The number of embedded generator connections to distribution networks in the UK will continue to rise. The existing electrical distribution system in the UK was not designed for connection of local generation and a number of technical problems exist that require a solution include:

- Voltage control/ Voltage rise
- Fault level increase in the network
- Impact on power quality
- Island Operation

The effect of independent generation on the following aspects of network operation were considered:

- the effect of network loading on the voltage supplied to adjacent consumers;
- the effect of connecting at higher voltage levels;
- the potential use of reactive power injections from independent generators; and
- the integration of Independent generation into an overall network voltage control policy

Seven networks were studied ranging from a 200kW connection on a 415V network to a 50MW connection close to a 132/33kV substation. These were chosen because they exist and contain real and proposed embedded generation and because they are representative of distribution networks within the UK.

Each network was analysed in terms of load flow and voltage profile. The output level in MW of the generation in each network was varied until there became an “out of specification condition”. In voltage terms this specification is ± 6%. This requirement must be met when considering the effect any embedded generation connection may make on consumers.

A number of voltage related problems were identified which will inhibit the continuing connection of embedded generators:

- Influence of Network Loading.
- The variable nature of the load within the network and the extreme minimum conditions encountered may affect the level of generation allowable at a particular location.
- Interaction between generators.

The location and output power of a second generator on a feeder or in the extreme on the same substation will be affected by the presence of any generation already in place.

- Effect of VAr transport on the network voltage. The voltage rise problems encountered with the export of power may be counteracted by the reverse flow of VAr.
- Connection at higher voltage levels. It is clear that providing a developer with a satisfactory high voltage connection alleviates most of the problems encountered. The financial constraints of cost become significant.

The results of the studies carried out coupled with practical experience led to the following solutions being proposed:

- Co-ordination of generators on the network that are “electrically close” The REC could be made responsible for the co-ordination of the power output/voltage support required the network.
- Use of semi-conducting devices to control voltage output from generators Equipment has been produced that provides the capability to transmit power from generation to a grid network without affecting the power quality of the receiving network.
- Develop commercial measures to encourage RECs to provide suitable connections at lower contributions from the developer. A mechanism is required so that the REC can receive payment for transport of electricity from a generation site similar to the charge made for transport to consumers.
- Review technical codes and recommendations for connection to networks The codes should be reviewed so that due allowance can be given to modern communication methods between the REC control room and the generator systems.
- Install higher voltage networks for local generation connection Only low levels of generation may be connected to 11kV networks. Consideration should be given to the development of new circuits at 33kV or even at 132kV that may be installed at the initial cost to the REC but which could be eventually shared by all of the embedded generator developers.
SOLUTIONS POTENTIELLES AUX PROBLÈMES DE RÉGULATION DE TENSION DES RÉSEAUX DE DISTRIBUTION CONTENANT DES GÉNÉRATEURS INDEPENDANTS

P. Glendinning

PB Power Ltd, Royaume-Uni

Le nombre de connexions de générateurs noyés avec des réseaux de distribution va continuer à augmenter au Royaume-Uni. Le système de distribution électrique existant au Royaume-Uni n'a pas été conçu pour être connecté à une production d'électricité locale et un certain nombre de problèmes techniques nécessitent une solution notamment :

- Régulation de la tension / élévation de la tension
- Augmentation des pannes sur le réseau
- Impact sur la qualité du courant électrique
- Exploitation insulaire

Les effets d'une production d'électricité indépendante sur les aspects suivants de l'exploitation du réseau ont été examinés :

- effet du chargement du réseau sur la tension fournie aux consommateurs de proximité ;
- effet de la connexion aux tensions plus élevées ;
- utilisation potentielle d'une injection de puissance réactive provenant de générateurs indépendants ; et
- intégration d'une production d'électricité indépendante dans une politique globale de régulation de la tension du réseau.

Les sept réseaux étudiés vont d'une connexion de 200 kW à un réseau de 415 V à une connexion de 50 MW proche d'une sous-station de 132/33 kV. Ces réseaux ont été choisis parce qu'ils existent et contiennent une production d'électricité noyée réelle et prévue, et parce qu'ils sont représentatifs des réseaux de distribution au Royaume-Uni.

Chaque réseau a été analysé en termes de débit de charge et de profil de tension. Le niveau de sortie de la production d'électricité en MW dans chaque réseau a été modifié jusqu'à ce qu'il soit "hors spécification". En terme de tension, cette spécification est ±6%. Cette condition doit être remplie lorsqu'on examine l'effet qu'une connexion de production d'électricité noyée peut avoir sur les consommateurs.

Un certain nombre des problèmes identifiés relatifs à la tension vont bloquer la connexion continue des générateurs noyés :

- Influence du chargement du réseau
- La nature variable de la charge au sein du réseau et les conditions minimales extrêmes rencontrées peuvent affecter le niveau de production d'électricité attribuable à un lieu spécifique.
- Interaction entre les générateurs

Les résultats des études effectuées joints à l'expérience pratique ont conduit aux propositions de solutions suivantes :

- Coordination des générateurs qui sont électriquement proches sur le réseau.
- Utilisation de dispositifs semi-conducteurs pour réguler la tension de sortie des générateurs. Il existe des dispositifs qui sont à même de transmettre le courant électrique, de la production au réseau, sans affecter la qualité du courant du réseau récepteur.
- Développement de mesures commerciales pour encourager les REC à fournir des connexions appropriées contre des contributions plus basses du développeur. Il faut un mécanisme permettant que le REC soit payé pour le transport de l'électricité d'un site de production de la même façon que le transport est payable par les consommateurs.
- Examen des codes techniques et recommandations relatives à la connexion aux réseaux. Les codes devraient être examinés de façon à assurer des méthodes de communication modernes entre la salle de commande du REC et les systèmes de production d’électricité.
- Installation de réseaux à plus haute tension pour la connexion de la production d’électricité locale. Il n'est possible de connecter aux réseaux de 11 kV ou une production de faible puissance. Il faudrait envisager de développer de nouveaux circuits en 33 kV ou même en 132 kV qui pourraient être installés initialement aux frais de REC, mais qui pourraient ensuite être partagés par tous les développeurs de générateurs noyés.
POTENTIAL SOLUTIONS TO VOLTAGE CONTROL ISSUES FOR DISTRIBUTION NETWORKS CONTAINING INDEPENDENT GENERATORS

P. Glendinning
PB Power Ltd., United Kingdom

INTRODUCTION

Even in a climate of falling energy prices there is a continued drive towards the development of renewable energy schemes. Indeed, the UK Government has stated that it would like to see 10% of the electricity market derived from renewable sources by the year 2010. Legislation may also cause a return of interest in CHP should the Government provide fiscal incentives through the requirement for energy efficiency and lower environmental emissions. Therefore, the number of connections will continue to rise.

The existing electrical distribution system in the UK was not designed for connection of local generation and a number of technical problems exist that require a solution include:

- Voltage control/ Voltage rise
- Fault level increase in the network
- Impact on power quality
- Island Operation

The aim of this paper is to examine the effect of independent generation upon traditional network voltage control and suggest possible solutions to the technical problems encountered.

THE STUDY

The effect of independent generation on the following aspects of Network operation were considered:

- the effect of network loading on the voltage supplied to adjacent consumers;
- the effect of connecting at higher voltage levels;
- the potential use of reactive power injections from independent generators; and
- the integration of Independent generation into an overall network voltage control policy

Selection of Networks

The networks studied exist within the distribution system in the UK and have been chosen as typical of the system. All of the networks considered either had a generator at a point in the network, or an application had been made to a REC for one to be connected (generator 1). In most cases a second generator at another point on the same circuit was added to assess the impact upon generator connected in location 1 (generator 2). Both had ratings of up to 50MW, typical of embedded generators. Table 1 details the networks chosen:

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>33kV</td>
<td>Overhead Rural Network</td>
</tr>
<tr>
<td>33kV</td>
<td>Teed Urban Network</td>
</tr>
<tr>
<td>33kV</td>
<td>Solution Network</td>
</tr>
<tr>
<td>11kV</td>
<td>Overhead Rural Network</td>
</tr>
<tr>
<td>11kV</td>
<td>Cabled Urban Network</td>
</tr>
<tr>
<td>11kV</td>
<td>Network with Induction machine Urban</td>
</tr>
<tr>
<td>415V</td>
<td>Distribution Sub Connection Urban</td>
</tr>
<tr>
<td>415V</td>
<td>Mains Network Urban</td>
</tr>
</tbody>
</table>

Each network was analysed in terms of load flow and voltage profile. The output level in MW of the generation in each network was varied until there became an “out of specification condition”. In voltage terms this specification is ± 6%. This requirement must be met when considering the effect any embedded generation connection may make on consumers. Studies were performed at three operating conditions within the network as follows:

- **Normal load**: the average expected load for a substantial part of the year.
- **Load multiplied by 160%**: this represents a high network load, for example in the evening peak. This is not expected to be a maximum load as the peak in the year is often found to be twice the average.
- **Load multiplied by 30%**: this simulates a very low load, for example in a summer night.

Voltages at various points on the network were noted. The most important of these were at the point of common coupling of the generator and at the terminals of the nearest consumer.

RESULTS

The results illustrate trends that could be applied to similar REC networks within the UK. Firstly, the approximate maximum output power from generator 1 was assessed in terms of maximum allowable voltage on the network. The results are shown in Table 2. This provides a reference for the studies and is important to understand the limitations of the networks within the UK.
### TABLE 2 Export power against Network Voltage

<table>
<thead>
<tr>
<th>NETWORK</th>
<th>EXPORT POWER (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33kV URBAN</td>
<td>18-25 (50 plus near Grid)</td>
</tr>
<tr>
<td>33kV RURAL</td>
<td>15-22</td>
</tr>
<tr>
<td>11kV URBAN</td>
<td>6-10</td>
</tr>
<tr>
<td>11kV RURAL</td>
<td>2-3</td>
</tr>
<tr>
<td>11kV Async URBAN</td>
<td>4-8</td>
</tr>
<tr>
<td>LV at Transformer</td>
<td>0.25-0.5</td>
</tr>
<tr>
<td>LV at distance URBAN</td>
<td>0-0.1</td>
</tr>
</tbody>
</table>

**Influence of Network Loading**

Figure 1 indicated the effect of differing load on the network. The results obtained clearly indicated that the potential voltage rise in a network is lowered when the network becomes highly loaded. There was a significant difference in the output power feasible from a machine at the system maximum compared to the expected minimum. It is usual for the host REC to impose the credible minimum load on the network as the criteria for assessing the feasible output power level from a perspective generator. This inevitably leads, as these studies indicate, to a generator that is lower in power output than may be achieved if the network were substantially loaded.

**Interaction Between Generators**

The results obtained Figure 2 illustrate at each voltage level there is a base voltage level shift as the second generator is connected. The gradients of the voltage rise per output MW are similar but shifted in terms of absolute voltage level. The voltage level rise on the 33kV system is not as significant as the 11kV and likewise the effect on the 11kV is not as significant as that seen on the 415V system. The effect is most significant where the location of the second generator is between the first generator and the source voltage control system.

**Figure 1 Comparison of different loading conditions**

**Figure 2 Effect of adding 2nd Generator**

**A Comparison of Asynchronous and Synchronous Connections**

It is clear from the values obtained in Table 3 that the import of VAr's to the generator site is beneficial to the problem of excessive voltage rise at the point of connection.

The real power (P) multiplied by the resistance (R) in the system is counteracted by the reactive current (Q) multiplied by the reactance (X) of the system if the reactive current was travelling in the opposite direction to the real current. This is the effect of the connection of an asynchronous generator, as induction machines require a flow of VAr to provide excitation current. It is apparent in rural locations or where voltage rise is a problem;
an import of VArV would help and would be preferable to standard synchronous units. It was also found that in the studies performed with an export of VAr on to the network that the voltage rose. This is because the flow of reactive current is, in this case, in the same direction as the real current.

**TABLE 3-11kV Asynchronous Connection**

<table>
<thead>
<tr>
<th>GEN 1 P+Q</th>
<th>GEN 2 P+Q</th>
<th>V1</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1.014</td>
<td>1.028</td>
</tr>
<tr>
<td>1.2</td>
<td>-0.242</td>
<td>0.19</td>
<td>1.032</td>
</tr>
<tr>
<td>2.4</td>
<td>-0.375</td>
<td>0.124</td>
<td>1.036</td>
</tr>
<tr>
<td>2.4</td>
<td>-0.375</td>
<td>0.29</td>
<td>1.041</td>
</tr>
<tr>
<td>4.8</td>
<td>-0.733</td>
<td>0.39</td>
<td>1.049</td>
</tr>
</tbody>
</table>

Notes: V1= V at Point of Common Coupling  
V2= V at the closest customer to location 1

**Connection at Higher Voltage Levels**

The 11kV urban connection was compared to the 33kV urban connection where an identical generator was used in both cases. The studies indicate (Table 4) only generators up to about 6 MW could be connected within the criteria currently set.

A direct connection to the substation was made to reduce the cable impedance from the connection and to prevent local consumer voltage rise. At times of low substation load, the generator supplied the whole of this load. Calculations indicate that should the generator trip i.e. an instantaneous loss of export power, then the voltage level in the network would suffer a transient that would prove unacceptable.

The preferred solution was to provide an 11/33 kV step up transformer and connect at 33kV. It can be seen from Table 5 that this has the immediate effect of solving the problems encountered with the connection at 11kV. The transformer also provides a protection buffer that allows better protection discrimination.

The studies carried out on the LV network indicated that it was suitable only for small levels (less than 500kW) of export power from generators. In the case of a hotel, which was connected at location 2 some distance from the 11kV/415V substation, any export power caused voltage rise problems to the closest consumer. The solution in this case is to provide a step up transformer 415V/11kV and a length of cable to connect to an existing 11kV network. Again, adding extra costs to the project.

**TABLE 4-11kV Urban Network**

<table>
<thead>
<tr>
<th>GEN 1 P+Q</th>
<th>GEN 2 P+Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1.2</td>
<td>-0.242</td>
</tr>
<tr>
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</tr>
<tr>
<td>4.8</td>
<td>-0.733</td>
</tr>
</tbody>
</table>

Notes: V1= V at Point of Common Coupling  
V2= V at the closest customer to location 1

**DISCUSSION**

**Influence of Network Loading**

The loading on a particular network varies considerably with the lowest loads experienced on summer nights. These half-hour periods are not representative of the average load for the substation. In this case the generator output could be reduced to provide "an acceptable" voltage rise for these periods while the generator provides a higher output power when the feeder load is higher.

For example, under light loading conditions the power output from a site would raise the voltage level in a section of the network to an unacceptable level and the power flow through transformers at the Primary would be reversed. A power transducer can be fitted to the transformer circuits to provide an indication of power flow. When this transducer indicates that the flow is reversed a signal is sent to the site instructing the generation to reduce output. This maintains the network within voltage tolerance. This type of co-ordinated approach can assist with the connection of embedded generators.

This control system could be extended to cover periods of system difficulty including faults, high loading, VAr support etc. The developer may incur a loss of revenue at times when he is requested to lower the output power but an incentivised payment structure for provision of power may compensate for losses at other times.

**Interaction Between Generators**

The REC's assessment of the feasibility must take into consideration the other connected consumers.
and generators. The impact of a second generator to general network voltage levels is considered with the generator situated in location 1 on full output power. Also the loading of the network is taken into account.

It is apparent from the voltage gradients in the studies that, at 11kV and below, should the generation be connected to the same feeder the possible output power of the second generator would be considerably lower than if generator 1 did not exist. The “ideal” or optimised generation output per feeder is then not obtained. The process of assessing the potential for connection should be reviewed to assess the optimum positions and output power levels that can be accommodated.

In a traditional network the voltage is maintained within limits by the action of the tap changers. The tap changers may take about a minute to step up or down one position. The change in voltage on the generation site is noticed almost immediately by the AVR and the excitation system acts to maintain a pre-set control point. This is often a power factor such that the output voltage level changes with the new level of VAr production. This can have the effect of disturbing the tap changer intentions as these changes can take place in a few seconds. In the extreme case “voltage hunting” can occur where the generators force more tap changes than are really necessary. Where there are two generators connected to a voltage control source the effects are more exaggerated as both of the machines operate to try and maintain their desired power factor.

There is evidence to suggest that some form of communication between the tap change system and the generator site would be beneficial. The network operation would benefit from the overall control of a master system maintained by the REC.

**A Comparison of Asynchronous and Synchronous Connections**

It is not common to find large induction generators being connected. However, a similar effect on voltage suppression can be obtained with synchronous generators. For example, an industrial CHP site with synchronous generation has a high VAr requirement for providing power to large machines. If the site begins to produce power from a CHP installation then it can be arranged for the site to continue to import VArs. This will mean that the impact of the voltage rise by exporting the power is reduced. The number of import MW hours during the billing period may be low providing the availability of the generation is high and there has been a constant import of VArs to the site. The traditional billing system used would penalise the consumer for the power factor in this case.

The import of VArs to the site is likely to be the same or slightly less than was used prior to the CHP installation. It is only the MW import that has changed substantially. This type of discussion of operating conditions should be started prior to the connection offer from the REC, but experience indicates that this is not always the case.

**Connection at Higher Voltage Levels**

The problem associated with connection at higher voltages is the increase in capital cost of the connection. Most generators are likely to be connected to a REC network will have an output voltage of 11kV (for machines over 1MW) or 415V for machines less than 1MW. Connection directly to the 11kV or 415V network respectively represents the lowest capital cost. This is unfortunate, since if the generators were say all 6.6kV then it would be more likely that a transformation would have been included in the project capital cost from the start of the project thus alleviating voltage rise problems.

The areas of a particular network potentially suitable for development of new higher voltage networks are likely to be well known to the REC as over the years multiple applications and enquiries will have been discussed for a particular location. The RECs would need an incentive to provide this form of investment in its infrastructure but with the current political pressure for greater penetration of renewable generation this may be forthcoming.

**CONCLUSIONS**

It is clear from the results presented that several issues have been demonstrated:

- Higher voltage connections are preferable;
- Cables and overhead lines reach their rating and limit generation capacity;
- Voltage rise can be controlled by the import of VAr;
- Local optimisation is required to maximise the generation feasible; and
- Real time communications would improve co-ordination between RECs and generators.

**POTENTIAL SOLUTIONS**

- Co-ordination of generators on the network that are “electrically close”
The REC could be made responsible for the co-ordination of the power output /voltage support required for a particular section of the network. There is technology available in terms of signaling and load scheduling software to enable predicted demand for an area. Should emergency action be needed then this could be done via a communication link.

- Use of semi-conducting devices to control voltage output from generators
  Equipment has been produced that provides the capability to transmit power from generation to a grid network without affecting the power quality of the receiving network. The product known as HVDC light from ABB Eriksson (1) provides this facility. At present the cost is comparably high but this may well reduce as the technology matures and its use becomes more widespread.

- Develop commercial measures to encourage RECs to provide suitable connections at lower contributions from the developer
  The DTI have issued a consultative document DTI, (2) in which several proposals are discussed to encourage (through pricing mechanisms) RECs to connect a greater proportion of renewable generation. A mechanism is required so that the REC can receive payment for transport of electricity from a generation site similar to the charge made for transport to consumers. Also the value of the RECs assets are used in part as a method of calculating the tariff applicable to consumers. Should this include generation utilised as an alternative to network reinforcement then this may encourage RECs to construct suitable connections for embedded generators.

- Review technical codes and recommendations for connection to networks
  The codes should be reviewed so that due allowance can be given to modern communication methods between the REC control room and the generator systems. The generation may be able to contribute to system security calculations and provide vital support in times of system weakness.

- Install higher voltage networks for local generation connection
  This paper has demonstrated that only low levels of generation may be connected to 11kV networks. There are also fault level limits that were not specifically addressed in this paper, which will restrict the connection of generation. Consideration should be given to the development of new circuits that may be at 33kV or even at 132kV that may be installed at the initial cost to the REC but which could be eventually shared by all of the embedded generator developers. Instead of the current system, the REC could “canvass applications for capacity.” This would have the effect of producing a commercially viable solution to the technical issues demonstrated.

Acknowledgement

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