DTI Centre for Distributed Generation and Sustainable Electrical Energy

Integration of Distributed Generation into the UK Power System

Summary Report

Goran Strbac, Charlotte Ramsay and Danny Pudjianto

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1. Executive summary

1.1 The present power system is dominated by conventional generation that injects large amounts of power into the extra high voltage transmission network, where it is transported to passive distribution networks, and delivered to end consumers at a number of voltage levels. A future power system based on high penetration of renewable and low carbon distributed generation (DG) is likely to be quite different to this existing system. Large numbers generators of a variety of technologies with operating patterns that may be very different to the traditional conventional generators will be connected at every level of the distribution network. Integration of these new resources into all aspects of the power system will be the key to ensuring the evolution of an economically efficient and effective system based on sustainable generation sources.

1.2 However, the existing system and the accompanying technical, commercial and regulatory arrangements have been optimised for the requirements of conventional generation. Many of these arrangements do not provide a level playing field for the introduction of DG or realisation of its full value, potentially acting as a barrier to the development of a cost effective decentralised system. At present, there is a disconnection between the vision set by Government targets for the penetration of significant levels of DG and the realities of the present system and arrangements. It is clear that facilitating the cost effective integration of DG into the existing system will require redevelopment of the regulatory, technical and commercial arrangements that underpin the current system.

1.3 At a high level this is illustrated by the value chain from power generation to consumption. Electricity produced by centralised generation is sold in the wholesale market for around 2-3p/kWh; by the time this electricity reaches the end consumer it is being sold at a retail price of between 4-10p/kWh. This increase in value is driven by the added cost of transmission and distribution services to transport electricity from the point of production to consumption. DG however, located close to demand, is delivering electricity directly to consumers with limited requirement for use of the network. This power may therefore have a higher value than that of conventional generation (e.g. an equivalent value of between 4-10 p/kWh) due to the potential of DG to reduce the demand for distribution and transmission network capacity and corresponding costs.

1.4 However, these potential system benefits are not fully recognised within the present technical, commercial and regulatory framework. Ignoring these particular features in the derivation of the value of DG results in non-competitive markets in which DG cannot compete on an equivalent level with conventional generation. Ultimately, this will lead to the creation of inefficient and non-cost reflective systems, whereby DG is not efficiently integrated into the system and the resulting framework relies on unnecessary network reinforcement, and inefficient solutions based on increasingly expensive, low-utilisation conventional generation.

1.5 This report highlights the gaps and inconsistencies in the present technical, regulatory and commercial framework across transmission, distribution and generation segments of the industry and points out that these issues will need to be resolved in order to establish a level playing field for competition in generation and to cost effectively integrate DG in the UK electricity system.

1.6 A summary of our findings on the impact and value of DG in the areas of transmission, distribution and generation is presented below:

1.7 Transmission:

- Despite its location in the distribution network, DG contributes to transmission network flows. The impact or value of this contribution will be dependent on location of the DG, and its pattern/time of output. DG in the South of England will reduce local load and so have a positive effect on North-South power flow. DG in Scotland and the North of England will have the opposite effect on power flow.

- Our work demonstrates that renewable forms of DG tend to drive less investment in transmission capacity and that diversity in output between conventional and DG technologies opens opportunities for sharing of network capacity.

- Transmission access for DG is the priority for integration of DG as this is a major barrier for connection of renewable generation in the UK system. The current method for determining access requirements, the Transmission Entry Capacity (TEC) calculation, is not a suitable proxy to be propagated into access arrangements for DG. TEC is based on conventional generation and in its present format is not capable of deriving efficient capacity requirements for DG.

- Access for DG at transmission level should take account of diversity in generation technologies and should recognise the contribution of demand. To allow the development of truly cost reflective arrangements, access rights and capacity calculations should be based on the net position of DG and demand at the transmission distribution boundary. The Distribution Network Operator (DNO) is the only agent capable of deriving the actual physical net position at the boundary between networks.

1.8 Distribution:

- DG has the potential to offer a range of non-network solutions that could potentially offer a cost effective service to distribution network security, planning and management.

- DG contribution in these areas will be dependent on a number of factors including location, pattern and timing of output, density of installations, rural/urban setting and proximity to load. All of these factors will need to be taken into account when evaluating the impact of individual DG.

- To realise the value of DG in the distribution networks requires the creation of a level playing field whereby DG can compete with network solutions to offer services to the DNO. Currently, most network management issues are resolved at the planning stage by designing networks with sufficient levels of redundancy to support most eventualities. DG services could be used as an alternative to network reinforcement, but the commercial and regulatory frameworks to facilitate this are not in place.

1.9 Generation:

- DG will impact the generation capacity margin required in future energy systems. Many DG technologies displace more energy than capacity from the system, and this will incur additional system costs. However, some DG technologies have a positive capacity margin, and provide positive benefits to system capacity costs. DG with this profile can displace generating capacity because it reduces system peak demand, as well as contributing to system peak.

- The current system has no mechanism for recognising or rewarding the capacity value of any generating technology. Increasing penetration of DG with low capacity value will change the generation mix, and change the utilisation of existing plant causing existing plant to run either at lower load factors or less frequently. This could ultimately affect the economic viability of marginal plant, and may impact the level of investment in this kind of generation required for system balancing and security.

1.10 In summary, this report underlines that a sustainable power system of the future is likely to consist of a diverse portfolio of generation plant including both DG and conventional generation, quite unlike the existing system, and that this will necessitate significant change in system arrangements. So, it is vital that any new technical, regulatory and charging framework for this changing system receive the same careful consideration that has gone into the existing framework designed for networks supporting a homogenous group of conventional generation.

2. Description of the issues

2.1 Integration of Distributed Generation into the UK power system

2.1 The present power system is dominated by conventional, load-following generation that injects large amounts of power into an extra high voltage transmission network, built during the middle of the last century. Transmission carries out bulk energy transport from these large generators to load centres, at which point the electricity is delivered to end consumers at a number of voltage levels via passive distribution networks.

2.2 A future, power system based on high penetration of renewable and low carbon distributed generation (DG) is likely to be quite different to this existing system. Large numbers generators will be connected at every level of the distribution network and integration of these new resources into all aspects of the power system will be the key to ensuring the evolution of an economically efficient and effective system based on sustainable generation sources.

2.3 However, the existing system has been optimised for the requirements of conventional generation and many of these arrangements do not provide a level playing field for the introduction of DG or realisation of its full value, potentially acting as a barrier to the development of a cost effective decentralised system. It is clear that facilitating the integration of DG into the existing system will require redevelopment of the regulatory, technical and commercial arrangements that underpin the current system.

2.4 As a further technical driver for this transition, much of the existing transmission and distribution network is reaching the end of its operating life, so considerable investment in these aging assets is expected in the next 10 to 15 years. Rather than replace these assets like-for-like, there is the opportunity to redesign integrated networks that recognise and facilitate the contribution of DG.

2.2 Realising the value and impact of Distributed Generation

2.5 DG will make a large contribution to meeting targets set for introduction of renewable and low carbon generation. However, there is a disconnection between this vision set by Government targets and the realities of the present system and arrangements. At a high level this is illustrated by the value chain from power generation to consumption, illustrated in Figure 1. This shows the value of electricity produced by centralised generation to be around 2-3 p/kWh, the price of wholesale electricity, by the time electricity reaches the end consumer this value has increased to around 4-10p/kWh. This increase in value of electricity up to the point of consumption is driven primarily by the added cost of network transportation and distribution services, required to deliver power from centralised generators to customers elsewhere in the network.

2.6 DG, is located closer to the consumer and has fewer requirements for the transport services afforded by the transmission and distribution networks. In essence, DG is delivering power direct to demand, power that should have an equivalent value of between 4-10 p/kWh, i.e. the avoided costs of not using the network.

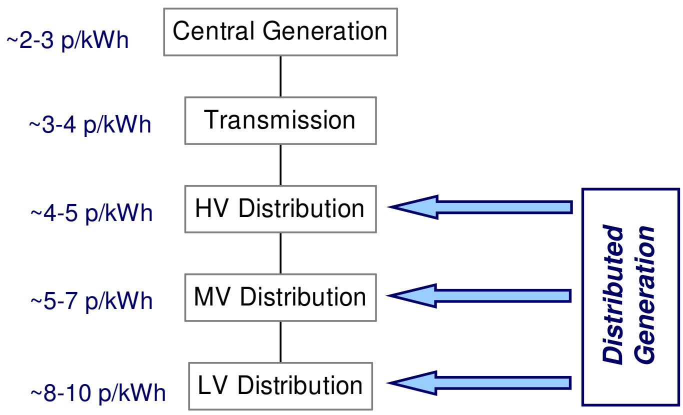

Figure 1: Value chain for electricity from central generation to LV distribution

2.7 However, these system benefits generated by the favourable location of DG are not fully recognised within the present commercial and regulatory framework. As a consequence, DG invariably is competing with conventional generation at a price (2-3 p/kWh) that may be significantly lower than the true value of electricity delivered from a location close to demand (i.e. 4-10p/kWh). Ignoring these particular features in the derivation of the value of DG results in non-competitive markets in which DG cannot compete on an equivalent level with conventional generation, and network solutions. Ultimately, this will lead to the creation of inefficient and non-cost reflective systems, whereby DG is not efficiently integrated into the system and the resulting framework relies on unnecessary network reinforcement, and inefficient solutions based on increasingly expensive, low-utilisation conventional generation.

2.8 This paper aims to provide an overview of the economic and technical impact of DG on the conventional power system. It provides a high level insight into the main challenges for developing the current system to accommodate DG, and identifies the major gaps in the existing regulatory, commercial and technical arrangements that have the potential to restrict the integration of DG1. The approach of the paper is first to identify of the technical impact and value of DG to the existing system. This is followed by an analysis of the current arrangements in terms of how and if they capture this value of DG and present a level playing field on which DG can compete with conventional generation and alternative network solutions.

[1] The paper uses a broad definition of distributed generation that covers all technologies connected to the distribution network. Demand side contributions are not explicitly considered in the paper; however as DG and demand side actions are equal (and opposite) many of the findings on the impact and value of DG in the system can also be extrapolated to the demand side.

3. The Impact of Distributed Generation on System Costs

3.1 The current policy of installing distributed generation has been focused on connection rather than integration; typically, DG has been installed with a "fit and forget" approach, based on the legacy of a passive distribution network. Under this regime, DG is not visible to the system so whilst it can displace energy produced by centralised generation it cannot displace this capacity. Without active management at the distribution level or representation to the transmission system, DG lacks the conditions required to provide system support and security activities, so centralised generation capacity must be retained to perform this function. With growing pressure to increase DG penetration, this passive approach will lead to rising costs for investment and operation of the system and ultimately impact the pace of DG adoption. Figure 2 shows a schematic representation of the capacities of DG, distribution and transmission networks as well as central generation of today's system and its future development under two alternative scenarios both with increased penetration of DG. The Business as Usual (BAU) future represents system development under a traditional system paradigm characterised by centralised control and passive distribution networks as today. The alternative, Active Future represents the system capacities with DG and the demand side fully integrated into system operation under a decentralised operating paradigm which allows DG to participate in both energy markets and system management. DG and the demand side will take responsibility for delivery of system support services alongside central generation. In this approach, DG will be able to displace not only energy produced by central generation but also its controllability and capacity.

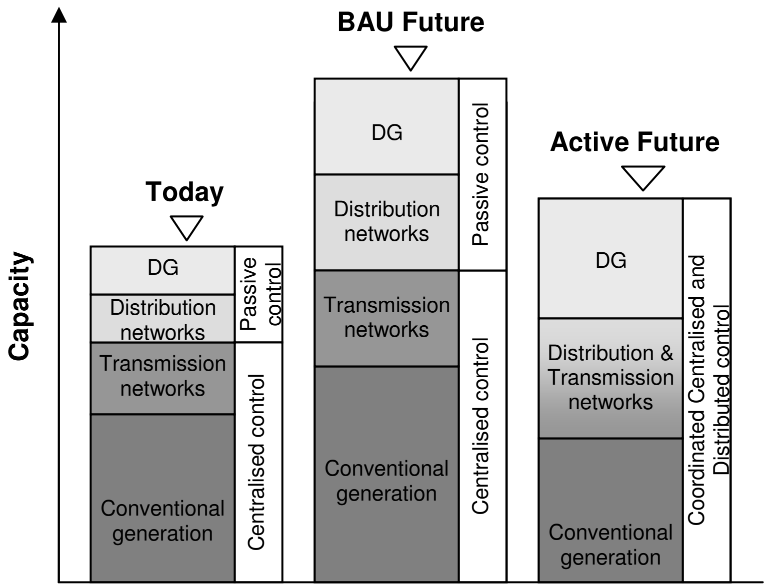

Figure 2: Relative levels of system capacity under centralised and distributed control strategies

BAU future

3.2 Under the BAU future, large-scale penetration of DG will displace a significant amount of the energy produced by large conventional plant. However, if DGs and demand side are not integrated in system operation, conventional generation will continue to be necessary for provision of system support services (e.g. load following, frequency and voltage regulation, reserves) required to maintain security and integrity of the system. This implies that a high level of DG will not be able to displace the capacity of conventional plant as indicated in Figure 2. Given that DG is connected to the distribution networks, maintaining the traditional passive operation of these networks and the philosophy of centralised control will necessitate increase in capacities of both transmission and distribution networks.

Active future

3.3 On the other hand, by fully integrating DG and demand side into network operation as proposed in the "Active Future", DG and demand side will take the responsibility for delivery of system support services, taking over the role of central generation. In this case DG will be able to displace not only energy produced by central generation but also its controllability, reducing the capacity of central generation as in shown in the figure. To achieve this, the operating practice of distribution networks will need to change from passive to active. This will necessitate a shift from the traditional central control philosophy to a new control paradigm of coordinated centralised and distributed control.

3.4 This future requires significant Information and Communication Technology (ICT) capabilities to facilitate interaction between thousands (potentially millions) of DG units and the system operators, as well as new decision support tools to interpret and act upon the new information presented by integrated DG. This will bring an increase in complexity of system operation; however, with the correct development and innovation this new paradigm of shared centralised and distributed control should facilitate the development of more reliable, cost effective and sustainable systems that achieve maximum utilisation of all the resources connected within them.

3.5 As illustrated in Figure 1, realisation of the full impact and value of DG is the key message. DG can claim significant additional value through its proximity to load and much of this value is caught up in the use of the networks, and contribution to system operation and balancing as described in the figure above.

3.6 Identification and realisation of this intrinsic value of DG is essential to allow the analysis of existing system arrangements and inform the development of new ways forward to accommodate DG. The discussion presented here is a summary of a more detailed analysis drawing on a number of previous quantitative studies. The review evaluates and quantifies the costs and benefits associated with integration of distributed DG into the UK system in terms of the impact on transmission, distribution and generation. Case study examples of characteristic DG technologies (e.g. micro CHP and PV) are explored to illustrate the main points relevant in each of these sections.

3.2 Transmission

3.7 Transmission network design is driven by the dual requirements of meeting high standards of network reliability and promoting economic efficiency in network development. For the transmission system operator this means optimising transmission design, reinforcement and operation, to find an optimal a combination of long-term infrastructure investments balanced against cost of real-time system operation. Planning this optimal system requires the consideration of a complex array of factors, including forecasts of growth in demand and generation with their temporal and spatial distributions together with the technical and cost characteristics of generation. In practice, simpler deterministic planning guides are used (also called network planning standards) that present a proxy of the comprehensive reliability and cost-benefit assessments for determining the amount of transmission capacity required to transport power across various system boundaries given a predefined set of generation and demand scenarios.

3.8 The Great Britain Supply Quality and Security Standards (GBSQSS) drives the design of the GB Transmission Network and was developed for systems with conventional generation. The key underlying philosophy of the standard is that generation in one area of the interconnected transmission system should not be unduly restricted from contributing to securing supply for loads in a remote area, via the interconnected system. If necessary, this requirement drives reinforcement of the network to ensure that this criterion can be met. To do this, network planners traditionally would consider conditions of peak demand to determine the need for transmission network capacity across the major transmission boundaries based on these security requirements. Historically, economic efficiency criteria would be automatically met when networks are designed to com ply with the security criterion.

3.9 However, the existing methodology was developed for conventional generation and considers contributions to the system at times of peak loading to be the primary driver for reinforcement of the network; and presumes that all generation plant is operating close to maximum output at times of peak demand. This is a suitable proxy for base load and load-following conventional generation, but for DG this extrapolation is not always appropriate as the output of many DG technologies is led by other factors un-correlated to demand (e.g. heat demand or weather conditions).

3.10 Under the current GBSQSS standards that define the capacity requirements of the current transmission network, the requirement for high standards of system reliability usually ensures that the system specification already exceeds the capacity that would be proposed under planning proposals for economic efficiency alone. However, the consideration of DG in system planning may change this balance. Many DG technologies make a limited contribution to reliability of the network due to low capacity values (see section 3.4 for further clarification of these issues). As such, planning the network on the basis of generation contribution to reliability alone may no longer be optimal

3.11 The impact of DG on transmission network requirements is significantly influenced by the location of DG given the predominant North-South power flows across the GB transmission networks[2]. DG that is located in the Scotland and North of England could increase the demand for transmission capacity while DG located further South has the potential to reduce the demand for transmission network capacity. Using regional projections of the location of DG across the UK for the placement of 10GW of capacity (as per the Government targets for CHP installations by 2010), initial analysis suggests that DG has the potential to reduce the requirements for transmission network capacity in the long term. The value of this benefit is estimated to be in order of £50-100/kW installed DG capacity.

3.12 On the other hand, significant penetration of wind power in Scotland will drive additional requirements for transmission capacity. However, a recent study [1] indicates that this form of DG will tend to drive less transmission investment than conventional generation. Furthermore, there will be benefits of diversity in output between DG and conventional generation that will mean that transmission capacity can be shared. In other words, the total transmission capacity required for a group of generators with diverse outputs will be less than the sum of their respective installed capacities.

3.3 Distribution

3.13 Historically, the structure of electricity distribution networks was driven by an overall design philosophy developed to support large-scale generation technologies. The distribution networks are characterised by passive network operation with real time control problems being resolved at planning stage. These passively managed networks are usually planned to accommodate single direction power flows, from the transmission system to demand customers, over a range of different supply voltages. The primary assets (transformers, switchgear, overhead lines and cables) on passive networks are specified to accommodate a set of pre-specified operating conditions, ensuring the technical parameters of supply (e.g. voltage and power flows) are maintained within statutory and safe tolerances, without the requirement for proactive network monitoring and reconfiguration.

3.14 Integration of DG into the Distribution Networks is fundamentally about enabling DG to offer non-network based solutions to the system operator, to compete with the traditional network solutions outlined above for the creating of a secure, reliable network that delivers quality of supply and minimises

[2] Although distribution connected generation may contribute to balancing demand locally, the nature of the interconnected GB system is that local activity and changes in net flows between transmission and distribution will have an impact on the system as a whole; particularly with reference to the existing North-South power transfer. Distributed plant generating in the South will effectively reduce local demand and have a beneficial effect on the North-South power flows. Conversely, generation connected at distribution level in the North and Scotland will reduce local demand in an area already dominated by generation, increasing export and possibly exacerbating system management issues associated with north-south power transfer.

losses. As described in Figure 2 this requires a fundamental shift in philosophy away from system management through planning, into active management of the network, using a range of network and non-network solutions to manage and build an optimal network.

DG and network security

3.15 Typically, Distribution Network Operators (DNOs) have used network based solutions to deliver the required level of security. In an era of significantly increased levels of distributed generation, with a suitably updated planning standard recognising a wide range of distributed generation technologies, there will be significant opportunities for generators to provide security contributions to network planners.

3.16 A recent update of security standards in the UK now requires DNOs to consider the contribution that DG can make in the context of network security. This covers a wide range of generation technologies including various forms of CHP and intermittent generation such as wind. The new standard does not differentiate between different sources of network security, e.g. distribution circuits and generation sources and in this context the standard facilitates direct comparisons between these different approaches to achieve appropriate levels of network security. This is a fundamental step towards integration of DG in the operation and development of distribution networks, because the key to integration is to allow distributed generators to substitute for network assets, i.e. provide non-network solutions to network problems.

Example: DG provision of network security

3.17 A simple example is set out in Figure 3 and illustrates how a DNO would traditionally comply with planning guidance in a 33/11 kV demand group. As can be seen, the group demand of 50 MW can be supplied through either distribution circuit such that if one circuit were to fail, the group demand could be accommodated through the remaining circuit. In this example, traditionally DNO would ignore the presence of the generator and no security contribution could be allocated.

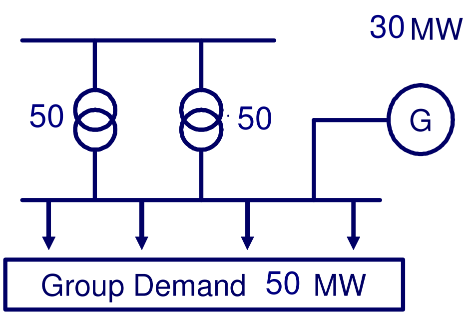

Figure 3: Example of ER P2/5 compliance without generation contributions

3.18 If the group demand in the above example were to grow to 55 MW, the supplying network would no longer be compliant, thus requiring the DNO to seek additional security contributions. Figure 4 illustrates two different approaches available to DNOs, which would secure sufficient additional security for network compliance under the old Engineering Recommendation (ER) P2/5 and the new ER P2/6. Under ER P2/5, assuming no generator contribution could be utilised, the DNO could be forced to seek a network solution to provide the necessary security shortfall. In the example below, this could be secured through the installation of a third distribution circuit. The rating of this third circuit would be at the discretion of the DNO but would need to accommodate any further load growth forecast during the life of the assets.

3.19 Under the new ER P2/6, it is possible to recognise the security contribution of the generator. Assuming the availability of the 30 MW generator resulted in a security contribution of say 60%, an overall security contribution of 18 MW could be recognised for network planning purposes. Through the addition of the generator security contribution, it can be seen that the original network becomes compliant and hence the requirement for DNO investment in a network solution is avoided.

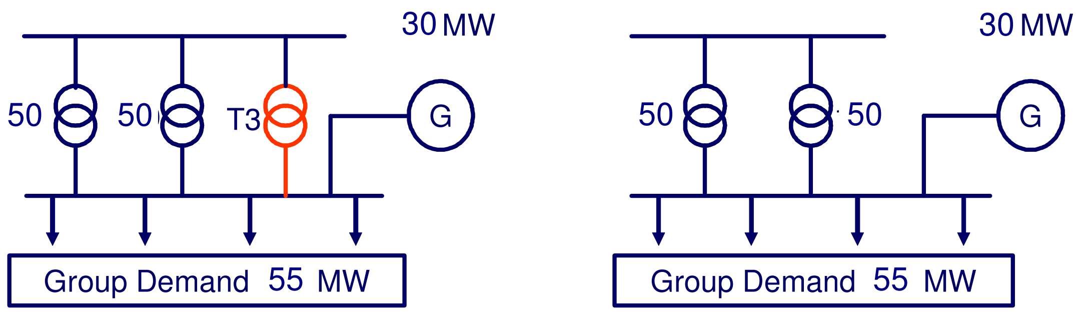

Figure 4: Possible solutions to a network security shortfall under P2/5 & P2/6

3.20 Considering the value created by substituting distribution network capacity by generation, our analysis suggests that value of micro CHP in the in the context of the UK distribution network would amount to about £50-100/kW of installed capacity of generation, depending on level of penetration and density.

Distribution Network losses

3.21 Energy losses from the network occur in the form of heat in transmission and distribution circuits. In the UK, annual losses from the distribution system account for around 7% of the electricity transported which equates to around 20TWh/year [2]. The magnitude of losses is influenced by a number of parameters, namely; electrical resistance of circuits, proximity of generation and load, temperature, network configuration, voltage level of transmission/distribution, voltage transformations, magnitude and diversity of the load and power factor.

3.22 Distributed generation can influence losses through altering these parameters. Through its location in the distribution network, appropriately sited DG reduces the transport distance to loads and can potentially make a significant contribution to reduction of losses. In addition, coincidence of generation from well located plant with system peak demand will also make a contribution to loss reduction through reducing peak loading when losses are most extreme. These contributions to loss reductions are entirely location specific, dependent on technology (size, type etc.), operating strategy, density of technology penetration, network topology, proximity to load, etc. The same generating technology in different locations can have opposite effects on network losses.

Example: Contribution of micro CHP and PV to reduction in losses

3.23 It is important to stress that peak losses (incurred during peak demand periods) could be significantly higher than the annual average of 7%. In this context small scale DG that would tend to operate during peak demand periods could have a very significant impact distribution network losses. Micro CHP output is coincident with the system peak loads (i.e. winter 5.30pm) and so has the potential to make a significant contribution to reduction in losses during this period. A recent study (see Figure 5) concluded that in rural networks, the level of losses can be reduced by over 40% (from 8.5% to 5%) by micro CHP with installed capacity of 50% of the total Grid Supply Point (GSP) peak load. In urban areas, the same capacity of micro CHP reduces the level of losses from 4.5% to 3% (reduction of 33%). Similar trends are shown for PV.

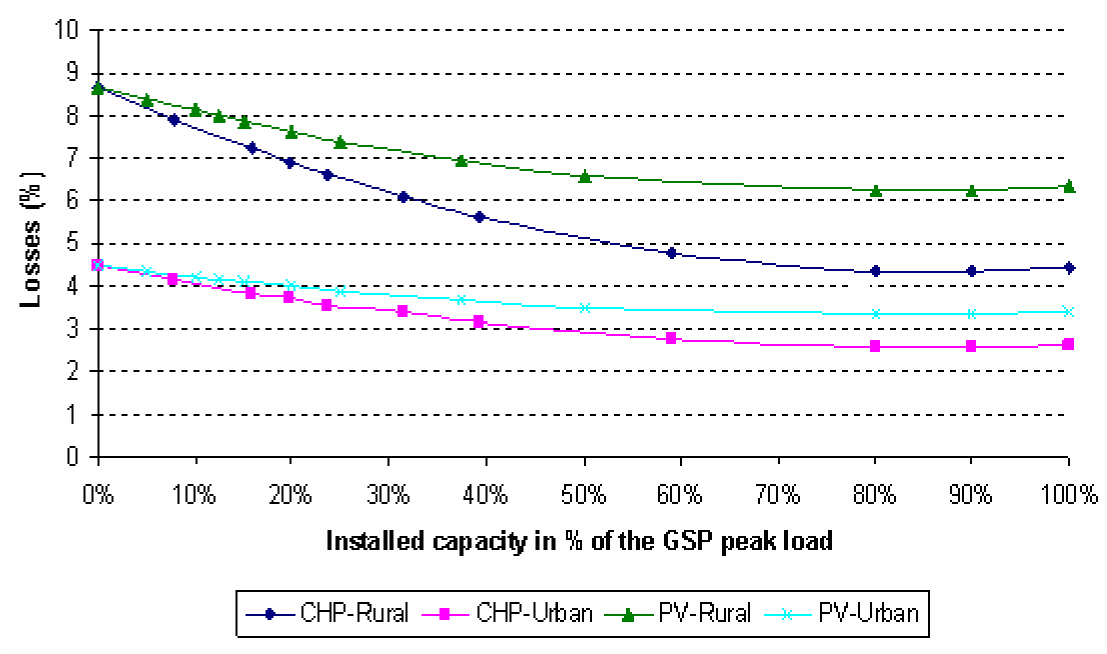

Figure 5: Impact of CHP and PV on distribution network losses for rural and urban locations [3]

3.24 The CHP contribution to loss reduction is larger compared with PV because the profile of micro CHP electricity production has a greater correlation with electricity demand compared with the electricity production profile of PV. In the UK PV, has a limited effect on losses incurred at the overall system peak. However, it should be noted that there are some localised exceptions to this observation; for example in central London where peak flows (driven by air conditioning demands) have been experienced during the summer months at around 3pm.

3.25 This study also highlights that above certain penetration levels micro generation begins to increase losses again (see Figure 5). This point is reached when the electricity output from generation can no longer be absorbed by the local load, and generation output starts to dominate peak flow conditions.

3.4 Generation

3.26 This section explores the role of generation in the power system and its function of balancing the system over a dual time horizon. Namely, contributing to system reliability in the long-term through the generation capacity margin, and providing system security in the short-term through availability of flexible reserve and response services. The addition of DG to the generation mix has an impact in both these roles, changing the generation capacity required to support the system, and affecting the mix of generation required to provide flexible reserve services. This section presents the major impact that DG has on the generation mix, and highlights the factors that drive and change this impact.

Contribution of DG to generation capacity margin

3.27 Whilst DG can displace the energy generated by conventional plant on a one-to-one basis, the contribution of DG technologies (or any generation technology) to the generation capacity margin is calculated by the extent to which a that technology can displace existing conventional generating plant without compromising system reliability. This is termed the capacity value (or credit) of a generation technology. Capacity value is determined by technology contribution in relation to system peak, and is derived as a measure of a generator's contribution to the total system.

3.28 To calculate capacity value for DG technologies, the starting point is to establish the amount of conventional capacity required to maintain a given level of security of supply. DG plant is then introduced into the model and the effect on system security is studied. A calculation is made to determine the amount of conventional generation capacity that can be retired to maintain the system security to its original level [4]. The cost of DG on system reliability is related to the relationship between energy and capacity displaced by the new technology and the net impact of these factors on the change in utilisation of incumbent plant.

3.29 Many DG technologies have a low capacity value, this means that they will displace proportionately more energy than generating capacity when introduced into the system, and some generating capacity may need to be retained to ensure that overall system reliability is not compromised. Disproportional displacement of energy over capacity means that the incumbent (conventional) generation is utilised differently. Power output from incumbent generation is not required to the same extent, but its capacity is still needed for system reliability. This means that existing plant must be retained, but run at lower load factors and/or used less frequently. Over time, DG will displace increasing levels of baseload generation, ultimately leaving existing conventional generation to operate only in response to system peaks or requirement for system balancing services.

3.30 The disproportion between energy and capacity displaced, and the resulting impact on average utilisation of the incumbent conventional generation is the primary driver for system costs associated with generation capacity and different technologies (DG and conventional generation) will have different impact on these system costs. For example, generation that displaces baseload generation in greater proportion to system capacity (such as wind or nuclear power) will have the effect of increasing system costs. In contrast, generation like micro CHP has a positive capacity value and can displace low utilisation plant capacity, reducing system costs.

Example: Capacity value of Micro CHP and wind

3.31 Unlike many other DG technologies, micro CHP actually reduces the amount of conventional generation capacity required to meet system peak demand, resulting in a positive capacity value. Micro CHP output will typically be coincident with the winter peak demand condition, as this is also the time of peak heating demands. Micro CHP output also effectively reduces the demand at the winter peak, thus reducing the capacity required to maintain system security. Averaged across many CHP units this effect would be fairly predictable and reliable, so micro CHP would not increase the need for reserve, and can actually displace additional capacity. As such, the additional benefit to system capacity costs of micro CHP can be calculated at around £14/MWh (i.e. micro CHP confers a positive benefit, and reduces system costs by this amount)[5].

3.32 Conversely, wind has a capacity value of less than 1, and produces disproportionately more energy than it displaces in capacity. A recent report estimates that the additional impact of wind on system capacity costs is an additional £2-5/MWh [4].

4. Analysis of the current arrangements and impact on DG

4.1 As outlined previously, there are two overarching problems facing the integration of DG into the UK power system; the lack of recognition and reward of the inherent value of DG to the system, and the unsuitability of the present arrangements for evolution towards a sustainable system including non-conventional generation sources. This section addresses the relevant regulatory, commercial and technical arrangements within which the integration of DG is currently taking place. With an understanding of the impact and potential value of DG, as outlined in the previous section, this section analyses the existing arrangements and determines whether the present frameworks are capable of recognising the inherent value of DG.

4.2 Under the headings of transmission, distribution and generation, this section identifies the key areas that are either contributing to- or preventing the realisation of value for DG, and highlights possible ways forward or routes for further work to address these discrepancies or distortions in the market.

4.3 Particular attention is given to the arrangements for DG access to transmission as this is perhaps the least advanced area in terms of understanding the fundamental impact of DG on the network, and most urgent area for attention in terms of integrating DG currently waiting to be given access to the transmission network. The current bottlenecks in timely connection of wind generation are one of the main short-term drivers for action on the issue of integration of DG technologies. Although discussion has been initiated on the issues surrounding transmission arrangements for DG, there is as yet no consensus on how DG drives transmission capacity, or on the regulatory and commercial arrangements to codify this interaction.

4.2 Transmission: Access arrangements

4.4 Development of a reflective methodology to determine the capacity requirements of DG at transmission level is a priority issue for the current UK system. This is exemplified in the current situation where there is the potential for 16GW of wind projects being delayed because of the perceived requirement for significant transmission system reinforcement to accommodate this new generation.

4.5 These delays to connection of wind are unnecessary, and caused by (amongst other factors) the fact that application of frameworks for network reinforcement designed for conventional networks are not appropriate when considering systems that include non-conventional generation such as wind (or any DG) with a significantly different operating profile.

4.6 The main tool for determination of transmission capacity requirements, the Transmission Entry Capacity (TEC) is the key to this inaccurate derivation of DG capacity requirements. The various inconsistencies between the derivation of TEC and DG, and the subsequent links between TEC and the investment and pricing process are explored in more detail in the following section.

Issues with TEC

4.7 The existing approach to determining transmission access for conventional generation is through the concept of the Transmission Entry Capacity (TEC), a user defined product that confers long term access rights to generators. TEC is used to determine user transmission charges, and also informs capacity requirements for investment and network planning purposes.

4.8 Although a suitable tool for these purposes in a system dominated by conventional generation it is likely that the concept of TEC will require significant redevelopment for it to be effective in a future sustainable energy system including a significant proportion of DG. In this context, the key feature of the future electricity system is diversity in generation outputs between various DG sources and conventional generation.

Appropriateness of the concept of TEC in systems with DG

4.9 Although the concept of Transmission Entry Capacity (TEC) is attractive in principle, the key problem of the present implementation and interpretation of this instrument is its lack of the consistency with the transmission investment process, transmission network pricing and possible adverse impacts on the efficiency of generation system operation and network investment in systems with diverse generation technologies.

Inconsistency of TEC and transmission investment

4.10 For DG, the TEC associated with an individual generator will not be directly linked with the need for transmission capacity on the main interconnected system that this generator imposes, particularly in systems with generators of different technologies as is the case in most areas with DG. It is clear that different (distributed) generation technologies may drive different levels of investment in the main transmission network and that this is not reflected in the value of TEC. This is critically important as the absence of a link between TEC for DG and transmission investment cost means that an efficient price for TEC cannot be transparently determined.

4.11 In other words, as TEC for DG cannot be directly linked with the need for transmission investment that the user imposes, there is no mechanism that would allow efficient and transparent valuation of TEC. As the concept of TEC, in its present format, does not provide the basis for transmission reinforcement, it should not be used as the indictor of user commitment for future network investment in systems with DG. .

Inconsistency between TEC and TNUoS charging methodology

4.12 Given that the TEC required by DG is not directly relevant in determining the impact that the user makes on long-term marginal transmission investment cost, then using TEC for pricing is clearly not cost reflective. Hence the concept of TEC has little significance in the context of network pricing in systems including significant penetration of DG.

Inefficiency of generation system operation caused by the introduction of TEC

4.13 Generators that purchase a certain amount of TEC that is lower than the installed capacity of their generation would be prevented from generating in excess of the TEC purchased, irrespective of whether the network is congested or not. This is clearly inefficient, as these users are unnecessarily prevented from accessing the transmission network (and hence the energy market) when the short-term marginal cost of using this transmission capacity is minimal (close to zero). This will require the operation of higher cost generation and in turn will lead to an increase in electricity prices.

Inefficiency of transmission investment caused by the concept of TEC

4.14 The process of converting TEC into investment capacity decisions is not clear. The present approach to assessing the need for transmission capacity between large areas does not adequately take into account the effect of diversity, which is fundamental to achieving efficient development of the transmission network. The values of TEC for individual generators tend to be simply added together and this will clearly lead to over-investment in transmission. Particularly with reference to DG, this gross treatment of access requirements will clearly lead to over specification of capacity as it fails to recognise the significant diversity in DG, and the opportunities for DG (and demand) to share transmission capacity.

4.15 Furthermore, if the amount of TEC issued to transmission network users matches the available transmission capacity, this would be clearly inefficient, because a constraint free transmission network is uneconomic. An economically efficient transmission system should be optimally constrained rather than operate in a constraint free mode.

Alternatives to TEC

4.16 It is clear that TEC in its current form will not facilitate cost effective integration of substantial amounts of DG into the UK transmission system. Revision of the concept of TEC to reflect the diversity of different DG technologies is essential if transmission access and related arrangements for DG are to be cost reflective and transparent. Some further discussion of this issue is included below and in section 4 of this report.

Transmission: Developing access arrangements for DG

4.17 To initiate the discussion of alternatives to TEC, it is important to look at the issues surrounding DG access to transmission in a broader context. The generation system is a fundamental part of transmission system management. Increasing penetration of DG is changing the use of boundaries between transmission and distribution. The impact of this effect on transmission in terms of driving network investment, and allocating costs to system users is not clear. But, as numbers of DG connected at the distribution level increase further there will be a growing pressure to devolve system control responsibilities, and enable DG to provide an increasing level of system operation services.

4.18 To facilitate this activity requires DG to be visible at the transmission level, to have access to the transmission network, and for there to be a clear methodology on how much access DG requires and how this should be priced. Although access products do exist for DG (e.g. BEGA[3] and BELLA[4]) the arrangements are complex, they involve DG interaction with both the DNO and TSO and are designed for single large generators, resulting in gross treatment of DG access to transmission (fundamentally treatment using the TEC approach).

4.19 Furthermore, there is the potential for millions of distributed units (generation and demand) to be making contributions to transmission level operations. It is not practical or feasible for the TSO to be handling such large numbers of individual interactions; ideally a third party or agent, would be used to aggregate the position of a group of generators and load. Making a single point of contact for DG, and for the TSO to access DG services.

4.20 In this context, arguably, the cost-reflective approach is to determine access requirements for all users, based on the net position of generation and demand within a particular distribution network; essentially characterising the net flow between transmission and distribution networks.

Net versus gross

4.21 Access to transmission for DG based on a gross approach would see individual distributed generators with separate arrangements for transmission access. Based on the current arrangements, this would resemble a system where all DG have an individual TEC (or BEGA/BELLA arrangement) for firm transmission access rights. Under a net model all DG within a fixed geographical area would be considered as a single unit, and transmission access would be based on the net requirements of the group, taking into account diversity in generation output. Under the net model there is also the opportunity for inclusion of demand, and consideration of access requirements on the basis of the actual net flow between transmission and distribution.

4.22 A fully cost reflective approach to enabling DG access to transmission should entail net treatment of DG within a particular geographic area, including the contribution of demand. Transmission capacity is driven by net power flows at the transmission/distribution boundary, so it is appropriate that the contribution of both generation and demand should be considered. Importantly, through net treatment, account can be taken of diversity in generation output and demand thus providing a more accurate signal of transmission capacity requirements.

Equal treatment of generation and demand

4.23 Generation and demand have equal and opposite physical impact on the network. However, the current charging regime does not reflect this as the Transmission Network Use of System (TNUoS) charges are levied 73% on

[3] Bilateral Embedded Generation Agreement (BEGA)
[4] Bilateral Embedded Licence exemptable Large power station Agreement (BELLA).

demand and 27% on generation, generation charges can be positive or negative, but demand charges are only positive. Demand access requirements and charges are based on metered volumes, whereas generation charges are based on user requests for firm access rights through the TEC. At present, as most DG have no formal TEC, they are usually registered with an Energy Supplier and all output is treated as negative demand that serves to reduce the Supplier's net demand position and associated TNUoS charges (known as "embedded benefits").

4.24 The embedded benefit is awarded to DG regardless of location, based on the principle that DG serves local load, reducing import flows and the requirement for transmission capacity. However, because of the 27/73 split of TNUoS charges on generation and demand DG will get proportionately more benefit than an equivalent conventional generator sited in the same geographic region (but on the transmission network). There is no consideration of the fact that DG in the North of the UK will reduce local loads, but that this will have the net effect of increasing north-south power flows and potentially increasing congestion and hence driving the need for transmission investment.

4.25 Under the existing arrangements, providing DG with universal access to transmission, effectively removing the embedded benefits reduction and exposing DG to generation (TEC based) charges for use of the system would not allow net consideration of the demand/generation balance. This would fail to recognise the value that can come from DG serving local loads and would simply change, but not resolve, the problems of distorted cost allocation with reference to DG driven transmission investment.

Agency models; Energy Supplier versus DNO

4.26 For DG to be represented at transmission level under the net model proposed a mechanism for aggregation and calculation of net position is required. The concept of a third party agent to represent DG at the transmission level and arrange access on behalf of individual units or aggregated groups of units has been proposed. The most obvious candidates for such a role would be the incumbent Energy Suppliers or DNOs.

4.27 Although many Distributed Generators are registered under an Energy Supplier (usually via a Power Purchase Agreement (PPA) for sale of their output) and this existing arrangement could be a useful platform for the purchasing of appropriate transmission access rights, there are difficulties with this approach posed by the competitive nature of the supply business.

4.28 Distributed generators are free to choose which Supplier they will register under, and can (subject to the contractual arrangements of the PPA) change Supplier if they wish. Transmission access for DG is best allocated on the basis of a net position for all DG (and demand) in a specific geographic area to account for diversity in the output of a group. An Energy Supplier is unlikely to be able to capture the full benefits of diversity as many Suppliers may be representing DG in a single distribution network area. In addition, if a Supplier determines the net position of a group of DG within a particular GSP this is calculated on the basis of the net access requirements of the group; mobility of DG to other suppliers will affect this net position. As the allocation of access is based on a net position, it is complex to confer individual rights to generators. So, for generators transferring to another Supplier, there will be significant issues around ownership of transmission access rights and transferral of those rights.

4.29 Under the Supplier agent model it is likely that this can only operate if all DG are given an individual access allowance (similar to an individual TEC – the gross model approach). This would negate any benefits of diversity, and forego the opportunity to include demand in the calculation of access requirements.

4.30 The DNO agent model overcomes these problems and facilitates the generation/demand net approach. Each DNO is responsible for calculation of the net position of all generation and demand in their jurisdiction; this allows maximisation of the benefits of diversity. Generators will interact directly with the DNO, who will make arrangements with the TSO on their behalf. Generators are free to change Supplier, but access arrangements for transmission will remain fixed with the DNO, and based on the location of DG in the network and its patterns of output in relation to other generators and demand.

4.31 Importantly, the DNO is also the only agent that is capable of providing detailed information on the actual state of the physical flows at the transmission distribution boundary. The distribution network sits between DG and the TSO, network constraints and losses at this level will significantly modulate the characteristics of DG as seen by the TSO. Distribution network topology changes in real time, such that the DNO is the only party with sufficiently detailed network knowledge capable of determining how individual DG (and demand) activity will contribute to the net flows at the transmission-distribution boundary.

4.32 Furthermore, in the future, distribution networks may be actively managed, and DG could be used to contribute to transmission system management. In this situation, the evaluation of feasible flows across the distribution – transmission boundary will require detailed knowledge about the real time topology and availability of distribution networks. Again, the DNO is the only agent with detailed information suitable for elucidating actual net transmission capacity requirements at the transmission-distribution boundary.

Implications of DG access for TEC

4.33 Optimal derivation of DG access requirements will be on the basis of a net consideration of all DG in a GSP (preferably including the contribution of demand). This is to take account of diversity in output that impacts the requirement for transmission capacity and recognises the fact that DG is not comparable to conventional generation in its patterns of use of the system or in the capacity that it requires. TEC in its current format is not suitable for translation to the case of DG as it cannot take account of these subtleties in DG operation that are crucial for the recognition and reward of its value to the system.

4.34 As outlined earlier, the fundamental principles of TEC have been developed for conventional generation, which differs from DG in several fundamental ways. As such TEC cannot be expected to be a suitable proxy for representing the access requirements of DG, or for relating these requirements to the associated investment and pricing arrangements to reflect the impact of DG on the network. Care should be taken not to propagate this inappropriate methodology into any new DG arrangements.

4.35 Full implementation of the net generation/demand approach would obviously require a review of the concept of TEC and the associated TNUoS charges. Further work is also required to explore the contractual relationships required between the DG and potential agents, to understand how the role of agent will interact with and/or change existing markets (e.g. balancing mechanism) and other related arrangements.

4.3 Distribution: Network security, investment and pricing

4.36 Integration of DG into the system requires access of DG to offering distribution network solutions and the opportunity for DG to substitute distribution network capacity investments. This issue has been recognised and led to the development of new distribution network security standards, which now quantify the contribution that DG can make to distribution network capacity displacement. This update of network planning standards in the UK requires DNOs to consider the contribution that DG can make in the context of network security. The new standard does not differentiate between different sources of network security, e.g. distribution circuits and generation sources and in this context the standard facilitates direct comparisons between these different approaches to achieve appropriate levels of network security. This is a fundamental step towards integration of DG in the operation and development of distribution networks, because the key to integration is to allow distributed generators to substitute for network assets, i.e. provide non-network solutions to network problems.

4.37 However, there is as yet no commercial structure developed to reward DG for their contribution to network security, and the mitigation of network reinforcement. Further work is required to explore possibilities for this interaction and explore the potential for DG to receive tangible benefits from this contribution.

4.38 The value that DG can create in the context of providing network solutions could be enhanced if the distribution network operation and planning philosophy change and move towards active management of distribution network operation. However, an appropriate incentives framework would need to be created to encourage such development.

4.39 As indicated above, the question of developing a level playing field for central and distributed generation is a network pricing question. In this context, recognising the difference in demand for network capacity that central and distributed generation impose is a key to achieving cost reflectivity and providing a level playing for competition in generation and supply. Generators (and loads) that impose the demand for network capacity (i.e. increases network costs) should be charged while generators (and loads) that reduce the demand for network capacity (i.e. reduce network costs) should be rewarded. There has been considerable effort from the regulator to explore the potential for cost reflective pricing in DG. However at the present time, there is a lack of a comprehensive charging methodology across DNOs. Generation and demand are not dealt with equally and there is little or no consideration of locational or time of use factors for the impact of DG on the network costs.

4.40 Furthermore, there is a concern that the retrospective approach to the Distribution Use of System charges that focuses on revenue recovery objectives, rather than sending efficient signals to users regarding their future network use and its relation to costs, may not deliver efficient integration of DG and facilitate the competition in generation and supply. All these issues exacerbate further the challenge of achieving consensus and clarity on cost reflective pricing issues.

4.4 Generation: Displacement of generation capacity margin & visibility

4.41 Sustainable energy systems with a significant penetration of DG will require a different mix of generation technologies to maintain security and reliability standards. Increasing penetration of DG into the system will displace energy produced by existing baseload plant, but will not displace a corresponding amount of generation capacity (required to provide flexible system balancing services, and long-term system reliability). This displacement of energy will change the current generation mix, increasing the need for lower utilisation marginal plant running to provide flexible capacity, while the present arrangement are encouraging only baseload plant.

4.42 The current system does not recognise the value of flexibility and capacity; as such, evidence suggests that it will become increasingly less economically viable to make investment in this type of flexible plant (as it is utilised so little) and lead to an inefficient generation mix (with too much base load plant) and, at the extreme that lack of investment in flexible plant may not be sufficient to provide adequate reliability in the future. Significant research is required to investigate these issues further, and to explore alternative market based solutions to support the provision of adequate generation capacity.

4.43 Improving the visibility and access of DG to system operation and demand-supply balancing will improve the capacity value of DG and could mitigate some of the issues described previously. Limited standing reserve and some frequency response services can already be provided by aggregated groups of smaller generators or controllable loads. To facilitate full integration of DG in this way will enable the devolution of system management responsibilities, and ensure that DG can adopt a comprehensive role in the system. Ideally, this opportunity should be available to all DG, however this is currently limited by a lack of infrastructure capable of enabling mass communication with potentially millions of individual DG contributing to system operation.

5. Way forward

5.1 Although the materiality of the proposed sustainable future involving a high penetration of DG has yet to emerge in the UK system, it is essential that the correct frameworks are put in place to realise the value of any new DG introduced into the system. The principles of cost reflectivity in network arrangements should facilitate non-discriminatory access, equal treatment of all participants and pricing of the system to reflect costs imposed by users, regardless of the generation mix and progress towards a decentralised future.

5.2 However, the successful integration of DG into the UK power system and adaptation of the existing regulatory, commercial and technical arrangements to support this integration will be a complex task. The issues of investment, pricing and access at both the transmission and distribution levels are intrinsically interlinked. Dealing with any of these issues in isolation, without recognition of this link, will result in the loss of cost reflectivity and introduction of barriers and distortions in the market arrangements.

5.3 The sustainable power system of the future is likely to consist of a diverse portfolio of generation plant, quite unlike the existing system; and this will necessitate change in system arrangements. So, it is vital that any new regulatory and charging framework for this changing system receive the same careful consideration that has gone into the existing framework designed for networks supporting a homogenous group of conventional generation.

5.4 With direct reference to the development of TEC; there is urgency for the resolution of these issues surrounding the redesign of TEC to reflect the requirements of non-conventional and distributed generation. Action on this point is required now to resolve the issues surrounding lengthy connection times for wind generation, ready to connect to the UK system. However, resolution of the issue of TEC will also have significant impact in developing comprehensive arrangements for DG that provide access and recognise the value of a range of DG technologies.

5.5 Further work to scope the possibilities for adaptation of TEC for DG is required using the coordinated approach described above. An exploration of the interaction of the current TEC with investment, access and network pricing is needed, to facilitate a clearer understanding of the issues involved.

6. References

[1] Strbac, G, Pudjianto, D, Castro, M, Djapic, P, Stojkovska, B, Ramsay, C & Allan, R (2007) Transmission Investment Access and Pricing in Systems with Wind Generation, DTI Centre for DG and Sustainable Electrical Energy.

[2] Ofgem (2003) Electricity Distribution losses a consultation document, Office of Gas & Electricity Markets, London.

[3] Cao, D. M, Pudjianto, D, Strbac, G, Martikainen, A, Kärkkäinen, S & Farin, J (2006) Costs and Benefits of DG Connections to Grid System, DG GRID project, Research Project supported by the European Commission, Directorate-General for Energy and Transport, under the Energy Intelligent Europe (EIE).

[4] Gross, R, Heptonstall, P, Anderson, D, Leach, M, Green, T & Skea, J (2006) The Costs and Impacts of Intermittency: An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network, UK Energy Research Centre.

[5] Strbac, G, Jenkins, N & Green, T (2006) Future Network Technologies, report to the DTI, April 2006.