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EMTP Simulation set 6
8/18/08

Test 6-1: Staggered islanding and small step load increase
MS: Set to 5kW of 15kW rating
ES: Set to -5kW of 15kW rating
SM: Connected, power set to 0.8pu (10kW@60Hz of 12.5kW rating)
On-Site load set to 35kW
Separation of Static Switch A at t=0.0sec
Full-island event at t=1.0sec
Additional 3kW load at t=2.0sec

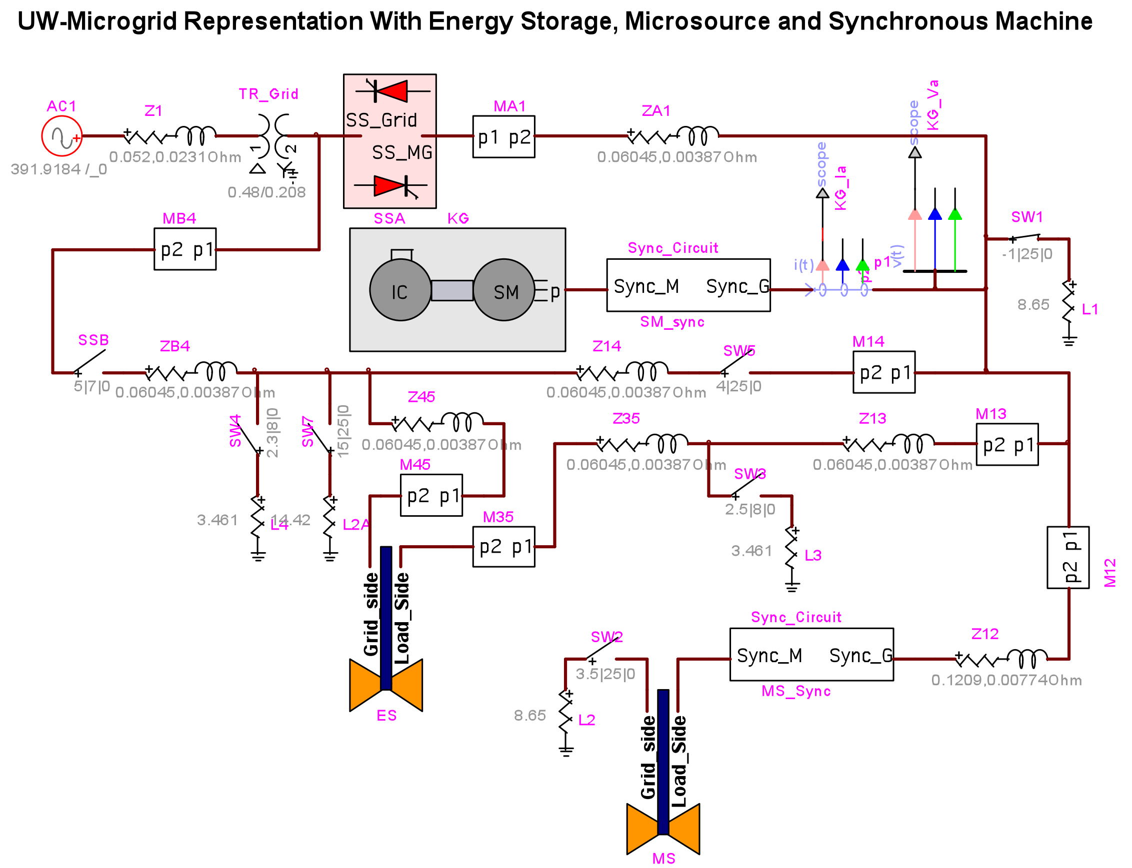

Figure 6.1.1 – EMTP model used for simulation 6-1

This test is the first to illustrate the usage of a meshed microgrid. Preliminary results reveal that the system remains stable when synchronizations function properly. Some synchronization difficulties have been found when attempting to synchronize two networks that are more than 1Hz from each other. This difficulty originates from a polarity check on the difference voltage envelope across the switch which could be easily remedied with further algorithm development or re-dispatching of sources to modify either frequency to within said margin of difference frequencies.

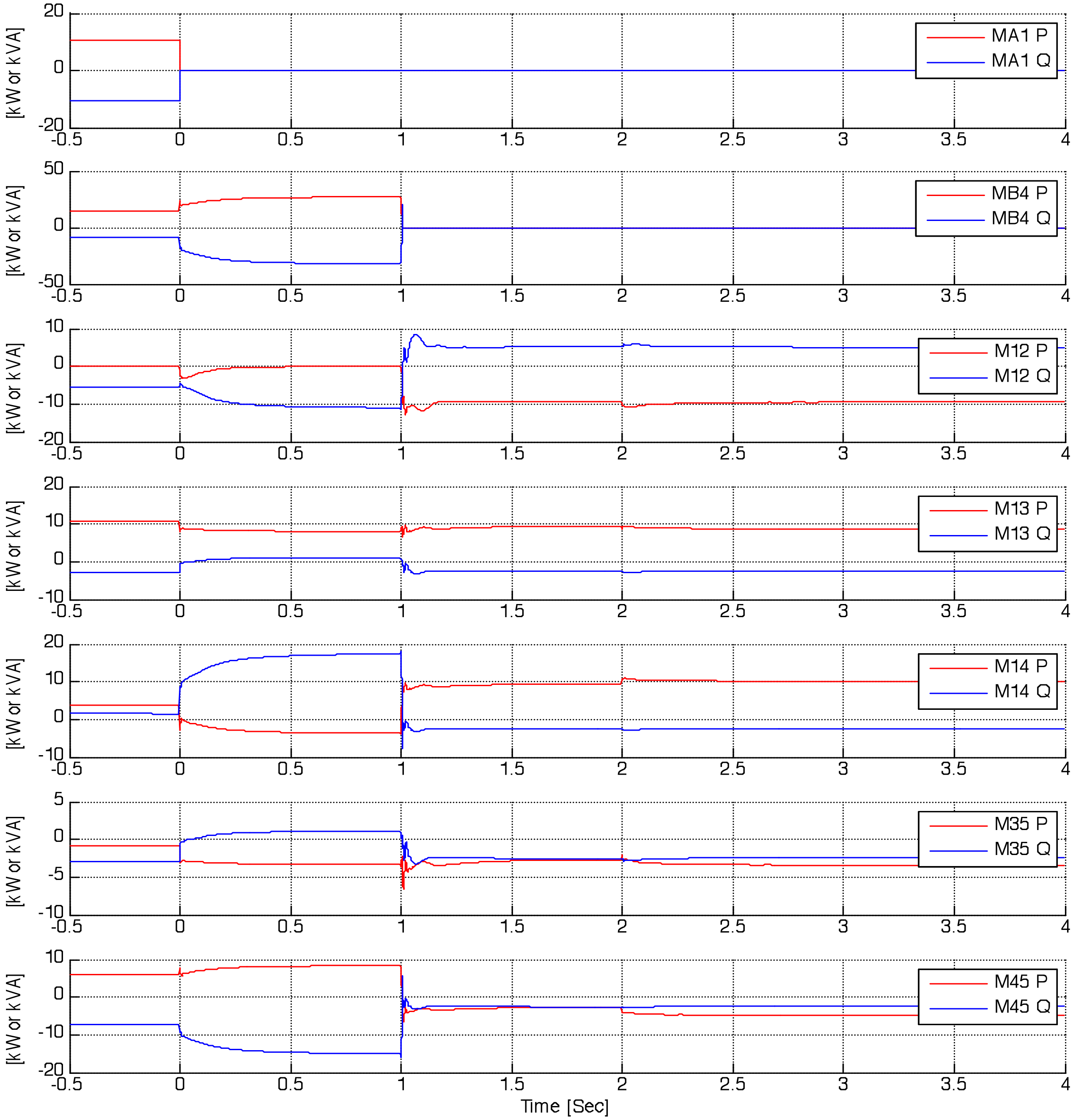

Figure 6.1.2 – Real and reactive power summary for measurement blocks

The figure 6.1.2 presents a summary of all the measurement blocks placed in the mesh network. It can be seen that at t=0sec, that when Static-Switch A opens, that the power flow in the microgrid changes significantly, but establishes steady-state within a second.

When the second Static Switch is opened at t=1sec, there is another large shift in power flow, most notably changes in reactive power at all points on the microgrid. Little net change is seen at t=2sec when a 3kW load is stepped in except on M45 which measures the pathway between the energy storage element and the added load.

It is important to note that both the microsource and the genset are at full load when in island operation.

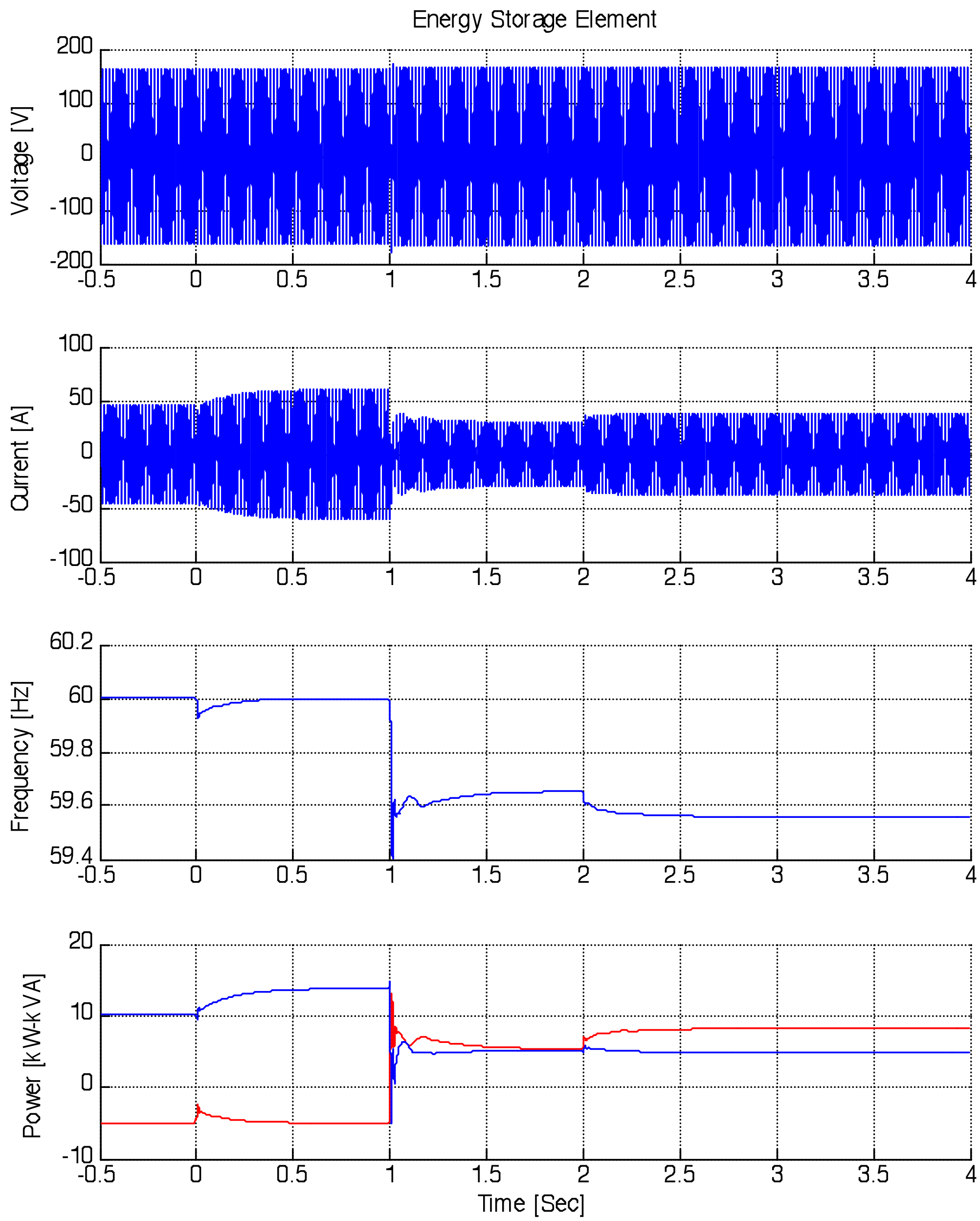

Figure 6.1.3 – Energy Storage Element Power Summary

The most notable features of the Energy storage element power summary are the large amount of reactive power that exists while grid connected and the associated current magnitude. The amount of reactive power increases when one of the static switches opens and increases the impedance to the grid, which is also expected because of the relative amount of power imported from the grid.

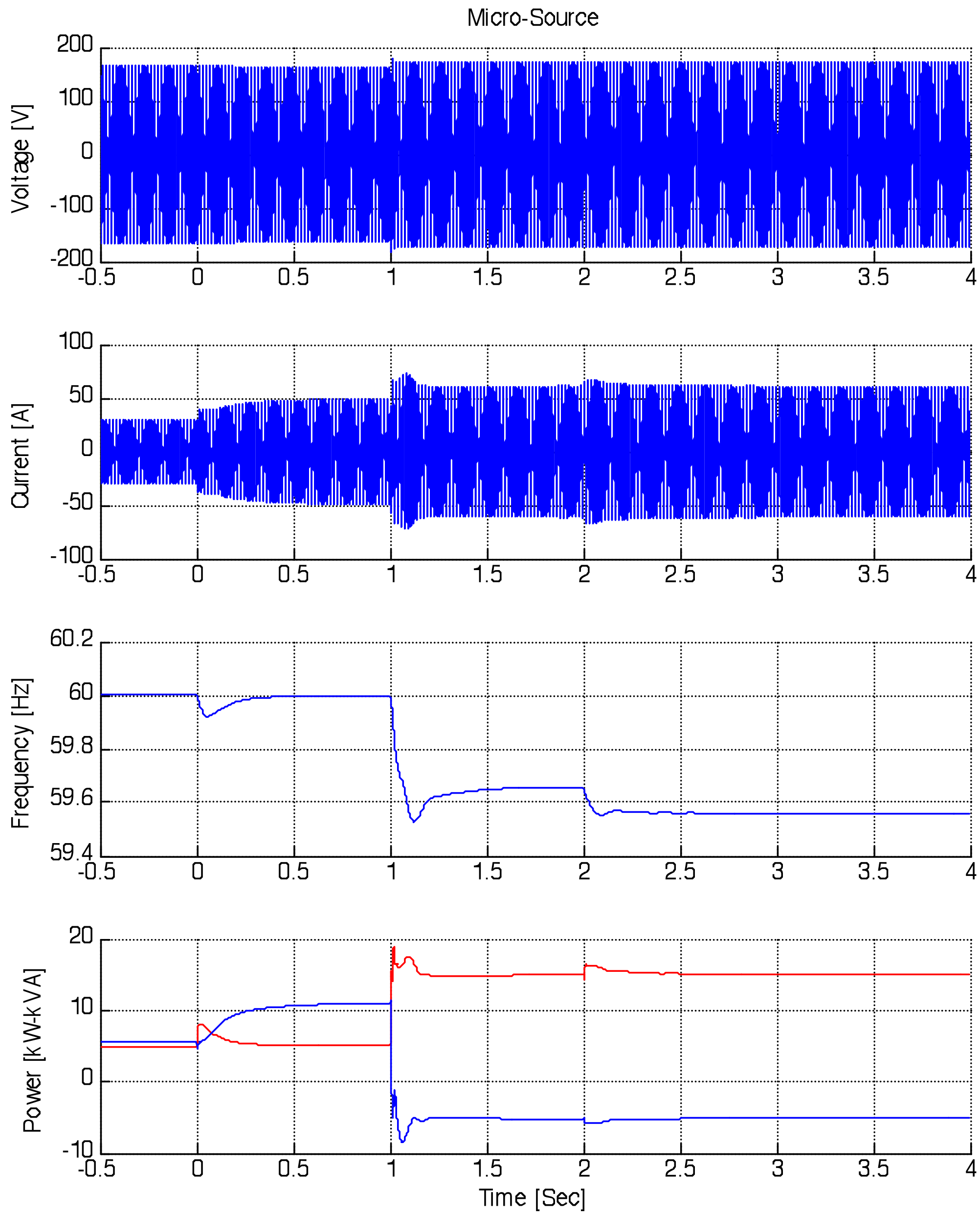

Figure 6.1.4 – Microsource Power Summary

Similar to the energy storage element, the microsource experiences large magnitudes of reactive power. Once islanded, the power flow from the microsource to supply some of the load on bus 4 causes a reactive power imbalance between the microsource and the energy storage element.

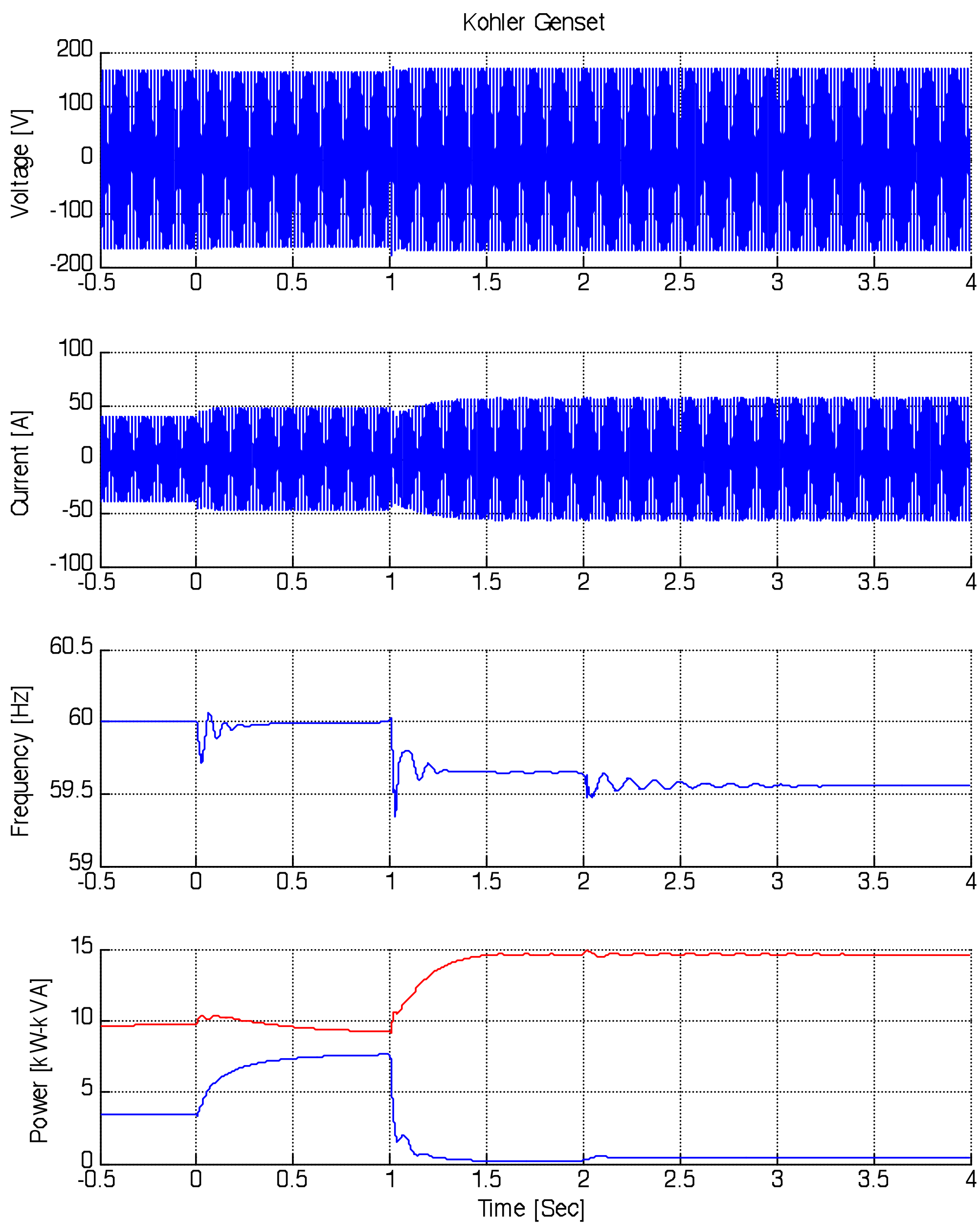

Figure 6.1.5 – Kohler Genset Power Summary

The relatively slow dynamic characteristics of the genset compared to the inverter-based sources define a power deficiency area that is supplied by that is compensated by the energy storage element and the microsource.

Test 6-2: Step load decrease in meshed microgrid
MS: Set to 5kW of 15kW rating
ES: Set to -5kW of 15kW rating
SM: Connected, power set to 0.8pu (10kW@60Hz of 12.5kW rating)
On-Site load set to 35kW
System initially in island operation
Removal of 25kW load at t=0.0sec from B3/4

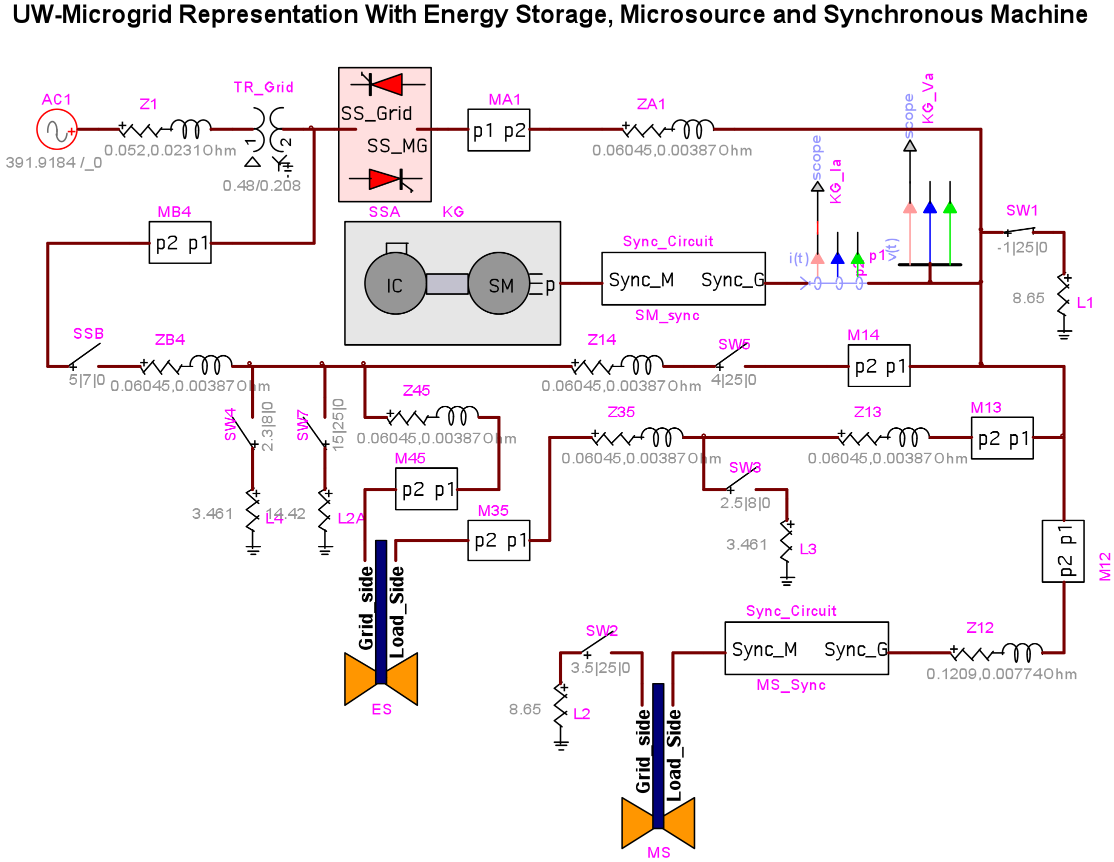

Figure 6.2.1 – EMTP model used for simulation 6-2

This test illustrates dynamic stability of a meshed microgrid during a step decrease in load. The remaining on-site load is 10kW which achieves a frequency of 60Hz as it satisfies the sum of the power set-points of the three sources. Responses to this transient appear to last as long as the genset response which indicates that the interconnecting system does not significantly contribute to decreased dampening or instabilities.

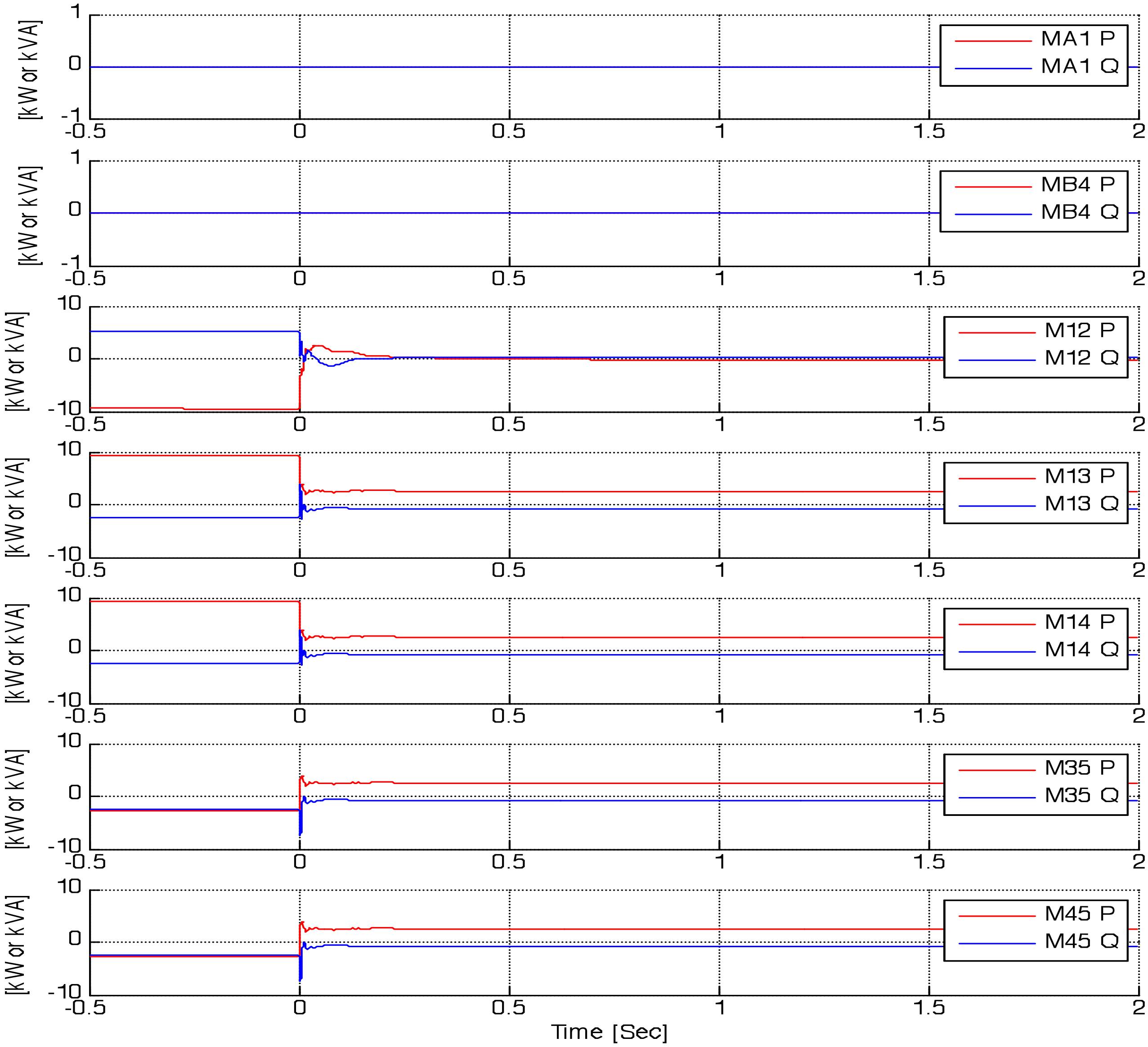

Figure 6.2.2 – Real and reactive power summary for measurement blocks

The figure 6.2.2 presents a summary of all the measurement blocks placed in the mesh network. It can be seen that at t=0sec, that when the load is removed, that the power flow in the microgrid changes significantly, but establishes steady-state within half a second.

Figure 6.2.3 – Energy Storage Element Power Summary

The energy storage element displays a quick response to the change in system load and does not exhibit a compensation or deficiency power region. This is somewhat expected as the loads removed were relatively close to the energy storage element on B5.

Figure 6.2.4 – Microsource Power Summary

The microsource exhibits the most interesting response as it shows some negative deficiency power characteristic at t=0.0sec that compensates for the injection of power from the genset that was not consumed by the load. Although the microsource has twice the cable length to the genset as from the genset to the removed load, the slow dynamic response of the genset (approximately half a second) is a significantly longer time than the settling time for 100yards of cable (0.121Ohms resistive, 0.00775Ohms reactive). This leads to a familiar condition with the faster reacting source compensating for the slower one.

Figure 6.2.5 – Kohler Genset Power Summary

The relatively slow dynamic characteristics of the genset compared to the inverter-based sources define a power deficiency area that is supplied by that is compensated by the microsource. What is not clear from this upper level analysis is why the energy storage element remained largely unaffected by the transient.

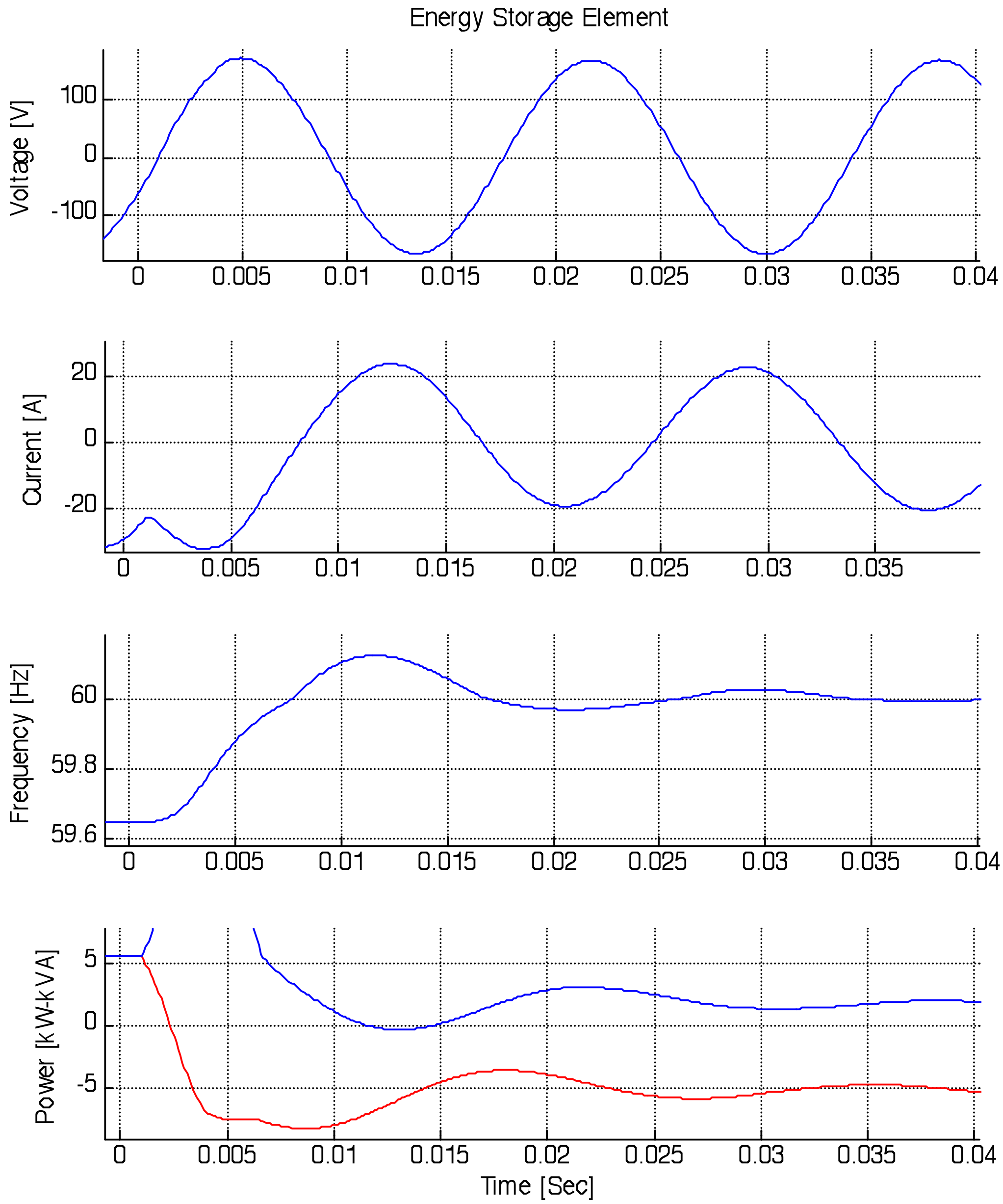

Figure 6.2.6 – Energy Storage Element Transient Power Summary

Upon closer inspection of the transient power characteristic in the energy storage element, it can be seen that the quick reversal of power due to the removal of the loads caused a quick change in frequency when compared to the microsource which took approximately 5 times as long to reach 60Hz. Assuming similar characteristics from the inverter-based sources, the difference is indeed due to line impedance causing the synchronous machine deficiency to be shouldered by the microsource alone. However, it should be mentioned that in the event that the microsource was beyond its power limits, some of the power deficiency would have been complemented by the energy storage unit.

Test 6-3: Meshed microgrid transition to radial grid
MS: Set to 5kW of 15kW rating
ES: Set to -5kW of 15kW rating
SM: Connected, power set to 0.8pu (10kW@60Hz of 12.5kW rating)
On-Site load set to 35kW
System initially in island operation
Switch SW5 between B1 and B4 opens to cause radial power flow at t=0sec

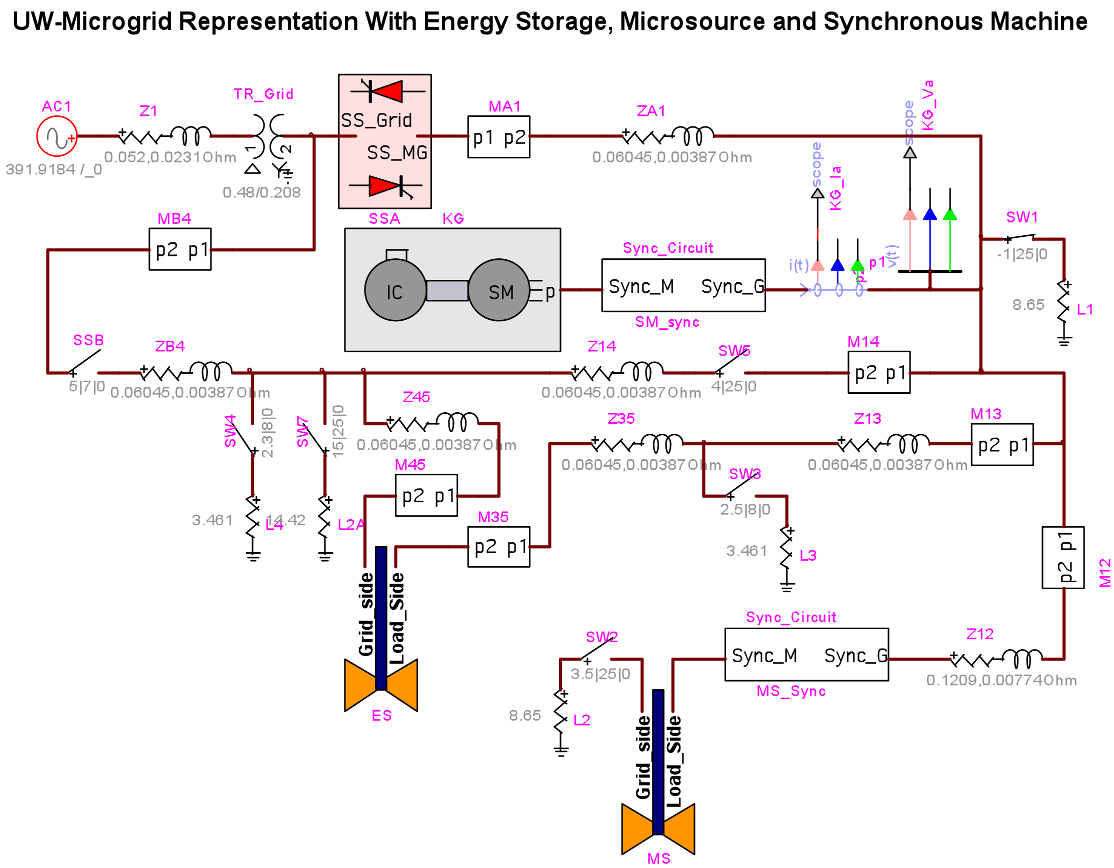

Figure 6.3.1 – EMTP model used for simulation 6-3

This test illustrates dynamic stability of a meshed microgrid during a transition to a radial orientation. The main result of this test was that the reactive power establishes a different steady state value as a result of real power being transferred across line impedances different than had existed previously. The real power is only affected slightly as an additional transmission loss component.

Further tests have revealed that this process is reversible with similar effects.

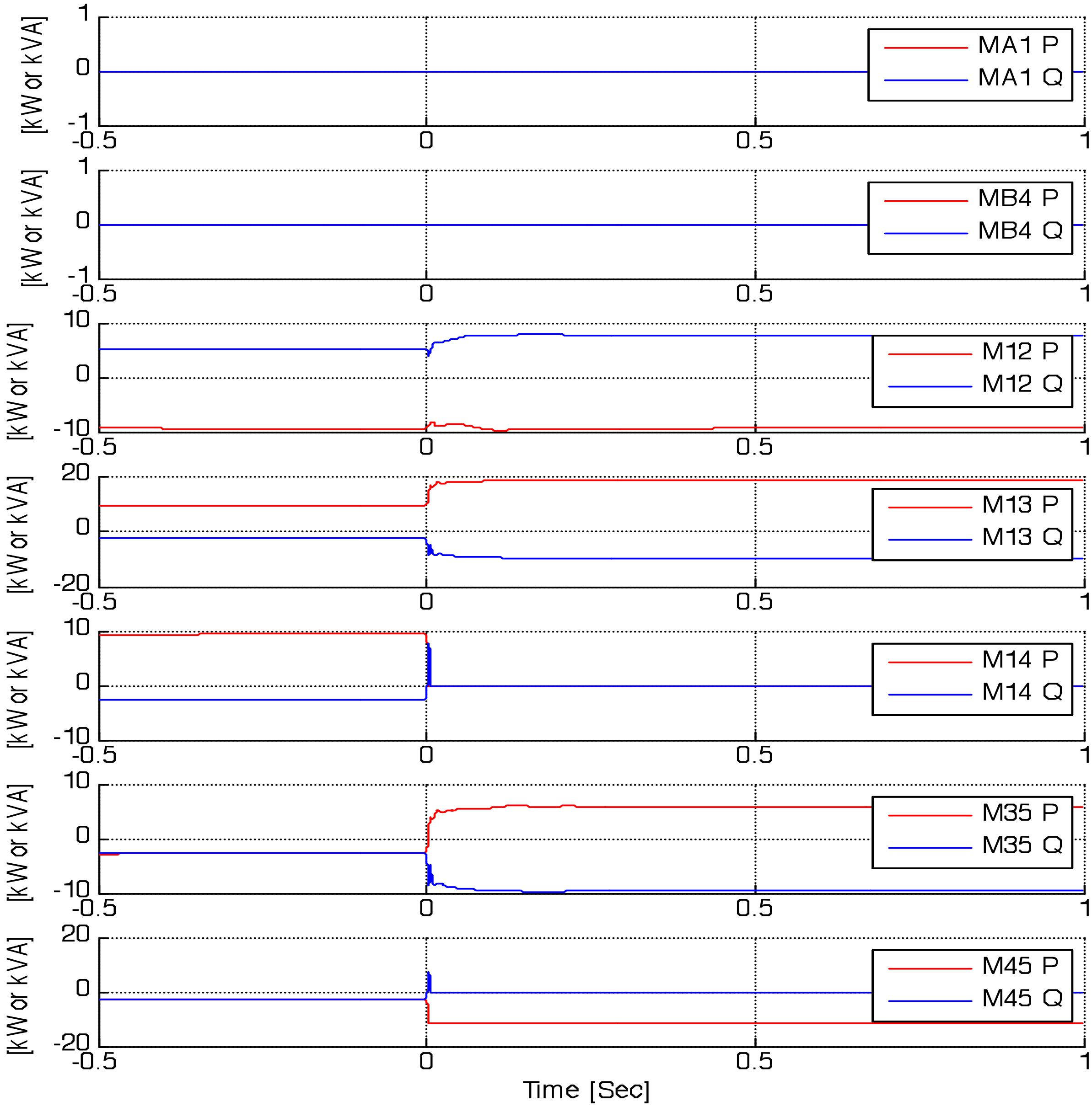

Figure 6.3.2 – Real and reactive power summary for measurement blocks

The figure 6.3.2 presents a summary of all the measurement blocks placed in the mesh network. It can be seen that at t=0sec when the redundant power path is removed that reactive power increases in all of the remaining branches except for a small decrease in the M45 branch.

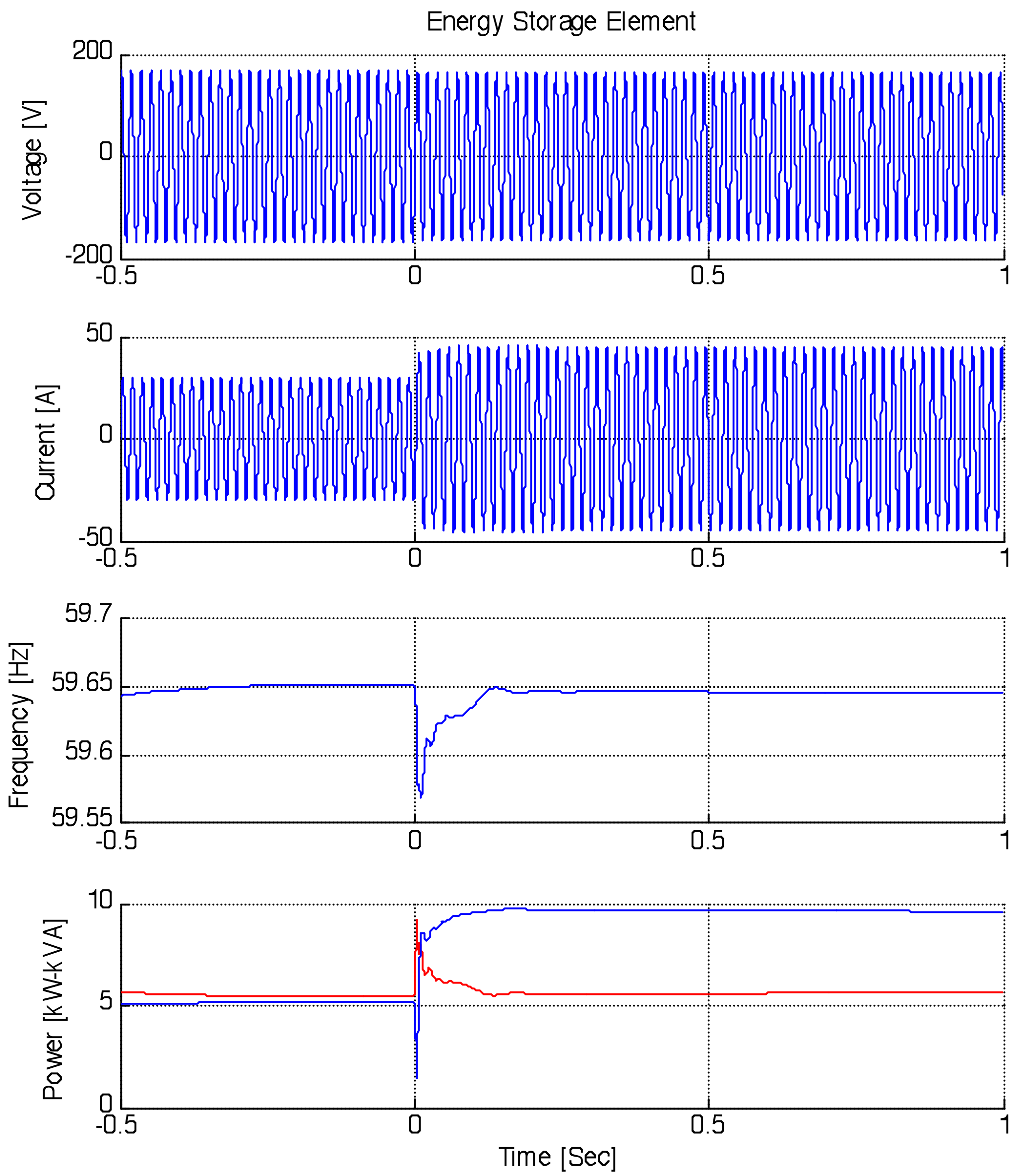

Figure 6.3.3 – Energy Storage Element Power Summary

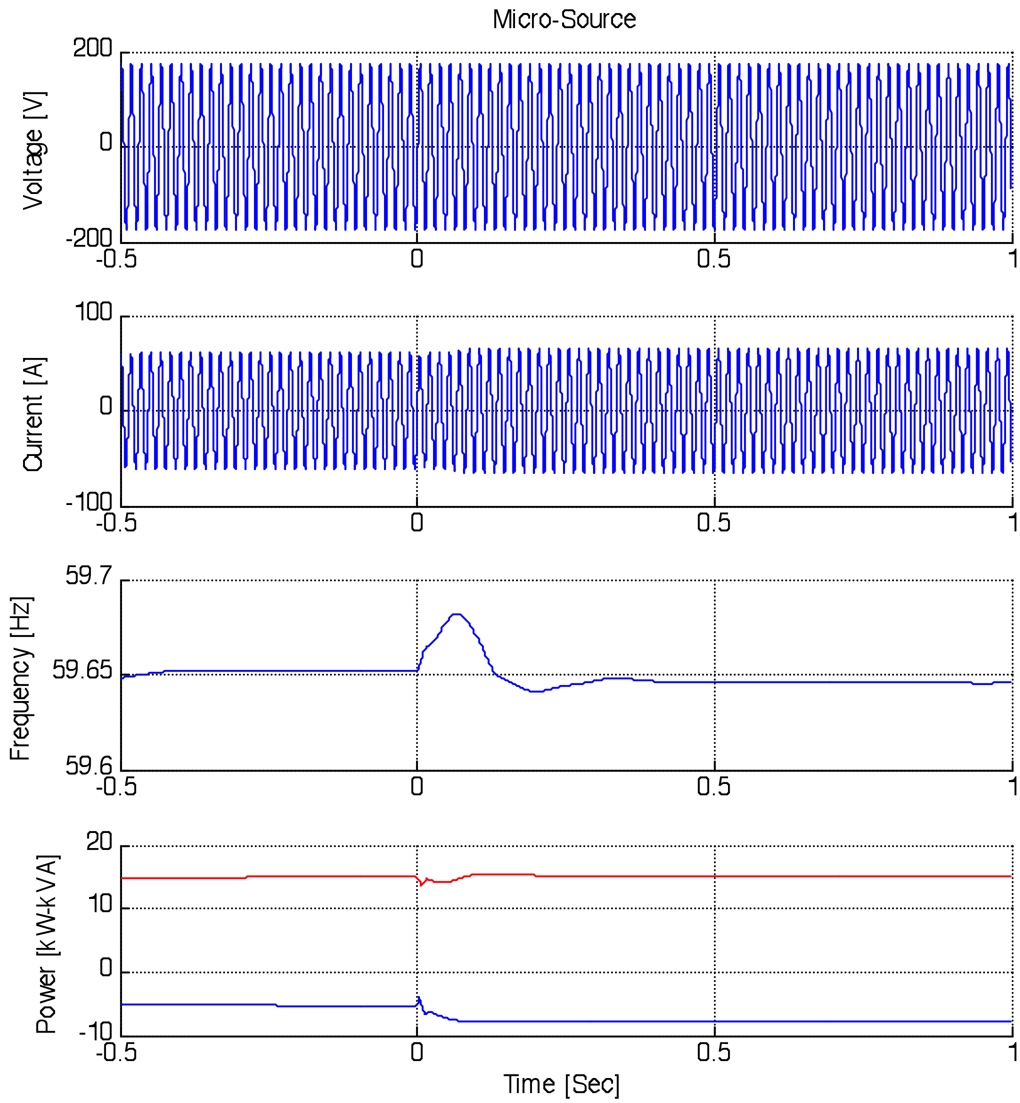

Figure 6.3.4 – Microsource Power Summary

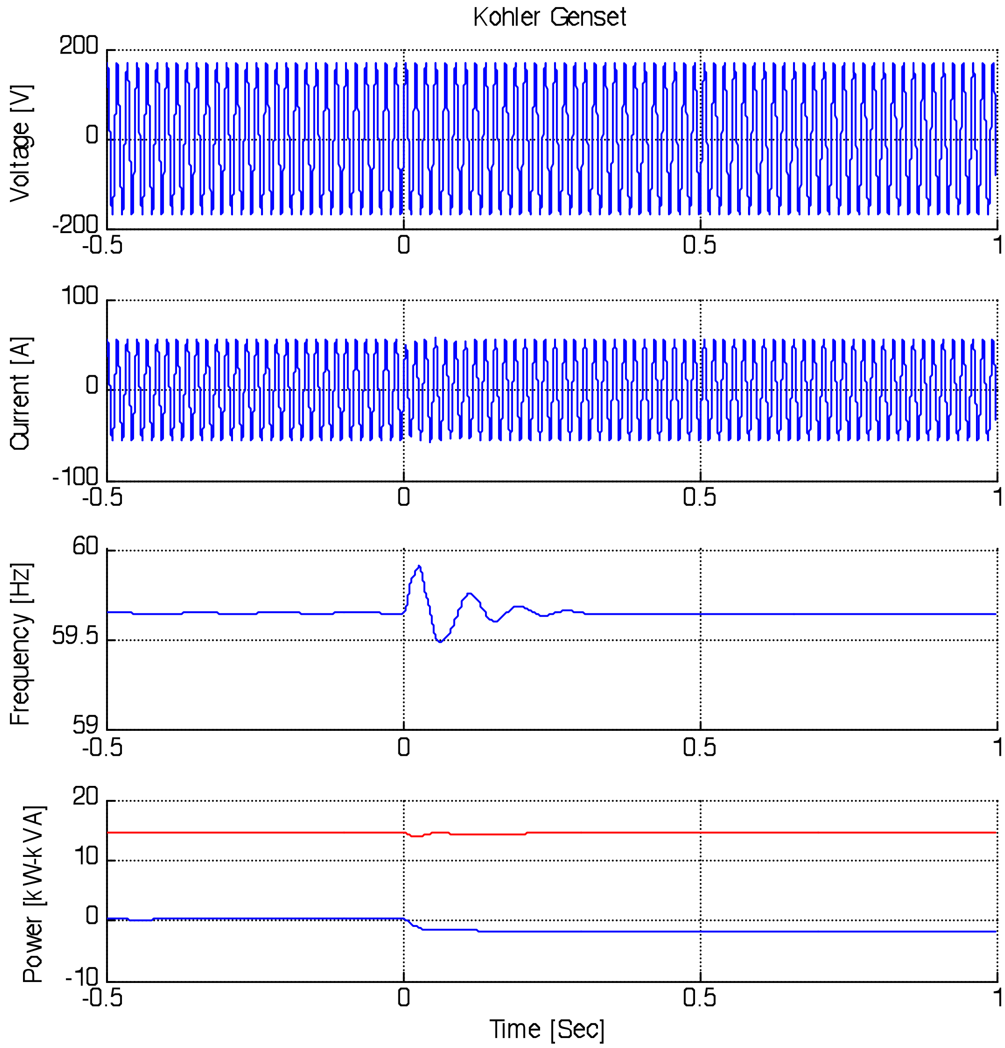

Figure 6.3.5 – Kohler Genset Power Summary

Test 6-4: Non-Essential load shedding under overloading due to loss of microsource
MS: Set to 5kW of 15kW rating
ES: Set to -5kW of 15kW rating
SM: Connected, power set to 0.8pu (10kW@60Hz of 12.5kW rating)
On-Site load set to 35kW
System initially in island operation
- Switch SW8 at genset connection opens, simulating loss of source at t=0sec.
- L4 (12.5kW) is disconnected by NEL when overloaded system droops frequency<59Hz at t=0.2sec.
- Nominally loaded system recovers (22.5kW on-site load, 30kW generation capacity) at t=1sec.

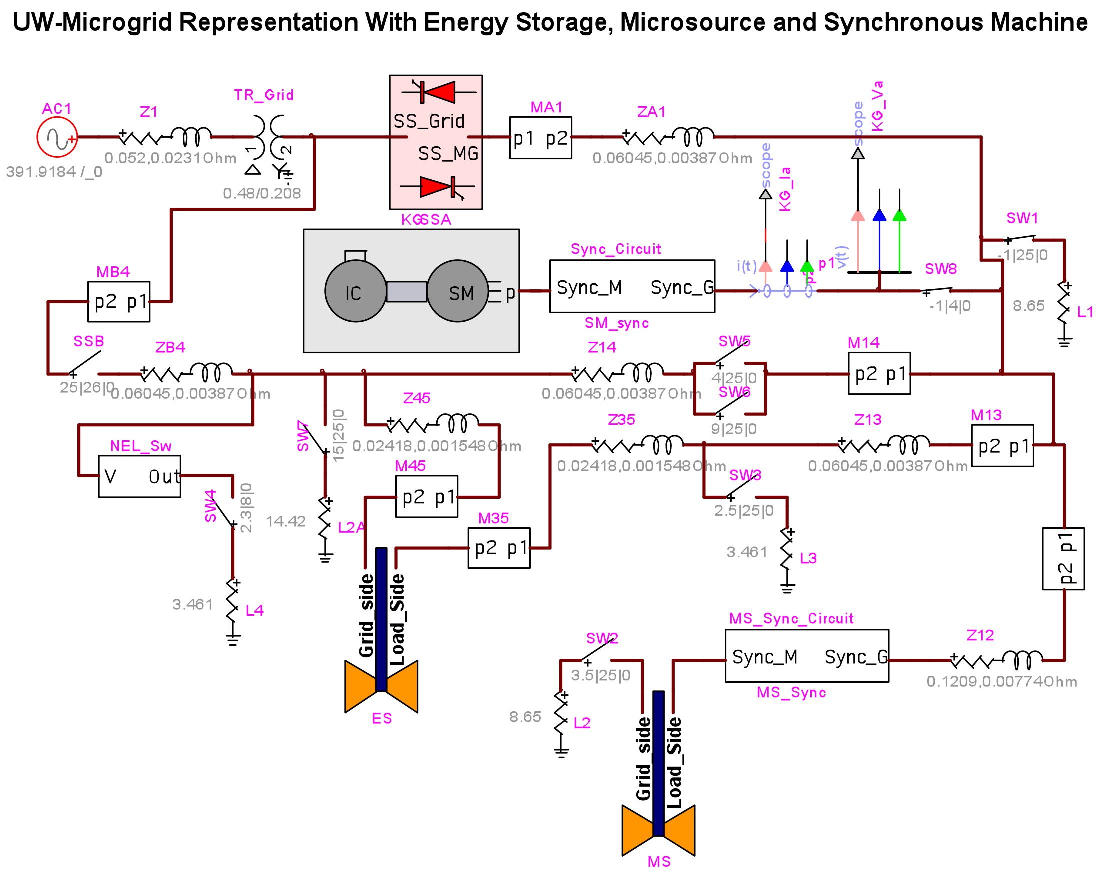

Figure 6.4.1 – EMTP model used for simulation 6-4

This test illustrates the response of an islanded mesh grid in a temporarily overloaded state. With the Non-Essential Load (NEL) switch in use, a 12.5kW load was shed from the system when the system frequency reached less than 59Hz. In this case, said condition came just over 200ms after the loss of one of the sources. As can be seen in the following figures within this test, the voltage magnitude remains relatively constant, discernable by only small variations in reactive power beyond that required of the microgrid. Nominal operating frequency is then restored within a second of the start of test.

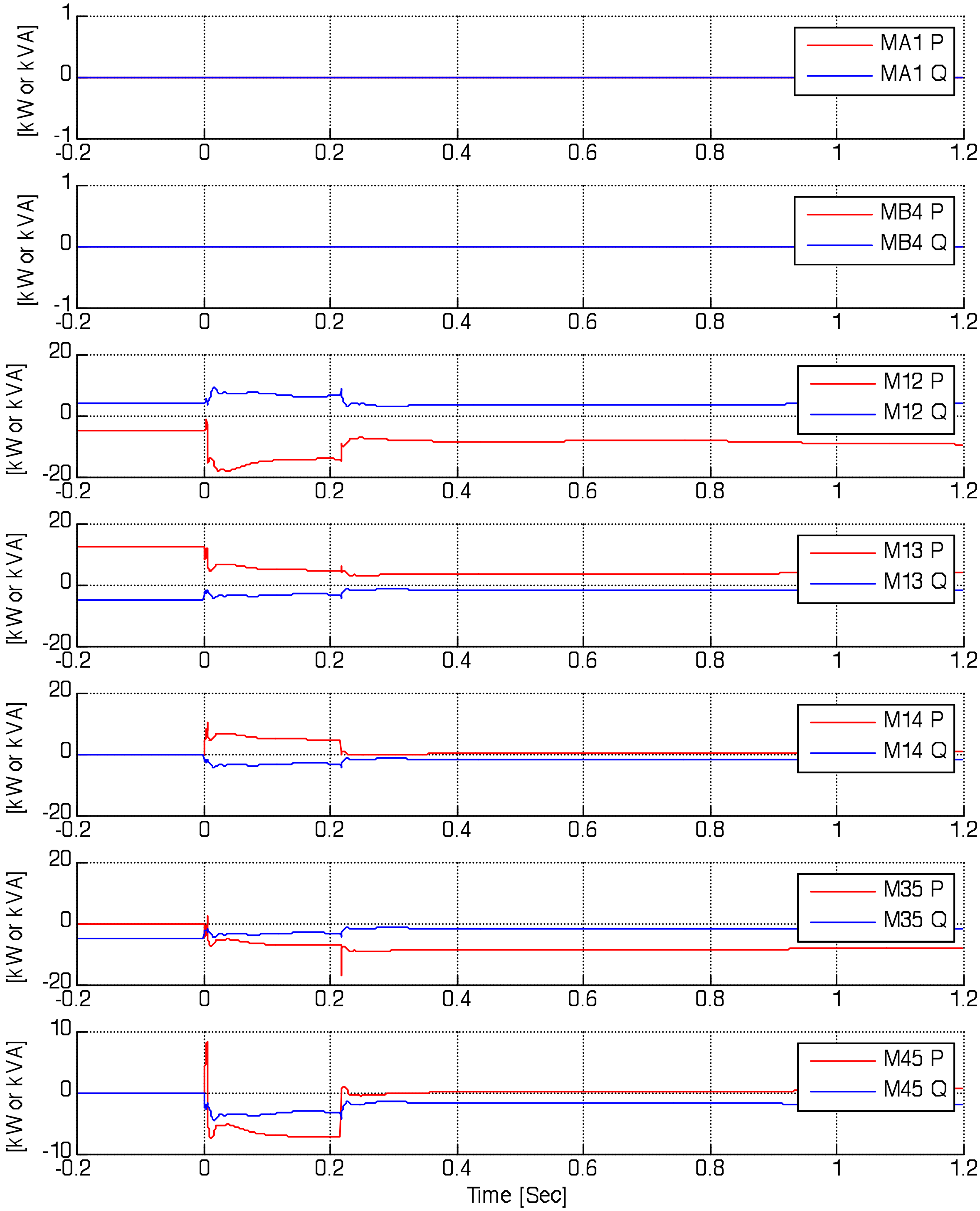

Figure 6.4.2 – Real and reactive power summary for measurement blocks

The figure 6.4.2 presents a summary of all the measurement blocks placed in the mesh network. At t=0sec when the genset is taken offline, power flow increases from the remaining sources to the loads and achieve steady state values just prior to the load shedding at t=0.2sec. A similar type of transient is visible after the load shedding.

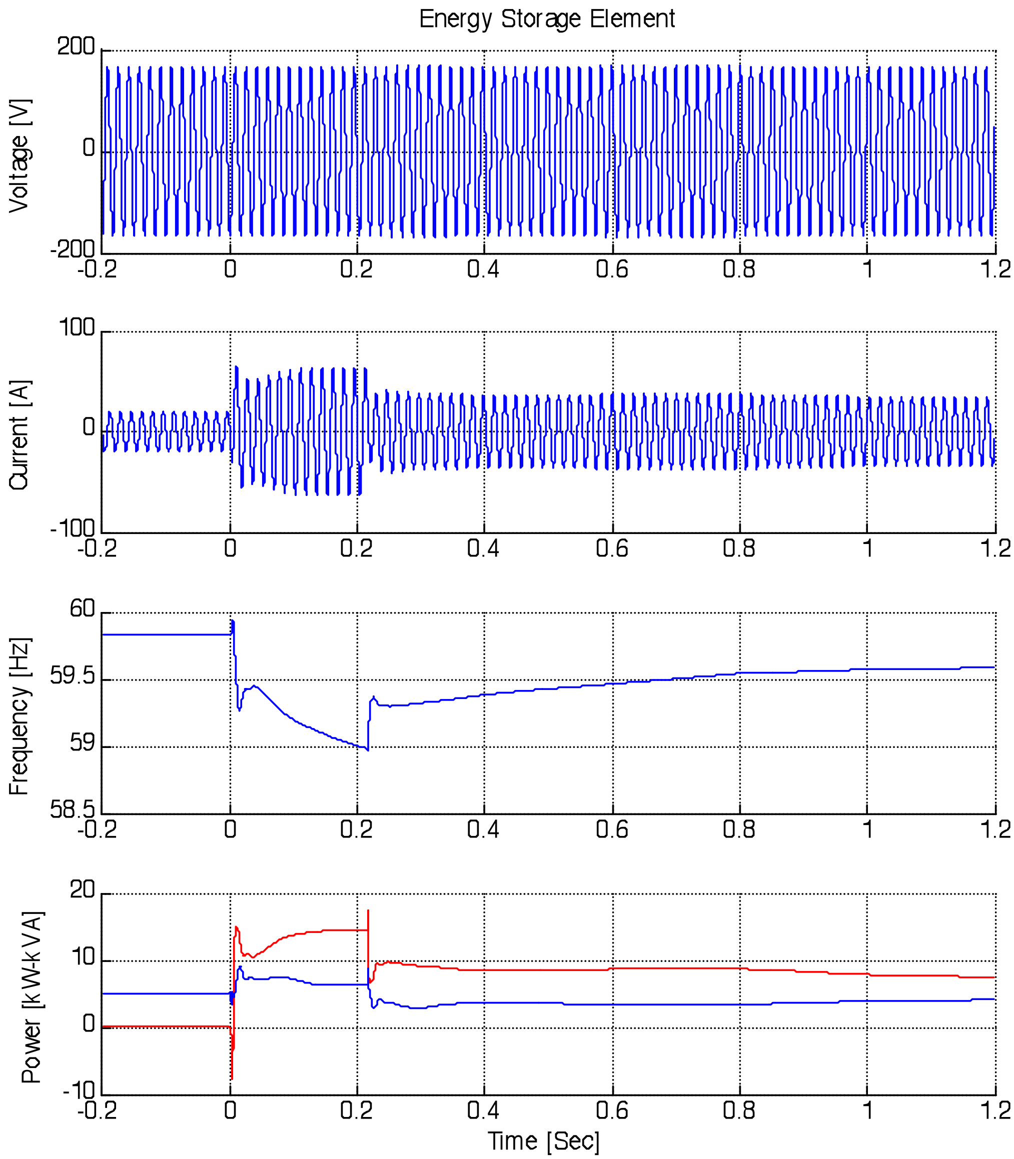

Figure 6.4.3 – Energy Storage Element Power Summary

The energy storage element displays a variation in power delivered after the t=0sec transient, but shows an ordered response once the system settles at approximately 50ms after the transient. The overloaded steady-state power of 15kW (P_Max = 11.25kW for this test) causes a consistent decrease in frequency until 59Hz is reached.

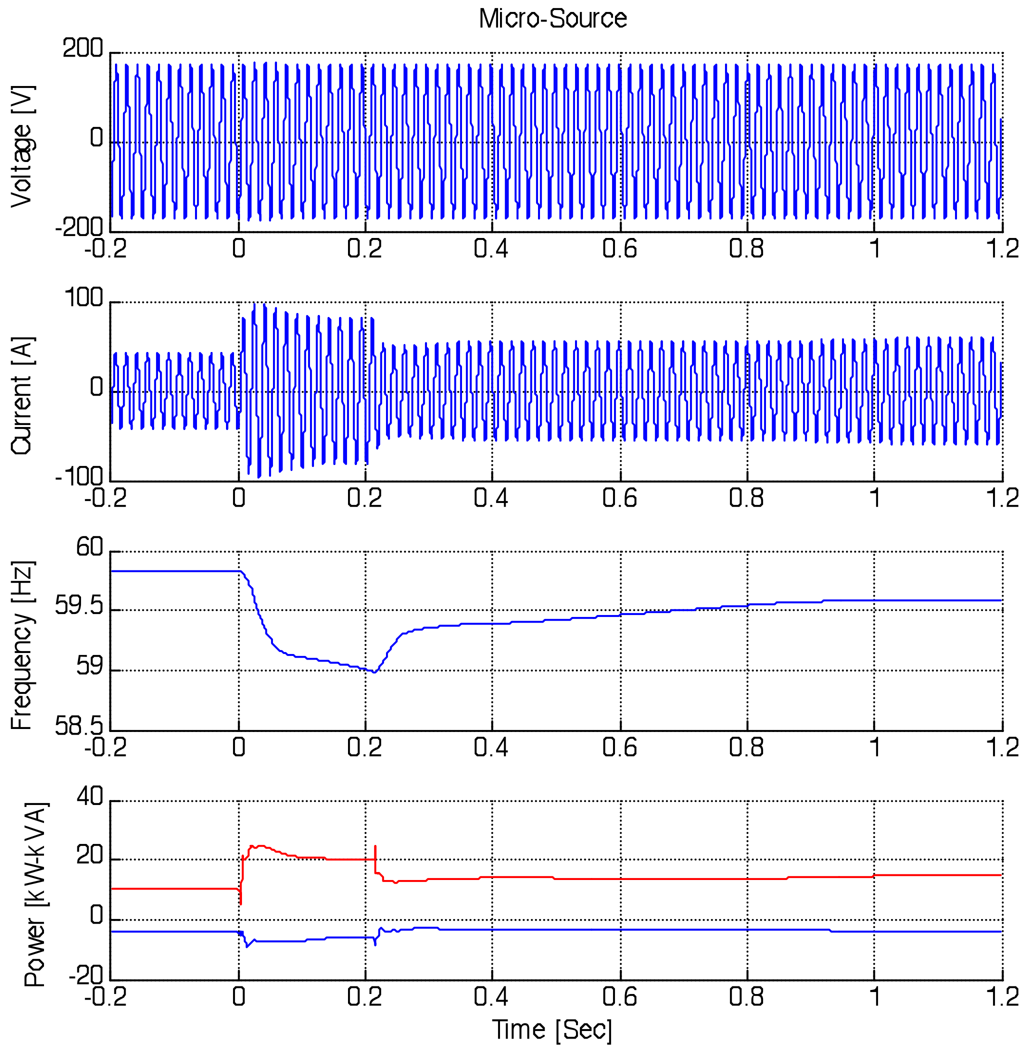

Figure 6.4.4 – Microsource Power Summary

The microsource displays a similar characteristic to the energy storage element, taking on 33% overloading during the first 200ms of the test. The recovery is ordered and relatively swift, achieving nominal frequency in less than one second.

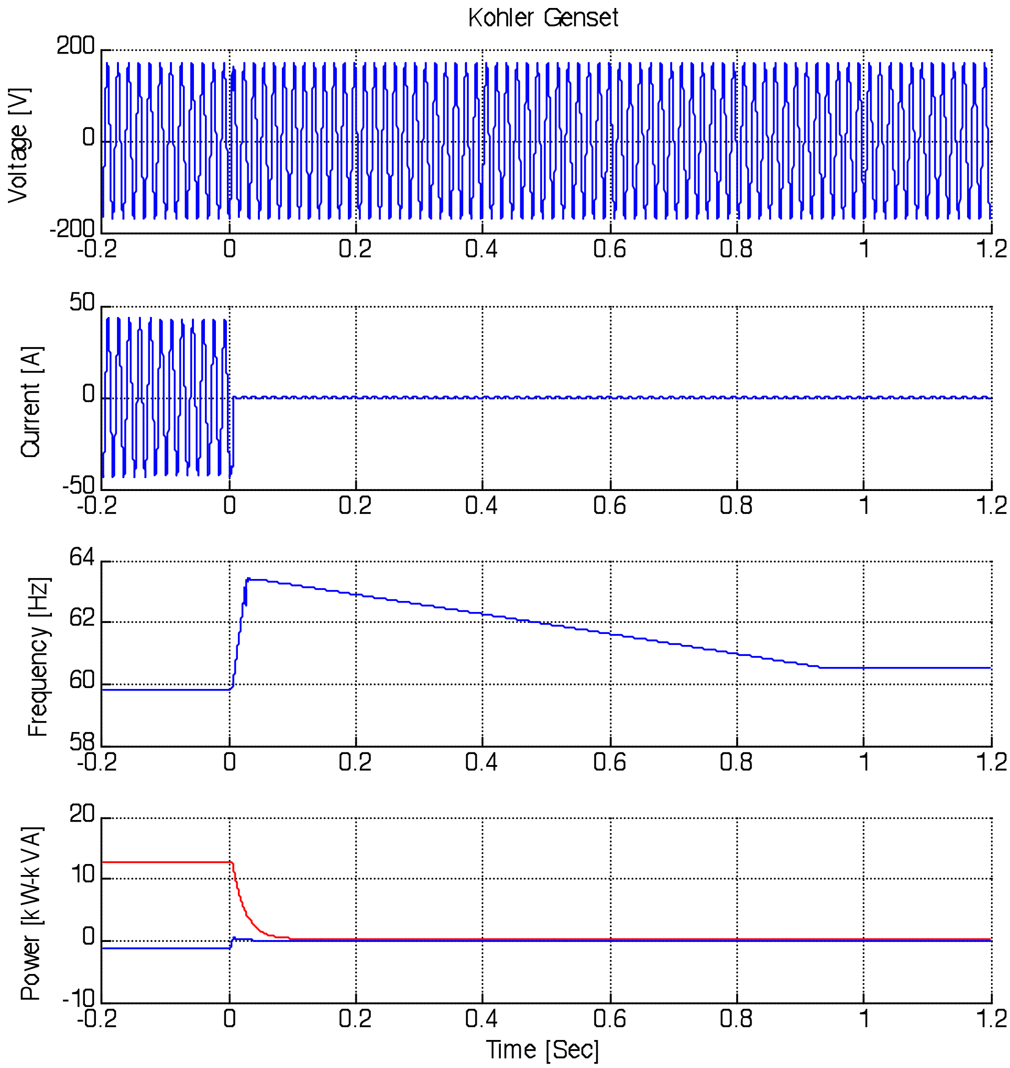

Figure 6.4.5 – Kohler Genset Power Summary

It can be seen that the power from the genset is removed at t=0sec.