QUANTIFYING BENEFIT OF ANGLE CONSTRAINT ACTIVE MANAEMENT ON 33 KV DISTRIBUTION NETWORK

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ABSTRACT

Active Network Management (ANM) is an effective approach to release more distribution network capacity for connecting distributed generation (DG) without expensive network reinforcements. A pilot project is commenced by ScottishPower Merseyside And North Wales Electricity Board (SP Manweb) in collaboration with Alstom Grid to trial a new ANM, namely Angle Constraint Active Management (ACAM), on the 33kV distribution network on Isle of Anglesey, North Wales. In the new approach, renewable generation is controlled based on voltage angle difference signals produced by Phasor Measurement Units, and a set of angle constraints derived through offline network simulations. ACAM would require fewer measuring devices and simpler control logics than other existing ANM solutions. In this paper, the approach to find the optimal capacity of non-firm windfarms that can be connected to the Isle of Anglesey distribution network with ACAM is described. The result are presented and compared to the capacity obtained using the 'fit and forget' method and a conventional ANM scheme.

INTRODUCTION

SP Manweb operates distribution networks in North Wales, where there is a large potential for renewable generation, particularly wind power. The pilot project aims to improve the capability of the almost saturated 33kV network on Isle of Anglesey to accommodate more renewable energy, whilst keeping the network secure and reliable and without requiring traditional reinforcements. Current practice is to provide DG operators with a firm connection. Such an approach requires that all the technical limitations such as voltage rise, thermal limits and reverse power flow are respected in any credible operational scenario (e.g., minimum demand/maximum generation, N-1 or N-2 contingencies, etc.). While this might be considered a secure, reliable and proven approach, it neglects the fact that wind power is inherently variable and hence there will be many periods when assets are not fully utilised.

An approach to active management of wind generation, namely Angle Constraint Active Management (ACAM), is proposed to be applied to the distribution network. The concept of ACAM is illustrated in Figure 1, where a non-firm (NF) windfarm is connected at the end of the radial network. Phasor Measurements Units (PMUs) are installed at GSP and the NF windfarm connection point. The voltage angle difference between GSP and the end bus is calculated in real-time and acts as an indicator of the overall network stress. The value is continuously updated and compared to a predefined threshold derived from offline network simulations. If the measured value exceeds the threshold, a constraint violation would occur in the network section and so the NF generation is controlled to ensure the real-time value stays below the threshold at all times [1, 2]. One advantage of ACAM is that it requires fewer measuring devices and simpler control logics than other existing ANM solutions [3].

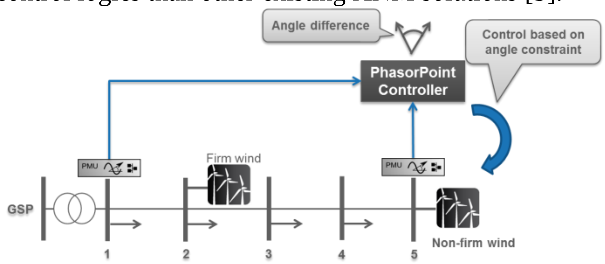


Figure 1: ACAM concept

Unlike other existing ANM schemes in which the windfarms are disconnected when an outage happens, SP Manweb expect the ACAM scheme to maintain its operation even in planned or unplanned N-1 and N-2 network conditions.

This paper gives updates on the current progress of the pilot project, including the network studies done for finding the angle difference thresholds and the optimal installed capacity of NF windfarms connected at different locations on the Isle of Anglesey Network. The results are also compared to those derived if the 'fit and forget' method and a conventional ANM approach are used.

ACAM DEPLOYMENT ON ANGLSEY ISLE

The Isle of Anglesey 33 kV distribution network is shown in Figure 2. The network is connected to the 132 kV transmission system via grid transformers at Amlwch and Caergeiliog. There are windfarms already in operation at Llyn Alaw, Rhydygroes and Trysglwyn, with the installed capacity in the range between 5 MW and 20 MW. Five PMUs have been installed (Figure 2). The locations were decided based on the following considerations:

- where non-firm future wind farms are likely to be connected;
- where the network is electrically strong, i.e. close to 132/33kV substations;

- where measurement CTs and VTs are available.

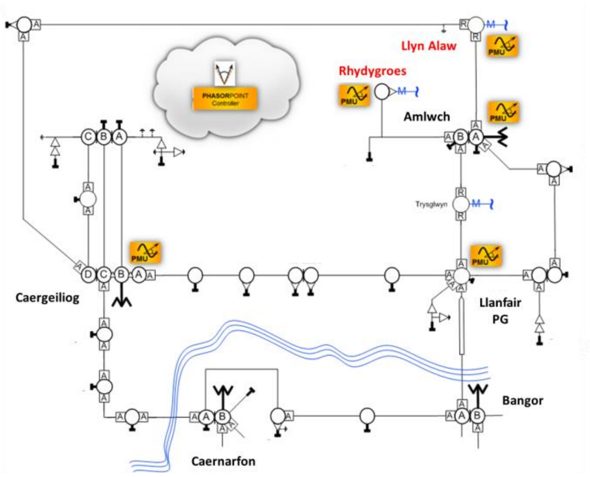


Figure 2: PMU deployment on Isle of Anglesey Network

There is no internet access at some of the locations where PMUs are installed. Therefore, machine-to-machine communication technology is adopted to transmit phasor measurements produced by each PMU to Alstom Grid's PhasorPoint - a software platform for phasor-based network wide area monitoring, control and protection applications. The phasor data communication diagram is depicted in Figure 3. At each substation, phasor measurements produced by the PMU are passed to a substation phasor data concentrator (PDC), which groups the phasor data into fewer data streams and also acts as a storage buffer.

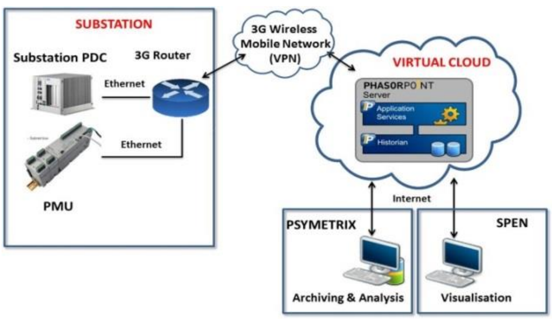


Figure 3: Phasor data communication based on machine-to-machine technology

With the PMUs, five angle differences are measured, as indicated in Table 1. Each angle difference represents the thermal loading condition of a network section it governs.

Angle Difference	Network Section Covered
θ_1	Amlwch - Llyn Alaw
θ_2	Amlwch - Llanfair PG
θ_3	Llyn Alaw - Caergeiliog
θ_4	Rhydygroes - Amlwch
θ_5	Caergeiliog – Llanfair PG

Table 1 Angle difference measurements for managing non-firm windfarms in Anglesey

Under the ACAM scheme, the output of NF windfarms will be regulated if any of the angle difference exceeds its predefined threshold. Llyn Alaw and Rhydygroes are the two candidate locations to connect a NF windfarm.

ANGLE THRESHOLDS CALCULATION

Angle thresholds are derived through offline network simulations considering extreme loading scenarios in different seasons. In each scenario, the intact network and a set of N-1 and N-2 outages are applied. More than 1000 network conditions were identified.

In each of the network conditions simulated, the output of a NF windfarm connected either at Llyn Alaw or Rhydygroes is increased until there is a thermal, reverse power flow or voltage constrain violation. If it is a thermal or reverse power flow problem, the network section that covers the constraint location is identified and the value of the associated angle difference (Table 1) recorded.

After all the network conditions have been studied, the threshold for each angle difference is equal to the lowest absolute value found.

The thresholds derived for managing NF windfarms are indicated in Table 2. The value could be either an upper or lower limit. There are no thresholds derived in some conditions (i.e. NA/NA); this is because in these conditions a voltage problem always emerged first. Voltage constraints are managed directly by voltage measurements.

Angle Difference	Normal	N-1	N-2
θ_1	**-2.45**/NA	**-2.35**/NA	**-2.16**/NA
θ_2	NA/NA	NA/**7.39**	NA/**6.93**
θ_3	NA/NA	NA/**3.89**	NA/**3.86**

(a) Llyn Alaw

Angle Difference	Normal	N-1	N-2
θ_1	NA/NA	NA/NA	NA/**2.25**
θ_2	NA/NA	NA/NA	NA/**6.95**
θ_3	NA/NA	NA/**2.83**	NA/**2.86**
θ_4	NA/NA	NA/NA	NA/**4.54**

(b) Rhydygroes

Table 2: Lower and upper angle limits for controlling NF windfarm at (a) Llyn Alaw and (b) Rhydygroes

One major advantage of ACAM over conventional ANM method was perceived in the analysis. In total, 6 lines were found overloaded in different conditions caused by the NF windfarm at Llyn Alaw or Rhydygroes. If a conventional ANM is adopted, to allow the operation in N-1 and N-2 conditions, 6 measuring devices are required. However, in ACAM, the NF windfarms can be managed with 4 angle differences with their limit values updated if an outage is detected.

It is possible that more constraint locations will be identified if other candidate locations for DG connection are considered. In such case, a conventional ANM will require more measuring devices to measure power flows.

However, it is likely that no additional PMUs will be required, only to update the angle thresholds.

ACAM BENEFIT QUANTIFICATION

It is imperative not just to check the technical feasibility of the scheme, but also to understand what benefit it will bring before the physical implementation.

In this project, the benefit of ACAM is measured as the realistic optimal installed capacity of NF windfarms that could be connected to the network. It is assumed that the optimal installed capacity is found such that a NF windfarm does not suffer from more than 10% of the annual energy produced being curtailed.

The steps towards finding the optimal capacity are described below.

Step 1-Time-series Network Simulations

The step involves finding the maximum generation of the NF windfarms at an hourly interval through a year, using the Anglesey load and generation profiles provided by SP Manweb.

For each hourly loading condition, the maximum generation is found when the network is intact and when the predefined set of N-1 and N-2 outages happen. The flow chart is shown in Figure 4.

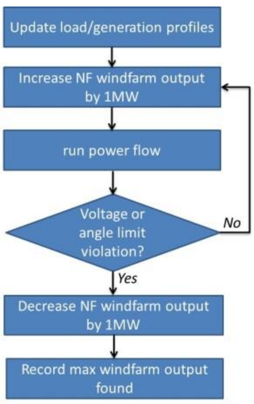


Figure 4: Flow chart for finding maximum NF windfarm generation in each network condition

Step 2-Annual Energy Production Calculation

It is assumed that the load factor variation of a NF windfarm through a year follows the same pattern as the existing windfarm connected in the same area. An hourly load factor of an existing windfarm is calculated by deriving its installed capacity with the corresponding historical hourly generation.

The generation of a NF windfarm before curtailment (unrestricted) at each hour is calculated by multiplying its installed capacity with the load factor of the same hour.

To find the generation after curtailment (regulated), two scenarios regarding the occurrence of outages are contemplated.

The first scenario is to assume no outage happens in a year. This is a normal assumption for calculating the annual energy production and amount of curtailment for a conventional ANM scheme. The hourly generation after the curtailment is equal to the minimum of the unrestricted generation and the maximum generation found in the normal network condition in Step 1.

The second scenario is to assume 4% probability of N-1 outage occurrence and 1% probability of N-2 outage. If an outage happens, the hourly generation after the curtailment is equal to the minimum of the unrestricted generation and the maximum generation found in the most critical outage event in Step 1.

The annual energy production is obtained by aggregating all the hourly generation converted from MW to MWh. However, in the second scenario, due to outages applied randomly to different network loading conditions, the process is repeated to generate large samples. The annual energy production is obtained as an average of the production found in all the samples.

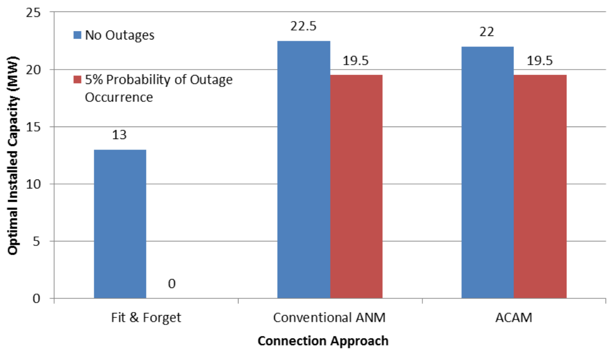
The annual energy production is also calculated for a conventional ANM scheme in a similar way. The only differences are that in Step 1, MVA limits are applied instead of angle limits, and in Step 2, the windfarm is disconnected if an outage happens.

Llyn Alaw NF Windfarm

The optimal capacities of the NF windfarm found with different connection approaches are shown in Figure 5.

With the assumption of no outages, the NF windfarm could have the firm capacity of 13 MW. The capacity increases to 22 MW and 22.5 MW with ACAM and a conventional ANM respectively. The small difference is due to that an angle difference is an approximate indicator of network thermal loading. ANM allows at least 12 GWh more energy to be exported by the windfarm than using the fit and forget approach.

However, if outages are considered, no windfarm can be connected using the fit and forget approach. The optimal capacity and annual energy production in ACAM and the conventional ANM become close, as some energy can still be produced in abnormal network conditions with ACAM.



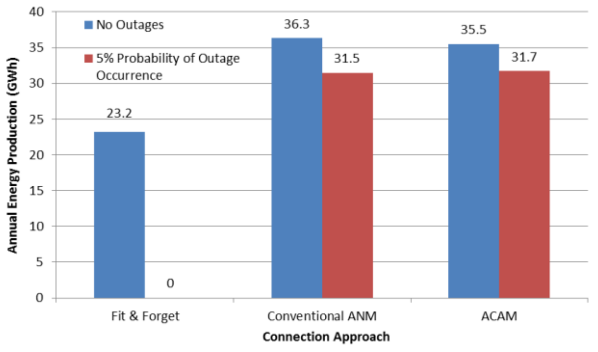


Figure 5 Optimal installed capacity and annual energy production of Llyn Alaw windfarm

Rhydygroes NF Windfarm

The optimal capacities of the NF windfarm found between different connection approaches are shown in Figure 6.

With the assumption of no outages, the firm capacity is 4 MW, compared to 10 MW with ACAM or conventional ANM. It can be noticed that the capacity and annual production in both ACAM and conventional ANM are the same. This is because in all network simulations considering no outages, the maximum generation was always limited by the voltage rise at the windfarm connection point. This validates the angle thresholds in Table 2, where no angle limit is obtained from analysing the normal network conditions.

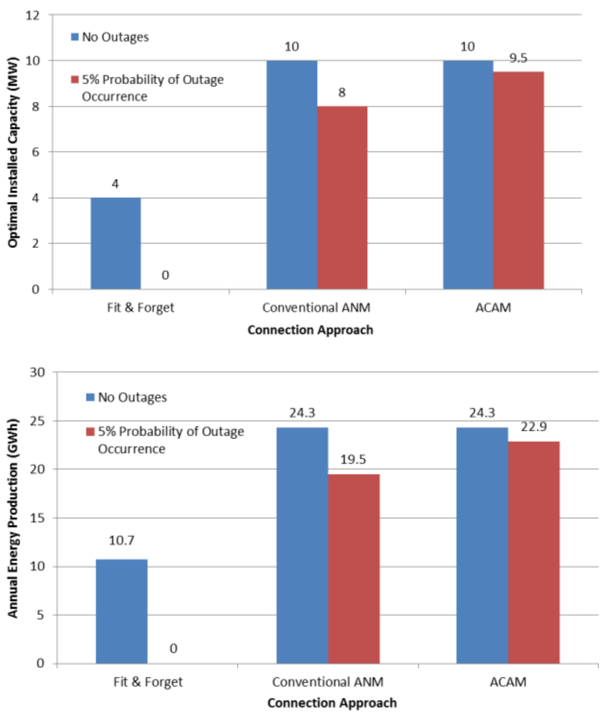


Figure 6: Optimal installed capacity and annual energy production of Rhydygroes windfarm

If 5% probability of outage occurrence is applied, no new windfarm at Rhydygroes can be connected by the fit and forget method. It can be noticed that, in this case, greater benefit is yielded if ANM stays operational in abnormal network conditions. The optimal capacity found in ACAM is 9.5 MW, 1.5 MW greater than the capacity found in conventional ANM. This is equivalent to an additional 3 GWh energy exported in ACAM.

CONCLUSIONS

In this paper, the benefit of Angle Constraint Active Management (ACAM) applying on the Isle of Anglesey 33 kV distribution network was investigated. The benefit was quantified as the optimal installed capacity of non-firm (NF) windfarms that can be accommodated by the network. It is assumed that the optimal capacity is at the level where the NF windfarm does not suffer from more than 10% of its total energy production being curtailed.

One major advantage of ACAM over a conventional ANM is its ability of manage renewable generation in N-1 and N-2 network conditions with minimum number of measurements required. Six thermal constraint locations of the Anglesey network were identified from offline studies, while these constraint locations can be managed by only 4 angle differences with ACAM.

The results showed that with ACAM, the optimal capacity of the NF windfarm connected at Llyn Alaw and Rhydygroes is equal to 19.5 MW and 9.5 MW respectively, while no capacity is available at the two sites if the fit and forget connection approach is adopted. The optimal capacity found in ACAM is also slightly higher than the capacity found in a conventional ANM. The higher capacity in ACAM is due to the ability to allow the NF windfarms to export some energy in outage events, while conventional ANM is most likely to disconnect the windfarm.

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