FIELD EXPERIENCE WITH ACTIVE NETWORK MANAGEMENT OF DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION

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ABSTRACT

The penetration of distributed generation is limited by a number of issues related to the passive operating methods of electricity networks. Passive voltage control is a significant factor in this limitation.

During the past six years a method for the active control of distribution networks has been researched and developed. The method has been embedded in a commercial product, GenAVC, which is now in operation in the UK. This paper describes the method of operation and gives some results from early field experience.

Results are presented demonstrating the success at maintaining the whole network within operational voltage limits and estimating the capacity for additional generation that can be connected to a network using this method.

INTRODUCTION

The way in which the electrical transmission and distribution system is currently designed, and the practice and techniques by which it is currently operated, mean that it is not capable of supporting significant quantities of renewable energy generation. Areas in which the system capabilities often fall short [1] include:

- fault level,
- protection system design,
- thermal capability and
- voltage control.

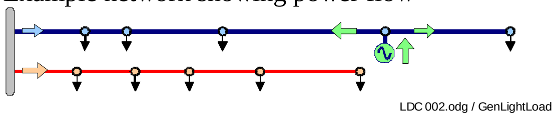
Among the limiting factors listed above, voltage is a common cause of restriction [2], particularly at the primary level (11 kV in most of the UK). These limits are caused, in part, by the primary network infrastructure, but also by the control methods applied. Development of the infrastructure and/or control methods would ease the constraints applied to generation capacity due to voltage.

If power is generated at a node in the network, it is possible for the voltage at the node to be higher than that of the primary substation (Figure 1). This situation of *voltage rise* is most likely to occur at times of low network load. The common AVC relay algorithms maintain the primary substation voltage assuming a load-only network, and therefore cannot detect this situation.

At the times when the voltage at the generator reaches the network operational limits the distributed generation output must be constrained. Lowering the voltage at the primary substation would allow more power to be generated, without the voltage upper limits being reached. However, this must be controlled dynamically, with full knowledge of the network state, in order that the voltage at other nodes of the network does not fall beneath lower limits.

This paper describes a solution to actively manage voltage levels, presents some results from operation in the field and provides estimates of the increased generation potential as a result of applying this technique. It follows up papers presented at earlier CIRED conferences [3, 4].

(a) Example network showing power flow



(b) Voltage profile for the network

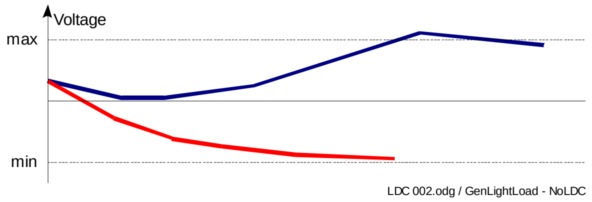


Figure 1 Example of Voltage Rise Effect of Distributed Generation

SOLUTION DESCRIPTION

A form of solution has previously been proposed to assist in the connection of distributed generation [3, 5]. State estimation, a technique more commonly associated with transmission networks, is applied to distribution networks to extend the observability of the network. The state estimation is proposed as part of a distribution management system controller (DMSC). This kind of solution is appropriate at higher levels of distribution voltage (33 kV and above).

At lower levels (below 33 kV) a simple solution, termed the *segment controller*, is possible based on the existing voltage control systems using on-load tap-changing (OLTC) transformers [3, 4, 6]. The estimated network voltages are compared with operational limits, and from this the setpoints of automatic voltage control (AVC) relays (attached to OLTC transformers) are dynamically adjusted up and down to maintain voltages within limits. The equipment is sited locally to the network segment to be controlled, rather than remotely at a control centre.

A diagram showing elements of the system is given in Figure 2. Existing AVC systems measure the primary substation voltage and transformer load, from which the OLTC is controlled.

The segment controller collects additional local measurements of feeder loads, and key remote measurements of voltage and load, which form the inputs to the state estimation. The aim of the estimator is to obtain as true a reflection of the actual system state as is possible. The estimator is provided with a minimum set of practical measurements required to achieve satisfactory control, reflecting the difficult and expensive nature of obtaining measurements remotely. It is likely that all local measurements of voltage and power will be used.

The estimated voltages are fed to a control block which adjusts the AVC target voltage up and down to maintain the voltage of all network nodes within operational limits. Using this method it is possible to maximize the utilization of the permissible voltage range (±6% at 11 kV) and the consequent level of distributed generation output.

FIELD OPERATIONS

Network Description

The results reported here are from equipment sited at an 11 kV primary substation in Norfolk, UK which is part of a network operated by EDF Energy. It is fed from a single source via three transformers connected to two incoming lines. Two of the transformers are identical and are connected in parallel using a single 11 kV circuit breaker. The 11 kV busbar is operated closed so the three transformers are connected in parallel. Each transformer is equipped with a SuperTAPP AVC relay. A reduced model of the network is given in Figure 3.

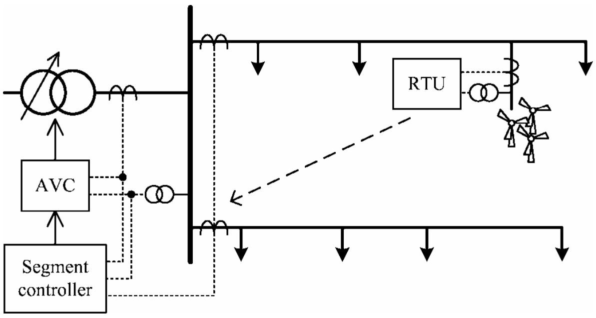


Figure 2 Outline of voltage control system with segment controller

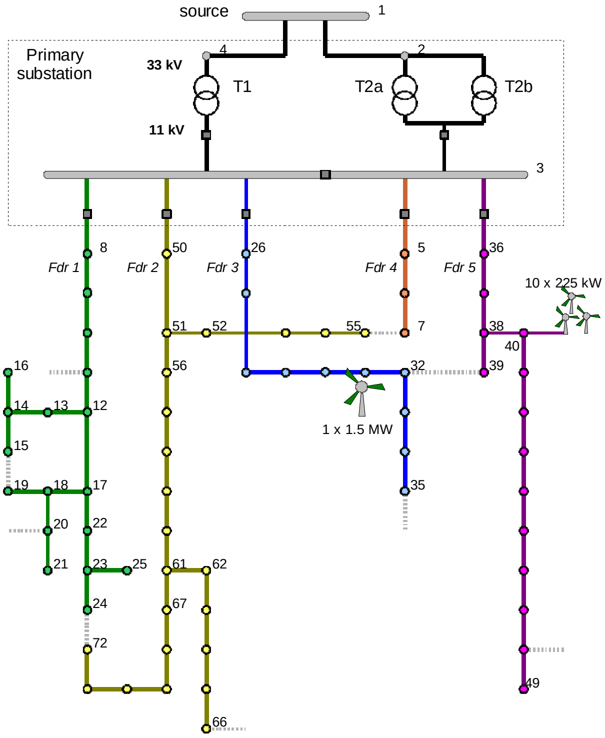


Figure 3 Reduced network diagram for reported network

The substation has five feeders connected to it (referred to as Fdr 1 – Fdr 5) and they are operated radially, although the possibility exists for connection as rings or to other 11 kV primary substations through normally open points.

Two of the feeders have distributed generation connected onto them in the form of a ten-turbine windfarm and a single wind turbine. Ten Vestas 225 kW asynchronous wind turbines are connected to Fdr 5 at node 40. A single Enercon 1.5 MW direct-drive wind turbine, is connected to the network by a DC link and inverters at node 31 on Fdr 3.

The network is in a rural area. Fdr 4 is short and supplies a village while the remaining feeders additionally supply the surrounding area. Fdr 1 and Fdr 5 are mainly domestic single-charging-tier loads while Fdr 2 has a higher proportion of two-charging-tier loads (e.g. Economy 7, night storage heating). Fdr 3 has a mixture of domestic and commercial load.

The segment controller is installed as a commercial system (GenAVC) in the primary substation, and receives measurements from the windfarm by licence-free directional radio.

Operational Results

Different voltage limits were applied at each node of the network to account for the distribution transformer ratio, its fixed tap-position and the properties of the LV network. The term *headroom* has been adopted to refer to the space between the upper (or lower) estimate limit and the upper (or lower) voltage operational limit of a node respectively. The control algorithm acts to keep this headroom greater than zero. To effectively display the activity of the segment controller, the minimum headrooms for the upper and lower limits across all nodes are displayed on a graph shown in Figure 4. This graph also shows the voltage target adjustments which are applied to the AVC relays in 1.5% steps. A small period covering two control adjustments is expanded in Figure 5. An upward adjustment occurred at 07:10 in response to the minimum headroom falling below zero. Previously, at 06:05, an adjustment was required but did not occur. This was because the upper headroom was too low to ensure that the resultant tap changes would not cause the upper limit to be breached, a situation that would cause "hunting" by the controller. Therefore, adjustment was prevented.

DISCUSSION AND CONCLUSIONS

The results demonstrate that the segment controller is able to maintain the voltage throughout the network within the required operational limits. This allows the connected windfarms to generate to the limits of the primary network infrastructure.

The amount of additional generation that can be connected using this method can be quantified. The voltage headrooms for the upper and lower limits can be summated to give a total available headroom, and this can be converted to an additional capacity figure. This conversion uses the impedance to the network source (the primary substation) from the generator and the generating power factor.

The equation used to arrive at this estimate is

$$P = \frac{\Delta V}{K} \quad \text{where} \quad K = \frac{R + X.\tan\left(\cos^{-1} pf\right)}{V}$$

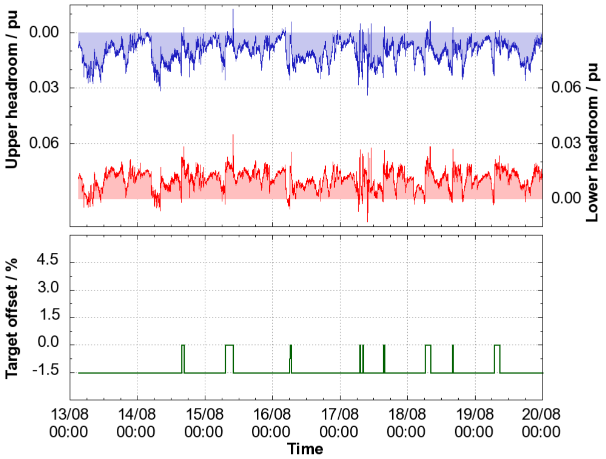


Figure 4 Operation Summary – Voltage Headrooms and Voltage Target Adjustments, August 2006

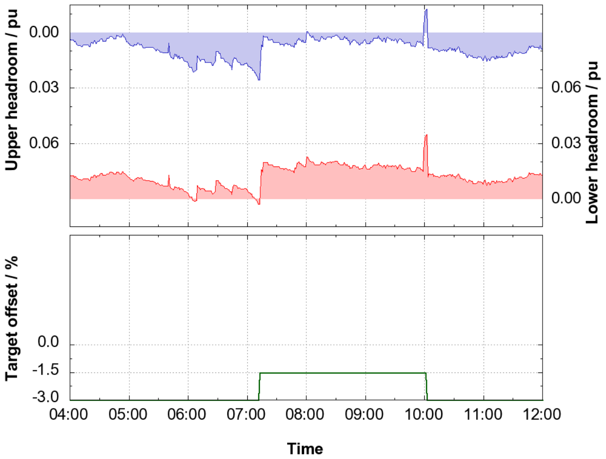


Figure 5 Target Change Operation – Voltage Headrooms and Voltage Target, 15th August 2006

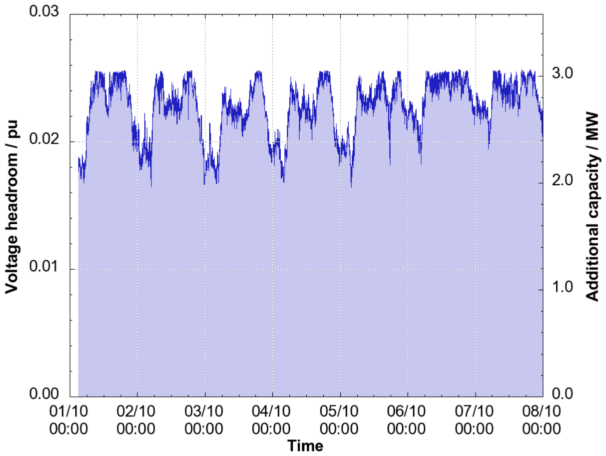


Figure 6 Potential Additional Capacity, October 2006

and a worst case voltage of 0.95 pu is assumed.

This method was applied to the network for a week in October and the potential additional generation which could be connected at node 39 is given in Figure 6. This demonstrates the potential for an additional 2 to 3 MW of generation to be connected to the network, assuming a power factor for the additional generation of 0.95.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support and assistance of EDF Energy.

REFERENCES

[1] C.A. Lynch, S.. Todd, W. Millar, H. S. Wood, 2003, *Technical Solutions to Enable Embedded Generation Growth*, London, Department of Trade and Industry, Crown copyright. URN 03/536.

[2] P. Smart, A. Dinning, A. Maloyd, A. Causebrook, S. Cowdroy, 2006, *Accommodating Distributed Generation*, London, Department of Trade and Industry, Crown copyright. URN 06/1571.

[3] M. Hird, N. Jenkins, and P. Taylor, 2003, *An Active 11kV Voltage Controller: Practical Considerations*, presented at CIRED, Barcelona.

[4] A. Shafiu, V. Thornley, N. Jenkins, and A. Maloyd, 2005, *Control of Active Networks*, presented at CIRED, Turin.

[5] G. Strbac, N. Jenkins, M. Hird, P. Djapic, and G. Nicholson, 2002, *Integration of operation of embedded generation and distribution networks*, Department of Trade and Industry, Crown copyright, London. URN 02/1145.

[6] C. M. Hird, H. Leite, N. Jenkins, and H. Li, 2004, *Network voltage controller for distributed generation*, IEE Proceedings - Generation, Transmission and Distribution, vol. 151, pp. 150-6.