertiary control) is chosen for each time interval based on the mean price and standard deviation; In option 2, the product split at maximum product price and product is chosen for each instant based on prices. The revenues are calculated based on optimal power flow results for several proposed product splits and product options.

1 Introduction

The provision of ancillary services from renewable and distributed sources has been a key area of investigation of the Swiss Competence Center on Energy Research FURIES, in collaboration with several Swiss DSOs and the Swiss TSO Swissgrid. This contribution covers the activities related to modelling and assessing distribution systems with ancillary services providers. Three case studies have been studied, with a mix of large-scale and small-scale wind and solar providers. In this contribution, the results of one of these case studies will be reported. The key questions discussed will be i) how much potential for ancillary services might be present in distributed renewable generators, ii) how technical distribution network constraints might affect its usage and iii) whether providing ancillary services is economically attractive for distributed generation owners.

Electric power system operators can operate their systems in a secure and efficient way only based on the deployment of ancillary services required for balancing the system or keeping the system voltage within acceptable levels. The main part of those services is currently delivered by generation units mainly connected to the transmission system. As in the future some of those generating units will be substituted by RES that are mostly feeding in the lower voltage levels, the participation of those units on the ancillary services market will have to be considered as well as the potential participation of the consumer itself on the process of controlling the power system. In order to address a part of this new challenge, the main actors of the Swiss electricity sector already established a market framework to involve new RES in the ancillary services market place via the pooling concept [1], [2]. The transmission system operators will have to design the future ancillary services market in such a way that ancillary services from different sources as today shall be considered and their capabilities shall be analysed correspondingly. According to the Swissgrid balancing roadmap [3], the ancillary services products definitions described in [2] will continuously evolve to match with new market needs. The market will then be closer to real time. In the future, the markets for frequency control power will be coupled at the European level. The Swiss energy transition can be expected to lead to a situation similar to Germany where the transition planed increases the needs of positive and negative secondary, as well as the positive and negative tertiary control power [4].

2 Case study description

This paper is focused on the case study "Solar Payerne" where the ancillary services capabilities of an MV connected PV system with an installed capacity of 5.44 MVA are examined. In order to analyse the provision of active or reactive power to the ancillary services market by a PV system, the MV, HV and EHV systems are modelled. The considered network consists of 279 lines, 224 nodes, 103 transformers, 111 loads and 68 generating units. All these elements are modelled in PowerFactory, based on data provided by the local DSO, Groupe E, the Swiss TSO, Swissgrid and MétéoSuisse.

3 Generation and load profiles development

3.1 High voltage system

The measured load profiles (of HV/MV substations other than Payerne) with a 15 minutes time interval are linearly interpolated to obtain profiles with a 10 minutes interval in order to be consistent with the solar irradiance measurements.

3.2 Medium voltage system

The MV system has been modelled as follows (Fig. 1):

- MV connected PV (Solar Payerne) generation is modelled using measured irradiance data.
- Industrial loads are modelled as constant loads since i) their contribution to the total load is low and ii) the behaviour of these loads does not fit to standard load profiles.
- LV grids comprise two variable loads attached to the MV/LV transformer. These loads represent:
    - The collective injection of all LV PV generators within the considered grid, based on measured irradiance data
    - The total LV load, based on profiles generated with the *LoadProfileGenerator* tool [5]. These profiles are weighted such that the resulting loading of the HV/MV transformer is consistent with the measured loading.

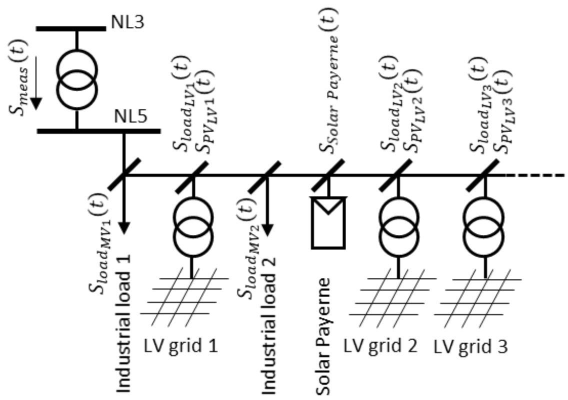

Fig. 1 Considered load and generation elements.

4 Methods and analysis

4.1 Generation units and network constraints

To study the active and reactive power potential to participate in the ancillary services market, constrains must be considered. These constrains are due to inverter rated current, network limits (lines loading, transformers and voltage standard violation at customer connecting points), and weather constraints. These constraints have been included into the formulation of an optimal power flow problem.

4.2 Optimal power flow set-up

The following constraints are set in the optimal power flow formulation:

- The reactive power limit of the inverter depends on the weather dependent active power capability *P(meteo(t))*, and the rated apparent power S_N of the inverter:

$$Q_{\lim} = \sqrt{S_N^2 - P(meteo(t))^2}$$

- Lines and transformers loading limits are set to 100% and 90% for EHV/HV and MV respectively.
- Node voltage limits are set at ±*3%* for MV, according to the D-A-CH-CZ 2007 recommendation.

The optimal power flow tool of PowerFactory maximizes the reactive power injected or consumed by the PV units.

4.3 Product split definition

Small generation units can participate to balancing ancillary services markets via the pooling concept. For voltage support, the generation units contribute to the DSO's position with respect to the swiss voltage support concept [3], which postulates that voltage support should not limit active power exports. This is the reason to use the reactive power limitation at the maximum active power (weather dependent) operating point as a fixed limit. The available active power can be divided between balancing ancillary services market (BM), P_{BM+}/ P_{BM-}, and energy market (EM), P_{EM}. Three different commercial behaviors for this repartition, so-called product splits, have been investigated.

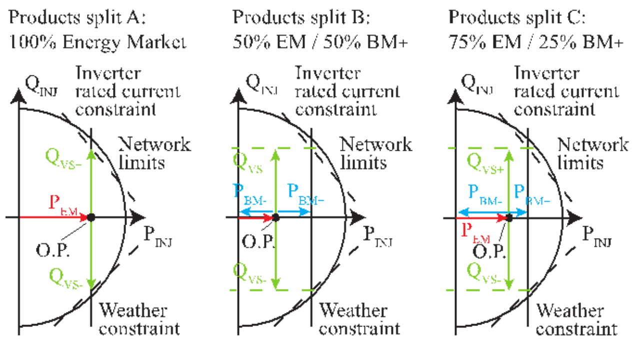

Fig. 2 Product split definition.

4.4 Usage factor of the capacity reserves

The difference between energy allocated (reserved) and energy activated (used) for balancing is modelled with usage factor representing the ratio (0…100%) between energy allocated and energy activated. The determination of these usage factors is described in [6]. When RES generation units are prioritized in balancing markets the usage factor is equal to 1.

4.5 Revenue determination

Revenues for energy generation are determined for both fixed published tariffs (current situation) and EPEX day-ahead prices (possible future option). Remuneration for voltage support by the DSO is estimated according to [6], i.e. according to the conformity of the DSO reactive power exchange with the transmission grid. Capacity and balancing energy prices are based on published data. With this information, the EPEX spot, the capacity and balancing prices used in this study are determined with a 10 minutes' time interval.

4.6 Product split remuneration calculation

The remuneration calculations, described in more depth in [6], have been performed for four cases:

- RES generation units are not prioritized and with fixed published tariffs used.
- RES generation units are not prioritized and with EPEX day-ahead prices used.
- RES generation units are prioritized and with fixed published tariffs used.
- RES generation units are prioritized and with EPEX day-ahead prices used.

The maximum yield potential for secondary respectively tertiary control power is the maximum of three product splits according to Fig. 2 at each time instant. The maximum total yield potential is the maximum of the yield from secondary or tertiary reserve provision (Fig. 3). In this case, the product split is selected for each time interval independently.
The ancillary services market prices-based revenue calculation introduces another approach: the choice of the product split and/or product is made prior the studied time instant based on balancing prices of the past years (2015 – 2019). Two options are studied:

- Option 1, illustrated in Fig. 4: when balancing power prices are below average, product split A is selected. For intermediate prices (standard deviation), product split C is selected. In case of high balancing prices, product split B is selected.
- Option 2, illustrated in Fig. 5: product splits A, B and C are used in fixed proportions of the year. The share of time where product split A is used (intervals with highest prices) is the same as in the maximum yield potential. The remaining time share is split evenly between product split C (intermediate prices) and product split B (lowest prices), Fig. 6.

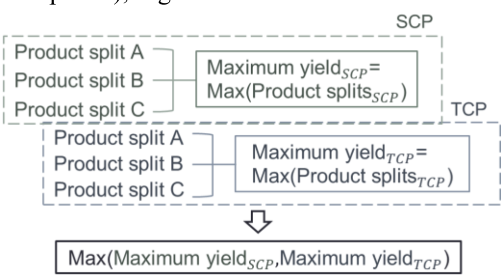

Fig. 3 Maximum secondary control power yield, maximum tertiary control power yield and maximum total yield potential.

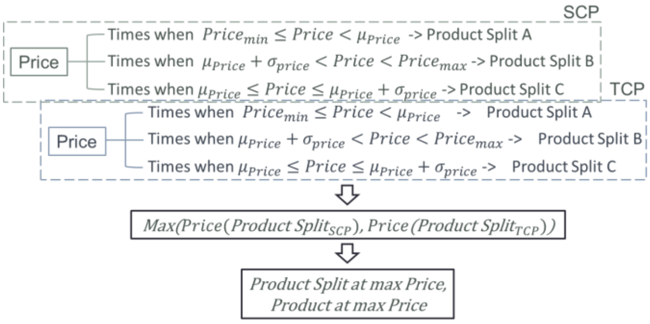

Fig. 4 Product split and product scheduling in option 1.

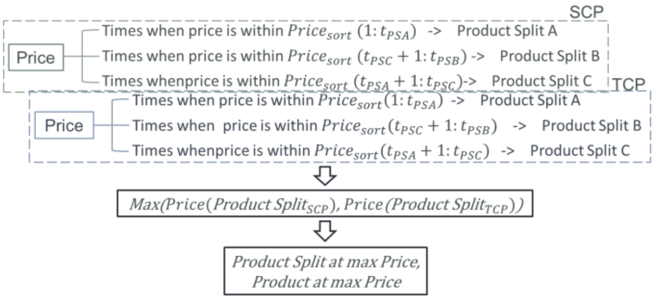

Fig. 5 Product split and product scheduling in option 2.

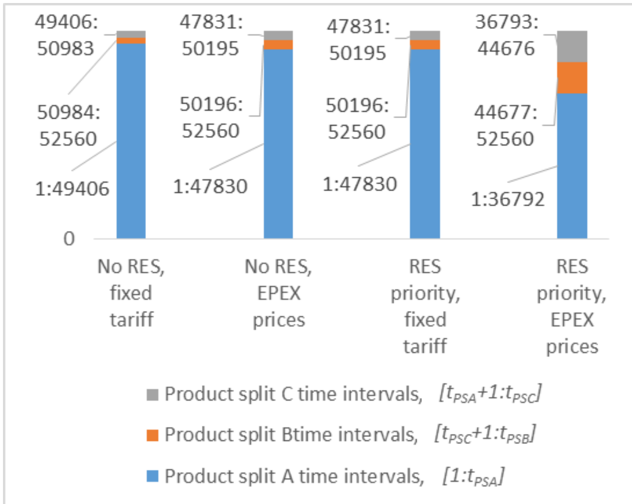

Fig. 6 Time intervals (10 min.) distribution for product splits used for each studied case.

For both proposed options two scheduling methods are compared: i) scheduled product split and scheduled product (secondary or tertiary), ii) Fig. 7a; scheduled product split and real time product selection, Fig. 7b.

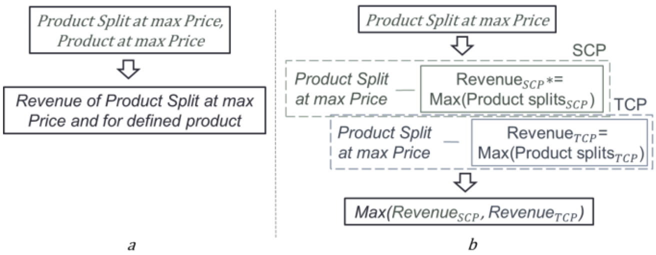

Fig. 7 Two scheduling methods: (a) Scheduled product split and product; (b) Scheduled product split and real time product selection.

In i), the product split (A, B or C) and product (secondary or tertiary control) are chosen prior the studied time interval based on past maximum average balancing prices (2015 – 2019). In ii), only the choice of the product split is made prior the studied time interval. Then the maximum between revenues of both products decides on the product choice.

5 Results

Product splits remuneration results for Solar Payerne as ancillary services provider when RES generation units are prioritized and with EPEX day-ahead prices used is shown in Fig. 8. All the proposed options are compared to product split A – energy market results (in green) and are compared to Maximum total yield potential (in light blue). Option 1 – scheduled product split and product and Option 1 – scheduled product split and real time product is shown in blue and in red respectively. Option 2 – scheduled product split and product and Option 2 – scheduled product split and real time product is illustrated in yellow and in purple respectively.

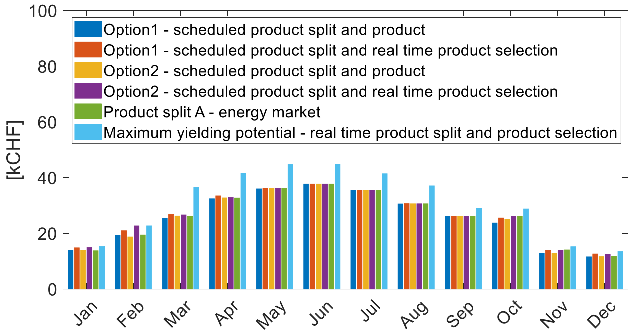

Fig. 8 Product splits remuneration (per month) results for Solar Payerne as ancillary services provider when RES generation units are prioritized and with EPEX day-ahead prices used.

The revenues for all options are below the Maximum total yield potential, which represents the theoretical benchmark. In order to compare the results with product split A the difference between all options and product split A, as well as the difference between maximum total yield potential and product split A has been calculated and shown in Fig. 9. For option 2 the yearly time share allocated to product split A is adjusted for each for each case. The remainder of the year is allocated equally to product split B and product split C as descried in section 4.

Obviously, participating in ancillary services markets would only be attractive to PV owners in case of positive revenue differences compared to product split A, which is the default behavior. In the case of no RES priority and energy market fixed tariffs, the revenue differences are negative or zero (left side of the figure). In case of no RES priority and energy market EPEX prices, the revenues differences are negative or zero for most of options (except Jan. Option 2 – scheduled product split and real time product, Feb. all options, Mar. Option 1 and 2 – scheduled product split and real time product, Dec. Option 2 – scheduled product split and real time product). In the case of RES priority and EM fixed tariffs, the revenues differences are negative or zero (except Jan. all options, Feb., Mar., Apr, Oct., and Nov. Options 2 – scheduled product split and real time product, Dec. Options 1 and 2 – scheduled product split and real time product). In the case of RES priority and EPEX prices, the revenues differences are negative or zero (except Jan. all options, Feb., Mar., Apr., May and Dec. Options 1 and 2 – scheduled product split and real time product).

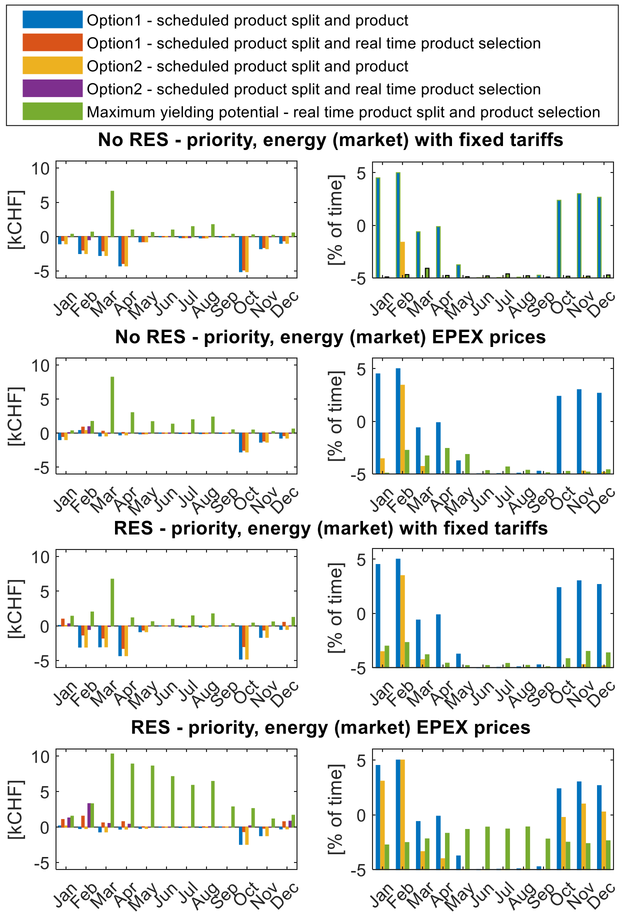

Fig. 9 Revenue difference between all options, maximum total yield potential and product split A (percentage intended to product split A is individual).

The monthly percentage of time when the balancing services are used is on the right side of Fig 9. Since only balancing prices are included in the scenario based on ancillary services market prices implementation analysis, the time intervals when the balancing services are used (product split B and C), are in winter, autumn, spring time and never in summer time. Therefore, only the use of EPEX-based remuneration for energy implies non-zero maximum potential during summer months.

The annual revenues for all options and for the maximum total yield potential scenario are determined and summarized in Table 1. The results show that the case of RES prioritization and EM EPEX prices is the most advantageous for ancillary services provision where the additional revenue is positive in January (all options), February, March, April, and December (options 1 and 2 – scheduled product split and real time product selection).

Table 1 Product splits annual revenue results

		Additional revenue [kCHF]	Relative to product split A [%]	[% of time]
		Fixed tariff		
Prioritized RES	OP1SPS&P	-19.42	-4.36	44.20
	OP1SPS	-9.09	-2.02	44.20
	OP2SPS&P	-18.27	-4.10	2.66
	OP2SPS	-0.22	-0.05	2.66
	MYP	18.62	4.11	2.66
No priority	OP1SPS&P	-18.27	-4.10	44.20
	OP1SPS	-16.63	-3.73	44.20
	OP2SPS&P	-19.42	-4.36	8.80
	OP2SPS	-0.59	-0.13	8.80
	MYP	14.63	3.28	8.80
		EPEX prices		
Prioritized RES	OP1SPS&P	-6.32	-3.37	44.20
	OP1SPS	4.01	2.14	44.20
	OP2SPS&P	-5.17	-2.76	8.70
	OP2SPS	6.34	3.37	8.70
	MYP	60.35	32.22	8.70
No priority	OP1SPS&P	-5.17	-2.76	44.20
	OP1SPS	-3.53	-1.91	44.20
	OP2SPS&P	-6.32	-3.37	30.25
	OP2SPS	0.76	0.40	30.25
	MYP	22.29	11.90	30.25

OP1SPS&P – Option 1: scheduled product split and scheduled product
OP1SPS – Option 1: scheduled product split
OP1SPS&P – Option 2: scheduled product split and scheduled product
OP1SPS – Option 2: scheduled product split
MYP – Maximum yield potential

The positive annual revenues for Option 1 - scheduled product split and real time product is only in case with EPEX prices and RES priority. The positive annual revenues for Option 2 - scheduled product split and real time product is in case with EPEX prices and regardless of RES priority.

6 Conclusions

In this paper the maximum total yield potential for balancing prices known prior the studied time interval are determined for an MV-connected PV system. The maximum total yield potential indicates the highest achievable remuneration in hindsight. Since real-time prices are unknown, two options are proposed to facilitate the choice of a product split and/or product prior the studied time interval based on balancing prices of past years. The results of option 1 show that the participation of PV system in ancillary services market is profitable only in case for prioritized RES when EPEX prices are used. Option 2 revenue results are more advantageous compare to product split A when EPEX prices are used. In order to engage RES to provide ancillary services, RES should be prioritized.

7 Acknowledgements

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