THE IMPACT OF LOW CARBON TECHNOLOGIES ON SHORT-CIRCUIT LEVELS IN MEDIUM VOLTAGE NETWORKS

Jonathan BERRY
Western Power Distribution – UK
jberry@westernpower.co.uk

Ali KAZEROONI
WSP | Parsons Brinckerhoff – UK
Ali.Kazerooni@pbworld.com

Michael EVES
WSP | Parsons Brinckerhoff - UK
Michael.Eves@pbworld.com

ABSTRACT

This paper describes the impact of short-circuit level on Medium Voltage (MV) networks resulting from the increase in Low Carbon Technology (LCT) integration on the UK Transmission and Distribution Network. Fault Level (FL) is an important network measure that can instigate network investment and is expected to change as a result of LCT connections such as renewable resources, Combined Heat and Power (CHP) plants, storage units and electric vehicles (EVs) connecting to the network. FL is anticipated to reduce in transmission networks and increase in Low Voltage (LV) and MV distribution networks. The impact on FL variation due to LCT uptake in MV networks is investigated as part of FlexDGrid, an innovation project in the UK by Western Power Distribution (WPD) investigating the fault level issues and mitigation techniques on MV networks.

INTRODUCTION

There has been a considerable increase in the uptake of LCTs as the UK seeks to evolve into a low carbon economy, significantly changing the UK generation/ demand mix. Transmission and distribution network operators are facing a new challenge to accommodate the integration of LCTs while ensuring the reliability, safety and security of the networks are not compromised.

One particular challenge is the efficient planning of networks when transitioning to the low carbon energy sector and the associated uncertainty concerning what investment will be required and when. FL is one of the key network parameters that can trigger reinforcement of network equipment.

Changes in network FL will be partly attributed to an anticipated increase in LCT connections such as renewable generators, CHP units, battery storage and electric vehicles. The type of LCT and the Point of Connection (PoC) location are the main factors which influence the FL contribution at the various voltage levels on the network.

In coming years it is expected that the FL on the transmission network will decrease due to the decommissioning of large conventional synchronous power plants and their replacement with converter-connected renewable power plants. Conversely it is expected that there will be increased FL contribution from distributed generators to LV and MV networks due to the installation of additional LCTs and other Distributed Generation (DG). Figure 1 provides an overview of the changes in distribution and transmission networks and the expected fault infeed contribution from LCTs at each voltage level.

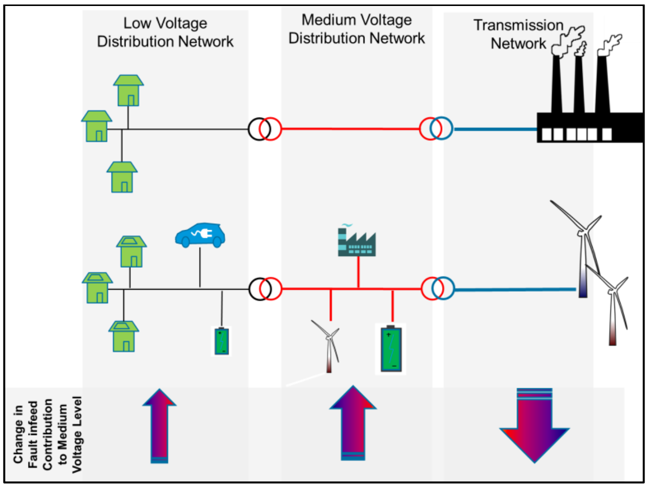

Figure 1: Expected Change in FL considering LCTs integration

As part of FlexDGrid [1] (a £17.1m Low Carbon Networks Fund project in the UK) the impact of increasing LCT uptake on fault levels at MV networks was investigated, considering a representative network model for LV and MV networks. The scope of this work is to assess how FL changes in LV networks and transmission networks may have impact on MV networks.

LCT UPTAKE IN THE UK

The uptake for various LCTs in the UK has been forecasted by different parties such as the Department for Energy & Climate change [1], network operators [2], the system operator [3] and research institutes [4] using different assumptions & scenarios. In each case, a significant increase is expected in LCT installations by 2030. However the actual uptake may come with some uncertainty due to government policy change, or political and economic climates. Table 1 demonstrates the anticipated scale for the uptake of LCTs in the UK.

Table 1: Anticipated LCT Uptake in the UK

LCT Type	Present Day Installed Capacity (MW)	Anticipated Installed Capacity in 2030 (MW)
Electric Vehicles [5]	1,500	27,000
PV [5]	2,500	40,000
Wind [6] [7]	14.000	40,000
CHP (projected capacity) [8]	6.100	12,100
Storage [4]	2,700	10,000

From Table 1, it can be seen that the anticipated increase of LCT uptake is projected to be significant across all LCT types which will be integrated at different voltage levels. The LV networks have recently been experiencing a significant increase in Photo-Voltaic (PV) integration and it is expected that EVs will be the next major LCT growth in LV networks. CHPs, wind farms, large scale PVs and storage units are the main LCT types increasingly connecting to the MV networks. Transmission networks are however, seeing a significant increase in large scale renewable generation connections.

FAULT CURRENT CONTRIBUTION FROM LCTS

The majority of LCTs which may inject power into a network can be broadly split into two categories:

- Directly coupled synchronous generators; and
- Decoupled converter-connected generators.

During a fault, synchronous generators (such as CHPs) will contribute between 5-8 times their nominal current [9]. In contrast, converter-based technologies are limited by the rating of the power electronics which interfaces between the generator and the network. This can lead to a typical fault level contribution of approximately 1.0 to 1.2 times their nominal currents [8]. Table 2 summarises the different types of LCTs and their expected fault contributions at the point of connection.

Table 2: Fault Contributions (in multiples of their rated current) from different LCTs [9]

Type of Device	Voltage (kV)	Network Coupling	
		Direct	Power Electronic
Small Synchronous Generator	0.4 - 33	5-8	N/A
Battery Storage Energy System	0.4-132	N/A	1-1.2
Micro CHP Generator	0.4	5-8	1-1.2
PV	0.4	N/A	1-1.2
Wind Turbine (Induction Generator)	0.4 - 11	5-8	N/A
Wind Turbine (Synchronous Direct-Drive)	11 - 132	N/A	1-1.2

OVERVIEW OF FLEXDGRID PROJECT

Birmingham Central Business District in the UK has been identified as an area where a high level of integration of CHP plant is expected on the distribution network by 2026. As a result of the anticipated level of CHP integration, fault levels on the MV network could exceed the short circuit ratings of the switchgear.

FlexDGrid explores the solutions to resolve fault level issues on Birmingham 11kV network through trial of three complementary methods:

- *Method Alpha: Enhanced Fault Level Assessment* Enhancing computer simulation processes to calculate and predict short-circuit currents more accurately.
- *Method Beta: Real-time Management of Fault Level* Installation of real-time FL monitors on the electricity network to provide greater level of detail.
- *Method Gamma: Fault Level Mitigation Technologies*

  Installation of new technologies that can limit the flow of short-circuit current when faults occur on the electricity network.

As part of the scope of work in Method Alpha, studies have been carried out to establish what impact may happen on the MV network due to fault level changes at other voltage levels (LV and Transmission).

TRANSMISSION NETWORK FAULT LEVEL REDUCTION

The UK transmission network FL is expected to decrease over the next 20 years as some fossil fuel power plants fitted with synchronous generators are decommissioned and replaced by non-synchronous power plants e.g. wind farms. The UK's transmission network operator, National Grid Company (NGC), published the System Operability Framework (SOF) 2015 report which outlines the anticipated variation in FL for the years 2025/26 and 2035/36, relative to the FL in 2015/16 [6].

The report estimates that FL will reduce between 35% and 68% due to the changes in generation type over 20 years. The Future Energy Scenarios (FES) NGC report was also produced and outlines four future energy scenarios based upon possible developments due to economic outlooks and government policy [7].

In order to determine the impact of the FL variation in the transmission network on the FL in 11kV (MV) distribution network the following steps were taken:

- The basis for the case study was the network supplying Birmingham and surrounding areas;

- A power system model was built from the equivalent transmission 400kV and 275kV grid supply points (GSPs) to the 11kV distribution network;
- The regions relevant to the case study were identified in the SOF and the average transmission FL reduction in those regions were calculated (4A and 4B from the SOF region breakdown). These regions have been highlighted green in Figure 2;
- Equivalent Thevenin GSP models were created to simulate the different scenarios of FL reductions in the transmission network. The transmission FL reduction for each future energy scenarios is shown in Table 3; and
- Short circuit analysis was carried out to calculate the FL at the 11kV busbars of the various primary 132/11kV substations in the case study area.

Table 4 summarises the FL reductions at the 11kV busbars corresponding to each energy scenario.

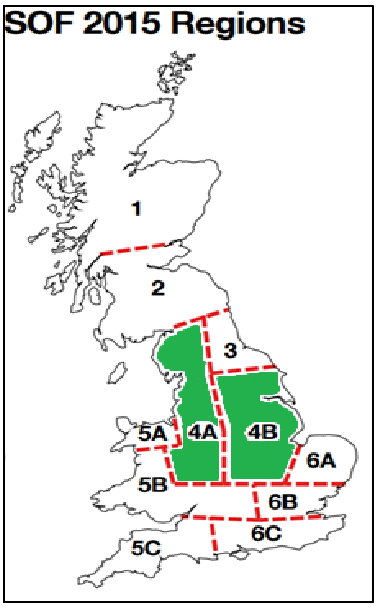

Figure 2: Regions selected from SOF 2015 report for case study [13]

Table 3: SOF 2015 FL reductions forecast

Future Energy Scenario	2025/26	2035/36
	Average for 4A & 4B	Average for 4A & 4B
Gone Green	64%	42%
Consumer Power	63%	59%
Slow Progression	35%	64%
No Progression	9%	25%

Table 4: Reduction in FL at 11kV network as a result of FL reduction in transmission

Future Energy Scenario	2025/26	2035/36
	Average for 4A & 4B	Average for 4A & 4B
Gone Green	2.20%	0.92%
Consumer Power	2.09%	1.83%
Slow Progression	0.69%	2.29%
No Progression	0.23%	0.46%

The results show that the FL reduction anticipated in the transmission network will have a minimal impact on the FL at 11kV primary busbars. This is mainly due to the large impedance including cables, overhead line circuits and transformers between the transmission network and distribution network which suppresses the fault contribution change from the transmission network.

THE IMPACT OF THE INCREASED LCT PENETRATION IN THE LV NETWORK

An increasing uptake of LCTs is expected in distribution networks. PVs, EVs and storage units are among those LCTs which potentially have the most contribution to the fault level in LV networks. Urban areas are expected to show continued growth of LCT technology following the same trend as seen in recent years. Using historical data for the UK West Midlands LV network, the cumulative installed capacity in 2016 is shown in Table 5.

Table 5: Total installed capacity of LV-Connected LCTs in 2016 to the West Midlands region in WPD's network

Type of LCT Technology	Cumulative Installed Capacity (kW)
Biomass & Energy Crops (not CHP)	720
Photovoltaic	137425
Storage (Battery)	15
CHP	4184
Onshore Wind	1181
Landfill Gas, Sewage Gas, Biogas (not CHP)	40
Other Generation	192

In order to study the impact of LV LCT uptake on MV networks an 'Urban' representative LV network was considered. This representative network was created as part of the output from the Smart Grid Forum Work Stream 7 - DS2030 project [10]. DS2030 looked at the impact of different LCTs in various network topologies, one of which was an urban region. The intention of this study was to look at a particular impact of the uptake of LCTs in LV network, therefore this model was appropriate to use. The network model consisted of an incoming feeder, a 500kVA MV/LV transformer, connected to four LV feeders supplying various loads at 400V as illustrated in Figure 3.

The following assumptions were made for modelling the integration of LV LCTs and their fault contributions:

- The level of total LCT uptake in the representative network can change between 50 to 250kVA. The maximum demand of the representative network is 500kVA so it was assumed the maximum level of uptake can be 50% of the maximum demand;
- The equivalent point of connection of LCTs can be any point along the feeders at 10%, 50% and 80% of the feeder length; and
- The LCTs are converter-connected type and the LCT's fault contributions at the point of connection is 1.0 p.u.

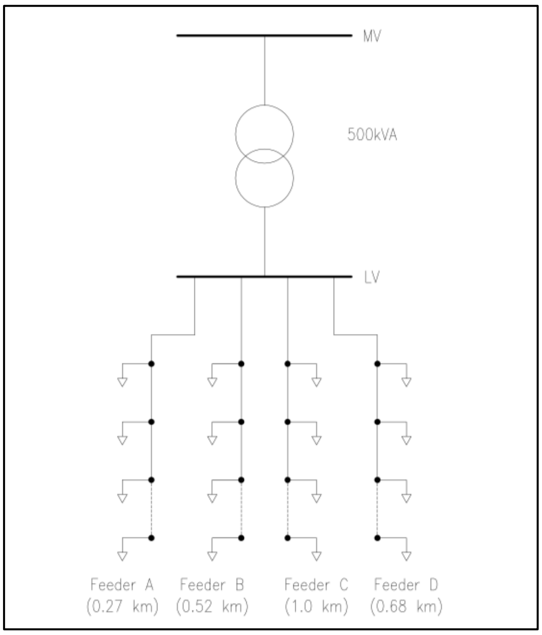

Figure 3: LV Urban Network Illustration

These assumptions were used together with the following approach to calculate the LV LCTs fault contribution to the MV network:

- An exhaustive list of LCT integration scenarios was created using Monte Carlo simulation. Each scenario includes different levels of LCT connections at four different locations along each of the four feeders in the representative LV network;
- The LCTs' fault contributions to the main LV busbar and MV busbar were calculated for each scenario; and
- The calculated FLs of each scenario were then compared with the total fault current contributions of the LCTs at the points of connections. In this way, the reduction in the LCT fault contribution due to network impedance is calculated.

Figure 4 shows the results of short circuit analysis in the form of a range of FL contributions from LCTs at different points of the network considering all the LCT uptake integration scenarios. The fault contribution range, at the point of connection, is the 1.0 p.u fault contribution for each LCT uptake scenario. This contribution is slightly smaller at the LV busbar due to impedance of LV circuit. However, the fault contribution from LCTs reduces significantly by around 96% if the fault occurs at the MV busbar. This is due to the impedance of the MV/LV transformer.

The results show that the fault contribution from LCTs may have a small impact on the MV network. It should be noted that this representative study and the main impact of that will be on the protection equipment in the LV side of distribution transformers.

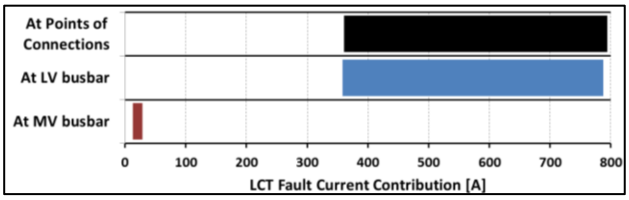

Figure 4: Range of fault contributions from LCTs at different locations of representative LV network

LCT UPTAKE CONNECTED ON MV NETWORK

Some larger LCTs such as Wind farms, CHPs, PVs and storage units are increasingly being connected to the MV networks. Figure 5 shows the total installed capacity of different LCT types connected to the West Midlands region of WPD's network.

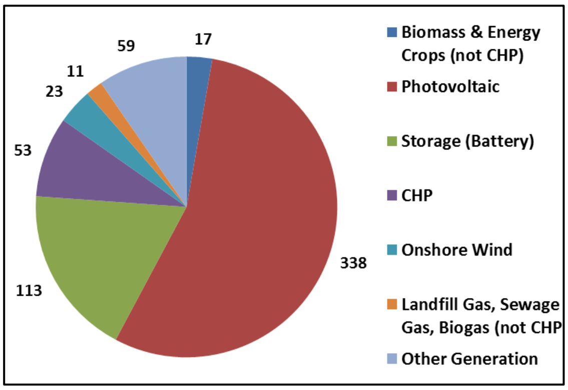

Figure 5: Total MW installed capacity of MV-Connected LCTs in 2016 to the West Midlands region in WPD's network

In order to assess the impact of LCT connections on MV networks, the 11kV networks of two 132/11kV primary substations in the West Midlands area were considered.

The following approach was taken to study the impact of LCT integration on MV networks:

- A 5.0MVA direct connected synchronous generator with fault contribution of 4.5p.u. was considered as the representative example of an LCT generator;
- Network scenarios were created each of which included the connection of the representative LCT at a secondary substation on the 11kV network; and
- Fault current contribution from the LCT generator to the 11kV busbars at the primary substation was calculated and the study was replicated at the next secondary substation on the 11kV network.

The fault current contribution from the representative LCT generator to the faulted points away from the LCT point of connection reduces due to network impedance. The results showed that the fault current contribution to the 11kV busbars of the two primary substations reduces between a range of 9.6% to 22.7% considering different point of connections for the LCT generator.

CONCLUSION

The studies described in this paper have shown that the growth in LCTs at different points on the network can have varying effects on the FL on the MV network.

The expected LCT uptake at transmission level will have a significant impact on fault level reduction (up to 65% reduction compared to fault levels in 2015) in the transmission network. This fault level reduction at transmission level will have a minimal impact (up to 2.2%) on the fault level on the MV network. The primary reason for this effect is the large network impedance (including transformers, cable circuits and overhead lines) between transmission and MV distribution network.

The integration of LCTs in LV distribution network will have a significant impact on LV FLs which is likely to result in enhanced protection arrangements for the LV network. However, the results showed that only a small FL contribution could be seen on the MV network from LV connected LCTs due to the impedance of MV/LV transformers.

The results of the studies have clearly shown that the connection of MV LCTs have the most impact on MV fault levels. However, the level of impact largely depends on the PoC of the LCT. To ensure that the impact of the MV LCTs is fully captured it is recommended that fault level assessments are carried out using a detailed model of network impedance from the PoC to the upstream primary substation.

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