DEMONSTRATION OF AN ACTIVELY MANAGED PLANNING APPROACH FOR CONNECTION OF RENEWABLE GENERATION

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ABSTRACT

U.K. carbon reduction targets have seen a rapid and sustained increase in renewable generation developers seeking connection to the distribution network. This paper presents through simulations, the positive results that can be seen by integrating Active Network Management (ANM) techniques into the network planning scheme. The method is devised to allow Distribution Network Operators (DNOs) to utilise the full available network capacity and as a result connect additional Distributed Generation (DG).

INTRODUCTION

To meet any increase in demand and/or generation under current planning practices typically requires network reinforcements. Controlling network constraints, such as, power flow limits and voltage variations, while maintaining sufficient Distributed Generation (DG) access, signifies one of the most important challenges [1]. Distribution Network Operators (DNOs) are investing time and money into implementing Active Network Management (ANM) solutions which will allow considerable amounts of DG to connect to existing networks while safeguarding physical power flow limits and statutory voltage limits are not exceeded.

To enable the use of ANM and increased levels of DG, new and novel planning procedures are required. The existing passive techniques are only suitable for the "fit and forget" approach which limits the capacity of DG able to gain connection. Moving to an actively managed planning scheme would allow more DG to be connected to the existing network and operate with real-time control of the active and reactive power output to mitigate constraints. If voltages and thermal constraints occur, the control mechanisms would be in place to maintain the network within a safe and secure environment. Employing network constraint management instead of reinforcing the infrastructure has the potential to save time and money.

This paper introduces an enhanced expansion planning method which integrates a multistage analysis process with an adaptive network control algorithm. Results from simulation of the enhanced expansion planning approach are presented.

EXPANSION PLANNING TECHNIQUES ON DISTRIBUTION NETWORKS

In planning the development of their networks and in integrating DG, DNOs have employed a passive approach, wherein the 'worst case' conditions drive the requirements for network capacity. Traditionally peak demand was the key condition but with DG minimum demand-maximum generation is normally critical in defining hosting capacity. In practice, these scenarios rarely exist, yet they drive the need for reinforcement. While 'automated' planning systems have not seen wide use in UK DNOs, there is substantial potential for dealing with the added complexity associated with greater DG capacities and variability.

Although focussed on peak demand conditions, [2] created an expansion planning scheme to determine whether DG could be used as an alternative to traditional reinforcement. It employed industry-standard software (PSSE) and the expansion planning analysis involved a successive elimination (SE) method combined with multistage planning. This was employed to determine the investment deferral benefit of DG.

The SE method is a heuristic method that overbuilds the network with a range of potential reinforcement options. Accounting for demand growth over the planning horizon, it then systematically tests the impact of removing reinforcement options. The least cost effective options are removed until any more removals would result in violation of the thermal and/or voltage limits. The final expansion plan to solely accommodate the increase in demand is now established.

The multistage planning component then defines the timing of each of the required reinforcements over the planning horizon. By inserting DG within the network, the approach allowed the level of investment deferral to be defined by deferring or avoiding traditional reinforcements. The value is calculated by reference to the present value cost for the reinforcement in the determined year. The investment deferral is calculated from subtracting the cost of reinforcement with DG from the cost with no connected DG.

The approach has been substantially enhanced to enable it to operate with variable generation and incorporate active network management systems.

PLANNING APPROACH FOR ACTIVE NETWORKS

The following approach is accomplished by integrating the existing multistage planning strategy together with an adaptive control approach for controlling voltage and thermal constraints [3]; both methods were developed at the University of Edinburgh. Introducing an adaptive control into the planning strategy allows DNOs to fully appreciate the potential actively controlled DG can bring to the planning and operation of the distribution network. Investment deferral is achieved by connecting actively managed DG strategically onto the network which helps delay reinforcements to the existing infrastructure.

The SE method is utilised to establish the minimum network required to function safely and securely with a fixed level of annual demand growth over a pre-defined planning horizon. The output from the SE method is employed within the multistage analysis to ascertain at what time along the planning horizon, the reinforcement is required. With no DG connected, the result details the present value (PV) cost for building out the reinforcements to maintain the network within the defined operational constraints. Including fixed DG offsets the increase in demand and warrants investment deferral. However, after the level of DG rises above the local demand or at times when local demand is low, network constraints occur. To mitigate this effect, including adaptively controllable DG will defer additional investment.

While a wide range of ANM control systems could be accommodated within the approach, the control scheme employed in this work is a decentralised method. It controls the active and/or reactive power output of the connected DG in real-time [3]. Control actions are identified once monitored data violates threshold values. Corrective actions are taken to maintain the voltage and power flow within the pre-defined limits. Real-time sensitivity analysis is applied to limit the level of curtailment or power factor control to maximise the output from DG. The voltage and power flow measurements are continually monitored to establish when control procedures can be restored to prevent unnecessary loss of renewable energy.

As an add on to the conventional multistage expansion planning method, adaptive control is considered at times when the voltage or thermal constraints are violated. Within the DG capabilities, power factor (PF) can be adjusted and active power can be curtailed. It has generally been the practice for DG to operate at unity

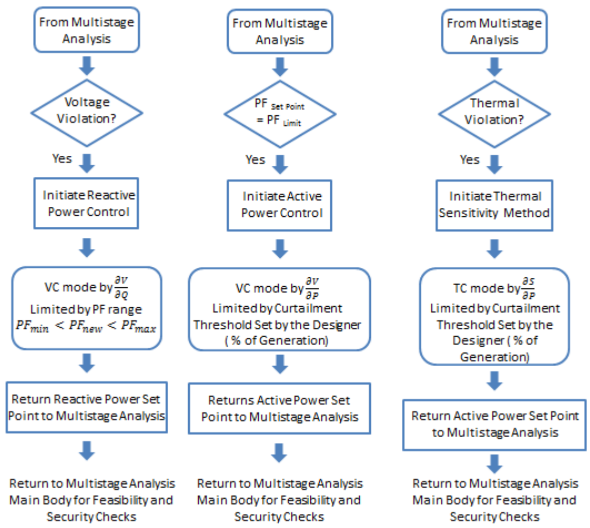

Figure 1 - Functional charts for reactive power, active power curtailment for both voltage and thermal control

power factor and at 100% of available generation. An alternative approach is to modify the reactive power for voltage variations issues and on occasion cutrail the active power to maintain both voltage and thermal constraints.

Within the multistage analysis, monitoring of the voltage and power flow against the pre-defined limits determines when voltage and thermal violations exist. Once it has been estblished that the voltage is beyond the statutory limits, the reactive power control is initiated. The new reactive power set point is defined by firstly calculating the variation of voltage for a 1MVar change. The reactive power required to reduce the voltage to within the limits is then estimated. The set point is returned to the main multistage analysis for further feasibility and security checks, as illustrated in the first chart in Figure 1.

Once the reactive power is at the maximum capability of the DG unit and if voltage violations still occur, active power curtailment is considered before regarding reinforcements as the only option. Active power curtailment for voltage control also uses the sensitivity analysis. However, the active power set point is calculated by obtaining the variation in voltage for a 1MW change. An estimation of the active power curtailment required to bring the voltage back within the limits is evaluated. The designer can stipulate a maximum level of curtailment if necessary as demonstrated in the middle chart of Figure 1.

Finally, consideration of active power curtailment for thermal constraints is very similar to the type for voltage control. Once a thermal violation has been identified, the calculation to determine the active power set point required to reduce the power flow to within the physical limit is computed. Firstly, the variation in power flow for

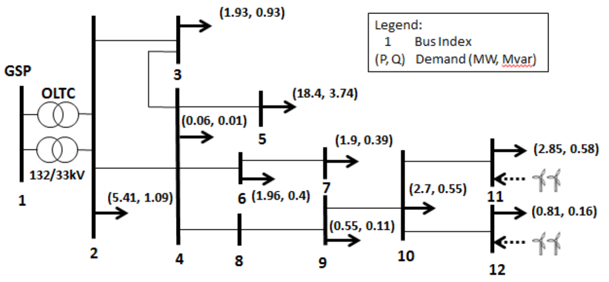

Figure 2 - 12Bus modified rural distribution network [4]

a 1MW reduction is calculated. This figure is applied to determine the minimum essential curtailment to reduce the power flow to below the limit. Likewise, the designer can specify the maximum level of curtailment as presented in the right hand chart in Figure 1.

SIMULATION

Test Network

The enhanced expansion planning approach was tested on a network based on a modified 12 bus rural distribution network (shown in Figure 2). The network is approaching maximum capacity and connection of DG without control would be subject to significant constraints at certain times when demand is low. The approach identified that actively managed DG could actually defer network investment by years with using power factor control and/or curtailment as a method of network management.

To illustrate the approach an increase in demand is required at the end of the 15 year planning horizon. Table 1 provides the final load data used with an annual demand growth of 5%. To facilitate comparison with the earlier work [2] all costs (in $) are retained.

Table 2 - Maximum demand at each bus at the end of 15 year planning horizon

Bus	Initial Max Demand (MW)	5% Increase Max Demand (MW)
2	5.41	11.25
3	1.93	4.01
4	0.06	0.12
5	18.40	38.25
6	1.96	4.07
7	1.90	3.95
9	0.55	1.14
10	2.70	5.61
11	2.85	5.92
12	0.81	1.68

Table 4 - Scheduling of new branches required along the 15 year planning horizon with no DG and 5% annual demand growth

Branch	Type	Capacity (MVA)	Cost/km (US$k)	length	year	PV cost (US$k)
2-3	Upgrade	2 x 60	120	12.5	6	2114.88
2-4	Parallel	1 x 35	96	18.5	0	1776.00
3-4	Upgrade	2 x 60	120	8.8	6	1488.88
4-5	Upgrade	1 x 60	120	2.1	8	158.11
8-9	Parallel	1 x 35	96	10.1	7	644.84
9-10	Parallel	1 x 35	96	22.3	4	1695.71
					Total	7878.42

Results

Initially running the simulation with no connected DG provides the minimum timeline for reinforcements required to maintain a safe and secure operation with a 5% annual demand growth. Table 2 represents the cost associated with infrastructure upgrades required for this benchmark condition, which is later used to determine the level of investment deferral achieved by permitting DG as an alternative to network reinforcements. Inserting 5MW of firm DG at Busbar 11 and running the simulation again, provides an investment deferral of 12%, as demonstrated in Table 3. This shows that each of the reinforcements is deferred by a minimum of one year and in some cases as much as 4 years.

Incorporating active control in the form of the sensitivity factor controller facilitates an additional 4% of investment deferral, thus raising total investment deferral to 16%. Table 4 shows that this results from delays to reinforcements at most branches, typically of one year, however, branch 2-4 does not see additional deferment from this control scheme. Figure 3 clearly demonstrates the increase in investment deferral from firm and actively managed DG.

Table 1 - Scheduling of new branches required with non-controllable DG

Branch	Type	Capacity (MVA)	Cost/km (US$k)	length	year	PV cost (US$k)
2-3	Upgrade	2 x 60	120	12.5	7	1995.17
2-4	Parallel	1 x 35	96	18.5	3	1491.16
3-4	Upgrade	2 x 60	120	8.8	7	1404.60
4-5	Upgrade	1 x 60	120	2.1	9	149.16
8-9	Parallel	1 x 35	96	10.1	9	573.90
9-10	Parallel	1 x 35	96	22.3	8	1343.16
					Total	6957.16

Table 3 - Scheduling of new branches required with controllable DG

Branch	Type	Capacity (MVA)	Cost/km (US$k)	length	year	PV cost (US$k)
2-3	Upgrade	2 x 60	120	12.5	8	1882.24
2-4	Parallel	1 x 35	96	18.5	3	1491.16
3-4	Upgrade	2 x 60	120	8.8	8	1325.09
4-5	Upgrade	1 x 60	120	2.1	10	140.72
8-9	Parallel	1 x 35	96	10.1	10	541.42
9-10	Parallel	1 x 35	96	22.3	9	1267.14
					Total	6647.77

DISCUSSION

Drawn from the results presented in this paper, it is possible to achieve additional investment deferral by including the decentralised adaptive control scheme within the expansion plan. Reinforcements are deferred by connecting DG which can effectively offset the increase in demand. Nonetheless, there becomes a level of DG which will then become a driver for reinforcements. However, this can be mitigated by the inclusion of actively managed DG, such as the adaptive control mechanism.

By including a method of controlling the output of the DG at times when network violations occur can save a further 4% of investment deferral or $309,000 in monetary value. Over a larger section of network or over various smaller networks, it offers substantial opportunities for capital saving.

CONCLUSIONS

This paper presents an enhanced expansion planning control mechanism. The mechanism is examined on a modified 12-Bus rural distribution network. From the simulations executed, it can be demonstrated that by incorporating active network management techniques within the planning strategy, further investment deferral can be achieved. This would release further DG capacity which currently is unavailable under existing "fit and forget" planning arrangements.

Acknowledgments

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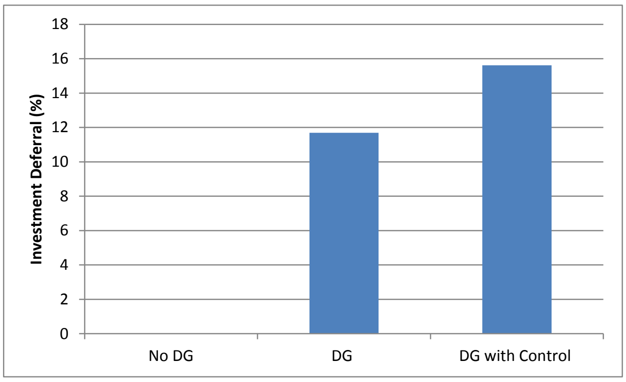

Figure 3 - Comparison of investment deferral for 5% increase in annual demand growth

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