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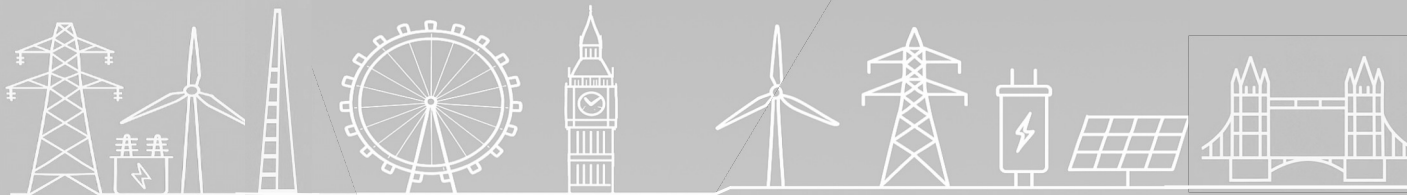


Challenges of Fault Current Analysis using IEC 60909 and ENA G74 in Grids Dominated by Converter Fed Generation

S. Sommerville, Dr Marko Aunedi & Prof. G.A. Taylor

Stephen Sommerville

Stephen.sommerville@brunel.ac.uk



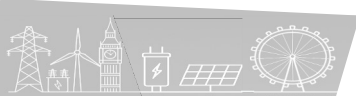
Introduction

- IEC 60909 is a widely use standard to determine fault levels and suitability of switchgear.
- IEC 60909 is now very old (2016) and does not consider modern network changes.
- ENA G74 is newer (2021) UK standard and considers CFG - but does not fully capture voltage dependent relationship of inverters.
- Simulation studies were showing unusually high results – investigations identified that the standards were over-estimating the contribution of Grid Following Inverters.
- Neither standard considers Grid Forming Technology.



Fault Calculation Method

- IEC 60909 uses a nominal bus voltage and 'c' factor to account for high system voltages.
- ENA G74 uses a pre-fault loadflow to consider the system state.
- Converts network into simple equivalent model of impedances and fault sources.
- CFG are treated as a constant current sources.
- Intentionally conservative – used to identify worst case.
- Computationally simple and fast to process.
- IEC60909 has a caveat the CFG contribution are assume as low.



Retained Voltage

- At the fault location the voltage collapses to zero, but on the rest of the network the voltage dips slightly. The closer to the fault (electrically) the larger the voltage dip.
- Remote locations will not experience a significant voltage dip. The voltage on the rest of the network is known as the retained voltage.
- For downstream faults, the upstream network voltage dip can be very small.
- Focus of the study was on 3ph faults as they are conceptually easier.



CFG – Fault Ride Through & Reactive Current

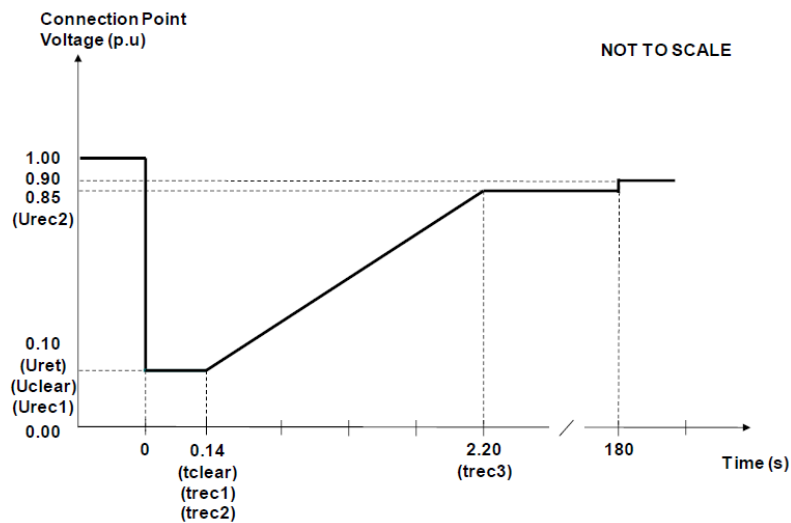


Figure 13.10 - Voltage against time curve applicable to Type C and Type D Power Park Modules connected below 110 kV

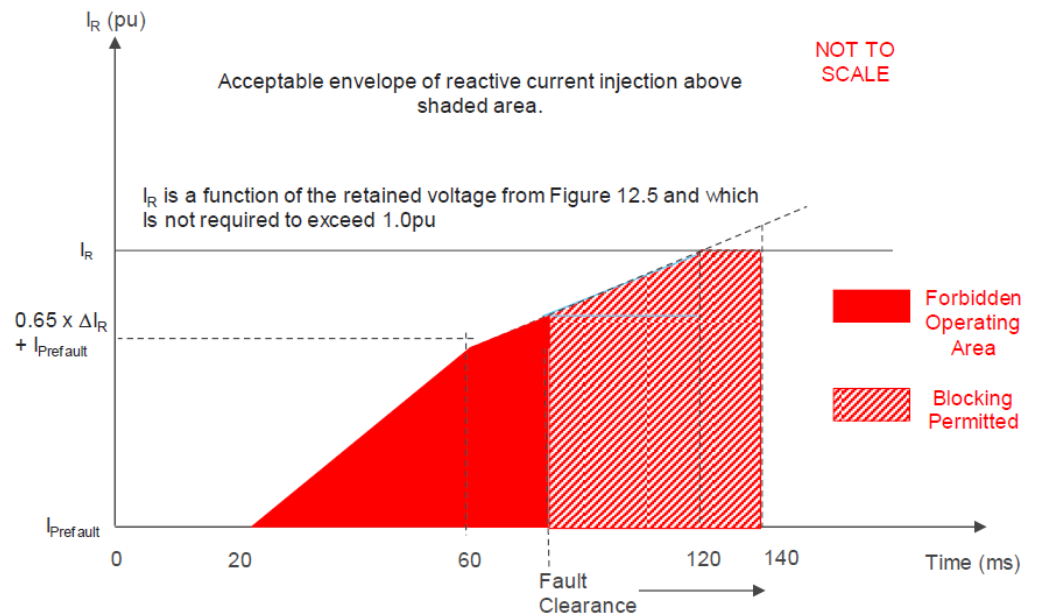


Figure 12.8(a) Chart showing area of reactive current injections for voltage depressions of ≤ 140 ms duration

CFG Fault Contribution – IEC 60909 / G74

- A CFG based generator (Grid Following) has a defined output – it is usually treated as a constant current source of output $\approx 1.1\text{pu}$ to 1.5pu
- In IEC 60909 the output is constant current.
- In ENA G74 it is voltage dependent, based on a tunable gain factor of K (see *below*)

$$\Delta I_{CDP} = K_j \Delta u_j \quad (3)$$

: if ΔI is below the maximum current

$$\Delta I_{CDPj} = I_{maxj} \quad (4)$$

: otherwise



Converter Fed Generation Output - Reality

- The CFG output is controlled by the Fault Ride Through / Reactive Current Injection control loops.
- These controls are only triggered if the network voltage dips below a specific threshold – V_{dip} .
- Various parameters in the control loops can be adjusted to increase the output magnitude and response.

$$\begin{cases} \Delta I_{CDP} = K_j \Delta u_j, \text{ if } V_{ret} < V_{th} \\ \Delta I_{CDP} = 0, \text{ if } V_{ret} \geq V_{th} \end{cases} \quad (12)$$

: if ΔI is below the maximum current set by I_{max} & I_{qh1}/I_{qh2}

$$\begin{cases} \Delta I_{CDP} = I_{maxj}, \text{ if } V_{ret} < V_{th} \\ \Delta I_{CDP} = 0, \text{ if } V_{ret} \geq V_{th} \end{cases} \quad (13)$$

:otherwise

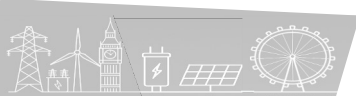
CFG Impact to Fault Results

- It was identified that the constant current output of the inverter was being summed with the existing network voltage, and increasing the network (retained) voltage to unrealistic values.
- It was more obvious in the IEC 60909 method as G74 uses a voltage reduction factor. However, it was still noticeable in G74 on weak networks with a high CFG K factor.

$$U_{B(flt)} \approx U_{B(preflt)} - Z_{Bus} \cdot I_{fault} \quad (9)$$

$$\Delta U_B \approx Z_{INV} \cdot I_{INV} \quad (10)$$

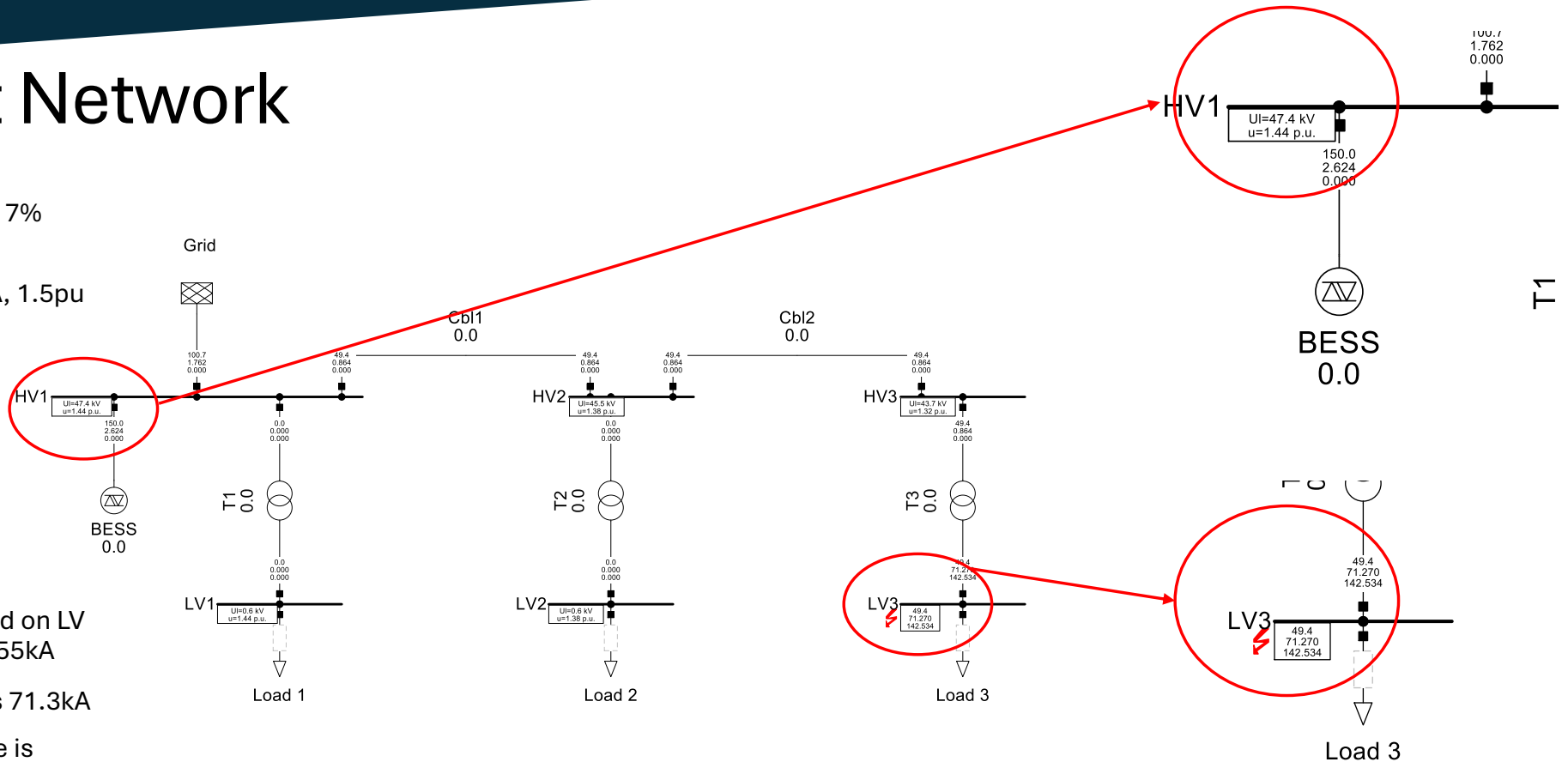
$$U_{B(flt)} \approx U_{B(preflt)} - Z_{Bus} \cdot I_{fault} + Z_{INV} \cdot I_{INV} \quad (11)$$



Test Network

- 33kV Bus
- $T_x = 2.5\text{MVA}$, $z = 7\%$
33/0.4kV T_x
- BESS = 100MVA, 1.5pu
Flt contribution

- MaxSC expected on LV would be circa 55kA
- Actual shown is 71.3kA
- HV1 bus voltage is 1.44pu

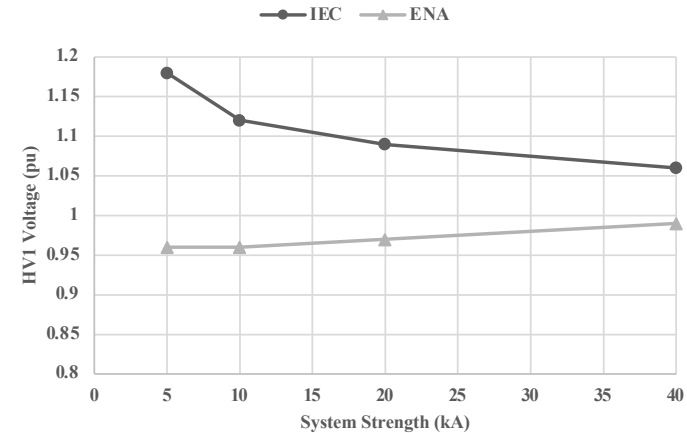


Initial Results

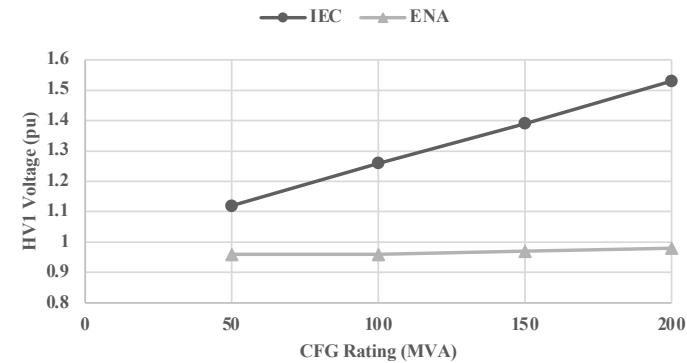
Case	Grid Strength (kA)	IEC 60909		ENA G74	
		HV1 Bus Voltage (pu)	LV1 Bus Fault Level (kA)	HV1 Bus Voltage (pu)	LV1 Bus Fault Level (kA)
1	40	1.06	52.5	0.99	47.0
2	20	1.09	53.9	0.97	46.3
3	10	1.12	55.5	0.96	45.9
4	5	1.18	58.6	0.96	46.0

Case	CFG Rating (MVA)	IEC 60909		ENA G74	
		HV1 Bus Voltage (pu)	LV1 Bus Fault Level (kA)	HV1 Bus Voltage (pu)	LV1 Bus Fault Level (kA)
5	50	1.12	55.5	0.96	45.9
6	100	1.26	62.3	0.96	45.8
7	150	1.39	68.9	0.97	46.4
8	200	1.53	75.7	0.98	46.8

HV1 Retained Voltage vs System Strength

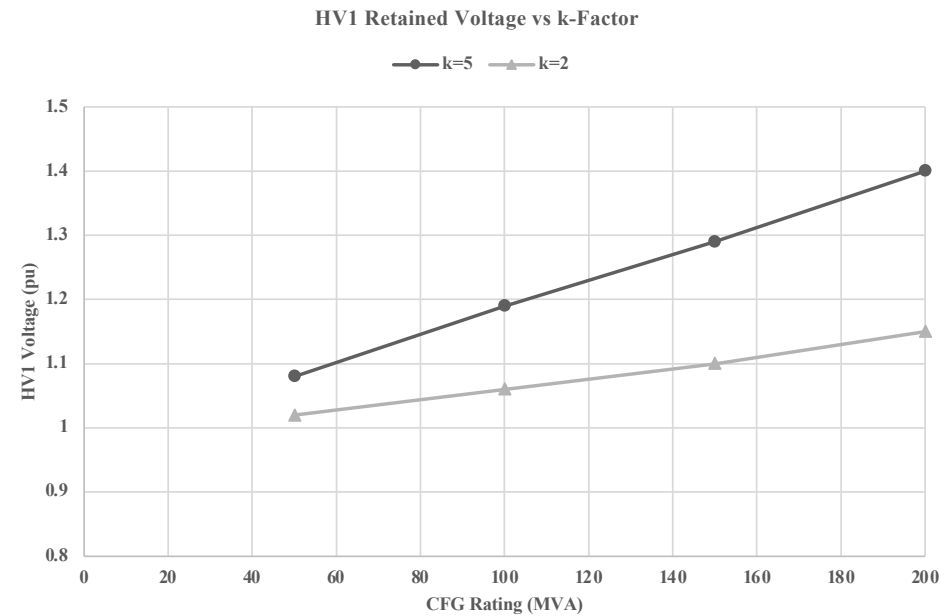


HV1 Retained Voltage vs CFG Rating



Results – Increasing K

Case	CFG Rating (MVA)	K=2		K=5	
		HV1 Bus Voltage (pu)	Fault Contribution From CFG (kA)	HV1 Bus Voltage (pu)	Fault Contribution From CFG (kA)
1	50	1.02	0.22	1.08	0.542
2	100	1.06	0.44	1.19	1.09
3	150	1.1	0.653	1.29	1.629
4	200	1.15	0.875	1.4	2.714



Grid Forming Inverters

- Grid Forming inverters are becoming increasingly common, and are being rolled out at Grid scale.
- There is no agreed method in any standard on how to model these. Different control strategies and fault response and output depend on the used technology.
- The best approaches appear to be either as
 - An equivalent Synchronous Machine where $X''_d = X'_d$ and $X/R = 1.0$
 - A simple voltage behind an impedance with $X/R = 1.0$



Summary

- It was identified that GFL based technology can cause misleading results in IEC 60909 based fault level studies. Similar issues can be identified in ENA G74 method but is less obvious.
- Issue occurs in networks with low fault level, high CFG penetration and if the inverter K factor is high (for ENA G74).
- The issue is caused by the standards failing to consider that the GFL output only triggers is $V_{retained} < V_{threshold}$
- Grid Forming Inverters are not considered at all in either standard.
- Further work in large meshed transmission networks.

