INVESTIGATING THE POTENTIAL TO MAXIMISE WIND PENETRATION ON DISTRIBUTION NETWORKS THROUGH ACTIVE CONTROL AND THE IMPLICATIONS FOR NETWORK USERS AND OPERATORS

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ABSTRACT

Meeting Irish wind generation targets had lead to very high penetrations of embedded wind generation on distribution networks and will continue to do so over the coming years, Current firm connection policy and little or no use of active voltage control from wind farms requires network reinforcement such that generation can output at its Maximum Export Capacity (MEC) under all network conditions (minimum demand, regular and contingency network configuration) regardless of the frequency of their occurrence. ESB Networks, the Irish distribution system owner and operator, has undertaken an innovative field trials to investigate the potential for active voltage control from wind farms can facilitate increased hosting capacity for generation on existing networks and aid network management in the presence of distributed generation. This paper looks at the application of a range of voltage control strategies including active restriction, demand management and wind turbine reactive control for these purposes, through investigating the potential export which could be achieved on an existing network were such mechanisms employed.

I INTRODUCTION

The MEC of any wind generation installation in Ireland reflects the maximum generation which could be delivered on the network to which it is connected under any loading conditions or under N-1 contingency back-feed conditions. An alternative approach allowing lower reinforcement requirements could be the employment of active approaches to voltage control including generation restriction under certain conditions, wind farm Volt / VAr control or demand response.

This paper addresses what additional hosting capacity might be available under such strategies taking the specific example of an existing network with embedded wind generation. By studying the export of the wind farm and network conditions over the course of a year, under a range of control solutions, the relative levels of export and the implications for the network are analysed.

The modelled test network comprises three lightly loaded rural medium voltage (MV) networks fed in parallel from a single 38kV / 10kV sub station. The networks are coastal and typical of Irish networks, almost 100% overhead and characterised by low load factors and long single phase spurs, posing challenges in network voltage control,. There is a single embedded wind generation site on one of these networks with an MEC of 600kW.

The network has been modelled in OpenDSS, a distribution system modelling tool developed by the Electric Power Research Institute. The model begins at the 38kV bus bar of the feeding substation and details down to 230 V loads on the network. 8760 hourly load flow simulations of the network were performed based on measured historical loading and generation. Increased generation profiles are derived through scaling the measured profile for the year in question.

II INCREASED CAPACITY AND EXPORTS WITH RESTRICTED ACCESS – MEANS OF VOLTAGE CONTROL

A Multiple MEC levels – active export restriction

A means of voltage control facilitating higher export would be for a higher MEC to be allowed with restriction of generation under no-standard conditions (onerously low load periods or in case of network faults) to a reduced MEC.

The base case (Case 0) addressed applies the MEC of the generation is that which is allowed under current policy, the existing thermal rating of the network (lines and substation transformer capacity) and which will not lead to voltage rise going outside of standards under both normal and contingency (N-1) fault conditions, over the full range of load and export conditions.

In case 1 the normal MEC is that allowed by network thermal limits (lines and station transformers), under normal and N-1 conditions. Generation is restricted to a reduced MEC (that of the base case) where the load / demand ratio can lead to voltage rise outside standard. The normal MEC in this case is the capacity of the smaller transformer in the substation and the summer night valley load of the networks fed from this station.

In case 2 the normal MEC is restricted only by the thermal capacity of the overhead network under normal feeding conditions In the case of any network fault, generation is restricted to the normal MEC of case 1. Where loading conditions could lead to overvoltage, there is further restriction to the base case MEC.

In case 3 the MEC is restricted by the full transformer capacity of the station under normal conditions, that of both station transformers combined with the summer valley load. In this case uprates are required such that the thermal rating of the overhead networks can bear this MEC. In the case of any network fault, generation is restricted to the MEC of case 1 and where there is over-voltage, to a lower MEC. This lowest MEC is higher than that of the base case as the increased conductor sizing mitigating voltage rise.

Case	Normal MEC [MW]	Reduced MEC under N-1 fault conditions [MW]	Reduced MEC for voltage control [MW]
Base	1.7	–	–
1	2.26	–	1.7
2	3.38	2.26	1.7
3	7.89	2.26	4.3

Table 1: Reduced MEC levels under restricted access scheme

Table 2 illustrates the absolute and % increase in exported energy in all of the cases described above. Employing this simple system of constraint, for relative increases of 56% 99% and 351% in MEC, there are increases of 39%, 45% and 263% in total energy exported. There is a higher relative increase in export for the initial increase in MEC (case 1) proportionally due to significantly less restriction being required. While there is a significant return on the increased capacity in case 3 due to the voltage rise now being mitigated by higher capacity conductor.

Case	Annual export [MWh]	% MEC increase	% MWH increase
0	5821		
1	8102	56.47%	39.19%
2	8451	98.82%	45.18%
3	21137	350.59%	263.12%

Table 2: Relative MEC and export increases with multiple MEC levels and constraint

For each case the energy not delivered and the number of hours of restricted generation are as in Table 3. As the dominant feature driving restriction is voltage rise, case 2 would be least appealing to the generator who sees the most restriction and loss of potential revenue.

Case	MWh not delivered	% MWh not generated	Restricted hours for voltage	Fault restricted hours
1	688	8%	702	0
2	2650	24%	1921	527
3	4012	16%	1260	527

Table 3: Generation constrained

B Wind turbine reactive control

Background and trials

Modern DFIG wind turbines increasingly have voltage control capabilities borne of decoupled active and reactive performance – once active generation is above a minimum level reactive power can be absorbed or delivered over the range of 0.95 leading to 0.95 lagging of rated MW capacity.

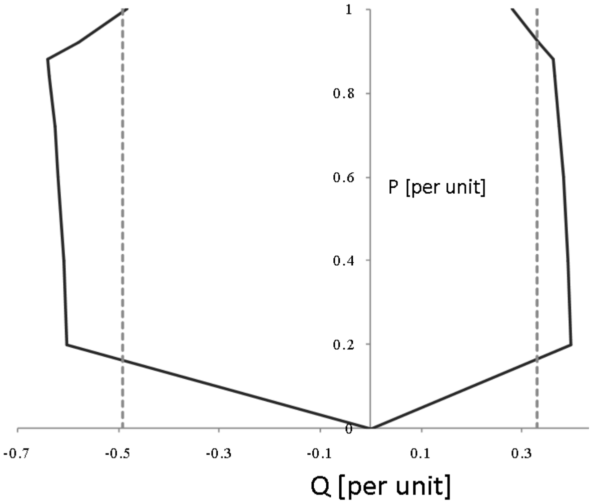

Figure 1: Reactive capability of wind turbines

Figure 1 illustrates this characteristic as demonstrated in ESBN field trials of distributed wind farm Volt / VAr control [1] . This trial demonstrated coordinated Volt / VAr control of two wind farms on live networks, MEC 17MW and 22.5MW, sharing a dedicated 38kV connection and 110kV / 38kV transformer at a load feeding substation. Each of the wind farms controlled the voltage at their point of network connection to a set point through varying reactive demand.

Figure 2 illustrates the decoupled active and reactive performance delivered, and the correlation between reactive demand and voltage along a specified droop slope.

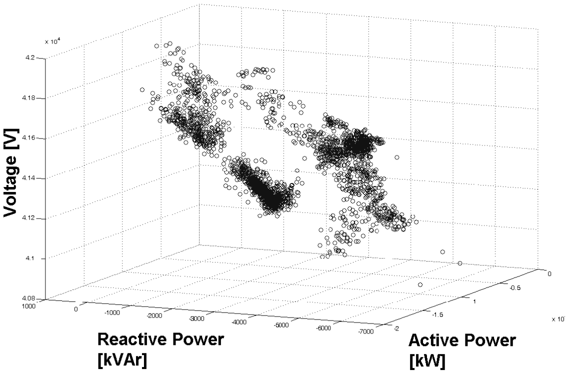

Figure 2: Decoupled P and Q, P V relationship

With voltage rise a significant parameter limiting the generation capacity of networks, this local voltage control demonstrated the potential to facilitate a further 5 MW of generation on the network in question without reinforcement. The level of additional generation is heavily dependent on the characteristics of the network in question. If this full hosting capacity were to be availed of then the potential for reactive power to be supplied as an ancillary service or exported to the transmission system would be extremely limited or precluded. As illustrated in Figure 3, at times of high active export, the wind farms must operate in inductive mode to keep their local distribution voltage in standard.

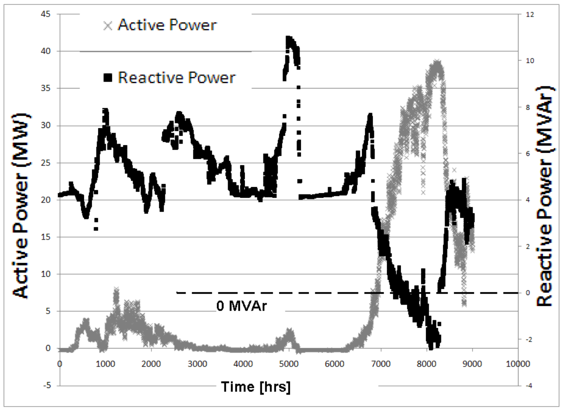

Figure 3: Rise in active generation causes reactive output change from capacitive to reactive

Increasing export capacity through voltage control

In simulations of cases 1, 2 and 3 as described above, where the voltage could go outside standard, reactive power was absorbed to reduce the voltage at the point of connection. This reactive power demand availability is as illustrated in Figure 4. As case 1 is the only instance where the network thermal rating is in excess of the higher MEC, there is more scope for reactive control at higher active export levels, when it is most likely to be required.

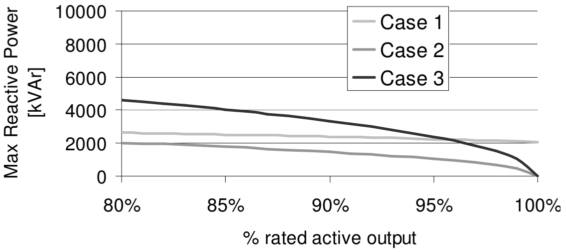

Figure 4: Reactive power at % of rated active export, as constrained by network thermal rating

Where the reactive control was insufficient to reduce the voltage within standard, generation was restricted, as in section A. Table 4 illustrates the additional active export facilitated over restriction as in section II A and the energy not generated as result of any restriction. As over-voltage was largely due to high wind generation as opposed to low network loading, there was often little available increase of reactive demand

Case	Export [MWh]	% MWh increase over restriction	MWh not generated
1	8274	2.12%	516
2	8819	4.35%	2282
3	24556	16.18%	593

Table 4: Additional generation and constraint with reactive power control

Due to the reactance of the networks being relatively higher than the resistance, reactive voltage control delivers greater voltage improvement in the cases of higher export, as illustrated by relatively higher success levels particularly in case 3.

C Integrating demand side management

In simulations of case 1, 2 and 3 a single commercial or industrial installation is sited locally to the wind farm, offering immediate voltage control potential. 450kW and 300kW were taken as potential load based on measured average demand response in Ireland run by the TSO.

It is assumed that the load must be run on a daily or near daily basis (no more than once in any day). Once the voltage at the wind farm connection hits the allowable limit the load is triggered, provided it is available. If not, wind farm output is restricted, as in sections A and B.

Case	Total MWh export	% increase over constraint	Total MWh not generated
1	8379	3.42%	411
2	8881	5.09%	2220
3	24557	16.18%	592

Table 5: Increased export with DSM

Table 5 illustrates significantly more effective in voltage control in case 3 than in case 2. Analysis of the average over-voltage seen in both cases without any voltage control shows that in case 2 this is 146 V, but in case 3 just 71 V. Thus the limited additional load seen by the generation is sufficient to negate voltage rise a far higher proportion of the time, indicating that this solution is best suited where the expected over-voltage is relatively low.

III IMPLICATIONS

Protection

Simulated power factors down to 0.63 and measured field trial ones near zero, with reactive power flows in excess of active ones as illustrated by measurements of simultaneous exports of 6.5 MVAr and 3.7 MW or 6 MVAr at 3.6 MW during the trials in section B, mean that protection will be called upon to operate over wider angles in the PQ plane.

At present differential over current protection on 38kV networks, has directional vision over the semi-circle centred around the 45° from the +P axis in the PQ plane, so should be sufficient for the operations described. However on MV networks at present there is only non-directional over current protection. With higher levels of embedded generation, a review of protection may be required addressing are directionality and installation of VTs for protection relays on networks which historically did not see power factors below 0.95.

Business cases

Realizing this additional export would require significant additional investment with installation cost estimates of €1.23m / MW [[2] in the EU and €1m / MW in Ireland [3] and significant cost in case 3 due to the uprate of almost 4km of overhead networks. Table 6 shows the increase in wind farm annual revenue which the additional generation in section II would earn based on Irish renewable feed-in tariffs.

		Increase over baseline [€m p.a.]		
Case	**Base line**	**Constraint**	**Reactive control**	**DSM**
0	0.34			
1	0.48	0.13	0.14	0.15
2	0.50	0.16	0.18	0.18
3	1.20	0.87	1.07	1.07

Table 6: Increase revenue based on Irish REFIT rates

	€m per annum			
	WDPRS payment	**If** 10% unreliable	**Increased REFIT revenue to WF with DSM (over constraint case)**	
300 kW, 2 hours	0.04	0.02	Case 1	0.02
200 kW 3 hours	0.06	0.03	Case 2	0.03
300 kW, 2 hours	0.07	0.04	Case 3	0.19

Table 7: Return of DSM relative to WPDRS revenues

Table 7 shows that the return a demand facility would see from existing DSM schemes such as WPDRS is relatively high in comparison with the additional revenue the wind farm would have generated in section II C, suggesting that a limited business case for such co-location from the demand customer's perspective.

CONCLUSIONS AND FURTHER WORK

This paper illustrates the additional hosting capacity on an existing distribution network. While the results are network specific and could not be directly applied to other networks., the test case is extremely typical of Irish networks in regions with high wind resources. There is a case for the wind generator, through reduced connection costs and increased revenues. However the implications for the DSO in terms of management and control warrant address as any active strategies rely on highly reliably communications and adherence of the generator in all cases.

Furthermore, were "restricted" hosting capacity to be made available on networks where there is already full uptake of the firm capacity, this could lead to reduced capacity factors for the existing installations. Additionally with multiple "restricted" installations, the relative levels of restriction and how they are applied would have to be subject to a strict technical framework, as yet not developed.

The technical capability of Volt / VAr control has been proven in practice through the field trials described above and developing the framework for its implementation on a wider basis, the implications for network management and a framework for the interaction between the DSO and distribution connected generation going forward must be addressed to realise this.

REFERENCES

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[3] Whiriskey, J, McCarthy, P 2006, *Wind Farms, Fact Sheet No 49*, Teagasc, Galway, Ireland