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FEASIBILITY STUDY OF A VIRTUAL POWER PLANT FOR LUDVIKA

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ABSTRACT

This paper presents the results of a feasibility study of a virtual power plant (VPP) in central Sweden designed to provide ancillary services to a 50-kV distribution network. The VPP consists of a wind park, hydro plant and reservoir as well as solar PVs and battery energy storage. The 50-kV sub transmission network was modeled in order to evaluate the ancillary services that could be provided by coordinating existing distributed energy resources in the network. Simulations were performed using measured hourly variations in production and consumption at all network nodes. The studied ancillary services include both reactive and active power control. Contribution from the VPP is evaluated for 1) balancing, to enable a producer to meet spot markets bids and avoid purchases of balancing power 2) minimize peak load in order to reduce subscribed power and tariff to the regional 130- kV network 3) decrease network losses, 4) the contribution from reactive power control using the power converters to reduce the reactive power flow to the overlying network. Quantification of the economic gains from each operation case is provided.

***Index Terms--** Distributed power generation, Energy storage, Power generation planning, Reactive power control, Virtual power plant*

1. INTRODUCTION

The use of electricity from Distributed Energy Resources (DER) like wind and solar power will impact the performance of the electricity network and this sets a limit to the amount of renewables that can be connected [1] [2]. If designed to react to minor fluctuations in the network DER units could become an important asset in the effort to keep the power network stable and allow for more variable energy resources. However, each DER is itself often too small to be effectively controlled and managed by power utilities and energy market actors. A Virtual Power Plant is a term used for aggregation of DER units in order to make them appear as a single, larger, power plant [3]. Whereas the market participation of the VPP is obtained by the joined production of all the DER units, the interaction with the network is different for each unit and depending on their location in the network. When evaluating the opportunities that a VPP offers, the electricity network should therefore be considered as well. This is not only because the network can limit the ability of the VPP to participate in the electricity market. The VPP units may also provide multiple ancillary services, supporting the network.

The value of these ancillary services goes beyond the mere market value of the produced energy. For example many DER units have power electronic converters that are able to operate in all four quadrants. Often these units are set to keep reactive power near zero at the DER connection point. The reactive power capabilities of the DER units are in this way not fully utilized. A more efficient operation of the grid would be possible by controlling the reactive-power flow between the DER units and the grid. The goal of this study is to quantify the potential and economic value of such ancillary services. There is a need to develop and evaluate the control, communication and operational stability of the VPP. The ambition is to implement the VPP described in this paper within an existing Smart Grid Research, Development and Demonstration (RD&D) unit at STRI in Sweden by providing real time communication between the DER units. For this reason the paper concludes with a section about the implementation of the proposed VPP.

2. STUDIED NETWORK AND DER CHARACTERISTICS

2.1 The Network

The interaction between the local network and a VPP has been studied for an existing 50-kV network in central Sweden, shown in Fig. 1. Next to the network data, we had access to three years of hourly data of consumption at all nodes over a three-year period. Hourly production data is used also from a 34-MW wind park and a 6-MW hydro-power unit within the same network. The availability of such hourly data is common place in Sweden, for these voltage levels.

For a number of locations, active and reactive-power data is available with a higher time resolution, from installed power-quality monitors.

2.2 Participating DER Units

The DER units listed below are included in the proposed VPP. All units are existing, even if the size of existing PV installation and Li-Ion battery storage is increased in the simulations. No demand response capability is included in the study. The DER units are envisioned to be monitored and controlled from the RD&D for closed loop testing of the VPP applications.

- A 17 turbine, 34 MW wind park, which cannot currently be extended due to limiting capacity in its 10/50-kV transformer. Currently the turbine converters set reactive power to zero in the two network connection points of the park.

- A hydro plants whose generator is rated 7.7 MVA at 6.6 kV and directly coupled to a vertical Kaplan turbine at 500 rpm. It features a rotating brushless excitation system. Rated power is 6 MW with an average production during 2010-2012 of just over 2 MWh per hour. The rating of the sole generator is low compared to the size of the reservoir thus enabling peak-power production. The local utility also controls all the upstream reservoirs in the catchment area [4]. Regulation is allowed between 44.3 and 44.5 m in summer and 44.0 and 44.5 m in winter, corresponding to a maximum “stored” production of 111 MWh.

  The VPP will be studied together with the STRI RD&D facilities. These facilities include small (30 kW) solar power and Li-Ion storage for one hour maximum solar production (30 kWh). Fuel cells, electrolyser and hydrogen metal hybrid storage as well as two electric vehicles are also part of the facility, but these are not included in this study. Based on an assessment of available roof area in the nearby industrial park the solar power is scaled up to 3 MW in the simulations. The battery storage size is increased in the studies up to 8 MW /32 MWh. The response from PV installation and Li-Ion battery storage at the RD&D facility is increased to represent the larger storage and PV in the studies when simulating the VPP effect on the network.

3. EVALUATED ANCILLARY SERVICES

Based on a literature study and discussions with the local Distribution System Operator (DSO) three applications of network services were selected. A fourth application, where the aggregator operating the VPP is a balance- responsible party, was also included. The applications are presented in Table I. Studies of similar applications of VPP for reactive power compensation are described in [5], for improved system efficiency in [6] and to optimize power flow and minimize the peak network load in [7] [8].

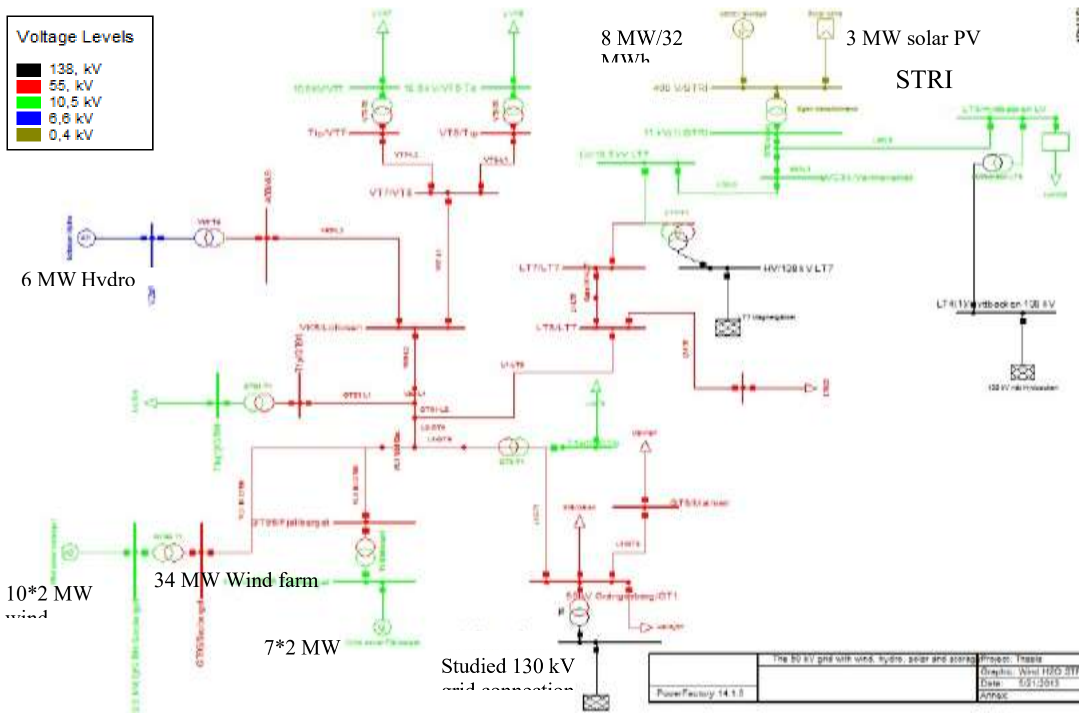

Fig 1. network was simulated but not shown in figure

TABLE I. SELECTED ANCILLARY SERVICES FROM THE VPP

Appl.	Network service
B	Balancing: Compensate for prediction error from non dispatchable DER. The hydro reservoir is used with battery storage to allow the VPP to act as a balance responsible party and meet the forecasted production of the day-ahead spot market of the wind and solar units. In this way the next day stated capacity of the DER units can be confirmed. The limitations set by the 50-kV network on market transactions are specifically part of the assessment.
P	Peak monthly power reduction: Reduce subscribed power to regional 130-kV network in order to obtain a lower tariff for the operator of the distribution network. This application also reduces thermal overload, increasing the networks hosting capacity.
L	Minimize network losses: By smoothing peaks in the power flow the losses in the overlying sub-transmission network are reduced.
R	Control reactive power flow: Lower the reactive power in the connection between 50- and 130-kV networks by coordinating DER reactive power control possibilities.

A detailed description of the implementation of each application can be found in [9]. Pure market oriented optimization of the VPP including maximizing profit from trading on the spot market was not included in the assessment. However, a commercial value of each ancillary service is presented in section IV.A to IV.D. For application B this is non-purchased balance power, for application P lowered tariff to regional network, application L reduction in costs to cover losses in the local network. For the fourth application the value is in the increased network hosting capacity (i.e. ability of the network to host more DER [10]) as well as lower network losses in the overlying network. The gain is also dependent on national regulation regarding e.g. balance responsibility and tariffs [11]. For this reason no assumptions on VPP ownership are made.

This application uses the battery as primary storage and the hydro reservoir as secondary. With higher production than predicted the hydro power plant lowers the power output and the battery is charged. The battery is discharged if the production is lower than predicted. The hydro power output is increased when the battery storage is not sufficient.

A simulation is made for increasing power ratings of the storage. Maximum charging power is 45 % of the maximum discharge power in accordance with the characteristics of the modeled Li-Ion storage of the RD&D. The reduction in prediction error (i.e. need for balancing power) as a function of battery size is shown in Fig. 3. Two curves are shown: for 2-hour and 4-hour ratio between storage capacity and rated power. Fig. 3 reveals only a minor improvement with the larger 4 hour capacity. As the cost of energy storage today is largely influenced by the battery cost it is important that the same converters with fewer batteries can achieve nearly the same effect.

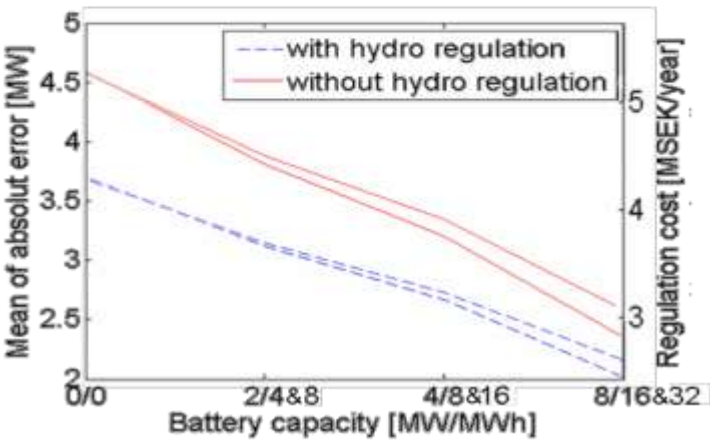

Figure 2. Reduction of prediction error from wind and solar production

4. RESULTS

4.1 Balancing

This application allows a balance responsible party to use the storage and controllable production units of the VPP to meet placed bids on the day-ahead spot market from wind and solar units. The application compensates for prediction errors from wind and solar production. The prediction of production is randomly chosen from a normal distributed curve based on data from [10]. The distribution of production error is given in Fig. 2. It was deduced from [12] that the prediction error of the solar power has similar error and distribution.

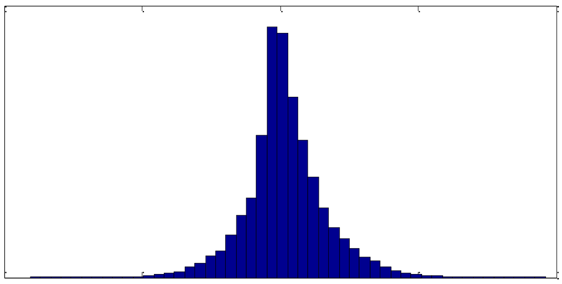

Figure 2. Distribution of prediction error for wind power in North-Eastern part of Germany 2009. The average production in each 15 minute period is 1754 MW.

when included in a VPP with hydro reservoir and different battery storage sizes. The two upper (solid/red) curves are with only battery storage.

The hydro plant and reservoir are able to eliminate 20% of the prediction error by itself. Together with an 8 MW/32 MWh battery storage, up to 60% of the requirement for balancing power can be eliminated. In order to quantify the associated economical gain from balancing, the cost of balancing power on the Nord Pool Spot market was calculated. The economic gain is up to 2 million Swedish crowns (SEK), currently about 230 000 EUR as seen in the right vertical axis scale of Fig. 3.

4.2 Peak Monthly Power Reduction

In this application the aim is to reduce subscribed power to the regional 130-kV subtransmission network in order for the DSO to obtain a lower tariff. The model is made to reduce subscribed power when the power consumption is higher than a limit chosen from historical data. The level is updated during the month so as not to compensate for high power flows that will not result in the hour with the monthly largest MWh power flow that governs the tariff. The application uses primarily the hydro reservoir and secondarily the batteries.

The possible reduction of the maximum hourly power flow during each month is up to 14 MW, as shown in Fig. 4.

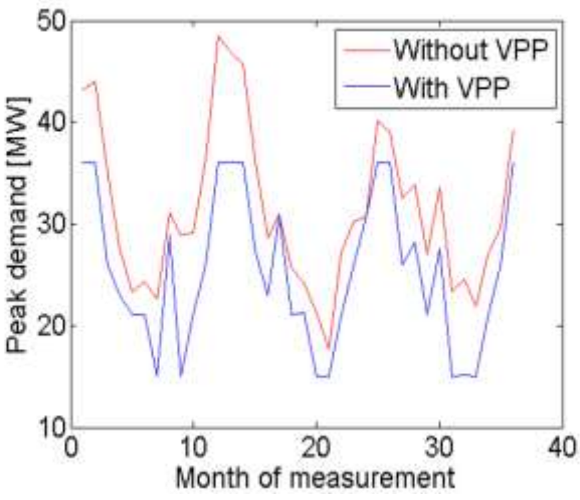

Figure 4. Reduction of maximum monthly power flow with the VPP. Upper (red) curve is the monthly maximum flow without VPP and lower (blue) with the VPP optimised to reduce peak power flow.

The DSO tariff for highest monthly power from the overlying network is equivalent to 70 kSEK (8300 EUR) per MW and year. Thus the annual saving would be 440 kSEK per year. The savings for an end customer from reduced power tariff to the DSO would be three times as large.

4.3 Minimize Network Losses

In this application the battery and hydro storages are used to reduce the power flow variations. This in turn will decrease the transformer and line losses according to equation (1).

With the measured values of active power flow and a power factor of 0.9, 80% of the network losses are due to active power and 20 % due to reactive power. It was found that the reduction of losses in the network with active power compensation from primarily the battery storage was insignificant.

To determine the maximum potential of this application simulations have also been done in which the active power was kept constant during each full day. Even this only resulted in a small reduction in losses in the 130-kV grid, see Table II. As will be shown in Section IV.D, reactive-power control has bigger opportunities to reduce losses.

4.4 Reactive Power Flow Management:

This application controls reactive power flow in the connection point between the 50 and 130-kV networks. The reactive power capabilities of the VPP's DER units are shown in Fig. 5. In Section IV.C the reactive-power control of the DER units was used to maintain voltages. In this application the reactive-power control is used to minimize the reactive power in the 50/130 -kV network connection point. The reactive power flow in the 50/130 -kV network connection was simulated with and without optimization of active power flow. The reactive power requirement results in maximal reactive power output from the storage and generation sources for most of the hours.

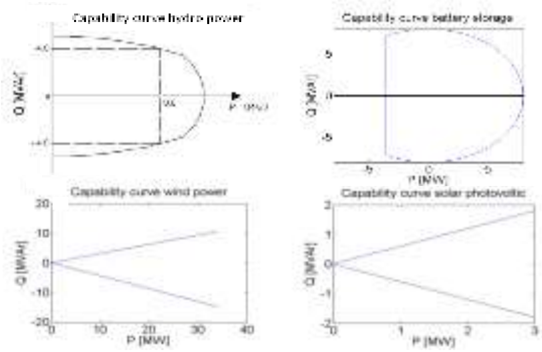

Figure 5. Capability curves of the VPP inverters

5. CONCLUSSIONS

The application most profitable for the Virtual Power Plant was to optimize use of dispatchable production and storage resources in order to meet placed bids on the day-ahead spot market of (non dispatchable) wind and solar resources. This could halve the cost for balance power, a saving of 2.5 million SEK, but it would require relatively large battery storage. To minimize peak load and thereby reduce the tariff could save on average 440 kSEK per year for the DSO. Benefits from reduced network losses and control of reactive power flow where also found but are greatly dependent on the network characteristics and therefore these results cannot be generalized. Especially when using reactive power compensation care must be taken not to violate voltage limits in the network. As reactive power product that cannot be transported over large distances, it is difficult to establish a proper market [14]. Therefore regulatory measures to maximize the hosting capacity for DER may be a more appropriate evaluation criteria then the economic metrics used here when evaluating such ancillary services.

Although gains from the describe VPP amount to 2-3 million Swedish crowns per year the current costs for grid- scale energy storage of these sizes would still mean payback times of several decades. Today the BESS cost is mainly related to the price of its batteries. Thus applications like balancing that rely mainly on a storages power rating are more cost efficient than using the battery storage for tariff or loss reduction (where the capacity of the storage is relatively more important than the power ratings).

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