System Operability Framework

nationalgrid

Low Frequency Demand Disconnection

The risk that the low frequency demand disconnection scheme is not effective is increasing due to a reduction in system inertia and increased penetration of distributed generation. This report quantifies the risk increase and we recommend that the low frequency demand disconnection scheme is reviewed to allow it to continue to be effective. National Grid will continue to co-ordinate with DNOs to realise the most effective responses to these impacts on LFDD effectiveness.

Executive Summary

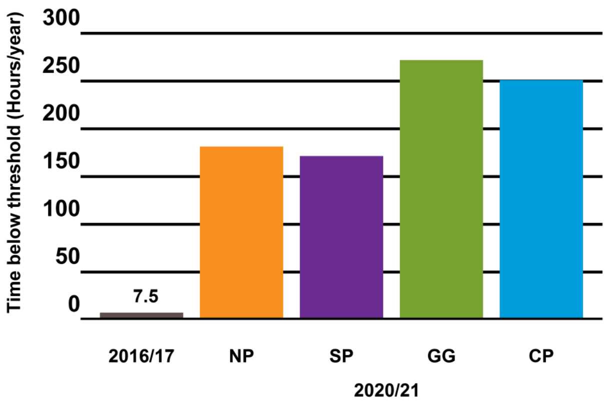
The low frequency demand disconnection scheme (LFDD) is designed to arrest frequency falls for extreme system events beyond those defined as secured in industry standards [1][2]. The LFDD scheme achieves this by ensuring demand from across the country is automatically disconnected to balance generation and stop a full system collapse. This is implemented by Distribution Network Operators (DNO) physically disconnecting demands from their network at defined low frequency levels. This report looks at how future trends on the system may impact the effectiveness of the LFDD scheme.

The analysis was supported by data received by representatives from all DNOs. It shows that increasing the amount of distributed generation behind the relays, decreasing system inertia and net transmission demand reduce the effectiveness of the LFDD scheme. The results further show that LFDD effectiveness is impacted by the output of the distributed generation behind the relays and by the number of relays that are triggered by the frequency dip observed. To address these issues an LFDD Industry Work ground has been established.

As discussed in the Future Energy Scenarios [3], and in our past SOF assessments it is expected that over the next 10 years and across all scenarios distributed generation will increase and system inertia will decrease.

We have shown that when inertia is below a threshold (of 140GVA.s) the effectives of the LFDD scheme reduces due to the interaction with rate of change of frequency (RoCoF) relays. Figure 1 shows the time that is spent below this threshold, and thus at higher risk, is increasing into the future across all scenarios.

Figure1: Time spent below inertia threshold



National Grid will work with the LFDD Industry Workgroup to investigate solutions to enable the LFDD scheme to continue to be effective. It is recommended that the Industry Workgroup identify any short-term actions such as reallocation of different physical network areas against each LFDD relay setting. We would also seek to work with the LFDD Industry Workgroup to consider the positioning of LFDD relays for new generation connections within the distribution systems. The above changes may be most efficiently made through a code change to Grid Code.

Background

National Grid as the system operator has a requirement to keep the system frequency within statutory limits for any secured system event. The definition of a secured event is defined in standards [1][2] and has been selected as a balance between the probability of an event happening and the cost to secure that event. However system events that are more extreme than those defined as secured, whilst unlikely, are possible. To protect the system for these events the LFDD scheme is used. (This is sometimes referred to as a load shedding scheme.)

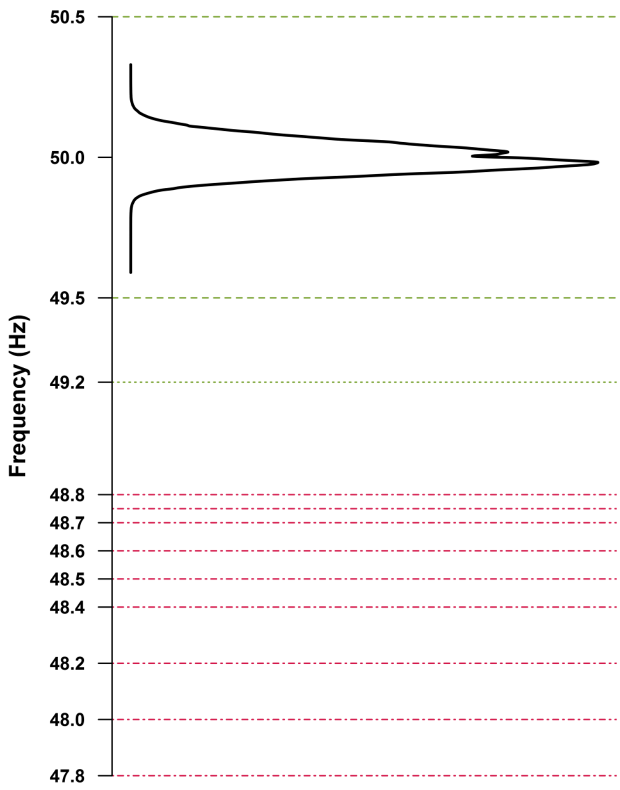
LFDD is an operational scheme that is defined in Grid Code OC6. The LFDD scheme acts during extreme low frequency events to arrest frequency falls. When frequency drops below each of 9 predefined thresholds relays trip a percentage of the system load, across the country. This loss of load balances the generation and demand and stops the frequency falling further.

The cause of a large system event of this kind is generally due to multiple unrelated generation or interconnector losses happening within a short time frame (minutes) or from a single event tripping multiple generation units but is deemed too improbable to warrant securing against. The impact of these events is therefore extremely large but extremely unlikely.

The last instance of LFDD triggering on the GB transmission system was 2008[4]. During this event two unrelated generators tripped within a short time period dropping the frequency to 48.795 Hz and triggering the LFDD scheme. Only the first relay was triggered and the system recovered.

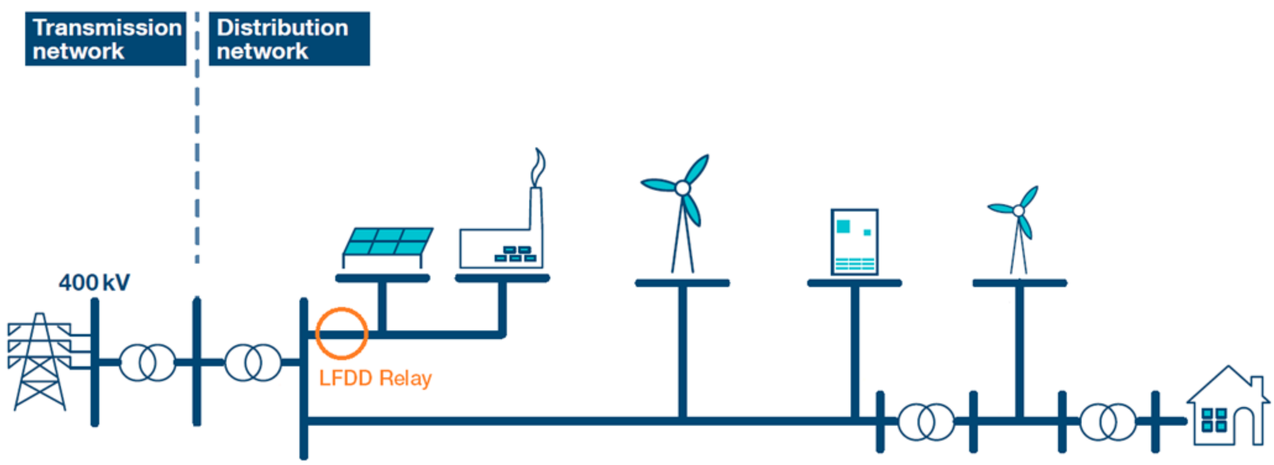
Figure 2 shows the 1 second average frequency of the system for the past year and the proportion of time spent at each frequency. On the same axis, the trigger frequencies for the LFDD relays are shown in red and the statutory limits in green.

Figure 2: System frequency and LFDD trigger frequencies



Lower inertia on the system causes the frequency to change faster and to a greater extent due to an imbalance of generation and demand. This will impact the LFDD scheme as there is a delay between the relays detecting the frequency and disconnecting their load. If the frequency is falling fast, more than one LFDD relay can be triggered in rapid succession. This may result in too much load being disconnected and a high frequency event being caused by an overreaction of the scheme to the event.

Figure 3: LFDD relay example



The increase in distributed generation behind the LFDD relays will impact the LFDD scheme. The LFDD relays are set to disconnect a predefined amount of demand. If distributed generation is at high output when the relay is triggered, the amount of demand may be less than expected. Conversely, if distributed generation is at low output, the amount of demand may be more than expected. This is show in the example in Figure 3.

In Figure 3, when the LFDD relay is tripped due to a frequency event, both the solar farm and the factory are disconnected. The amount of demand disconnected is the net amount of demand and generation at that time. Therefore during a sunny day, the amount of demand disconnected will be less than during an overcast day. If this is repeated across the country, the effect will be amplified.

Method

The LFDD scheme was tested using an exhaustive method against; a range of system conditions , a range of event sizes and a degree of distributed generation effects. Approximately 963,000 simulations were run covering all system conditions and system events within defined bounds. These bounds were selected to encompass an extreme range of conditions. The range of variables studied is shown in Table 1.

Table 1: Range of study variables considered

Variable	Lower bound	Upper bound
Total System Demand (GW)	20	65
System Inertia (GVA.s)	75	350
Generation loss [Trip event] (MW)	500	6000
Percentage of DG generating behind LFDD relay (%)	10	90
Upwards Generation frequency response (MW)	200	1000
Downwards Generation frequency response (MW)	400	1600

The simulations were tested against the criteria of meeting the capability range of the system and connected users as defined in the Grid Code;

- frequency fall is arrested above 47Hz
- demand disconnection does not cause frequency to go above 52Hz

This report defines the effectiveness of the LFDD scheme by the percentage of the 963,000 simulations that keeps frequency within the Grid Code criteria. This is referred to in the report as Pass(%).

Analysis

The model looked at the effectiveness of the LFDD scheme for the loss of generation of different sizes. This was done for three scenarios. Firstly, for a system that reflects the current system with 13 GW of distributed generation. This was compared to future systems with distributed generation increasing to 20 GW and 30 GW respectively. For each of these system conditions a range of operating conditions and loss events were studied.

Figure 4: Generation loss against LFDD effectiveness for different

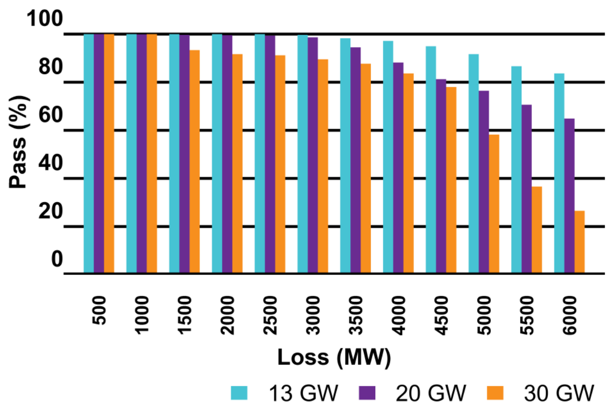
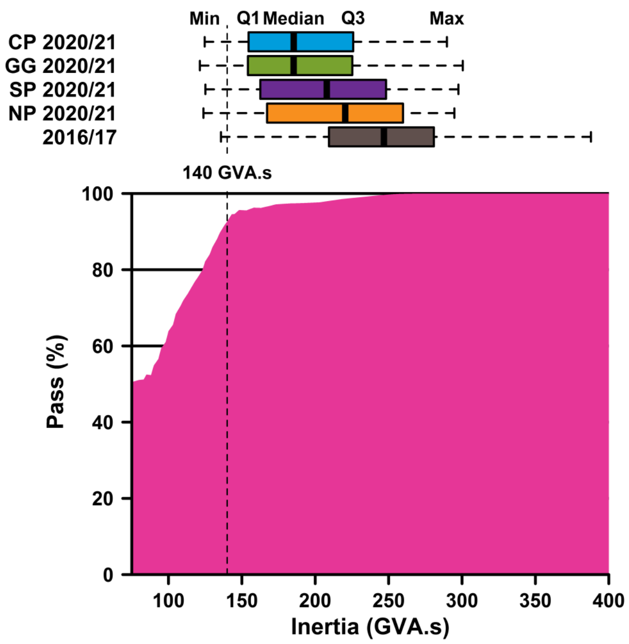


Figure 4 shows the percentage of these cases that passed the test criteria for each size of loss. It can be seen from the figure that for a small loss the LFDD scheme is effective for current and future systems. As the loss size increases the effectiveness decreases. As the amount of distributed generation on the system increases the effectiveness of the LFDD scheme reduces.

Figure 5 models the effectiveness of the LFDD scheme against the inertia of the system. It can be seen from Figure 5 that at higher levels of system inertia the LFDD scheme is near 100% effective. It can also be seen that as inertia decreases the effectiveness of the scheme reduces. At approximately 140 GVA.s there is a change in gradient when the scheme become less effective more quickly. This is due to RoCoF relays becoming relevant in the studies. Our analysis is based on current RoCoF settings and any changes to LFDD arrangements will need to take into account plans for new RoCoF settings.

Figure 5: System inertia against LFDD effectiveness & inertia annual distributions



Levels of system inertia are decreasing as transmission demand decreases. To show this on Figure 5 the unconstrained annual distribution in inertia for 2016/17 and 2021/22 are shown [5]. The box plots shows how much of a year is spent with the system at different inertia levels. The boxes represent the median, upper and lower quartiles of the data and the dashed line the maximum and minimum values. Therefore the area inside the box represent the middle 50% of data and the dashed lines all of the data.

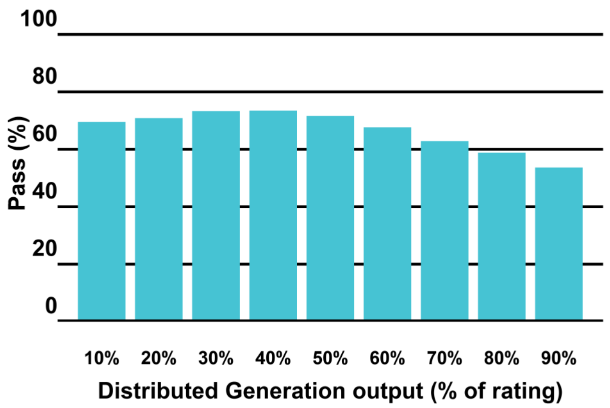
It can be seen from the annual distributions that for future years the system inertia is reducing and is spending more time at lower inertia. This lower inertia is the same system condition for which LFDD has been shown to be less effective.

A threshold is defined to capture the effect of the sharp drop in LFDD effectiveness at approximately 140 GVA.s. Figure 1 shows the number of hours a year that is spent below the 140GVA.s threshold. It can be seen that the amount of time that is below this threshold is increasing into the future across all scenarios.

The LFDD relays have been set against the historic range of frequency variation reflecting historic system inertia. As the inertia declines the potential for more LFDD relays to be activated more often increases.

Currently the LFDD relays are set at a single value that is reviewed annually but does not change within the year or day. However both the generation and demand behind a relay can change throughout the day. The effect of the changing output of distributed generation behind the relays is shown in Figure 6.

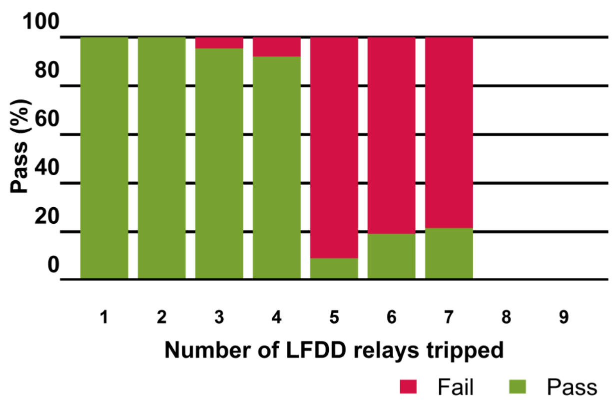
Figure 6: Percentage distributed generation output against LFDD effectiveness (30 GW distributed generation case)



It can be seen that the LFDD scheme is most effective with distributed generation at a central value and that the effectiveness of the scheme reduces as generation moves away from this value. The settings of the LFDD relays are made assuming a certain proportion of generation. If at the instant the LFDD is triggered the generation is different from this assumption then the effectiveness of the scheme decreases. This effect is compounded by the lack of visibility of distributed generation which may lead to problem relays not being identified.

Each of the LFDD relays has a different amount of demand and distributed generation behind them. The effectiveness of the LFDD scheme against the number of LFDD relays is triggered is modelled in Figure 7.
It can be seen that the LFDD scheme is more effective when the first 4 relays are triggered. Once the 5th relay is triggered the effectiveness of the scheme is reduced. This trend is driven by the current LFDD setting; the 5th relay currently has the highest proportion of distributed generation behind it. There were no cases where the 8th or 9th relays were triggered.

Figure 7: Number of LFDD relays tripped against LFDD effectiveness



Conclusions

We have shown that for increasing penetration of distributed generation, there is a reduction in effectiveness of the LFDD scheme in arresting system frequency. We have shown that reductions in the transmission demand and the system inertia also reduce the effectiveness of the LFDD scheme. There are clear trends on the system that over future years the amount of distributed generation is expected to increase and that the level of inertia on the system is expected to reduce.

We therefore conclude that the LFDD scheme is becoming less effective at arresting frequency during extreme events. It is recommended that further work be undertaken to explore changing the LFDD scheme to allow it to continue to be effective.

We showed in the analysis that the effectiveness of the LFDD scheme reduces when inertia goes below 140 GVA.s. This inertia range is the same that is considered a concern for loss of mains RoCoF relay erroneous operation. We can therefore conclude that for low inertia systems, when considering RoCoF studies, the performance of LFDD should not be assumed to be 100% effective.

To facilitate the further work on making LFDD more effective we have shown in the analysis that the variation in output of generation behind the LFDD relays impact the effectiveness of the LFDD scheme. Further, that the LFDD relays from 5th onwards, which contained higher percentage of distributed generation, were less effective.

We recommend that further work focus on the setting levels of the LFDD relays and design changes allowing the scheme to better deal with variations in distributed generation output over the course of a day.

We recommend that the LFDD Industry Workgroup identify any short-term actions such as re-allocation of different physical network areas against each LFDD relay setting. The working group should consider the positioning of LFDD relays for new generation connections within the distribution systems. The above changes may be most efficiently made through a code change to Grid Code OC6.

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- Western Power Distribution

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