POTENTIAL OF SMALL HYDRO POWER PLANTS FOR DELIVERING ANCILLARY SERVICES IN GERMANY

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ABSTRACT

A high penetration of renewable energy sources leads to a higher demand on ancillary services. To ensure the stability of the network, new approaches need to be developed. Small run-of-the-river hydro power plants offer the opportunity to control the network voltage by reactive and active power. Furthermore, the units can participate on the power balancing market to ensure the operation of the transmission system. For this purpose, the main aspects of ancillary services are presented. Especially, the fundamental regulatory requirements for control reserve and for voltage control are descripted. The efficiency of voltage control in medium and low voltage networks by reactive power variation is investigated in a case study. Thereby, the reachable deviation by this control measure is determined considering high feed-in and high load scenarios, respectively. The deliverable control energy of small hydro power plants is estimated and evaluated concerning the fundamental technical aspects. Especially, the potential for the control reserve capacity for each TSO will be analysed.

INTRODUCTION

Beside a further increase of energy efficiency, the development of renewable energies is an important point to meet environmental and climate change objectives. The power generation from run-of-the-river power plants is free of greenhouse gas emissions and one of the oldest environmental friendly technologies. Furthermore, hydro power plants have a positive economic benefit for the operator. After high investment costs for the plant construction the very low operating costs induce high cost efficiency. Especially in the field of small hydro power plants, with an installed power of lower than 500 kW, a high extension potential is expected. A growth rate of more than 50 % is probable, which means an additional capacity of more than 200 MW [1].

Despite the benefits of this renewable energy source (RES), disadvantages for the ecological system in the rivers are unavoidable. The locations of the plants restrict the path for fish and the transport of sediments. Hence, to enforce the growth of the number of small hydro power plants, the manufacturers and operators argue with the possibility for the contribution of ancillary services. Due to the intensive expansion of photovoltaic- and wind turbine systems, an extension of the existing grid and also a higher use of ancillary services are needed for stability issues of the electrical network. Beside the opportunity for contributing to the voltage control the possibility of delivering control energy is one of the main arguments that are presented. Although, power generation by hydro power plants is an established technology, there is little experience with delivering ancillary services. Until now, this has not been considered for units in the lower power range of smaller than 500 kW because the units are only operated for delivering base load power.

This paper investigates the potential of small hydro power plants for delivering ancillary services in Germany. At first, the main aspects of ancillary services are shown. Especially, the fundamental regulatory requirements for control reserve and voltage control are descripted. Then, the potential for delivering ancillary services by hydro power plants are estimated. Finally, the results are discussed and the conclusions are drawn.

ANCILLARY SERVICES

To ensure the operation of the electrical network, ancillary services are needed. The responsibility for the operation of electrical grids is separated systematically. Whereas the transmission system operators (TSOs) are responsible for the frequency control in their control area, the distribution grid operators (DSOs) have to keep the voltage in the prescribed limits.

Frequency control

For a stable operation of the electrical grid, the frequency target needs to be kept from straying from its value. A mismatch of generated electricity and the demand influences the frequency. Load fluctuations, power plant failures, and volatile power generation by renewable energy sources impinge upon the frequency. If the demand is higher than the feed-in of electricity, the difference of the electric power ΔP leads to a decrease of the frequency Δf. The strength of the deviation is described by the coefficient K_T that depends on the droop characteristic δ of the electrical network. Equation (1) shows the interdependency of these parameters [2].

$$\frac{\Delta P}{\Delta f} = -\frac{1}{\delta} = -K_\mathrm{T} \tag{1}$$

To equalize an unexpected mismatch in power, control reserve is needed. Balancing power can be contributed by technical units like pumped-storage power plants and thermal power plants that hold a part of their power available or by dispatchable loads. Holding the frequency in balance is one of the main responsibilities of the TSOs. The German electricity transport system is divided and controlled by four TSOs: “Tennet TSO GmbH“ (TENNET), “Amprion GmbH“ (AMPRION), “EnBW Transportnetze AG“ (ENBW) and “50Hertz Transmission GmbH” (50HERTZ). The German TSOs procures control reserve jointly on a common internet platform, where the needed amount of control reserve is tendered. Operators of technical units can participate as bidders at the tender auction. Balancing power can be distinguished in three types: the primary, secondary and tertiary or minute reserve.

Primary control reserve (PCR) is provided jointly in the synchronous area to counteract the frequency deviation. It is activated automatically and decentralized by the contributing units within seconds. The tendering period is one week. A minimum lot size of ± 1 MW has to be reached. Units have to provide positive and negative power as well. Secondary control reserve (SCR) is needed to return the frequency towards its target value. It is activated automatically by the TSO in whose control area the incident occurred. The minimum lot size is ± 5 MW. Thereby, positive or negative power has to be contributed. Similar to the primary control, SCR is tendered once a week. For longer disturbances tertiary control reserve (TCR) is needed. It is activated manually by the TSO by means of a telephone call. The minimum lot size accounts for ± 15 MW. It is tendered daily. The following table summarizes the three qualities of control reserve.

TABLE I
Qualities of Control Reserve [3], [4]

	Qualities of control reserve		
	Primary Control	***Secondary Control***	***Tertiary Control***
Control range	positive and negative	positive and/or negative	positive and/or negative
Minimum lot size	± 1 MW	± 5 MW	± 15 MW
Tendering period	weekly	weekly	daily
Activation	decentralised (automatically)	central (automatically)	central (manually)

Beside the requirements above, additional conditions according to the referred literature have to be complied with.

Voltage Control

A deviation from the voltage set point in electrical networks is caused due to the impedance of cables and the number of RES and electrical loads that are connected to the electrical network. Thereby, two various cases are possible. If the sum of electrical loads is bigger than the sum of RES, the voltage will decrease as the distance to the transformer increases. However, the voltage will increase as the distance to the transformer increases, if the sum of RES is bigger than the sum of electrical loads. According to EN 50160, the voltage must not exceed a deviation of ± 10 % of the nominal voltage [5]. The deviation from the voltage set point ΔU_{n} depends on the active power P, the reactive power Q and also on the impedance of the electrical network:

$$\Delta U_{\mathrm{n}} = \frac{PR + QX}{U_{\mathrm{n}}} \quad (2)$$

The impedance $(R + \mathrm{j}X)$ of the electrical network is determined by the used cable. Thereby, various types of cables and various cable cross sections result in different ohmic resistances and inductive reactances. The relation between these two parameters (R/X-ratio) defines the influence of active and reactive power with reference to the voltage deviation. Beside the impedance of the electrical network the voltage can be influenced by a variation of the displacement power factor cos φ of RES. Accordingly, an adjustment of active and reactive power feed-in can be made. The displacement power factor can be defined as the relation between the absolute value of active power to the apparent power S:

$$cos\varphi = \frac{|P|}{S} \quad (3)$$

To reach the maximum active power feed-in, RES are operated at a cos φ of 1.0 in normal operation. The voltage can be decreased or increased by a variation of the cos φ in inductive or capacitive direction. Thus, the RES receives reactive power, if it is operated inductive and provides reactive power, if it is operated capacitive.

Technical Requirements

For the delivering of ancillary services several technical requirements with the focus on the electrical network and the needed communication equipment have to be complied with. To provide a sufficient level of ancillary services a pooling of several small hydro power plants is necessary. Therefore, the units have to be operated and management in a virtual power plant (VPP) as an enclosed unit.

The pooling of technical units creates specific requirements for the VPP operator. The actual operational status has to be transmitted to the TSO/DSO, as well as in the event of ancillary services being required, the activation signals needs to be transmitted to the units immediately. Thus, failure-free and redundant communication equipment is necessary. Furthermore, the VPP operator has to keep a permanently staffed coordination office. The VPP operator is solely responsible for the costs of installing and running this equipment. Fig. 1 shows the general interfaces.

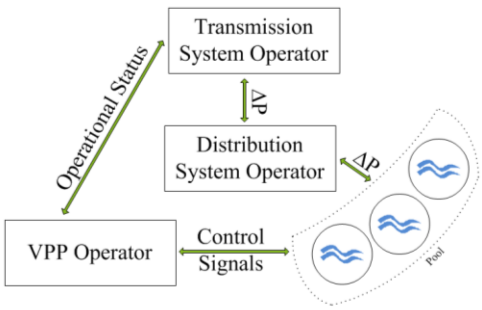

Fig. 1. Pooling of Small Hydro Power Plants to a VPP

The units are connected to the low or medium voltage (LV/MV) distribution grid in the majority of cases. Accordingly, these networks have to be suitable for a bidirectional load flow.

POTENTIAL FOR DELIVERING ANCILLARY SERVICES BY SMALL HYDRO POWER PLANTS

In the following the potential for delivering ancillary services by small hydro power plants is estimated. For this purpose, the reachable voltage deviation by reactive power control is determined and the deliverable control energy of small hydro power plants is estimated.

Frequency control

For the estimation of the fundamental suitability of delivering control energy, the installed power needs to be considered. In 2010 there were 7,040 units with an installed power of 1.87 GW remunerated by the EEG in Germany. 6,488 of these units have a power range smaller than 500 kW. The installed power in this range amounts to at least 0.46 GW. The following table shows the units and the installed power for the four German TSOs.

TABLE II
Installed Power and Number of Units per TSO [6]

Number of units				
	50HERTZ	*AMPRION*	*ENBW*	*TENNET*
0-100 kW	311	846	1151	2871
100-500 kW	201	228	380	500
Sum	512	1074	1531	3371
Installed power [MW]				
0-100 kW	10.14	25.14	38.56	77.22
100-500 kW	52.62	54.80	90.73	106.11
Sum	62.76	79.94	129.29	183.33

For participating on the power balancing market it is necessary to reach the minimum lot size. According to table I, the units in the power range taken into consideration cannot meet this requirement at all. Consequently, a pooling of the units is required. Only through merging and a central control can the units participate in the tendering process. For the primary control a pooling of units is only allowed, when they are in the same control area. For the secondary control a pooling across several zones is only allowed until the minimum lot size. For the tertiary control only units within a control zone can be pooled.
Thereby, not all of the units are generating power at the same time. Due to maintenance, disturbances, etc. some units cannot provide control energy. Furthermore, throughout the year the available water flow and water-level varies. Due to the fact that detailed data for each unit is not available, the average amount of available power P_{av} needs to be estimated. For this, the installed power P_{ins} is weighted with the average of the annual operation time $T_{a,av}$ = 4,500 h and the number of hours per year T_a = 8,760 h.

$$P_{av} = P_{ins} \cdot \frac{T_{a,av}}{T_a} \quad (4)$$

With this simplified assumption the average available power for every TSO can be estimated. According to the minimum lot size, the potential for the contribution of control energy is estimated for each TSO. Therefore, the needed share of available power per TSO for reaching this requirement is determined by pooling the units. In principle, small hydro power plants regardless of the amount of installed power can be pooled inside a control area. However, units can be classified according to their power range to obtain homogenous characteristics of the units. In addition, a classification in two more classes is considered. The classification is 0-100 kW, 100-500 kW and 0-500 kW. Table III shows the results of this approach.

TABLE III
Percentage of the Needed Average Amount of Available Power to Reach the Minimum Lot Size

	50HERTZ	*AMPRION*	*ENBW*	*TENNET*
0-100 kW				
PCR (1 MW)	19 %	8 %	5 %	3 %
SCR (5 MW)	96 %	39 %	25 %	13 %
TCR (15 MW)	288 %	116 %	76 %	38 %
100-500 kW				
PCR (1 MW)	4 %	4 %	2 %	2 %
SCR (5 MW)	18 %	18 %	11 %	9 %
TCR (15 MW)	55 %	53 %	32 %	28 %
0-500 kW				
PCR (1 MW)	3 %	5 %	2 %	1 %
SCR (5 MW)	16 %	12 %	8 %	5 %
TCR (15 MW)	47 %	37 %	23 %	16 %

It can be seen that the minimum lot size cannot be reached in every control area anyway. This is the case for tertiary control in the control area of 50HERTZ and AMPRION, where the minimum lot size is higher than the available power. Also, more than three-quarters of the available power is needed in the control area. The minimum lot size for primary and secondary control can be reached in every control area with the exception of 50HERTZ. Approximately, the total average amount of available power for reaching the minimum lot size for the secondary control is needed. It can be seen from this that the attainment of the minimum lot size is not stable. Due to the needed number of units to reach the minimum lot size, a pooling of units is only reasonable for small hydro power plants from 100 to 500 kW installed power.

Voltage Control

To reach the maximum active power feed-in, RES are operated at a cos φ of 1.0 in normal operation. By varying the displacement power factor, active and reactive power feed-in can be adjusted and thus the voltage in the distribution network can be varied as shown in equation (2). In order to determine the suitability of small hydro power plants to control the voltage by reactive power control, a typical German distribution network is taken into account. The MV network consists of ten 10 km long feeders with ten substations each. Cables of the type NA2XSY 3x240 mm² are used. The R/X-ration of these cables is 1.23. Ten small hydro power plants are connected along one MV feeder. Each MV/LV transformer feeds 144 customers, which are distributed on six LV feeders (length of each feeder: 300 m, cable type: NAYY 4x150 mm²). To determine the potential of small hydro power plants to control the voltage by reactive power control a case study is considered. For this case study the following configuration for the LV network is taken as a basis.

TABLE IV
Considered Cases within the LV network

	Case 1 *(high load)*	**Case 2** *(high feed-in)*
Load per housing unit	0.97 kW	0.68 kW
$P_{n,\ photovoltaic}$	/	5.00 kW
$P_{n,\ electrical\ heat\ pump}$	5.00 kW	/
Share of photovoltaic systems	95 %	/
Share of electrical heat pumps	/	43 %

As can be seen from table IV, a high feed-in, as well as a high load scenario is taken into consideration. The assumed share of photovoltaic systems accounts for 95 % and of electrical heat pumps for 43 %, respectively. The values apply to all housing units in the distribution network. In both cases the number of small hydro power plants is increased hypothetically up to the maximum number of 10. Additionally, the nominal power of the power plants is set to 100 kW, 300 kW and 500 kW. The results of the load flow simulations are presented in the following figure. Thereby, the reachable voltage deviation that occurs at the terminal node is shown, if the small hydro power plants are operated at a cos φ of 0.95. The represented results are related to a cos φ of 1.00.

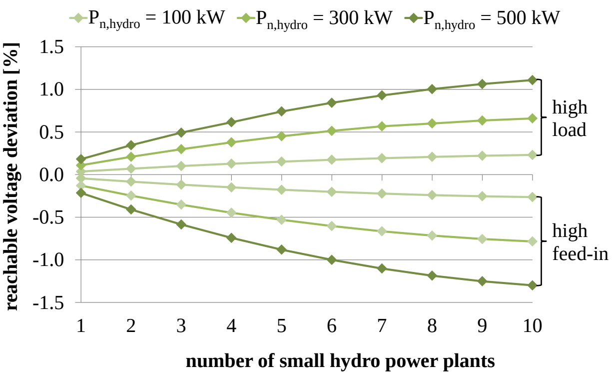

Fig. 2. Reachable voltage deviation at a cos φ of 0.95 (capacitive and inductive, respectively) related to a cos φ of 1.00

It can be seen that the maximum reachable voltage deviation is about 1.3 % in times of high feed-in by photovoltaic systems (case 2). In times of high loads, the maximum voltage deviation is about 1.1 % (case 1). With a considerable effort, by using ten small hydro power plants with a nominal power of 500 kW in one feeder, only a limited effect can be achieved. This points out that the control of the voltage by reactive power is inefficient. A huge number of small hydro power plants with a high nominal power is necessary, to influence the voltage noticeable. If only five small hydro power plants with a nominal power of 300 kW are connected to one MV feeder, the reachable deviation is only about 0.5 % in both cases. In proportion to the used units, voltage control only based on reactive power is insufficient. Additionally an effective active power control is necessary.

CONCLUSIONS

The contribution of ancillary services by small hydro power plants is under the current conditions not reasonable. Due to the average amount of the available power the contribution of all qualities of control energy is not possible for every TSO. Especially in control areas with a small installed power, the minimum lot size cannot be reached safely. Considering the number of small hydro power plants, the reactive power control is inefficient. A more efficient voltage control possibility offers the active power control of the units. As long as the power supply is mainly based on fossil energy resources, an active power control is ecologically not feasible. Because suitable energy storage devices are currently not available, an active power control would result in a squandering of renewable energy resources. This voltage control possibility would require electrical storage devices, which are currently relatively expensive.
The pooling and operation of small hydro power plants to a VPP requires a failure-free and redundant communication equipment. Furthermore, system concepts with integrated electrical storage systems need to be developed. This would increase the grade of flexibility of the units and counteract the disadvantages of an active power control. Assuming a high amount of renewable energy sources for the future power supply, the use of small hydro power plants for ancillary services is ecologically viable.

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