MTS DYNAMIC POSITIONING CONFERENCE

Fault Analysis of DC Electric Hybrid Power Systems used in DP Vessels
October 10 - 11, 2023

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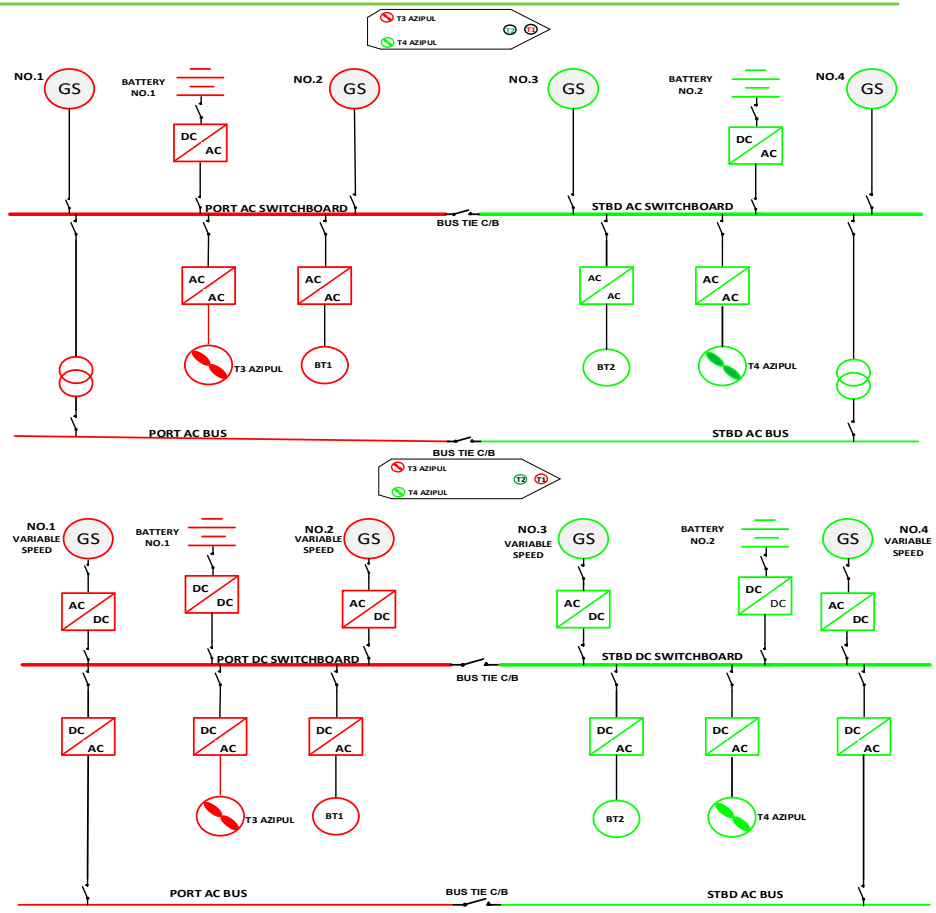
Introduction to hybridization (AC and DC configurations)
Power conversion methods from AC to DC and DC to AC
Overview of Voltage Source Converter (VSC) and DC to DC Converters (Boost and Buck)
PS-CAD model of one redundant group of a DP-2 hybrid system
Performance review of hybrid system including load sharing
Failure analysis of the hybrid system showing simulated results
Conclusion

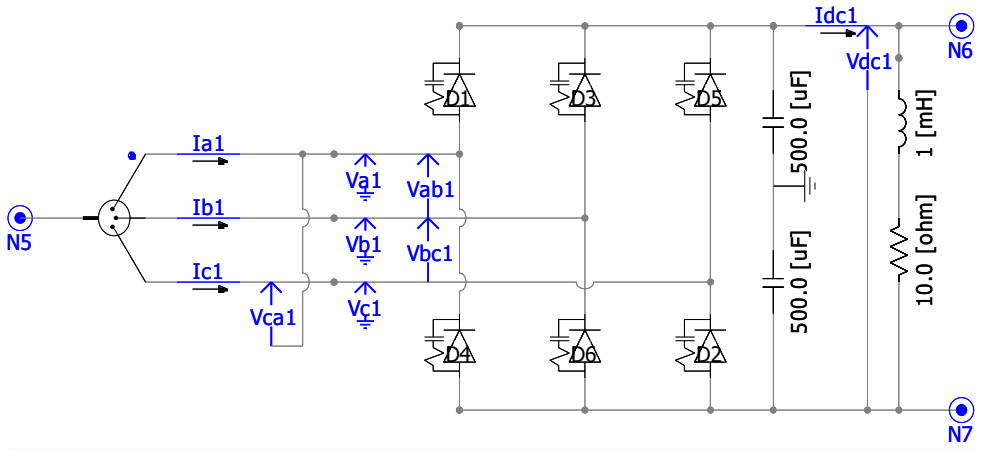
AC & DC Hybrid System

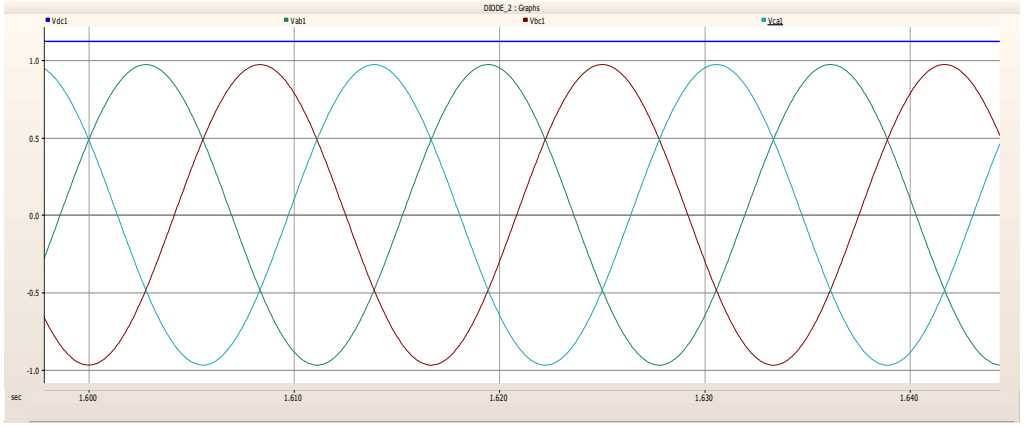
Battery output is converted to AC using inverter for synchronisation with DG
Inverter has to be AFC as power flow on both the direction is needed for battery charge and supply the load
DC System – DGs can operate at variable frequency
Battery power is integrated with DC bus using DC – DC converter
DC-DC converter needs to operate on boost and buck mode.
Inverter output must match and synchronise with the ship operating frequency
Stability of DC system voltage can be maintained by several ways



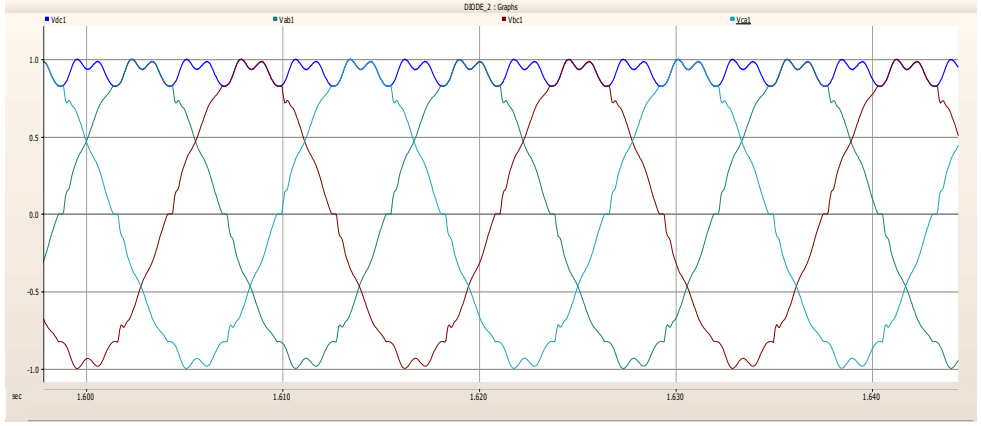
AC to DC Conversion – Six Pulse Diode Bridge

- Natural commutation of diodes
- DC voltage is regulated by control of excitation of generator
- Maximum output Voltage is 1.35 x Input Voltage
- Even harmonics cancelled due symmetry of the bridge & only odd harmonics to be treated





No Load



With Load

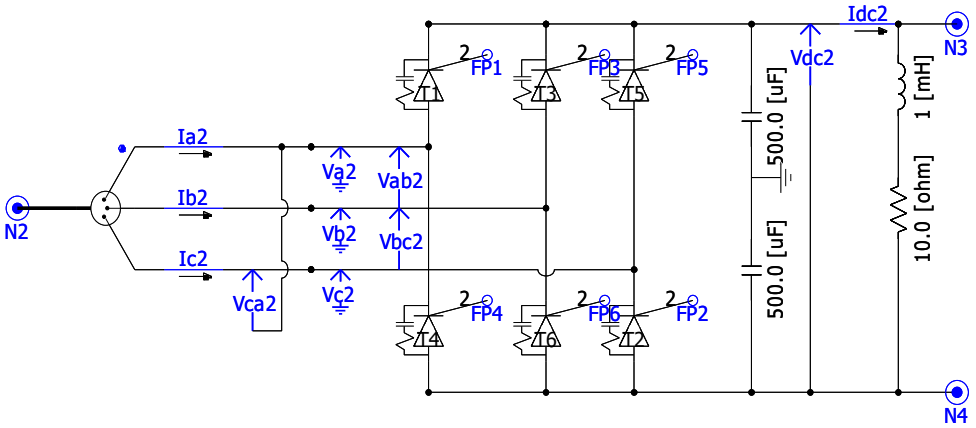
AC to DC Conversion – Thyristor Bridge

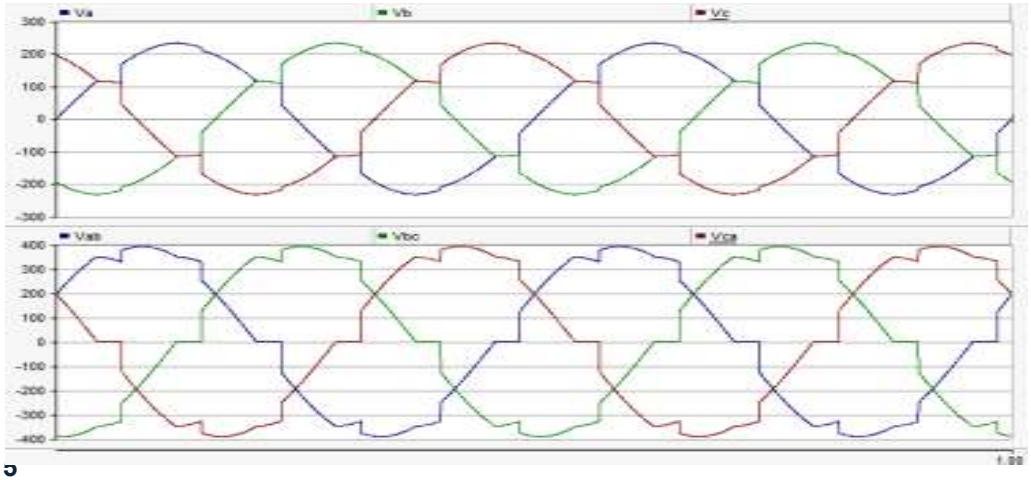
DC voltage is regulated by control of firing angles (α)

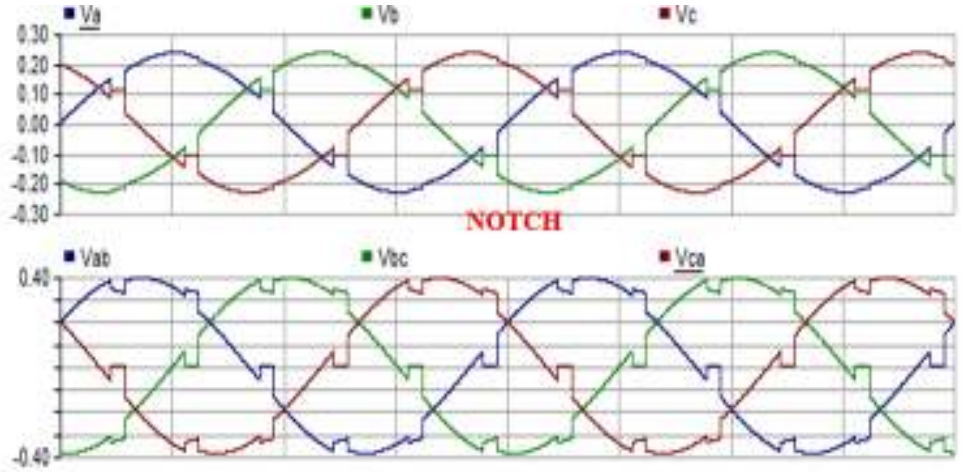
Output Voltage is 1.35 Cos α x Input Voltage

Harmonics are similar to diode bridge with commutation notches

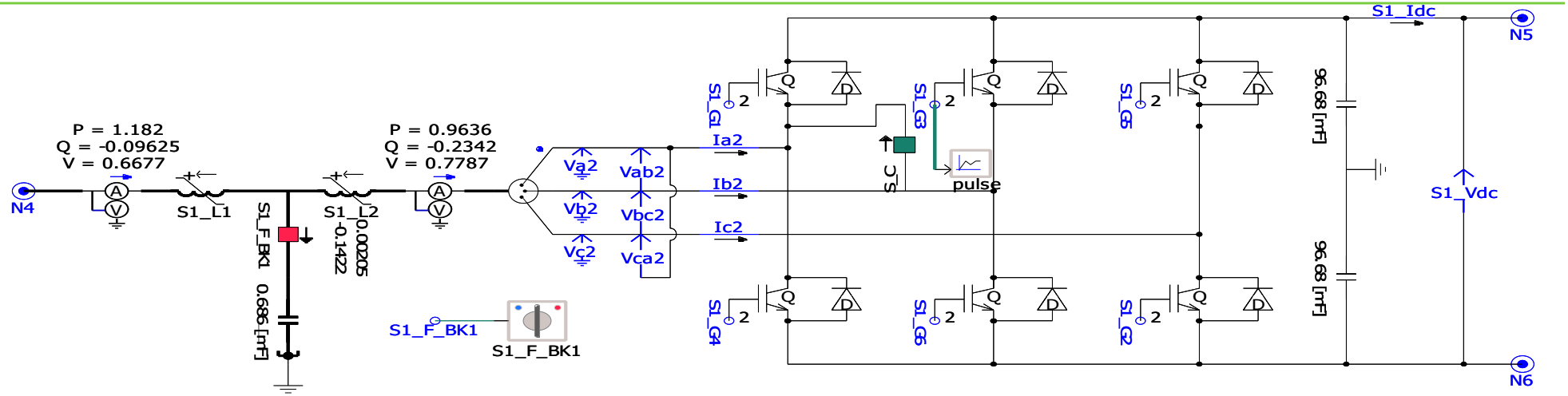
Less distortion for α = 0, increased distortion α > 0 degrees

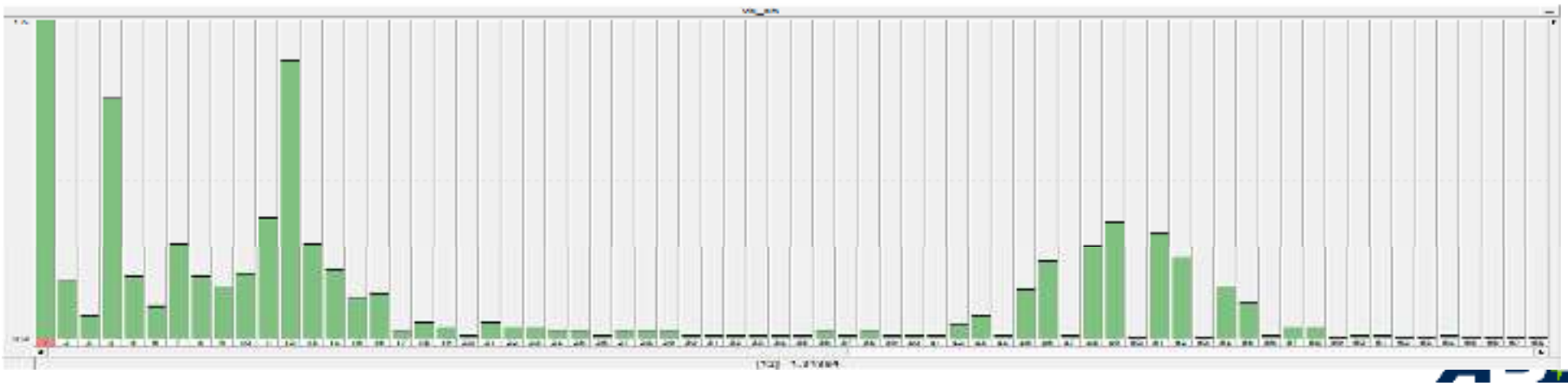




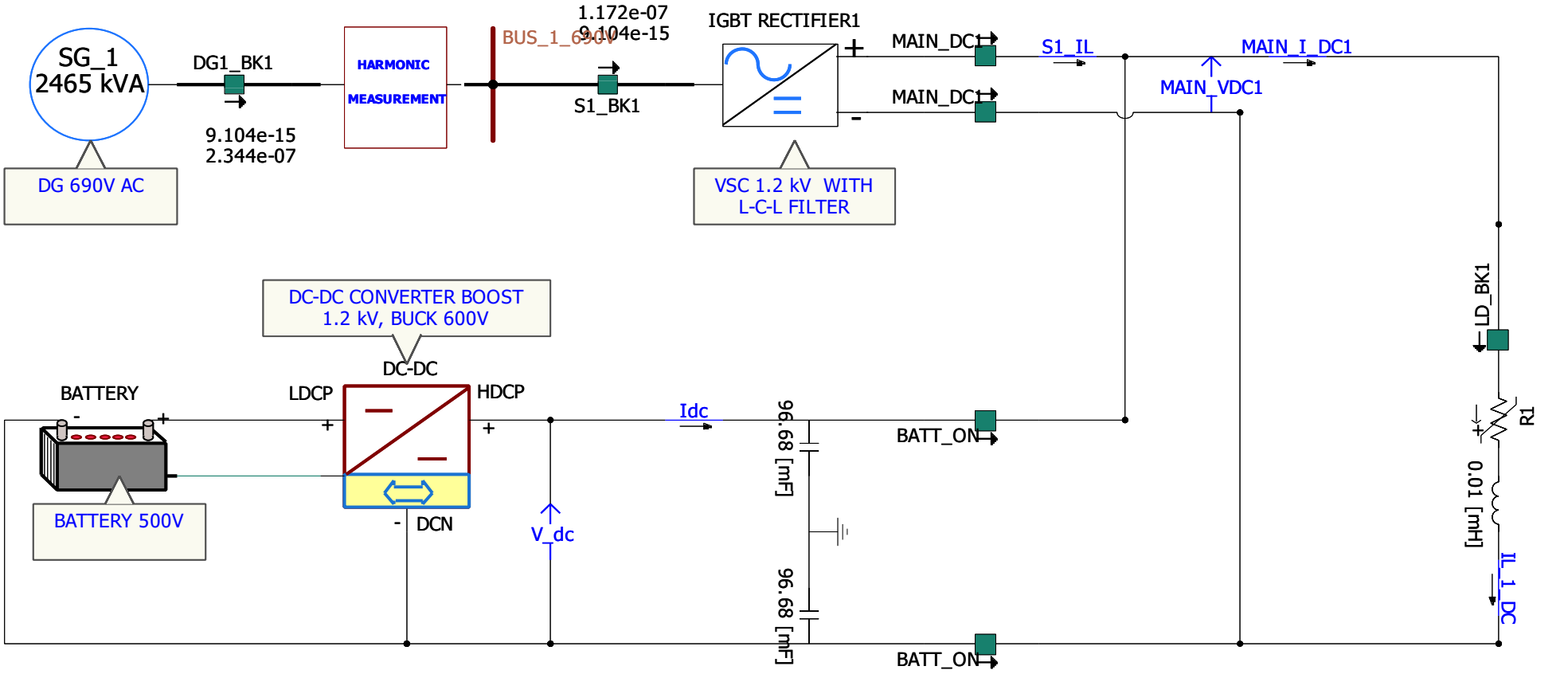


AC to DC Conversion – VSC SVM

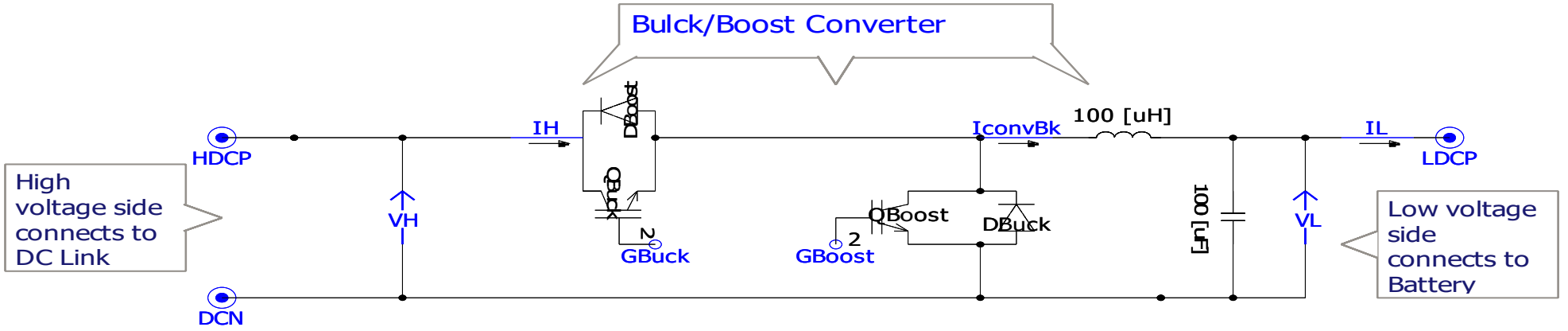


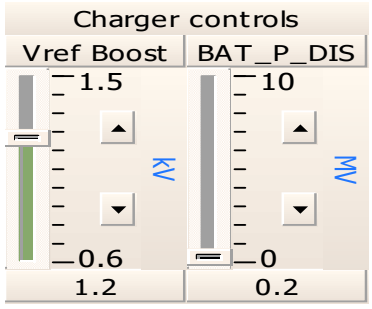


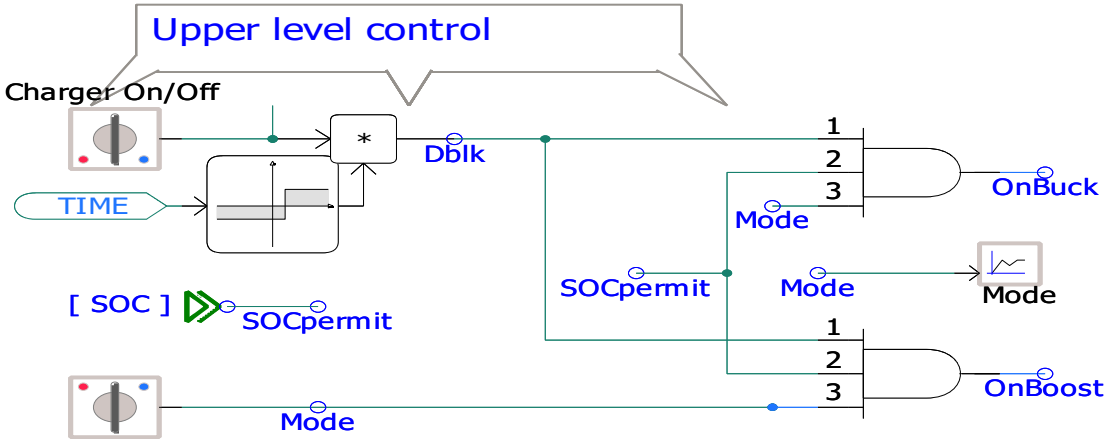
One Redundant group of hybrid system model

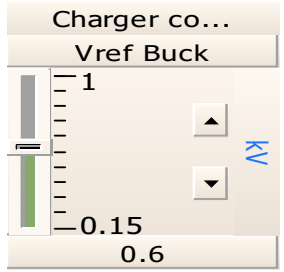


DC-DC Converter









DG-VSC supplying step load up to 2 MW

Top overlay shows the DC bus, VSC, DC-DC converter o/p & battery voltage

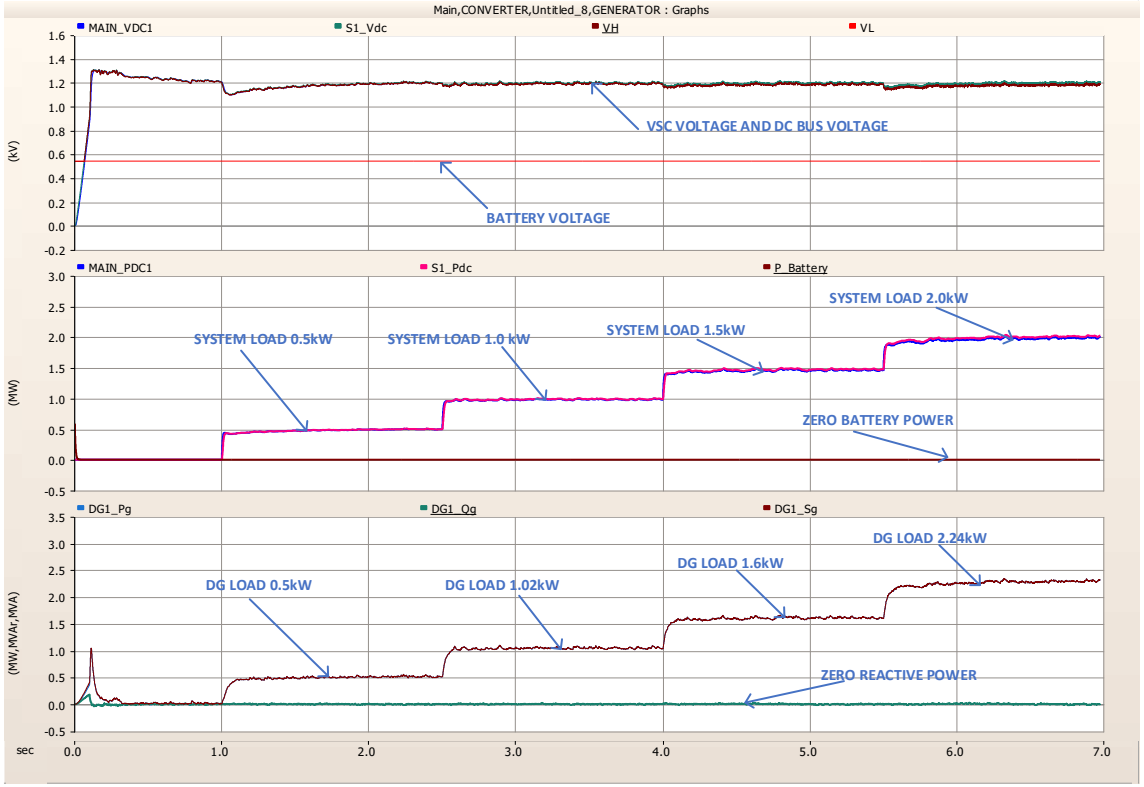
Middle overlay shows the power on main DC bus, VSC O/P and battery O/P

Battery is not contribution any power as the power demand of 2MW is supplied by DG

Graphs in bottom overlay shows DG power delivered

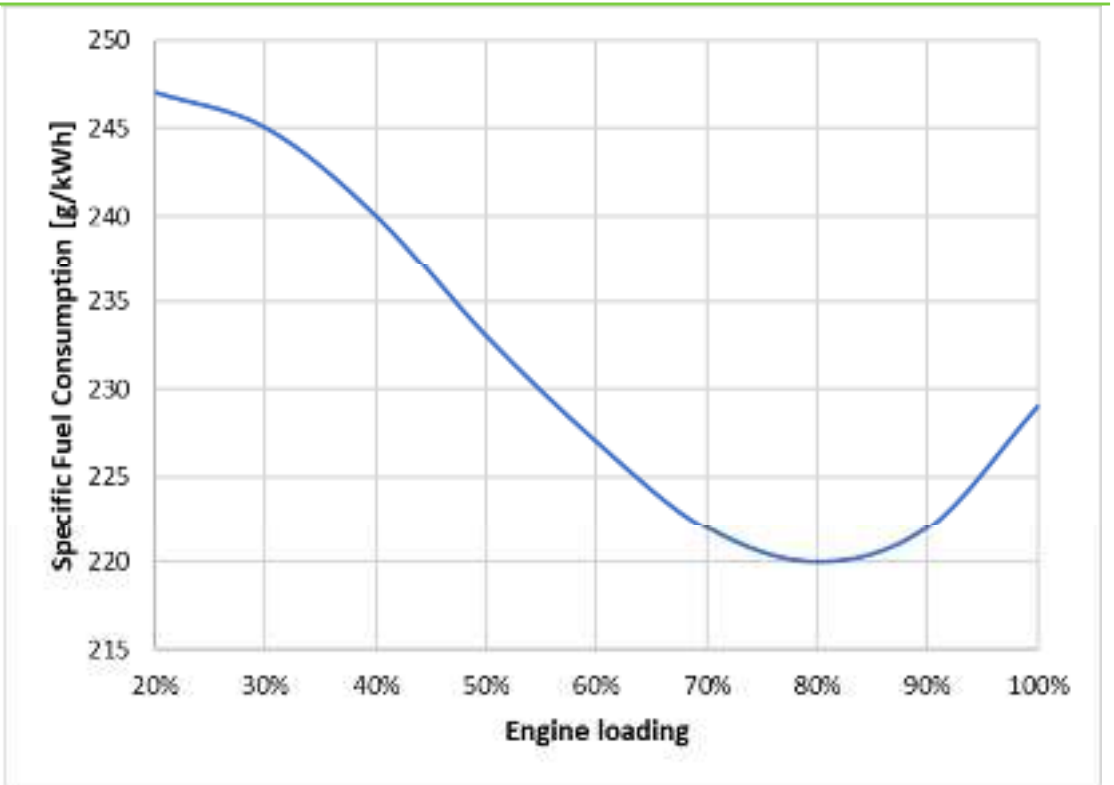
DG is delivering only active power and zero reactive power

The VSC is tuned to take zero reactive power from DG.



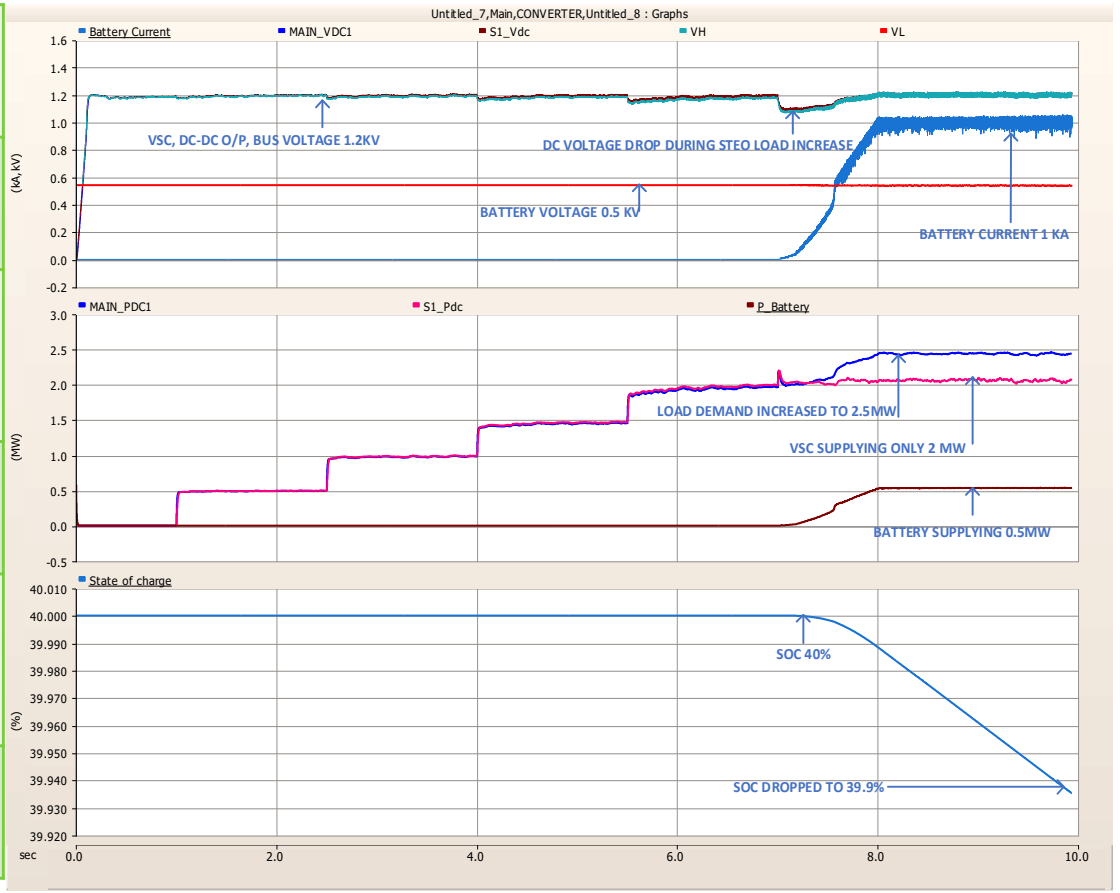
Optimisation of hybrid power systems

DGs have to be operated at optimum load for lowest fuel consumption.
The graph shows an example of an operating point of a DG
The peak efficiency is at 80% load
Challenge is to optimise the power plant under all operating conditions
PMS is to be configured to operate the generators at 80% whilst other sources takes the excessive load



Battery load sharing with DG set to 0.5 MW and 2.0 MW

Top overlay shows the DC bus, VSC, DC-DC converter o/p, batt voltage & Batt current
Middle overlay shows the power on main DC bus, VSC O/P and battery O/P
Battery is not contribution any power until 7 secs after start as the demand of 2MW is supplied by DG
Battery start delivering power when the demand increased to 2.5 MW
DG continues to deliver 2 MW and battery supplies to extra 0.5MW to keep optimum operation of the DG
Bottom overlay shows the SOC of the batteries during discharge for 2.5 seconds



Battery load sharing with DG set to 1MW and 1.5 MW

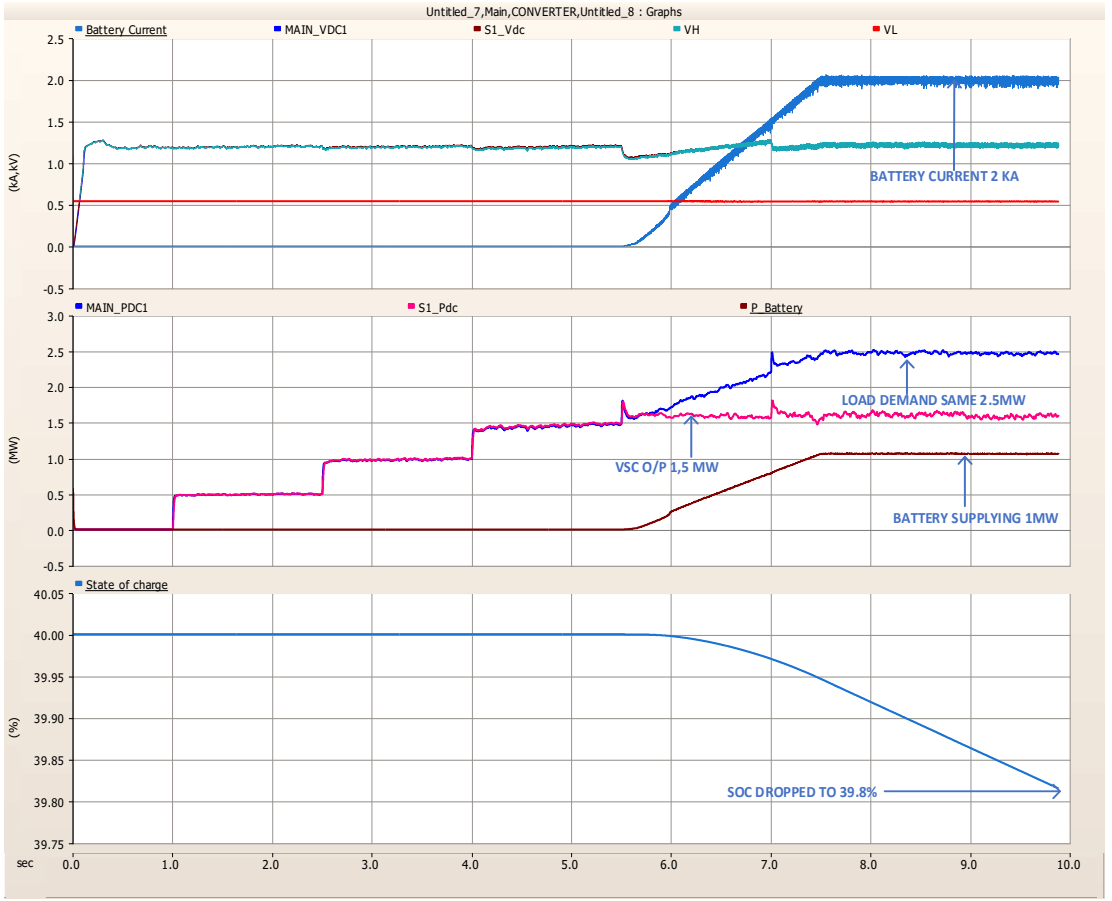
Battery is not contributing any power until 5.5 secs after start as the demand of 1.5MW is supplied by the generator

PMS is now set for DG to supply maximum 1.5MW

Battery starts delivering power when the demand increases more than 1.5MW.

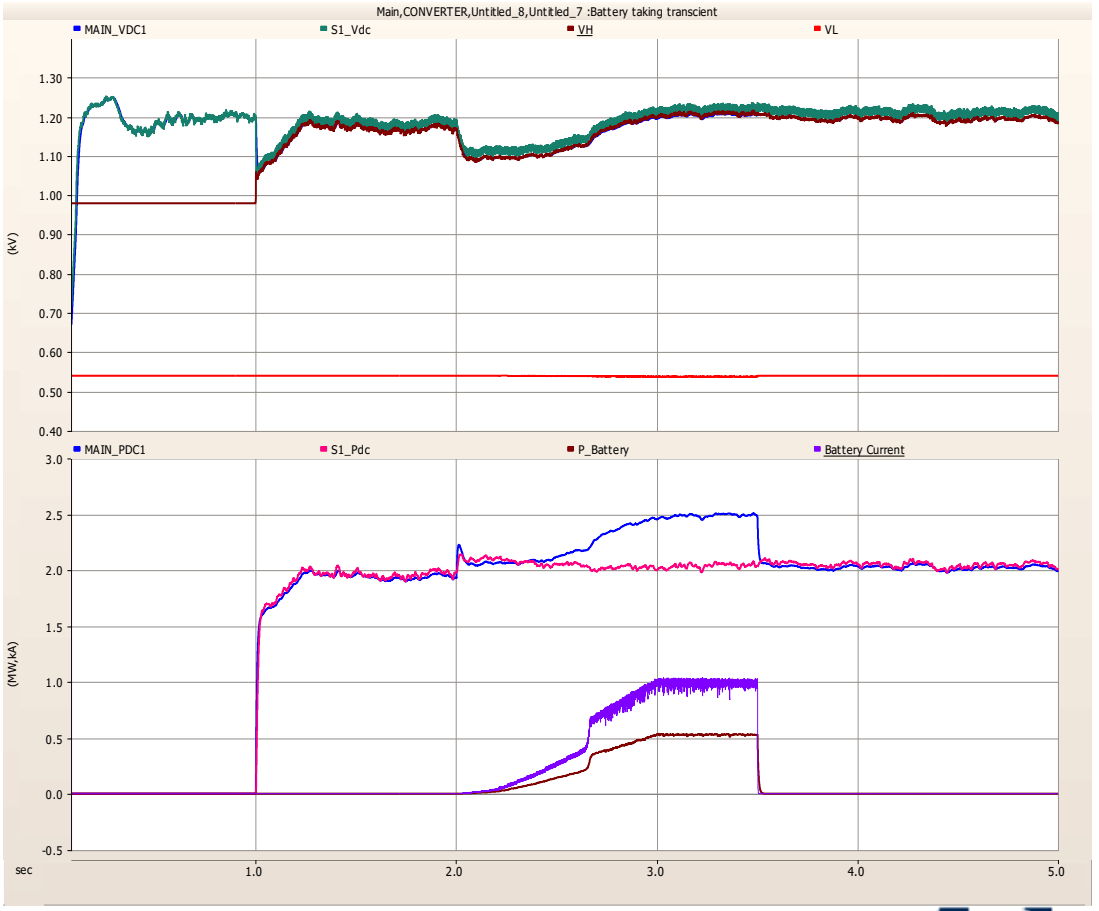
DG continues to deliver 1.5 MW and battery supplies to extra 1 MW to supply the load demand of 2.5 MW

Battery current in top overlay increased to 2 kA at 7.5 sec



Battery taking transient of 0.5MW

The graphs show how battery can be used for providing transient load demand
One second after start, DG supplies step load of 2MW (2nd overlay)
Two seconds after start, load demand increases to 2.5MW for 1.5 seconds (transient)
Battery starts delivering power at 2 seconds and take the full deficit of 0.5M in 1 sec.
The DC voltage drops to 1.1kV (8%) for 0.5 sec and recovers to 1.2 kV
Battery stops feeding the load at 3.5 sec when load remand reduces to 2MW
This demonstrates the capability of PMS for stable system when transient load demand is available



PMS failure to limit the battery power to 0.5 MW

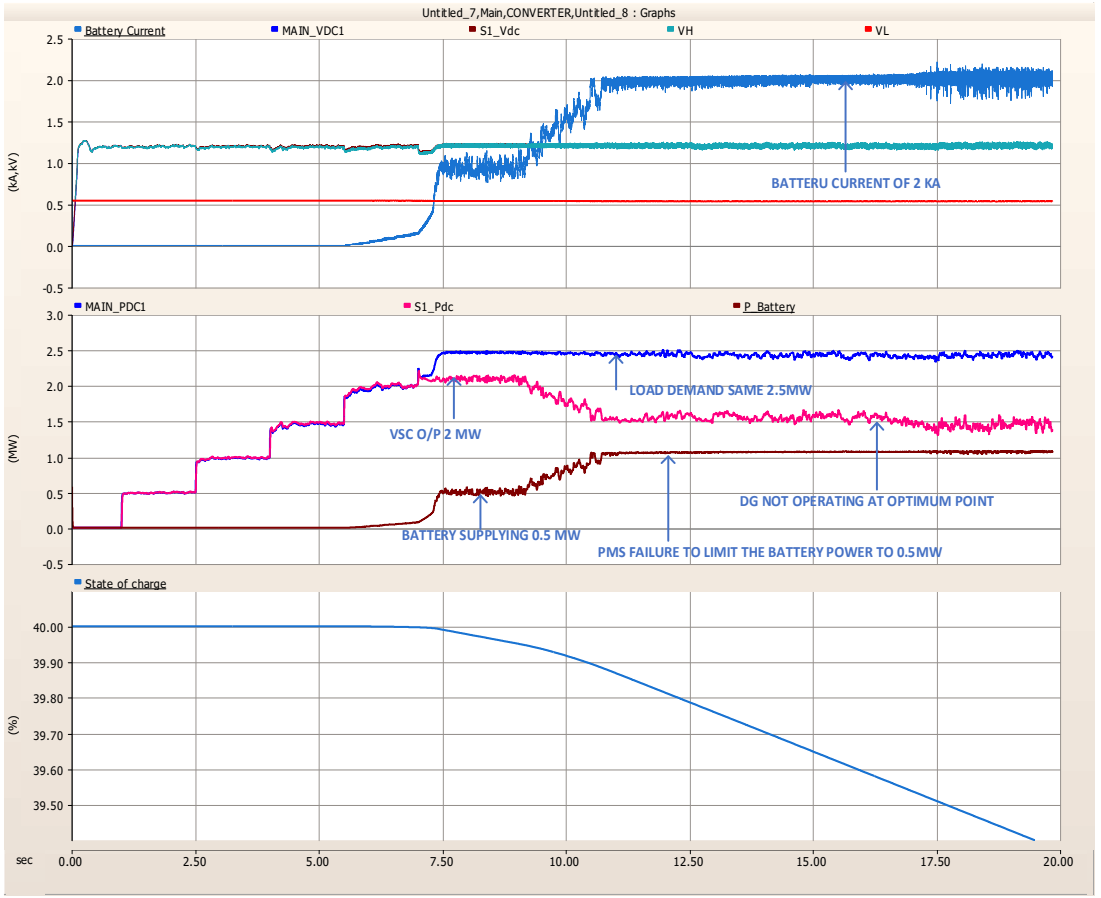
The graphs show a failure within the PMS or control system to maintain correct load sharing

The graphs in middle overlay show that DG was delivering 2MW and battery was providing 0.5MW to supply load demand of 2.5MW at 7.5 sec

A failure within the PMS to limit the battery power to the deficit of 0.5 MW caused battery supplying 1MW and DG supply reduced to 1.5 MW instead

This failure causes the DG to go out of optimum limit leading to in efficient operation

It is important that detection of these kind of failures are included in the detection principle



VSC failure during hybrid mode

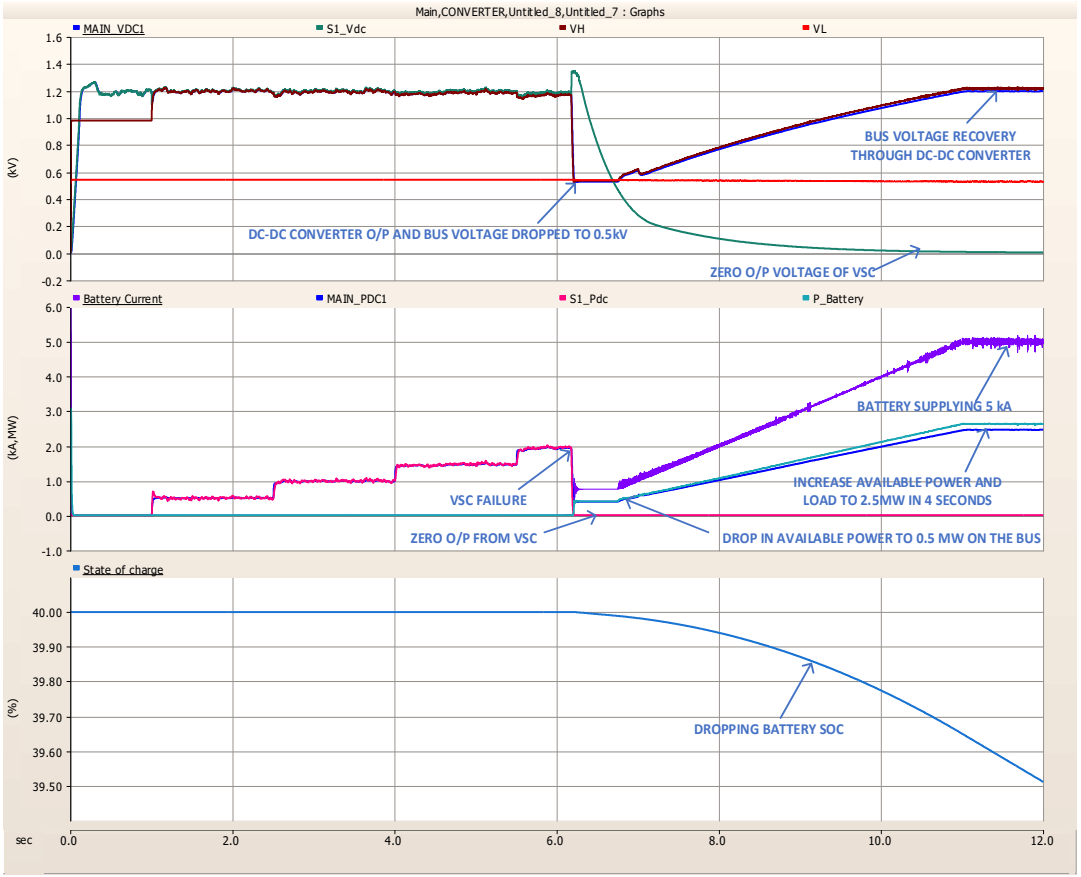
The graphs show the effects of a failure within the VSC leading to trip the output of the VSC

VSC failure occurred just after 6 seconds from the start when it was delivering 2MW of power

The DC bus voltage dropped to zero and battery took more than 2 seconds to regain the bus voltage and to take the load of 2.5MW

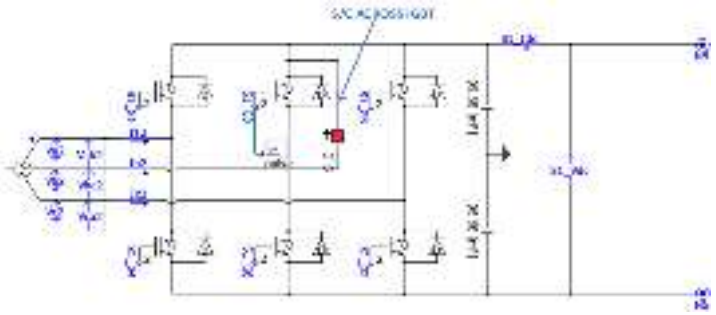
Battery response time is excessive as the consumers can drop due to voltage dip

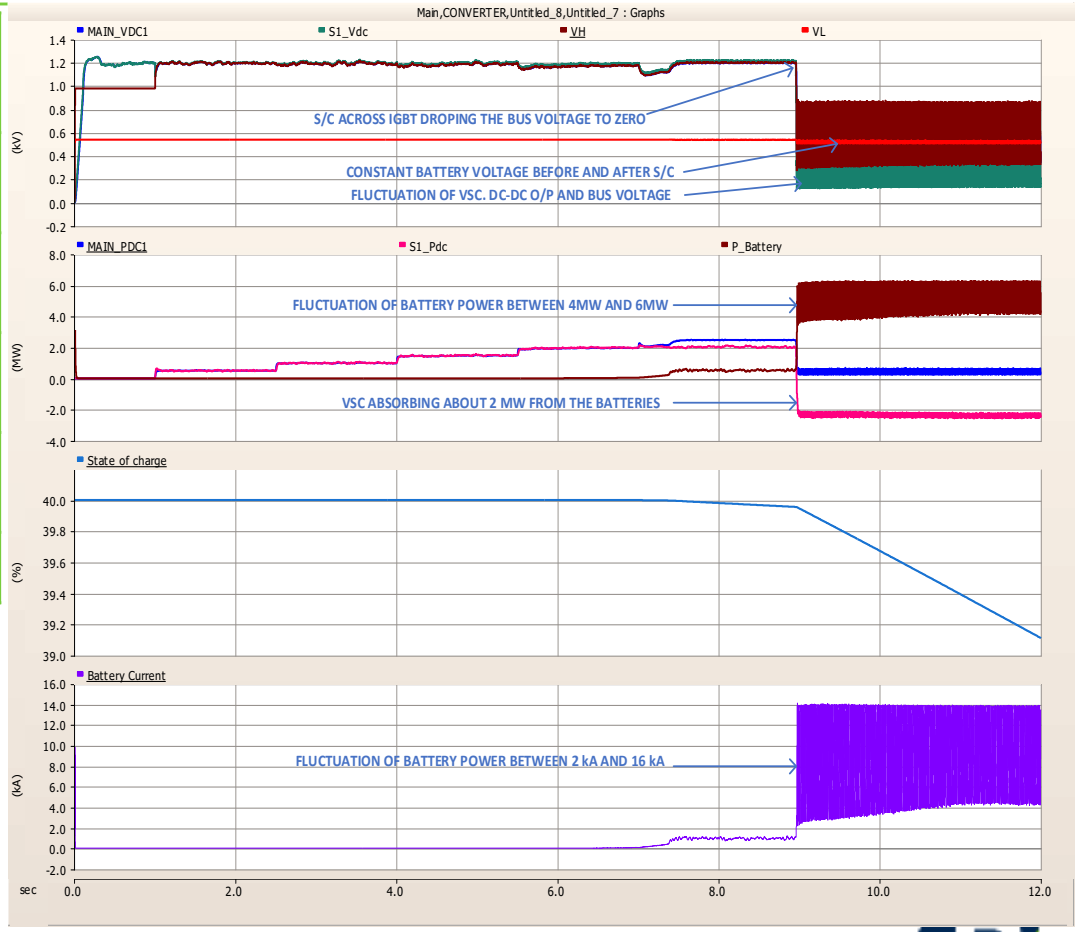
This shows that DC-DC converter needs further tuning for fast response of battery.



Short circuit across an IGBT of the VSC during hybrid mode

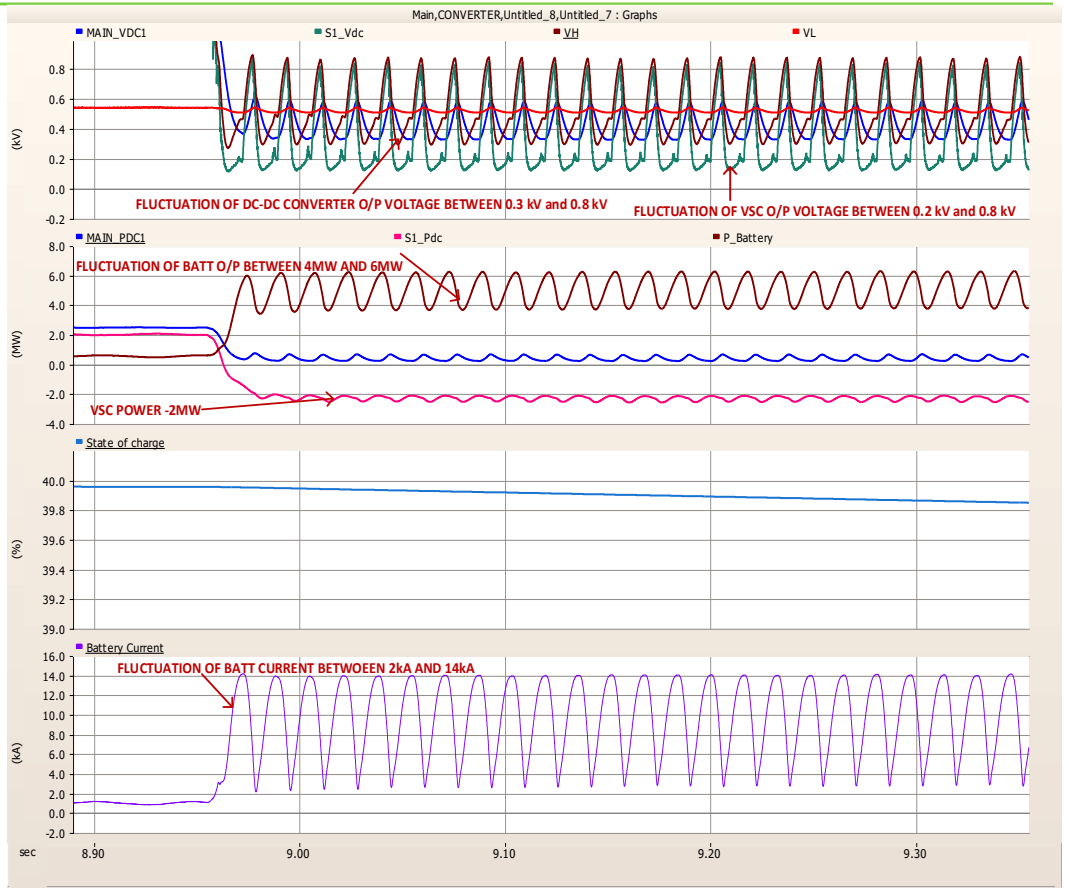
The graphs show the effects of a short circuit across IGBT G3 of the VSC (9 seconds)
VSC started drawing the 2MW of power from battery
VSC output started oscillation
DC-DC converter O/P started oscillation
Battery O/P current started oscillates
SOC reduces from 40% to 39% in 3 seconds



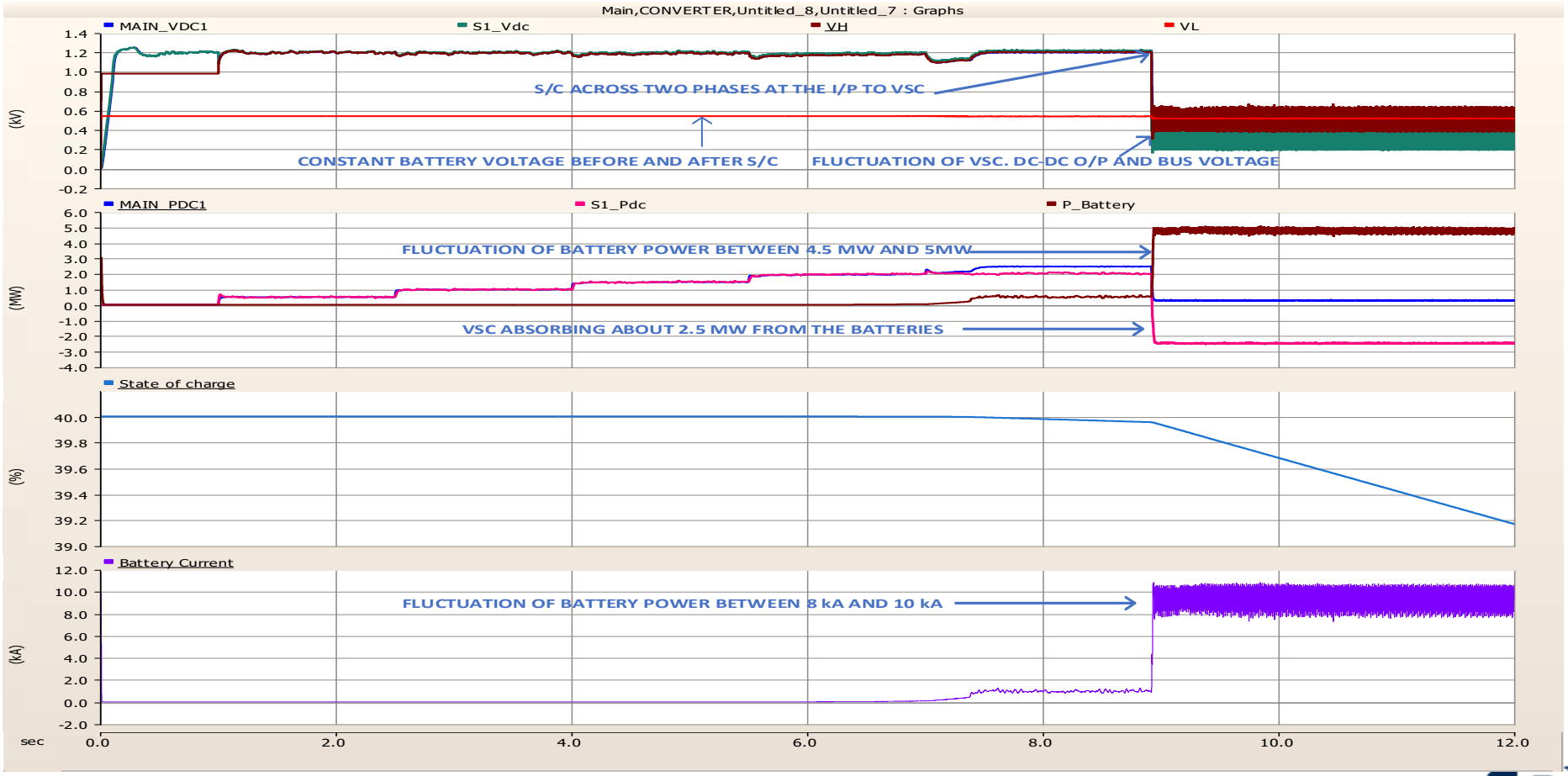


Continuation

The slide shows zooming of the graphs in faulty area
Green graph in top overlay shows the oscillation of VSC O/P between 0.1kV and 0.8kV
Brown graph in top overlay shows the oscillation of DC-DC converter O/P between 0.3kV and 0.8kV
Brown graph in 2nd from top overlay shows the oscillation of battery power between 4MW and 6MW
Red graph in 2nd from top overlay shows the power drawn by the VSC from Battery – 2 MW
Battery O/P current oscillates between 2 kA and 14 kA
Effective protection system is needed for safe operation



S/C between two phases at the I/P of the VSC during hybrid mode



Open circuit within one IGBT of VSC during hybrid mode

The graphs show the effects of an open circuit between two IGBTs of the VSC (9 seconds)

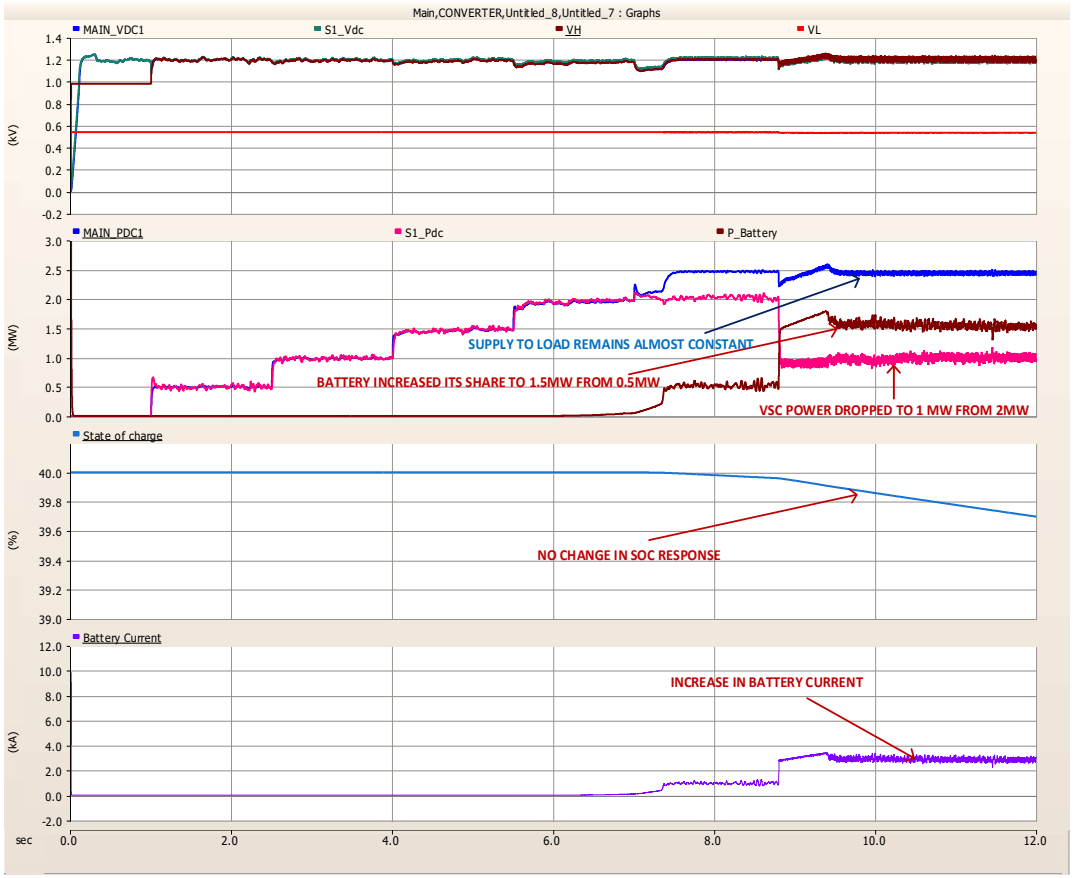
Graphs in top overlay shows that the bus voltage is stable during the faulty condition.

Supply to load remains steady as seen in blue graph of 2nd overlay from top

VSC reduces its supply to 1MW (red graph) and battery increased its share from 0.5 MW to 1.5MW

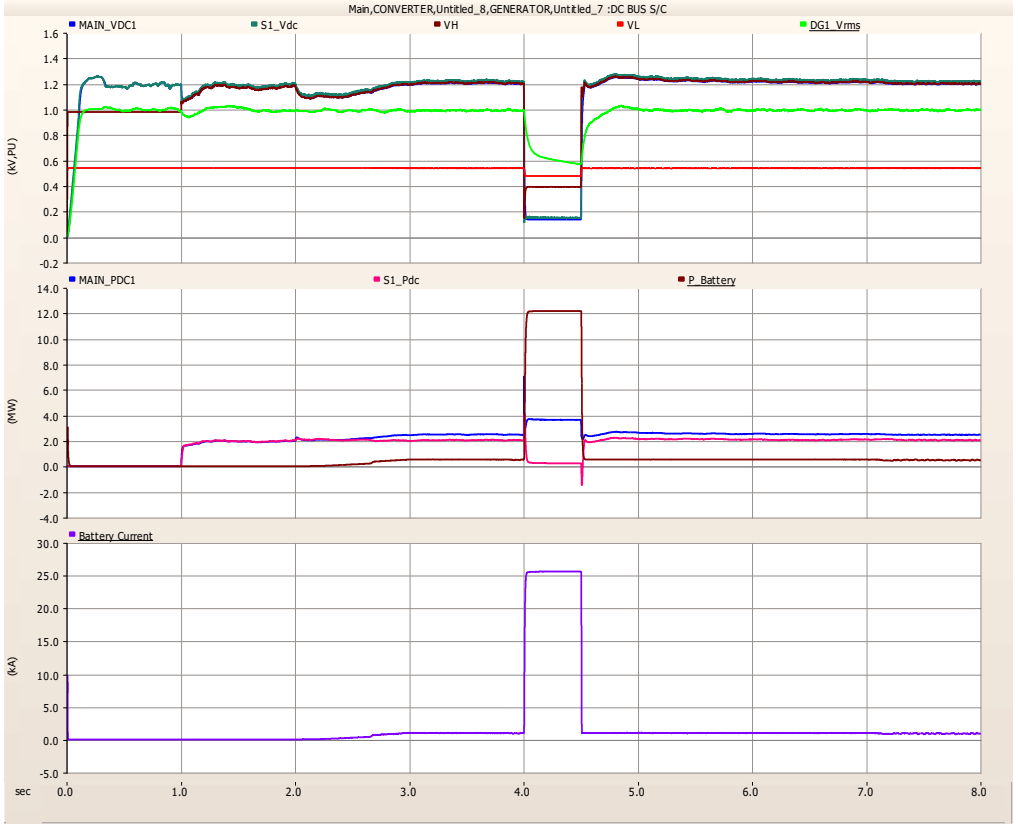
Battery current increased and SOC dropped from 40% to 39.7%

Protection system can be arranged to trip the faulty VSC and start standby DG to continue the operation



S/C on the DC Bus (VSC alone and with battery hybrid mode)

Without battery



With battery

Conclusions

Hybrid power system can be AC or DC distribution systems with storage device integration
Hybrid system can be used for fuel saving and low emission with proper control algorithm such as advanced PMS
Simulated results show that batteries could absorb the transient load while allowing DG to continue at optimum operating point
Overall process will benefit in reducing the operational cost and emission
Failures within power electronics systems (VSC, DC-DC converter) can lead to complete system failure unless proper detection and protection methods are used
Failure testing of power electronics can be disastrous, needing advanced testing methods
Difficult failure testing can be done by using test rigs and be properly documented and available for review
Proper understanding of all the novel systems (main and sub) is needed without treating them as black boxes
Further studies and analysis are needed to develop confidence in the emerging technologies

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