Background on Fast Fault Current Injection

The Power System, traditionally comprised of Synchronous Generating Units directly connected to the Transmission System with the Distribution Systems simply acting as networks to supply the net power to consumers. Under these arrangements, the volume of Generation connected to the Distribution System was very small.

Synchronous Generators also have a unique set of characteristics, the speed of the mechanical shaft rotates in synchronism with the system with contribution to voltage control being achieved by changing the machines excitation. This arrangement also delivers many system benefits which until recently have been taken for granted, for example contribution to System Inertia, fault infeed, contribution to Synchronising torque etc which all have a significant impact on the behaviour and characteristics of the Transmission System.

Under fault conditions, a synchronous machine can supply very high levels of fault current (5 – 7pu current) which is also an important characteristic of Power System Protection (ie equipment necessary to detect, discriminate and isolate faulty items of equipment). This is also an important benefit in maintaining the voltage profile across the System during fault conditions.

The down side is that management of fault levels can sometimes be an issue. In addition, high speed protection systems are required to maintain generator stability. Had the Power System originally been designed with power electronic converters, then the integration of Synchronous plant is likely to have created problems in respect of protection operating times, circuit breaker ratings and the need for adequate levels of system synchronising torque.

So far as fault current injection is concerned, converter based plant has very different characteristics to its synchronous counterparts and this starts to become an issue as the volume of synchronous plant starts to fall away. Certainly studies conducted as part of the System Operability Framework (SOF) have demonstrated that operating the system post 2021 with falling volumes of synchronous generation starts to become an increasing challenge.

Unlike a Synchronous Generator which can supply an instantaneous injection of fault current upon fault inception, this characteristic is not replicated in converter based plant. In addition, as the fault current from a synchronous machine is injected instantaneously upon fault inception (ie as soon as the voltage starts to drop) the fault current injection from all the synchronous generators are in phase with the System.

In a converter based plant, the power output can be configured depending upon the design of the converters control system. In general, the primary purpose is to protect the switching devices (IGBT's) from excessive currents during faulty conditions. Any form of over rating adds additional cost to the converter.

The problem is that the converter will at best only supply 1 – 1.5pu current (compared to a synchronous generator of 5 - 7pu) and secondly the injection of reactive current to the system is generally delayed as a result that the measurement functions within the controller are i) protecting the IGBT's and ii) determining the system conditions at the connection point prior to providing any form of injection. This design philosophy is an common approach used by many manufacturers and is based on the Phase Locked Loop (PLL) concept. An example of the typical fault current injected from a XMVA Synchronous Generating Unit and a XMVA Power Park Module is shown in Figure 4.1 below.

INSERT FIGURE 4.1

Insert Figure 4.1 (Fault current infeed – Synchronous Plant v Power Park Module)
The problem with this approach is that i) the injection of reactive current is already low (ie 1 – 1.5pu compared to 5 – 7pu) and ii) when fault current in injected it is likely to be several tens of milliseconds after fault inception, so the injection of reactive current is out of phase with the System which further compounds to a diminishing voltage profile across the system during system disturbances.

An illustration of this effect is shown in Figure 4.2(a) and 4.2(b). Figure 4.2(a) shows the effect of a solid three phase short circuit fault at Walpole 400kV substation and the contour of the voltage depression across the system immediately prior to fault clearance. This study has been conducted on the basis of a high volume of synchronous generation. In Figure 4.2(b) the study is repeated although in this case the generation background comprises a high percentage of converter based plant.

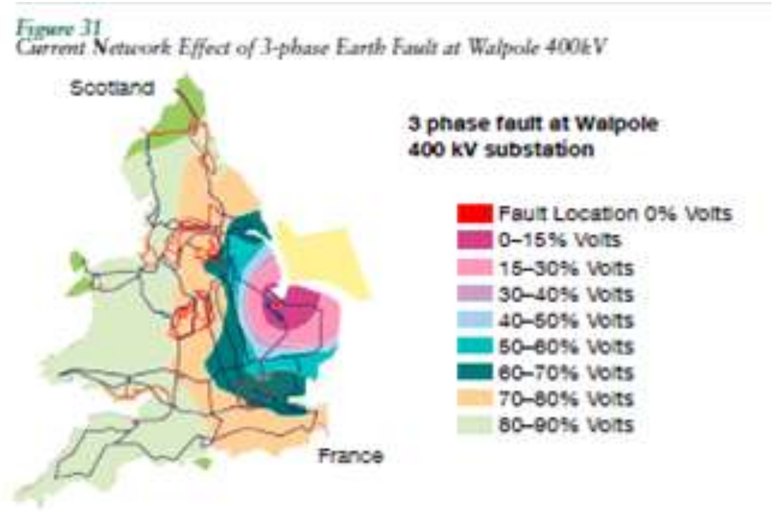

Figure 4.2(a) Effect on Voltage Profile of a solid three phase short circuit fault at Walpole 400kV substation under a high Synchronous Generation background

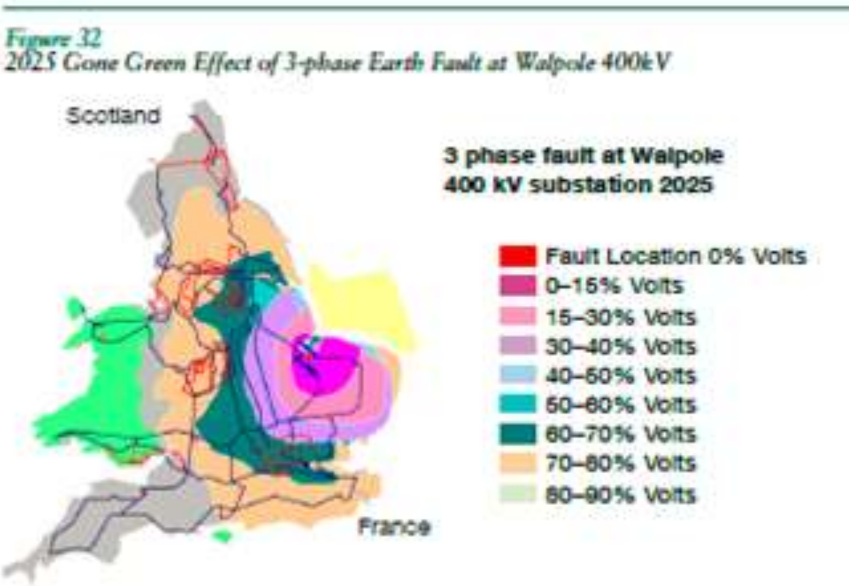

Figure 4.2(b) Effect on Voltage Profile of a solid three phase short circuit fault at Walpole 400kV substation under a high Converter Generation background

To understand these effects in more detail, and develop a set of requirements for fast fault current injection, National Grid ran a set of detailed studies. The details of these studies are shown as a set of slides in Annex 3 of this Workgroup report. These slides were discussed with Workgroup members in April 2017.

In summary, the purpose of the study work was to assess the performance on the Transmission and Distribution System of different converter topologies against that of a system made up mainly of synchronous plant with a view to understanding the impact on the System.

The study considered the effect on the system of
i) Synchronous Generation,
ii) negative demand (i.e. the generator is modelled as negative demand and has no real dynamic effect nor provides any form of fault current)
iii) a standard Static Generator Model with PLL taken directly from the Power Factory library,
iv) A converter model based on PLL technology which also includes Fast Fault Current Injection capability (where changes to the injection of reactive current can be varied (eg delay times, ramp rates and ceiling values) and
v) a Virtual Synchronous Machine model in which the converter controller is set up to reflect the performance of a synchronous machine. An example of the performance from these technologies is shown in Figure 4.3 below.

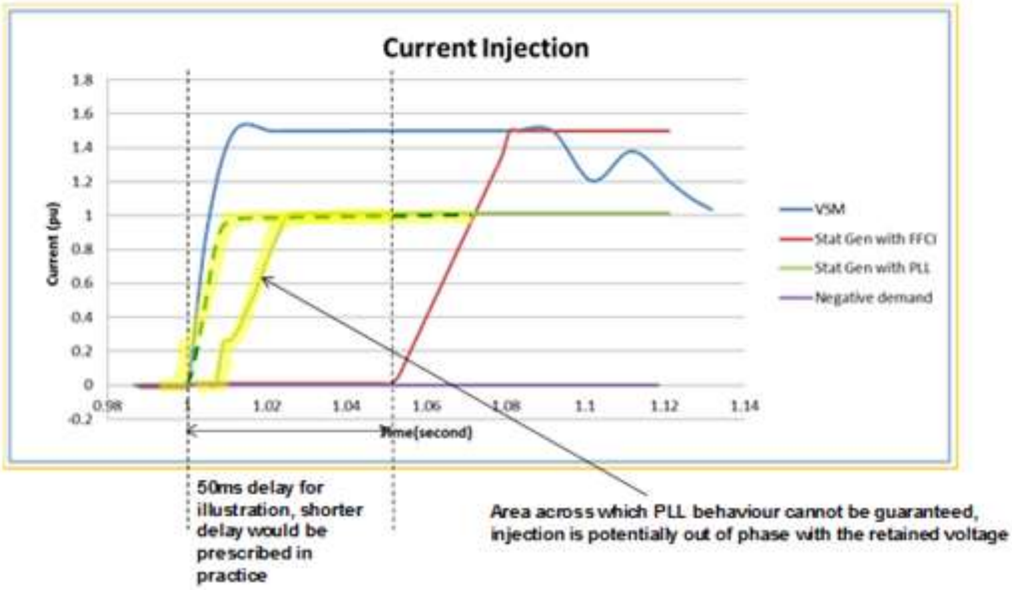

Figure 4.3 – Comparison of Converter performance used to assess the impact on the system under fault conditions.

The concept of the Virtual Synchronous machine is, as its name suggests, aims to control the output of a power electronic converter in the same way as a synchronous machine. The concept is not new with papers and concepts being published on this subject some 20 years ago.

Similar technologies have also found practical applications in the marine industry, but it has not been widely used in public Grid Systems due to the dominance of Synchronous Generation. However, as the volume of Synchronous Generation, particularly at Transmission levels starts to decline, there is growing concern over the ability to operate a power system with very high levels of non synchronous generation.

Conventional converters suffer from two major drawbacks when compared to synchronous generators, these being i) they are unable to supply high fault currents due to the need to protect the converter devices and ii) they are decoupled from the generator and as such do not contribute to System inertia or supply any form of synchronising torque with any form of response being delayed.

The majority of Power Electronic converters use a Phase Locked Loop (PLL) which in essence means the controller aims to keep the phase shift between the input signal and the voltage control oscillator (ie the device which ultimately controls the IGBT's) to zero. The down side of this type of current source control is that it needs to detect a drop in voltage at the converter terminals and then determine any form of phase change before undertaking any processing. Whilst this processing can probably be achieved in 5 cycles (eg 100ms) this speed is still very slow when compared to a Transmission System fault which can be cleared by system protection within say 80ms at 400kV and consequently the need to inject fault current.

In the VSM configuration the converter has slow controls and no PLL so that the phase angle of the voltage source reference oscillator is frozen to the same state it was in prior to the fault. The rate of rise of fault current is initially limited by the output filter components however the converters typically rely on very fast measurement feedback of terminal voltage or current to protect the IGBT's by shutting them down or reducing pulse width. With the current under control or limited, the device then produces fault current within its rating by reducing the internal AC source voltage. Consequently the phase angle of the current drawn is typically determined by the load and is generally reactive in nature which is the same approach of a synchronous machine.

From an electrical perspective, a synchronous machine is basically a balanced 3ph voltage source connected to the system via an impedance that is largely reactive. The frequency and phase angle of this voltage source changes relatively slowly as they are directly related to the angle of the machines rotor which is very heavy and has a high inertia. Likewise the voltage magnitude also changes relatively slowly as it is related to the current in the field which is highly inductive and therefore slow to change.

The AC current however is dependent upon the load and network impedance. Load changes or switching operations such as tripping machines or switching in and out transmission lines, therefore result in very fast network impedance changes. Consequently theis results in almost instantaneous changes in AC current and this explains why conventional synchronous generators naturally respond to load changes instantaneously without having to measure feedback signals such as voltage or frequency. The aim of this proposal is therefore to require converter based generation to behave in the same way as a Synchronous Generator.

This VSM technology offers significant advantages to the System Operator and is also believed to be a lower cost solution than other alternatives such as connection restrictions or the installation of Synchronous Compensators which it is acknowledged are a necessity but would not necessarily be required all year round.