Title	Reactive Power Support from Distributed Generation — Ireland's Demonstration Initiative
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Publication date	2012-07-26
Publication information	Keane, Andrew, Ellen Diskin, Paul Cuffe, Daniel Brooks, Tony Hearne, and Teresa Fallon. “Reactive Power Support from Distributed Generation — Ireland’s Demonstration Initiative.” IEEE, July 26, 2012. https://doi.org/10.1109/PESGM.2012.6345027.
Conference details	The 2012 IEEE Power and Energy Society (PES) General Meeting, San Diego, California, United States of America, 22-26 July 2012
Publisher	IEEE
Item record/more information	http://hdl.handle.net/10197/25710
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Publisher's version (DOI)	10.1109/PESGM.2012.6345027

Reactive Power Support from Distributed Generation - Ireland’s Demonstration Initiative

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Abstract-- **The integration of increasing penetrations of renewable energy sources is one of the key drivers for the increased deployment of control and optimization on power systems. Much of this wind generation is connected to the distribution system, which presents a range of challenges to the operation of these networks, traditionally utilized solely for power delivery. This paper describes a demonstration programme in Ireland which addresses key challenges in delivering high penetrations of wind energy in a cost effective and efficient manner. The paper addresses the advanced reactive power control capabilities of modern wind turbines, along with other voltage control technologies, investigating how these resources can be better utilized from a distribution and transmission perspective.**

Index Terms-- **Voltage control, power distribution planning, reactive power, wind power generation, distributed generation**

I. INTRODUCTION

Electricity networks of the future will need to be smarter, more accessible and more efficient. In Europe the SmartGrids technology platform has set out deployment priorities for smart networks [1]. European Union policies mandate ambitious targets for renewable generation [2]. These targets stipulate renewable energy penetration for the year 2020: Ireland is to derive 16% of its total energy use from renewable sources by that year. To that end, the target for renewables penetration in electricity generation has been set at 40%; the vast majority of this will be met with wind generation. About 3,900 MW of additional wind capacity must be connected to deliver this, which will bring the total connected capacity to 6,400 MW, on a system with a peak demand of approximately 5,500 MW. This rapid growth of renewable energy resources, in particular wind energy has led to numerous well established challenges to power system planning and operation. Consequently, ESB Networks (ESBN), the Irish distribution system operator, and the Electric Power Research Institute, working with University College Dublin, have initiated a Smart Grid Demonstration project which aims to address key questions on the integration of distributed wind energy.

A trial of the advanced reactive power control capabilities of modern wind turbines, investigating how this resource can be better utilized from a distribution and transmission perspective is presented here. The trial results indicate that the reactive power capabilities of modern wind turbines can be used for a range of objectives, such as loss reduction, local voltage control and reactive power export. It is important to note, however, these objectives may be conflicting, dependent on a range of factors such as wind power output, network impedance and the state of the transmission system.

Section II outlines the results of a field trials of voltage control and reactive power management on a 38 kV section of distribution network in Ireland. Section III describes a separate trial of autotransformer to regulate the voltage and facilitate increased generation capacity on existing networks. Section IV gives the conclusions and outcomes of the trials to date.

II. WIND FARM REACTIVE POWER MANAGEMENT

A. Demonstration Network

The network selected for this trial is a section dedicated to wind energy, without any demand customers. It is a section of 38 kV network which connects two wind farms to a 110 kV transmission node as shown in Fig. 2. These wind farms are located in the rural South West of Ireland, in a sparsely populated region with only a modest level of distribution system development.

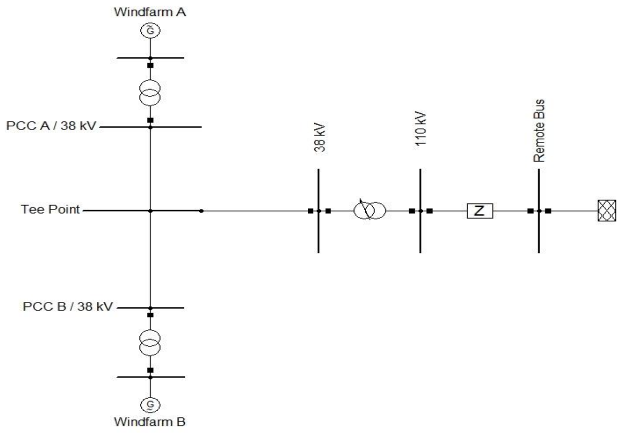

Fig. 2 Single line diagram of test wind farm network

Wind farm A has a maximum export capacity of 22.5 MW. This is realized with nine 2.5 MW turbines. Wind farm B comprises thirteen 1.5 MW turbines, with a total maximum export capacity of 17.2 MW (installed capacity is 19.5 MW). The interface point between the distribution network section and the transmission system is a 110/38 kV transformer rated at 63 MVA. These transformers have historically been the principal means of distribution system voltage control, with their on load tap changers maintaining sending voltages on the 38 kV side within a tight band in the face of varying voltage at the transmission level. PQ meters were installed at each wind farm and at the Bulk Supply Point (BSP) recording data at a 30 second resolution. The absence of load on the network

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This work was partly conducted in the Electricity Research Centre, University College Dublin, Ireland, which is supported by the Commission for Energy Regulation, Bord Gáis Energy, Bord na Móna Energy, Cylon Controls, EirGrid, ESB Energy International, ESB Energy Solutions, ESB Networks, Gaelectric, Siemens, SSE Renewables, SWS Energy and Viridian Power & Energy.P. Cuffe is funded through the SFI Research Frontiers Programme under grant number 09/RFP/ECE2394. P. Smith and A. Keane are funded through the Science Foundation Ireland (SFI) Charles Parsons Energy Research Awards.

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B.

identifies it as a sensible test platform for demonstrating a new voltage control regime.

B. Reactive Power Capability

Each of the wind farms comprise modern wind turbine generator technology that offers reactive power that is largely decoupled from active power output. The objective of utilising the voltage control capability of the network is to investigate if a coordinated policy can be developed for the operation of these farms. The question being addressed is firstly to assess voltage control operation on a live network and beyond that to determine the optimum setpoints and overall strategy for managing voltage and reactive power on distribution networks with wind energy. Of particular interest is the potential for voltage control at distribution level and to investigate the potential for export of reactive power from the wind farms, determining if there is potential for distributed wind to be part of the solution of the power system's reactive power needs.

As shown in Fig. 3 modern wind turbines such as those employed in this trial have a significant reactive power capability, which is decoupled from active power over a wide range of operating points. The dashed line indicates the extra capability of wind farm B over wind farm A at active power outputs below 0.2 pu. For wind farm A, the reactive power capability and it is not fully decoupled from active power. As had been demonstrated in [3] this capability is network and turbine dependent.

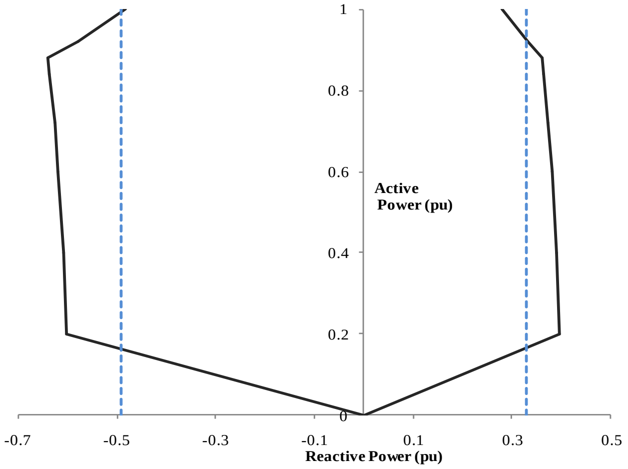

Fig. 3 P-Q Capability chart for the two wind farms

C. Time Series Power Flow Simulations

The first stage of this demonstration was to determine the existing state of the network and the wind farms and based on that base case data run simulations to determine what voltage controller settings to deploy. Fig. 4 shows the active power output of the two wind farms over a sample period with a data resolution of 30 seconds. It illustrates what is evident from all the time periods of investigation, which is a closely related active power output for the wind farms, as expected given their locations 9 km apart.

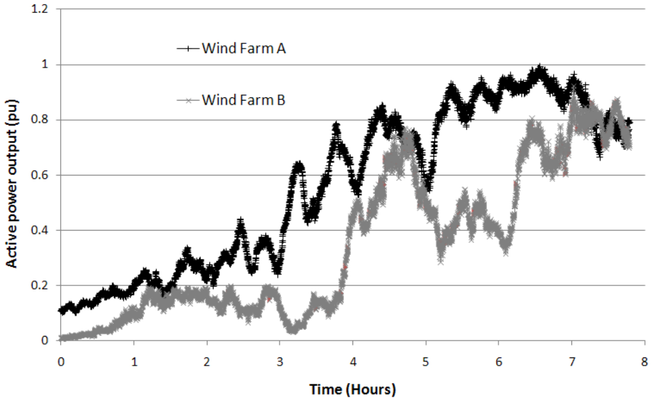

Fig. 4 Active power output of the two wind farms for a sample period

The tap changer at the BSP is an important variable in the control of local voltages and consequently in determining the reactive power output of the wind turbines. Time series power flow simulations at a resolution of 30 seconds were carried out under varying scenarios to determine what voltage set points, droop and tap changer configuration would provide the maximum insight into the controller performance and network operation for the duration of the trial. Two scenarios are described here in detail as means of illustration.

1. Voltage control is enabled at both wind farms, regulating voltage to 41.6 kV and the sending voltage at the BSP set to 41.6 kV
2. The tap changer is locked to a low tap setting, resulting in a no load voltage of 39.36 kV and again control is enabled at both wind farms[1].

From Fig. 5 the reactive power exchange at the bulk supply point over the period of simulation can be examined. In scenario 1 it is evident that the network is demanding reactive power from the transmission system, even with both voltage controllers enabled and regulating to a high local voltage set point. This is due to the active power output of the wind farms and the tap changer set point. Over the eight hour period the influence of the active power output is particularly evident. The increasing active power output causes local voltage rise, which is counteracted by the voltage controllers resulting in an increased reactive power requirement at the local wind farms and thus the 110 kV BSP. The degree of voltage rise and the relative effect of active and reactive power on the voltages is a function of the network impedance and in particular the X/R ratio.

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[1] 39.36 kV is outside planning standards and normal busbar operation standards

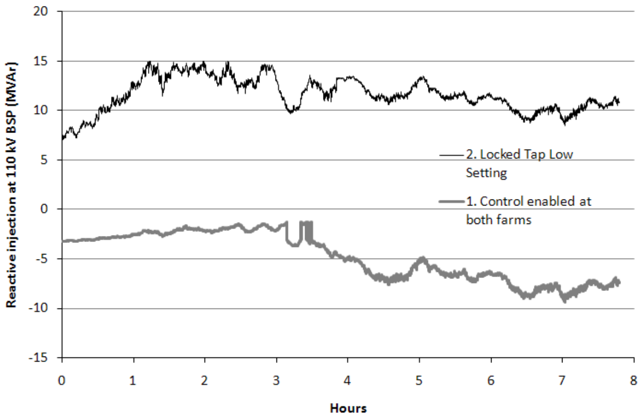

Fig. 5 Reactive power at BSP under scenario 1 and 2

In scenario 2 the low sending voltage depresses the voltage out along the feeders to the wind farms. This lower voltage results in the voltage controllers specifying capacitive operation with the resulting supply of reactive power from the wind farms at the BSP evident in Fig. 5.

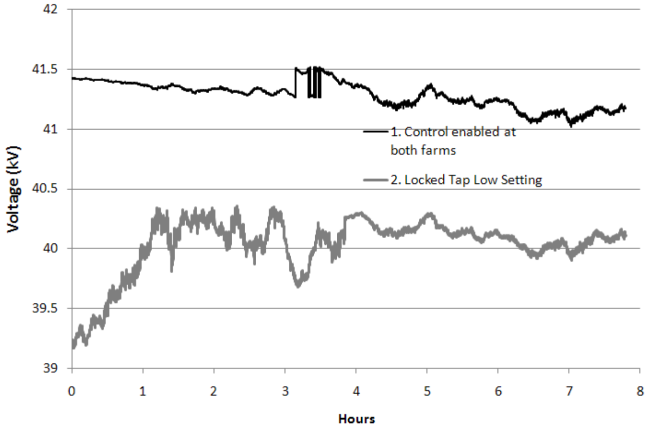

Fig. 6 Voltage at the BSP under scenario 1 and 2

Fig. 6 shows the resulting voltage at the BSP. It can be observed that devolving control to the wind farms in scenario 2 results in a more variable voltage at the BSP, whereby the voltage at the BSP is now driven largely by the active and reactive power flows from the wind farms, assuming a nominal voltage on the transmission system.

D. Trial Results

The next stage of the trial was to enable voltage control at each wind farm individually, with the other wind farm operating at the business as usual fixed power factor of 0.95 inductive. The network was operated under each configuration for a period of approximately three weeks each starting in May 2011 and running until August 2011. Initially, wind farm A was specified to operate with a 1% droop (regulation slope) and a voltage set point of 41.6 kV. Fig. 7 shows a sample of the measured data from wind farm A. The operation along the droop characteristic is evident, with reactive power operation in both inductive and capacitive halves of characteristics as was desired for the purposes of the technology trial.

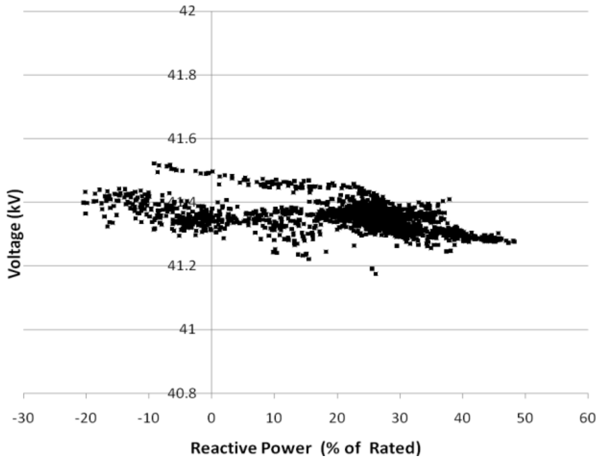

Fig. 7 Q-V measurements from wind farm A with voltage control enabled

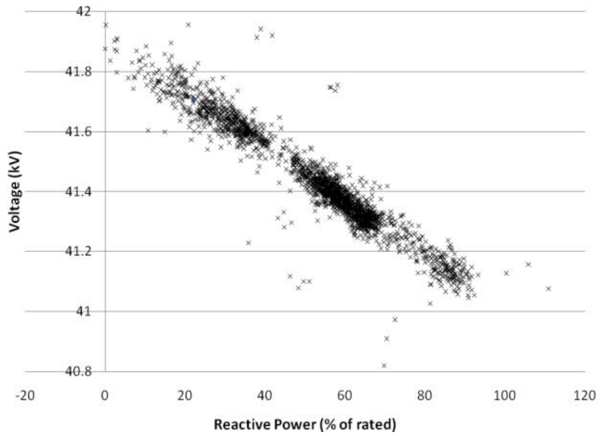

Fig. 8 Q-V measurements from wind farm B wind voltage control enabled

The same procedure is followed with wind farm B, in this case operating with a voltage set point of 42 kV and with a droop of 4%. The 4% droop as compared to 1% introduces a wider variation in the achieved voltage. Fig. 8 demonstrates the successful operation of the wind farm in constant voltage mode. The turbines can be seen to be operating successfully along the defined droop. One feature to note in comparing Fig. 7 and 8 is the different width of the cluster of points. It is evident that wind farm B controls the voltage with a greater degree of adherence to the droop setting. Relevant factors at play here may be the time constant of the controllers, along with other controller gain inputs, which are tuned on a wind farm by wind farm basis.

E. Potential System Benefits

The maximum generation capacity that can be connected to a given network is another important consideration for network operators. From load flow simulations, the enabling of voltage control and the tap changer at appropriate set points allows the voltage constraint at all local buses to be overcome and the thermal line rating becomes the binding constraints. In the case of this network there is an extra 6 MW of generation capacity permitted. This increase in capacity also indicates that the use of voltage control may be a useful consideration at the planning stage of wind connections. It should be noted that any extra capacity is enabled through inductive reactive power operation to overcome the voltage rise constraint, which will be at the expense of the potential for reactive power export.

The potential for distributed wind to provide ancillary services is an increasingly relevant topic. At times of high wind power output, distributed wind can represent a significant penetration of overall system generation. For example, in Ireland this instantaneous penetration has reached ~25% [15]. As a result the reactive power of DG is an important consideration for voltage security and stability. In Fig. 11, the reactive power exchange is shown at the 110 kV bulk supply point. It can be seen that in this trial stage with both wind farms operating with voltage control enabled supply of reactive power from the wind farms is achievable. It is evident that at times of high active wind power output, in order to satisfy local voltage constraints, the wind farms reduce their reactive power and even switch to inductive operation at times. This illustrates a key trade-off between accommodation of active power and provision of reactive power support.

It is important that the relative merit of different outcomes of this kind of control (local voltage management increasing the hosting capacity of the network, provision of reactive support for the transmission system) be assessed from the perspective of both system operators and all network users including generators. With high distributed wind generation, customer power quality must be maintained to a high level at all times, without any degradation or additional cost to mitigate this being incurred by society. If an ancillary service provided by a generator is for the sole purpose of mitigating local voltage variation due to the active export of this generation itself, then it should be considered technology necessary for connection (i.e. a system in place of built infrastructure otherwise required) as opposed to a commercial resource. Any integration of such voltage control into network operational and connection policy, network standards and any contractual arrangements in future must reflect this while realising the benefits such voltage control can offer.

For integration of dynamic reactive voltage control on a wider basis it would be of merit to consider the impact on network power factors and a review of policy in this regard, even on a specific-case basis may be necessary.

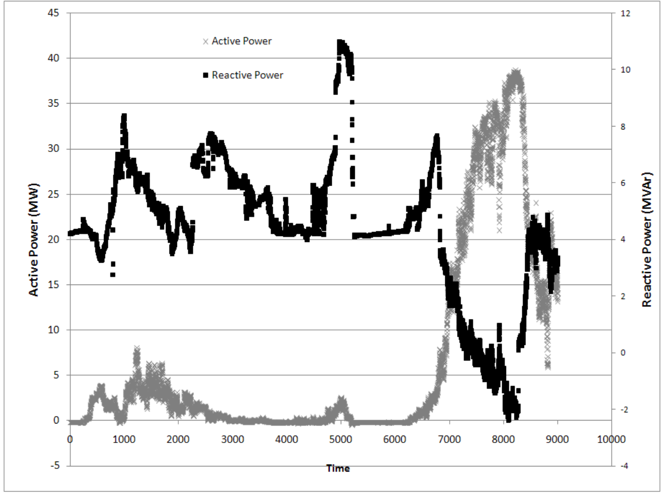

Fig. 11 Active and reactive power flow exchange at BSP

III. VOLTAGE CONTROL AND OPTIMIZATION

This section outlines a separate trial of an autotransformer as a means of facilitating wind generation capacity on an existing section of network. The current approach to ensure that voltages do not rise outside standard for supply customers is the reinforcement of the network to cater for the worst case scenario of high wind and low load conditions. Currently, ESBN is trialing the novel use of an autotransformer on a network with two wind farms to buck rather than boost the voltage at the point on the network from which customers are fed. Fig. 9 shows the tap changer position of the autotransformer and the voltage on either side of the transformer. From 2pm the wind power output increases and load reduces causing an increase in the line voltage, seen in Fig. 9. However, the regulator tapping ensures that during this period the voltage at the demand busbar is kept below the line voltage and within strict limits. This method of regulation moves the over voltage to beyond the demand busbar to the far side of the regulator. This sterilizes a portion of network, which is not currently serving any demand customers and is at the start of a long line back to a 38 kV station. This has no effect on the current load serving capability of the network while enabling the accommodation of the two wind farms without the need for network reinforcements.

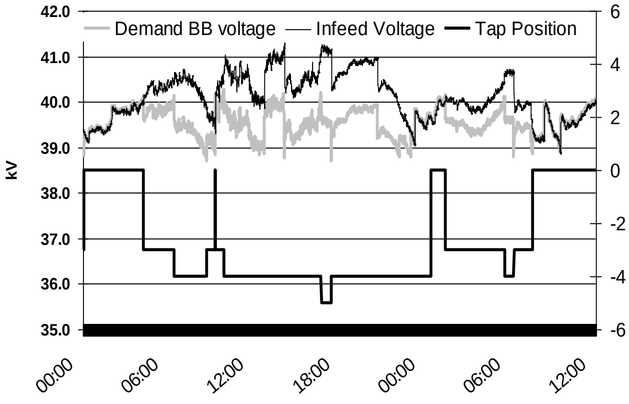

Fig. 9 Load point voltage regulation mitigating wind generation induced voltage rise

IV. CONCLUSIONS

The management of reactive power resources is an increasingly relevant challenge for system operators. The trial described in Section II demonstrates the technical capability of modern wind turbines and provides important insight into the variables and parameters at play in determining network generation capacity and the required control equipment to facilitate higher penetrations of distributed wind generation. The trial results indicate that the reactive power capabilities of modern wind turbines can be used for a range of objectives, such as loss reduction, local voltage control and reactive power export. It is important to note, however, these objectives may be conflicting, dependent on a range of factors such as wind power output, network impedance and the state of the transmission system. With a strong emphasis on monitoring and the quantification of all benefits, this research and demonstration programme ensures that ESBN can develop and integrate the high levels of wind generation required in a coordinated and evidence based manner.

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Ellen Diskin graduated with a B. Eng Hons (Electronic) from Dublin City University in 2009 and has worked and research experience in telecommunications. In 2009 she joined ESB, in network planning and then Smart Networks from 2010. In conjunction with work in ESB Smart Networks she is undertaking research towards a PhD at University College Dublin, supported by ESBN, in integration of distributed energy resources initially focusing on high penetration and non-firm wind integration.

Daniel Brooks (M'92, SM'07) received his BSEE and MSEE degrees from Mississippi State University and his MBA degree from University of Tennessee-Martin. He manages EPRI's Grid Operations & Planning research groups in Knoxville, TN. Daniel's research interests include renewable integration, T&D efficiency, dynamic modeling, and DER integration. Mr. Brooks is a registered professional engineer in the state of Tennessee.

Tony Hearne received an Honours degree in Electrical and Electronic Engineering from University College Dublin in 1996. He is Manager of Renewable Planning for ESB Networks, Ireland, with responsibility for the design of connection methods and network planning associated with the connection of generation to the ESB Distribution network. Since then he has managed the issue of connection offers for some 3000MW of generation connection, most of which is wind.

Teresa Fallon graduated with a BEng Hons. in Industrial Engineering and Information Technology from National University of Ireland, Galway in 1992. She has worked in ESB since graduation and has carried out many roles in this organisation. Teresa's most recent role was the Network Investment Manager for Distribution Capital Work. Since June 2010, Teresa has taken up her current role as Manager of Smart Networks.