ESB NETWORKS

ASSESSMENT OF THE SCOPE FOR HIGHER PENETRATIONS OF DISTRIBUTED GENERATION ON THE LOW VOLTAGE DISTRIBUTION NETWORK

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KEY POINTS

1. ESB Networks is committed to assisting Ireland's decarbonisation of the energy sector.

2. The analysis in this report largely focuses on solar PV as it is likely to be the most common form of microgeneration installed.

3. Customers installing microgeneration should notify ESB Networks in advance of the installations, by means of a completed NC6 form.

4. Customers with microgeneration already installed should still complete an NC6 form so that they can be factored into ESB Networks smart meter replacement plan.

5. A review of the urban network shows that up to 4 kW_p export per house can be accommodated on the distribution network with little thermal capacity or voltage rise issues and limited associated reinforcement costs in most cases.

6. A review of the rural network shows that up to 3 kW_p export per house can be accommodated on the distribution network with little thermal capacity or voltage rise issues and limited associated reinforcement costs in most cases generally where the capacity of the local 15 or 33 kVA transformer is exceeded.

7. Any generation installation that exceeds 6 kW_p (single phase) and 11 kW_p (three phase) will require and will continue to require ESB Networks to complete a study before connecting to the grid as per regulated policy. ESB Networks is reviewing the connection application process for projects in this range 12-50kW_p including a trial on decentralized technical studies as well as a possible revised application form and connection agreements for projects in this range.

8. ESB Networks is now examining the use of an export limiting control which would facilitate larger installed capacity as long as the export was limited to an appropriate amount, and that harmonic levels were not exceeded.This will minimise the need for network reinforcement and support an equitable development of the network for all our customers,

9. ESB Networks is currently assessing network development and possible implications of increasingly renewable energy on the distribution network. ESB Networks is cognizant of the future expected increased level of microgeneration and are currently making provision for this in the new planning and security of supply standards for the distribution network

The power sector is undergoing transformative change with the growth of low carbon technology and changing consumer preferences. European policy and legislation, such as the Clean Energy Package and the revised Renewable Energy Directive (RED II), are driving a change in behaviour and supporting the decarbonisation of the European power sector.

The Irish government recently published the Climate Action Plan[1] (CAP) which sets ambitious targets to facilitate and enable the transformation to a low carbon future. This ambition includes the goal of reaching 70% of electricity generated from renewable energy by 2030. Renewable energy of all scales, from large-scale to small-scale renewable generation, community energy renewable energy projects, and microgeneration, will all play a part in contributing to Ireland's decarbonisation goals. As Distribution System Operator (DSO), ESB Networks has an important role to play in facilitating this transformation. Facilitating a low carbon future is a key objective for ESB Networks within PR5. ESB Networks is committed to enabling the move towards low carbon technologies and facilitating government policy requirements to develop microgeneration resources and enable participation in the energy market.

This report focuses on solar PV as it is likely to be the most common source of microgeneration installed and the discussion is also directly relevant to other inverter connected generation (i.e. single phase fuel cell CHP, single phase micro-wind generation and possibly Vehicle to Grid (V2G) in future) of similar size. Non-inverter connected generation, such as some forms of CHP, has different characteristics and would require a different level of discussion.

In this report the term 'microgeneration' is defined as per the Commission for Regulation of Utilities (CRU) 'Arrangements for microgeneration' which refers to small generators which can be connected on an 'inform and fit' basis at levels of up to 6 kW (at single phase) and up to 11 kW (at three phase)[2] .

The report is intended as a guide for the interested public rather than a detailed technical paper, so certain simplifications have been used, but these should not materially change the information provided. The report highlights the distinction between PV which is not exported but instead used for self-consumption, and that which is exported and hence has a greater impact on the network.

How PV is used in a typical household

Typically, rooftop PV Panels are installed, with the amount of electricity produced proportional to the area of the panels. The actual amount of electricity produced by a particular household installation is highest if the panels are installed on unshaded sections of the roof and pitched to best catch the sun. In general, south facing panels will catch twice as much sun as north facing ones, so that not all roof space is equally suitable for installation of panels.

In practice, the amount of electricity produced by a panel is about 80% of its theoretical output due to various technical factors, so that the overall output depends on the area of the panels installed, the amount of sunlight falling on them and the rate at which they convert the sunlight to electricity.

For example, for 8 panels of $1.3m^2$ each the overall area would be $10.4m^2$, with each square metre receiving between 0.4 (North facing) – 1 kWh/m^2 (south facing) annually. This means that such a PV array, if south facing, could produce nearly 1,200 kWh[3] per year.

As a typical customer uses 4,300 kWh of electricity annually this amounts to nearly 30% of their current electricity consumption, which is quite significant.

However, the PV generated within the household can only be used when household loads are also in operation during the day when the PV is generating electricity. In practice, the household loads will vary during the day and may be especially low if the house is unoccupied during the day.

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[1] https://www.gov.ie/en/publication/5350ae-climate-action-plan/

[2] CER/07/208 Arrangements for Microgeneration https://www.cru.ie/wp-content/uploads/2007/07/cer07208.pdf

[3] Details of these calculations are available in an SEAI publication 'Best Practice Guide' – Photovoltaic (PV) https://www.seai.ie/publications/Best_Practice_Guide_for_PV.pdf

Any PV that is not used within the household goes out through the ESB Networks Meter and onto the local networks where it is absorbed by other households. However, if neighbouring households also have significant PV, then the excess travels up through the connecting wires and transformers until it can finally be absorbed by other customers, although this could take place a considerable distance away.

It is currently more economic for householders to use PV they generate within their home ('Self-Consumption') rather than have it exported onto the grid. Accordingly, customers often arrange that appliances which use a lot of electricity, such as immersion or storage heaters switch on to divert any electricity that was being exported back into the household. Batteries can also be used in a similar way to store electricity.

It is likely that a proportion of the electricity generated by PV panels will not be used within the house itself and will travel onto the network. The larger the amount of PV panels installed compared to the load available in the house then the greater the proportion that will be unable to find a use within the house and will be exported to the grid. Currently such exported electricity is not generally paid for by the market, but it is now proposed within the CAP that there will be a future payment for such exports.

In 2019, ESB Networks commenced the Smart Meter replacement programme which will result in the upgrade of 2.4 million electricity meters. Smart meters will enable domestic customers to measure the export power from their microgeneration. For non-domestic or larger customers, an alternative meter is required. Smart meters are being installed in a Phased Approach and on a regional basis. Stage 1 completes at the end of 2020 with the exchange of 250,000 meters. In 2021, the rate of installation of smart meters will increase considerably with an additional 500,000 meters per annum being installed through 2024. Customers who have completed an NC6 form by the end of October 2020 will be included in ESB Networks smart meter replacement plans and ESB Networks will endeavour to install a smart meter by June 2021.

As set out in CRU's recently published Microgeneration Information Paper (CR20059) *"ESB Networks will have limited programme capacity available to install smart meters for microgenerators during 2020, so the availability of meters will be dependent on demand and cannot be guaranteed within this timeframe."*

As more and more customers install PV on their rooftop, and especially if the amounts installed per household are greater than what is required for self-consumption, then it is expected that increasing levels of PV will be exported onto the network. In turn this means that there are practical limits on what can be installed on the network without having to carry out network reinforcement. Customers installing microgeneration should complete the Microgeneration Installation Notification Form (Application Form NC6[4]). The microgeneration connection application process is the same for new builds as it is for customers who choose to add microgeneration to an existing connection[5]. There is no application fee or charge to the customer when sending an NC6 form to ESB Networks for processing. Currently microgeneration connections seldom require any detailed examination as they are low in volume and size, so that their impact on the network is generally small. However, this could change if microgeneration began to have a more significant impact on the network.

In larger installations i.e. where the exporting capability is greater than 6 kW_p (single phase connections) or 11 kW_p (three phase connections), there would be increased likelihood of such instillation having a technical impact on the electricity network, especially where other customers were installing with PV, and for these larger installations ESB Networks will need to examine the proposed generation in relation to the network and the surrounding loads and generators. We will now explain how such exports affect the network and other customers, as well as the likely amounts of PV which the network can accommodate.

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[4] https://www.esbnetworks.ie/new-connections/generator-connections/connect-a-micro-generator

[5] https://www.esbnetworks.ie/docs/default-source/publications/ conditions-governing-connection-and-operation-of-micro-generation-policy.pdf?sfvrsn=ad5c33f0_8

How the Network Works

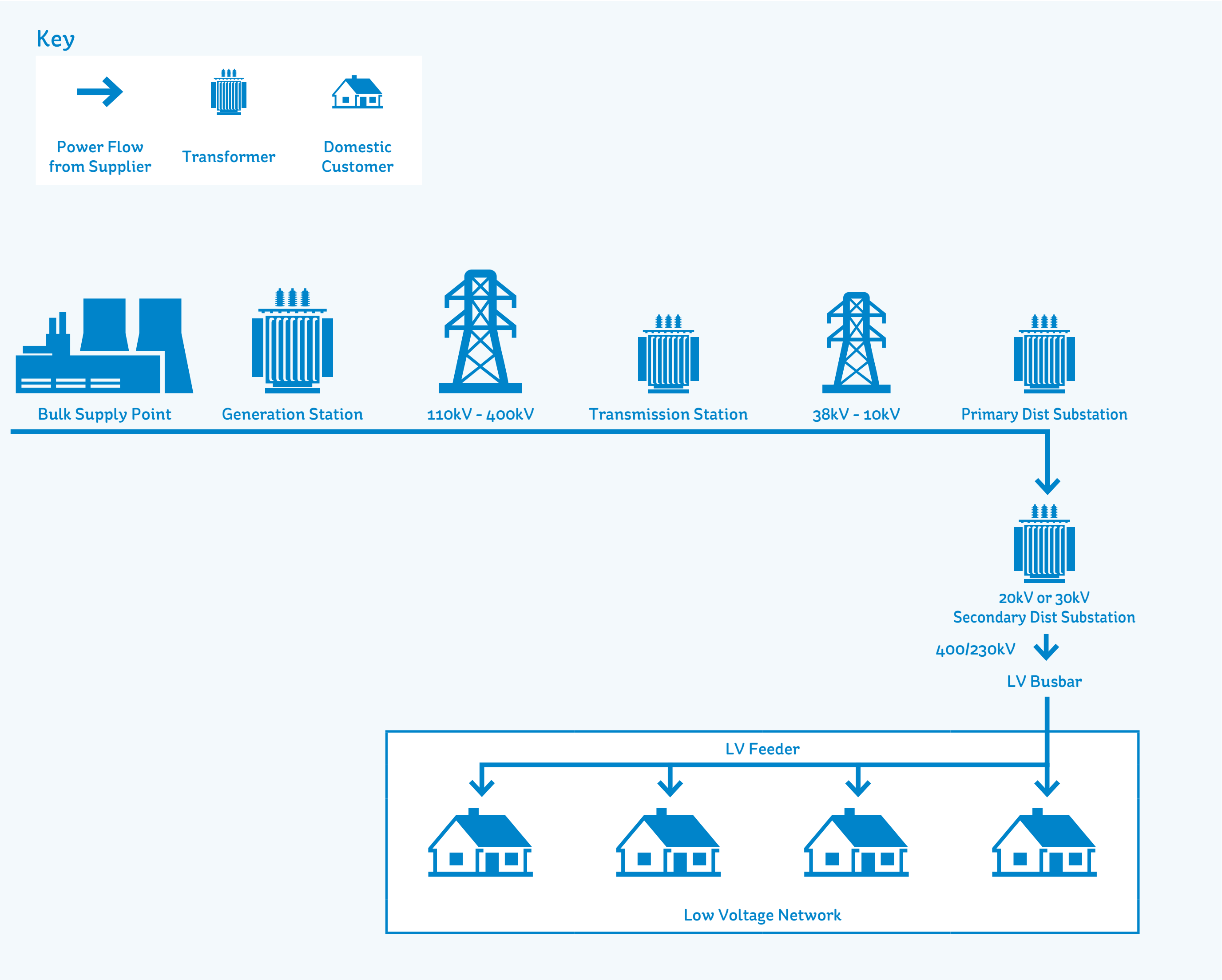

Fig. 1 Overall Diagram of the Electricity Network.

In Fig 1 we show a typical electricity network with larger generators feeding into collection points called 'Bulk Supply Stations; then travelling on high voltage transmission networks akin to 'electricity motorways' before being transformed down in voltage using a series of transformers, with the distribution network akin to 'national roads'; with the final stage being the transformation of electricity at 10,000 or 20,000V (Medium Voltage or MV) to households and small business voltages to 230V single phase and 400V three phase (Low Voltage LV). The cables and wires along suburban streets operate at these lower voltages and 'distribute' the electricity to every house.

Urban and Rural Networks

There are significant differences between networks used to connect large numbers of customer living in the one area (urban networks) and these used to connect small groups of up to about 10 customers living in rural areas, and it will be seen that these networks operate somewhat differently with PV.

People will generally be familiar with pieces of ESB Networks equipment they see in the street or in fields but may not understand how they operate together so the following pictures of typical network arrangement will show how the network operates.

Electrical Blocks for Housing Scheme

Unit Substation

This has transformer and switchgear. It takes power at 10kV/20 kV and changes it to 400V/230V

Minipillar

Junction Box which splits cable from Unit Sub and connects individual houses

Fig. 2 Urban Housing Estate ESB Networks' equipment

In the first picture a transformer substation is shown, and this takes its power cables at medium voltage and steps it down to 230/400V. Low voltage cables (three phase[6]) are taken from the substation and brought along the street with tap off points called minipillars connected to the cables. These minipillars shown in the second picture are simply electrical junction boxes that allow a smaller cable to be tapped off the main street cable and bring power into the meter box, as shown in the diagram below.

There are a few main variations on this theme as will be shown in the photos below, but essentially the sequence is the same, i.e. take in medium voltage electricity, step it down to 230/400V and then connect customers to these circuits.

Sometimes the circuits are not underground cables but overhead wires, particularly in older parts of larger urban areas (Fig 3).

Fig 3 Urban housing estate showing three phase overhead circuits from which each house is connected via single phase wires.

In Fig. 4 the arrangement is somewhat similar to Fig. 3 in that the main three phase circuit travels down the street on poles, but instead single service overhead wires going from the poles to each house, larger cables are brought from the pole to the frontage of the house where they travel along the frontage with 'drops' into each cable at the front door.

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[6] Three phase' simply means that there are three single phase circuits so such circuits can carry three times the power of a single phase circuit

Figure 4: LV cables - black wiring on house frontage

Finally, in Fig 5. the diagram shows a an MV substation which is mounted on a pole (near the trees) and feeds the nearby houses in a way similar to Fig. 3

Figure 5 Pole mounted three phase 100kVA transformer feeding three-phase LV line from which single-phase circuits are extended to each house

In contrast the pattern of housing in rural areas is very spread out so that here are large distances between houses. There is still an MV transformer involved to step the voltage down to 230V, and there is an overhead single-phase overhead wire travelling along the road/field from which individual houses are tapped off.

There are over 220,000 such arrangements supplying power to about 800,000 rural customers in contrast to the approximately 1.4 million customers connected from urban networks such as those shown in Figs 3 – 4.

How PV interacts with the Network

Electricity networks are made to connect multiple customers, but not every customer will have all their appliance in use at any one time – some appliances will be on, some off, some just idling. This means that whilst an individual customer might have a peak usage of 8 – 12 kW, the average at any time is much less, about 2.5 kW per customer.

To provide better value connections to customers the network is then designed on the basis that the average customer usage at any time is 2.5 kW, although one customer may use 12 kW. This provides a significantly more affordable network – instead of designing a network of 1,200 kVA for 100 customers the network could instead be designed for 260 kVA, which is less than a quarter of the size. In general terms, most housing estates in the last 30 years have been planned for using an After Diversity Maximum Demand (ADMD) of 2.5 kW per customer. This is standard design practise when designing electricity networks in Europe and much of the rest of the world.

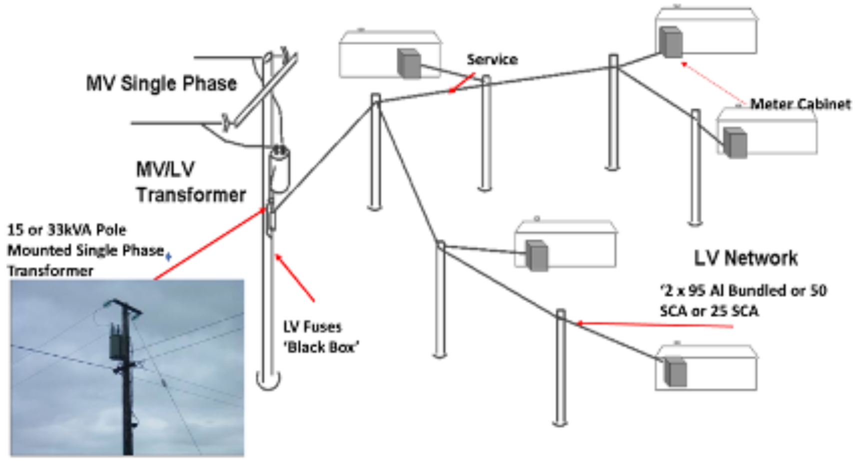

Fig. 6 Small Rural Group showing connections to 15kVA Transformer

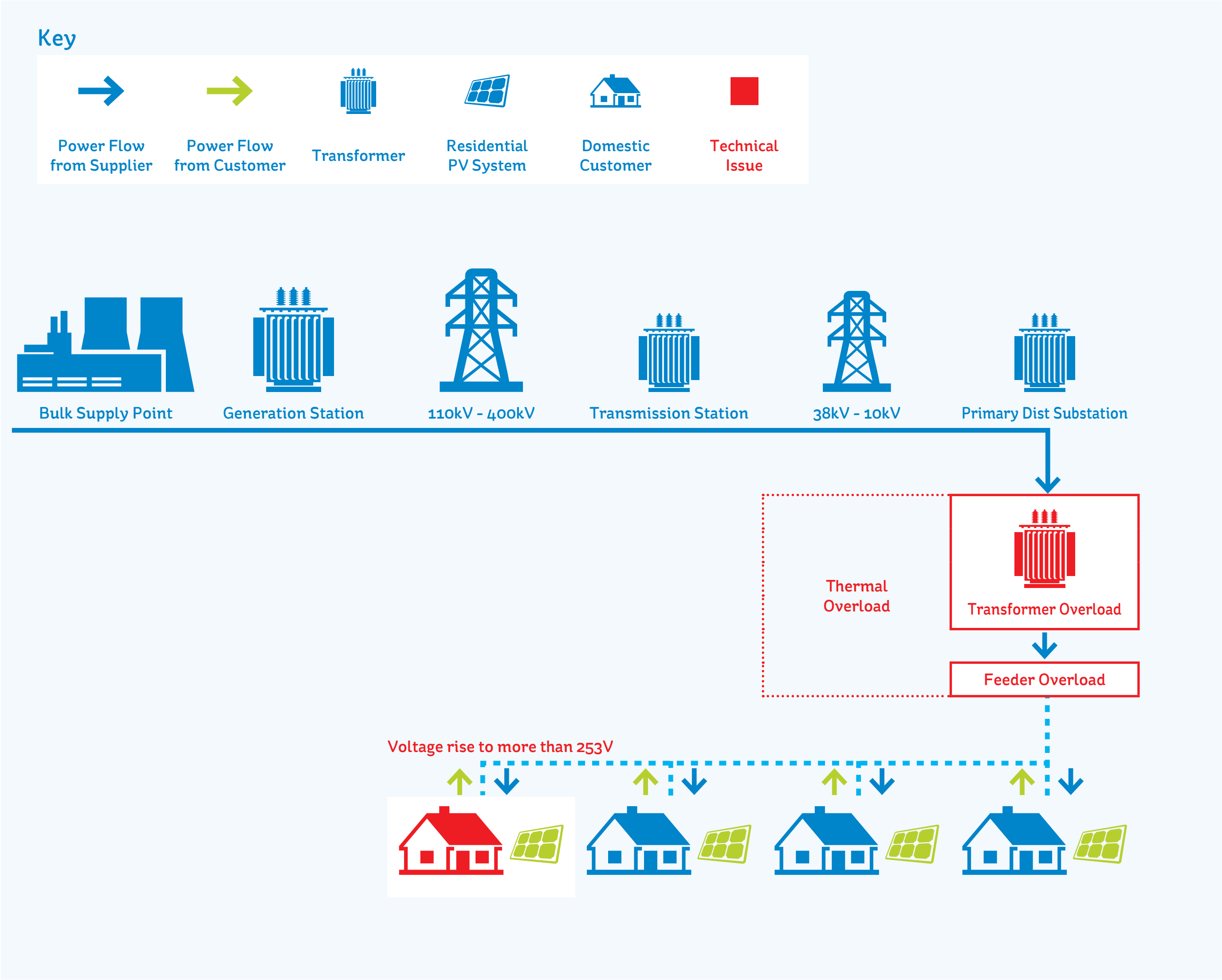

Fig. 7 Effects of excess PV Exports

Use of ADMD means that the size of the transformer and cables /wires used to connect the customer needs to be much smaller and does not need to cope with the heating effect that would be produced if every customer used their full power simultaneously. Feeding power through a network is very akin to distributing water through a main pipe with services pipes tapped off – as the water travels through the main pipe it loses pressure and to ensure everyone can have enough water the pressure drop must be kept within limits and not allowed go too low.

Similarly, this means that electricity networks must be designed so that the voltage drop produced by the load demands does not result in customers experiencing voltage that is outside an acceptable range.

With the predicted future electrification of heat and transport, ESB Networks has examined the ADMD requirements of domestic units (in keeping with Action 174 of the CAP) and future housing schemes will be designed to an ADMD of 5.5 kW per customer.[*]

[*] Subject to consideration by CRU

So what difference does PV make?

Essentially the network was historically designed for loads of an average of 2.5 kW per customer and a voltage drop of 10% produced by these same loads.

If the PV installed is less than the design load then it is absorbed within or adjacent to the household and has little effect, the worst case being when the households are unoccupied so that there's no load to absorb the PV and the full amount is then exported from every household and up through the transformer and out onto the upstream network.

However, if the amount of PV increases substantially then, depending on the amount exported, it can have increasingly severe effects on other customers through the network.

In Fig. 7 some of the effects of excessive PV are shown – the voltage on the network increases beyond the 253V maximum allowed at the house as each PV arrays has to increase its voltage to push export power up through the network, and this larger export of power may be greater than the amount for which the network was designed overloading the thermal capacity of the transformer.

Obviously, this effect depends not only on the amount of PV installed per household but also on how many houses in the estate install PV ('penetration rate').

In urban networks, it is anticipated that the individual size of each PV installation is small compared to that of the rating of the network equipment so high penetration rates are required to produce such effects. This means that in typical urban estates about 4 kW_p could be realistically installed, probably until 50% of the transformer capacity was reached, after which a review would be required*.

Typically, voltage rise would be more likely to occur where long overhead circuits were used as they have higher impedance than underground cabled housing schemes.

Rural networks by contrast are quite different, mainly because of the typical size of the rural 15kVA transformer, as the PV panel is quite significant in size compared to it.

So, in a typical rural group with a 15kVA transformer there could be about 5 customers on such transformers, which would mean that the transformer would be overloaded at 4kW_p per customer, especially as such a situation would be most likely to arise in summer when loads are lower and the transformer is already hot due to solar gain.

Additionally, the LV circuits connecting rural houses can be much longer than in urban areas and are of lower thickness so that they do not let current flow as easily so that more voltage rise is necessary to push power out.

In turn this would mean that the total export PV power in a rural group cannot be more than 15kVA – say an average of 3 kW_p per customer so that the transformer is unlikely to be overloaded.

There are also impacts upstream at MV from high levels of PV export, as such exports will add to exports from other generators and create potential bottlenecks at other upstream plant such as 38kV substations.

ESB Networks is currently assessing network development and possible implications of increasing renewable energy on the distribution network. Microgeneration will play a part in delivering the governmental target of 70% of electricity generated by renewable sources by 2030 as set out in the governmental CAP. ESB Networks are cognizant of the expected increased level of microgeneration and are currently making provision of this in the ongoing review of the planning standards for the distribution network.

All of the above challenges related to the export of power through the distribution network – where the power is mainly used within the home, the export will be much less than the amount generated and consequently the impact will be less – in theory, if the PV power is used completely within the home then there is little impact on the network.

As technical issues with generation arise generally from the export of power onto the grid, it should be possible to increase the size of generation installed if the export were restricted. This would facilitate greater levels of self-consumption and could be arranged through the development of an export limiting scheme. There are such schemes in operation in the UK but require an analysis of the network before installation. Voltage control by limitation on kW exports to avoid excessive voltage rise (as in Australia) is also being considered. For maximising self-consumption it could be possible to develop an export limiting scheme which controls exports but allowed more PV to be installed by the customer to facilitate self-consumption. ESB Networks is now examining the use of an export limiting control which would facilitate larger installed capacity as long as the export was limited. In addition, ESB Networks is considering the use of type tested equipment to simplify connections of packaged installations up to 50 kW installed on three-phase network connections.

Electrification of Heat and Transport

It is expected that customer demand will increase appreciably with additional electrification of heat and transport. Consequently, in any part of the network the mix of PV and additional load will tend to net off against each other and on average usually reduce the load on the transformer at these times.

However, this will not prevent network reinforcement being required when there is extra PV or electrification. This is because the maximum power flows for each technology occur at separate times – the determining scenario for PV is a hot summers week day with low loads so that PV generated is at a maximum and all is exported through the transformer. In contrast, for electrification of heat and transport the highest demand is likely to be in winter during the later afternoon/evening when PV is at minimum but electrified heat and EV loads are a maximum.

Consequently, the interaction between PV and electrification of heat and transport arises as a result of either one or both of them stressing the system and requiring reinforcement – once the system has been reinforced for either, then there is some extra network capability to cope with the other. It is also likely that areas likely to require reinforcement will have both PV and electrification of heat and transport, simply because reinforcement will only be required where there are enough customers to load the transformer sufficiently and sufficient numbers to then add Low Carbon Technologies (LCT) such as solar PV or electrification of heat and transport.

However, the uprating on networks to accommodate LCT will only provide modest additional capacity for extra microgeneration export, as LCT loads are spread throughout the day/week and hence require less peak capacity than the same amount of installed PV, which has no diversity. The addition of LCT loads would provide greater scope for self-consumption of microgeneration but not for additional export.

Industrial and Commercial PV

If a customer wishes to install export capacity of generation greater than microgeneration, the customer should apply to ESB Networks, in line with regulated grid connection policy (known as Enduring Connection Policy) using the process outlined on the ESB Networks website. ESB Networks will complete a system study (the level of the system study required depends on where the generator is being connected, the capacity of the existing network and the size/type of generation).

As per CRU's recent ECP-2 decision, CRU intend to review the grid connection policy over the coming year for generation and storage projects with MEC greater than 6kW (single phase)/11kW (three phase) and less than or equal to 50kW. ESB Networks is reviewing connection application process for projects in this range including a trial on decentralized technical studies as well as a possible revised application form and connection agreements for projects in this range.

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* kW_p is the peak power of a PV system the total amount of PV is the sum of the output of all the panels, but consideration may be required the fact that panels may not be optimally aligned to produce their full output. However, one recent UK study indicated that in practice PV panels did produce their full output for 3-4 hrs per day.

[7] ECP-2 https://www.cru.ie/wp-content/uploads/2020/06/CRU20060-ECP-2-Decision.pdf

Conclusion

This report seeks to outline the possible technical impacts on the distribution network of increasing levels of microgeneration on the distribution network for a non-technical audience. ESB Networks is committed to assisting Ireland's decarbonisation of the energy sector and hope that the information contained within this report provides useful information which can assist in Ireland's decarbonisation journey.

All of the networks are connected together to form one overall electrical network and this means that power connected at LV, such as microgeneration, can also flow from where it is generated to where it is consumed. This means that if there is more local generation than consumption at any time then the excess electricity flows upwards through the network until it is consumed. The network was not historically designed for generation at low voltages.

A review of the urban network shows that up to 4kW$_p$ export per house (up to about 50% transformer penetration) can be accommodated on the network with limited associated reinforcement costs and that no thermal capacity or voltage rise issues will arise in the majority of cases. The review indicates that at 3 kW$_p$ (up to about 50% transformer penetration), there are no thermal capacity or voltage rise issues in the majority of cases.

It must also be borne in mind that whilst PV might not have impacts at one particular level, the fact that all PV is accumulated as it exports to the network will mean that there can also be issues of congestion upstream as the microgeneration PV adds to existing/contracted generation connected to the same network.

Any PV installation more than the existing installed capacity 6 kW$_p$ single phase and 11 kW$_p$ three phase would require a study before connection to assess any potential impacts to the network if these levels were used for export. If concentrations of 6/11 kW$_p$ connections were high in a circuit, then attention would also need to be paid to these prior to connection as at high volumes above 3 kW$_p$ the network is likely to require reinforcement. As DSO, ESB Networks has an important role to play in facilitating Ireland's decarbonisation goals. We aim to support our customers along each stage of the process as they adopt small-scale low-carbon technologies and hope that this document is informative for our customers.

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