islanding occurs at 1.0s in this simulation. The magnitude ratio of the 2nd order harmonic voltage to the fundamental voltage maintains at 0% under the voltage unbalance. However, when the islanding occurs, the magnitude ratio rises and reaches 0.2%. So, the proposed scheme provides an accurate and fast islanding detection under the unbalanced grid voltage.

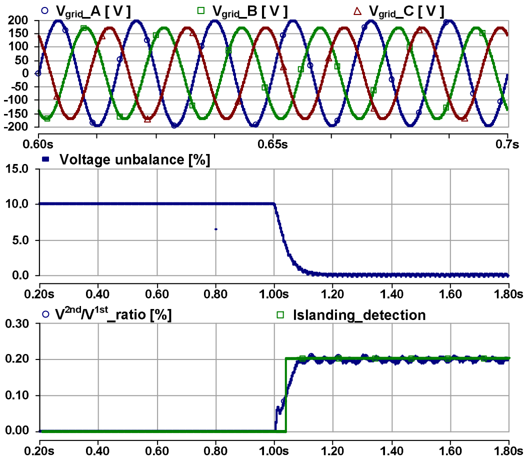

Fig. 8 Analysis under Unbalanced Grid Voltage

C. Islanding detection under unbalanced load

In this case study, all conditions comply with the UL1741 test condition except that the load resistance is not balanced. Simulation was performed to evaluate the islanding detection accuracy and the detection sensitivity due to the load unbalance. It is assumed that the load in phase-A is changed with a step variation of ±10% between 0.2s and 1.8s.

Fig. 9 shows the load current, the magnitude ratio of the 2nd order harmonic voltage to the fundamental voltage, and the islanding detection signal. Balanced three-phase load is operated between 0.2s and 0.5s.

Unbalanced three-phase load reduced Phase-A load by 10% is operated between 0.5s and 0.75s. Unbalanced three-phase load increased Phase-A load by 10% is operated between 0.75s and 1.0s.

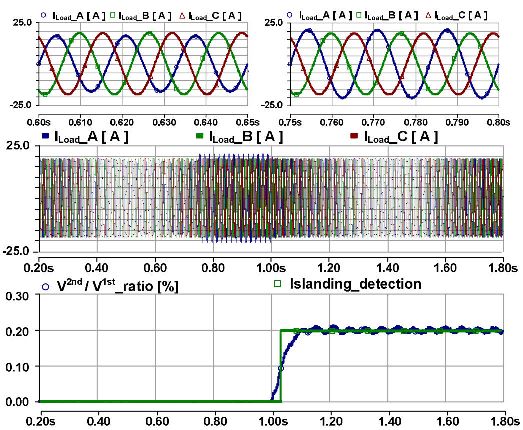

Fig. 9 Analysis under Unbalanced Load

The magnitude ratio of the 2nd order harmonic voltage to the fundamental voltage maintains at 0% in spite of the load unbalance and the step variation. However, the voltage magnitude ratio rises and reaches 0.2% when islanding occurs at 1.0s. So, the voltage magnitude ratio can be used as a stable detection signal for islanding.

5. Hardware Experiments

Fig. 10 shows a hardware test set-up to verify the proposed islanding detection experimentally. The entire system was configured using a 5kWh lithium-polymer battery, a 5kVA Inverter, a main controller, an RLC load, and a 5kVA power transformer. To verify the validity of the simulations, all conditions for the experiment were set identically to those set forth in Table 1.

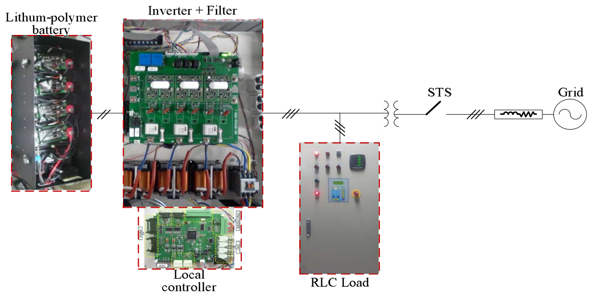

Fig. 10 Experimental Setup for Islanding Detection

Fig. 11 shows experimental results for islanding detection when the grid voltage is balanced. From the top, the figures show the variations of system frequency, the instantaneous grid current, voltage ratio, and islanding detection signal. Before the occurrence of islanding at 1.0s, small amounts of current flow into the grid because the power consumption of the load and the amount of power supplied by the BESS are the same. As the results in the simulation, frequency variation cannot be used for islanding detection because the frequency variation is negligible.

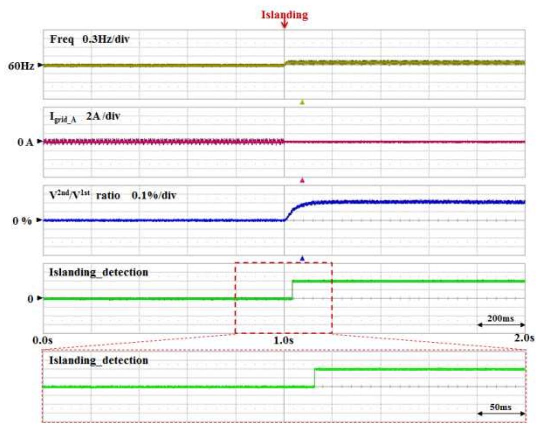

Fig. 11 Test Result under UL1741 Test Conditions

However, since the 2nd order harmonic current of 0.8% magnitude is injected after the occurrence of islanding, the grid is blocked and the level of 2nd order harmonic voltage measured at the PCC rises simultaneously. However, the voltage magnitude ratio rises slowly and reaches 0.2%. So, this value can be utilized to detect the islanding state.

Fig. 12 shows experimental results for islanding detection when the grid voltage is unbalanced. The unbalanced ratio was set 10% same as in the simulation. The voltage ratio of the 2nd order harmonic voltage to the

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fundamental voltage does not increase before 1.0s. However, once the islanding occurs, the 2nd order harmonic voltage at the PCC appears due to the injected 2nd order harmonic current. So, the voltage ratio of the 2nd order harmonic voltage to the fundamental voltage increases rapidly. The proposed method can effectively detect the islanding state under the unbalanced grid voltage.

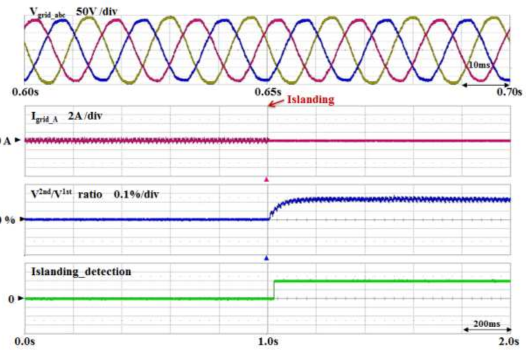

Fig. 12 Test Result under Unbalanced Grid Voltage

Fig. 13 shows experimental results for islanding detection when the load is unbalanced. The unbalanced ratio was set same as in the simulation. From 0.2s to 0.6s the load in one phase was increased by 10% of the rated power, and from 0.6s to 2.0s the load in one phase was decreased by 10% of the rated power. The voltage ratio of the 2nd order harmonic voltage to the fundamental voltage under the load unbalance is maintained at 0% before the islanding occurs. After islanding occurs at 1.0s, the voltage ratio increases proportional to the magnitude of injected 2nd order harmonic current. The proposed method can effectively detect the islanding state under the unbalanced load voltage.

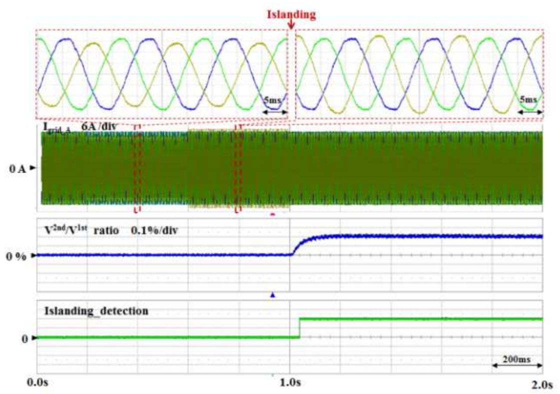

Fig. 13 Test Result under Unbalanced Load

5. Conclusion

This paper proposes a new islanding detection method by measuring the magnitude ratio of the 2nd order harmonic voltage to the fundamental voltage at the PCC after injecting 0.8% of the 2nd order harmonic current.

In order to measure the 2nd order harmonic voltage and the fundamental voltage, proportional resonant (PR) controller and PR filter were adopted. The proposed method was verified through simulations with PSCAD/EMTDC.

The proposed method can offer the islanding detection time within 25ms that is much faster than the international standard of 2.0s.

Acknowledgement

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