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Technical Report TA User Project

ARTUPS

Adaptive reclosing technique for providing uninterrupted power supply to microgrid system

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Abbreviations

ARTUPS	Adaptive Reclosing Technique for providing Uninterrupted Power Supply
BESS	Battery Energy Storage System
CB	Circuit Breaker
DER	Distributed Energy Resource
DG	Distributed Generation
DSM	Demand Side Management
KEPCO	Korea Electric Power Corporation
PCC	Point of Common Coupling
PV	Photovoltaic system
SLG	Single Line-to-Ground
SOT	Second Order THD
TA	Trans-national Access
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply

Executive Summary

This document is the technical report on the ERIGrid TA project ***ARTUPS***. The report describes the objectives, experiments, and comprises the obtained simulation results and conclusions derived from the experiments.

Main motivation of the research is the detection of faults and their classification based on the superimposed component-based technique, to overcome the drawbacks of conventional reclosing techniques. The method is tested for different fault types, fault positions and various switching events like active and reactive load and capacitor switching operations. The real-time monitoring of the test signals for voltage and current allows the identification of faulty section and its isolation from the healthy part. An abrupt increase in second order harmonic current values for faulty phase and healthy phase clearly indicates the fault clearance time.

The adaptive reclosing operation proposed by ARTUPS has been validated offline with a reduction of the outage time and improvement of reliability. ARTUPS is effective and accurate in detection of faults and faults classification, and the algorithm accurately verifies the fault clearance detection and synchronism check process using frequency and phase angle.

ARTUPS operation is found to be accurate during various switching operation and different system configuration including islanding as well as grid connected modes. Further improvement is needed in ARTUPS algorithm to increase its speed of operation of circuit breaker to reduce the transients occurring due to single pole operation.

1 General Information of the User Project

USER PROJECT PROPOSAL	
User Project title	Adaptive reclosing technique for providing uninterrupted power supply to microgrid system
User Project acronym	ARTUPS
Host infrastructure	Smart Grids Technologies Laboratory (SGTL) – TECNALIA, Spain
Name of the ACCESS PROVIDER representative	Emilio Rodríguez
Access period	14/06/2019 - 07/07/2019
N° of Access Days	15
Name of the User Group Leader	Ms. Ruchi Chandrakar (NIT Raipur, India)
User group members	Ms. Ruchi Chandrakar (NIT Raipur, India) Prof. Nand Kishor (MNNIT Allahabad, India)

2 Research Motivation

The conventional reclosing adopts a fixed dead time, irrespective of fault type whether a fault is temporary or permanent in nature [1]. The drawback of conventional reclosing technique is having a large dead time despite fault clearance before reclosing [2]-[4]. If the hybrid Distributed Generation-Battery Energy Storage System (DG-BESS) is connected under fault conditions and supplies power to a healthy phase, the outage time will be significantly reduced, and thus it will improve the reliability of the power supply. The BESS can also be used for frequency regulation and peak load shaving.

The conventional reclosing technique experiences a problem of synchronism in the distribution network because the BESS will not be disconnected from the distribution system even under fault conditions and will maintain the power supply to a healthy phase. Conventional reclosing schemes do not consider a synchronism problem between the utility and the BESS when reclosing is attempted. Due to the existence of both sources at the sending and receiving ends, the synchronism problem including voltage, phase angle, and frequency must be considered. Hence, proposed adaptive reclosing technique can be used to overcome this problem of synchronism, as the BESS and loads are completely dis-connected from the grid system. Thus, they can form a small micro-grid if voltage and frequency are maintained within steady state limit.

This study proposes a new adaptive reclosing technique for microgrid system, so that uninterrupted power supply can be provided to end users. In a hybrid micro-grid system with BESS the power interruption can be avoided. With the one-set of fault in any line, the proposed detector first identifies the faulty section and isolate it from the whole system. During the isolation process, the BESS system provides supply to the rest of the loads connected to the system. In the existing methods, during fault conventional reclosing schemes do not consider a synchronism problem between the utility and the BESS when reclosing is attempted. Due to the existence of both sources at the sending and receiving ends, a reclosing in distribution systems with BESS is very similar to reclosing in a transmission line, and thus the synchronism problem including voltage, phase angle, and frequency must be considered.

The proposed algorithm performs an adaptive reclosing after the fault occurrence. The fault clearance is judged using the THD value which is suddenly increased at the fault clearance instants. The detection of the fault clearance is obviously possible regardless of the fault types. When the SLG faults have occurred, the detection of the fault clearance using Second order THD value should be confirmed at the faulted phase. Similarly, when two-phase or the three-phase faults have occurred, the detection of the fault clearance using the Second order THD should be confirmed at the faulted phases.

In this work, the main motivation of the research stands on the detection of fault and fault classification which stands on the positive superimposed component-based technique. Positive superimposed component-based technique for directional relaying algorithm is proposed for microgrid protection integrated with hybrid DG-BESS. This project proposes a new directional relaying algorithm that considers the BESS in a distribution system. The proposed technique focuses on operation of the BESS as an uninterruptible power supply (UPS). In the proposed approach superimposed detector is used to identify the faulty event in microgrid system. Based on the obtained decision from the detectors, the final decision will be declared by the proposed algorithm to detect the faulty part from rest of the microgrid. The fault classification is based on the logic diagram which considers the angular difference between positive and negative sequence component of fault current. The method is tested for different fault types, fault positions and different configuration of microgrid including both islanded as well as grid connected mode. The proposed algorithm is also tested for various switching events like load switching of active as well as reactive power load and capacitor switching operation. The method is also verified for high resistance fault. The adaptive reclosing algorithm is run in *MatLab* software, with measured test signals obtained from real time simulator OPAL-RT. Results prove the efficacy of the proposed method.

2.1 Objectives

The objectives of the research are:

1. To overcome the drawback of conventional reclosing technique having large dead time despite fault clearance by using hybrid DG-BESS system to reduce the outage time and improve the reliability of power supply.

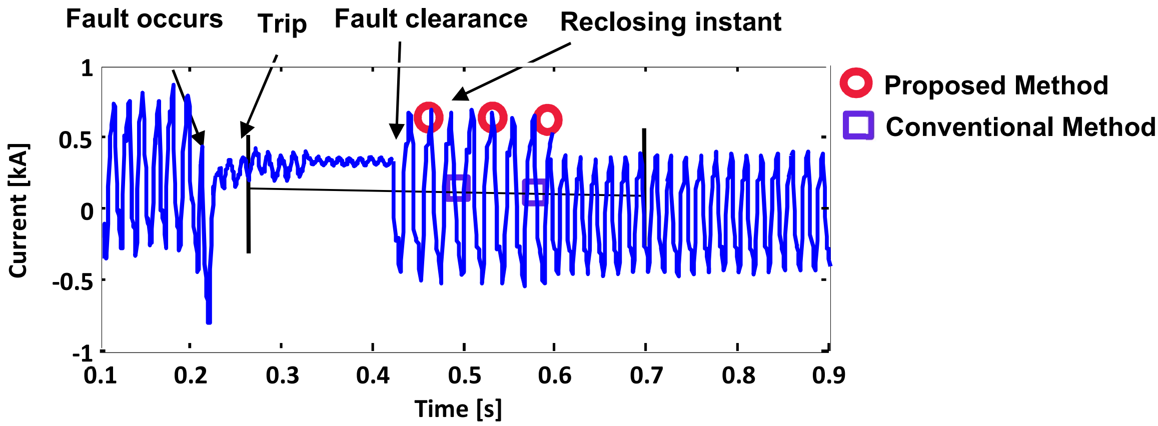


Figure 1. Load current of faulted phase

2. To provide uninterruptible power supply to the healthy portion using new adaptive reclosing technique under different critical events.

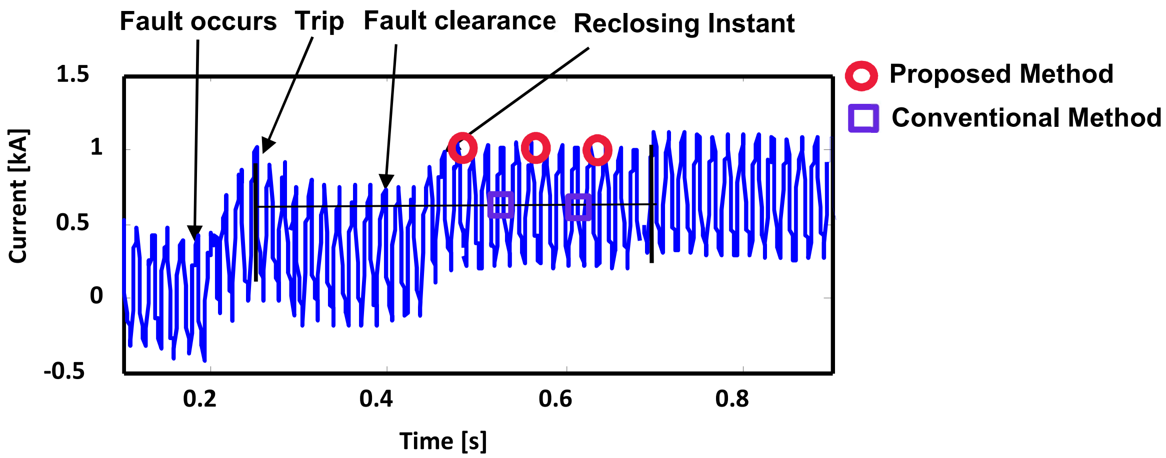


Figure 2. Load current of healthy phase

3. To verify the performance of proposed method during nonlinear load switching of active and reactive power load, capacitor switching and change in system configuration including both islanded as well as grid-connected mode.

4. To overcome the drawback of conventional technique of fault clearance detection using abrupt increase in THD value of faulty phase as compared to healthy phases.

5. To overcome the synchronism issue of conventional reclosing technique by complete disconnection of the PV-BESS from the system leading to formation of a small micro-grid to feed local loads and emergency feeders (if frequency and phase angle are within acceptable steady state range).

2.2 Scope

The proposed research in ARTUPS can contribute in many ways to make the stressed grid, a healthy and smart grid.

In this work, a superimposed component based directional relaying algorithm is proposed for microgrid protection integrated with PV-BESS.

The ARTUPS approach applies using PV-BESS to feed critical loads and emergency feeders such as hospitals and communication system. This project proposes a new directional relaying algorithm with BESS connected in the distribution system. The proposed technique focuses on operation of BESS as an UPS.

In the existing microgrid technology, at the time of fault or any disturbance, BESS system continues to supply power to the system. With reclosing technique, faulty phase is generally isolated and power supply continues other healthy phases. Now-a-days reliability of power supply is ensured through renewable sources at every distribution bus so that power interruption rate can be reduced. So, at the time of fault any faulty section can be completely disconnected from the system to avoid system unbalance condition and as well as back feeding from BESS system to the fault point.

In the proposed approach angular difference logic is applied for fault detection with calculation of angle difference between positive and negative sequence components of fault current. Based on the obtained decision from the detectors, the final decision will be declared by the proposed algorithm to isolate the faulty part from rest of the microgrid. The method is tested for different fault types, fault positions and different configuration of microgrid; islanded and grid connected mode. The proposed method is verified for different events such as load switching of active as well as reactive power load and capacitor switching. The method is also verified for high resistance fault. The fault clearance is assessed with calculation of THD value of faulty phase as compared to healthy phase, which suddenly increases at fault clearance instants. The detection of the fault clearance is obvious regardless of the fault types.

Also, Synchronism problem is overcome by frequency, phase angle and voltage measurement of both side grid as well BESS side. The plots for synchronism check are shown in Figure 3 Figure 5. The threshold values of different parameters have been tabulated in Table 1. $\gamma_{frequency}$, $\gamma_{Voltage}$ and γ_{angle} for the synchronism check are independent of the system conditions and these values are determined based on [21]. $\gamma_{frequency}$, $\gamma_{Voltage}$ and γ_{angle} are set to 0.2 Hz, 5%, and 15 degrees, respectively, in the simulation.

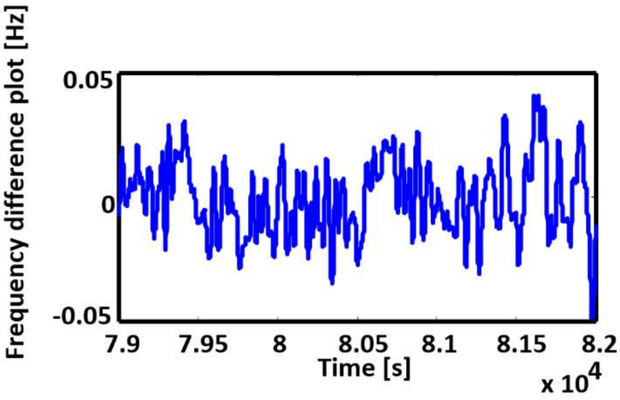


Figure 3. Plot of synchronism check for frequency f1-f2

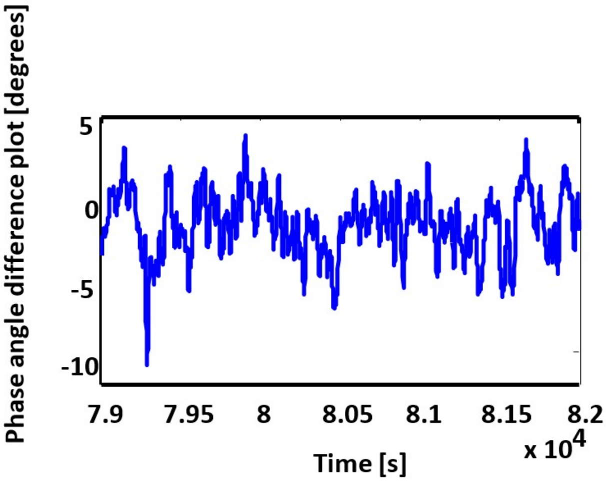


Figure 4. Plot of synchronism check for phase angle $\theta 1$-$\theta 2$

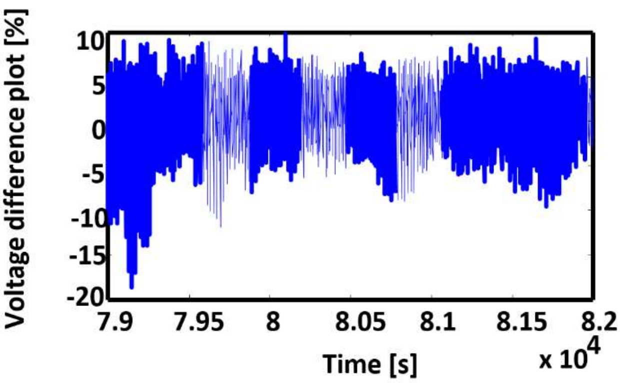


Figure 5. Plot of synchronism check for voltage |V1| - |V2| / |V2|

Parameter	Threshold Values
(f1-f2) $\gamma_{frequency}$	0.2 Hz
(V1-V2/V1) $\gamma_{voltage}$	15 %
(θ1 – θ2) γ_{angle}	15-degrees

Table 1. Threshold values of parameters

The complete study is carried out in *MatLab* software, with measured test signals obtained from real time simulator OPAL-RT. Results prove the efficacy of the proposed method.

3 State-of-the-Art/State-of-Technology

The conventional reclosing adopts a fixed dead time, irrespective of fault type whether a fault is temporary or permanent in nature. The drawback of conventional reclosing technique lies due to existence of large dead time despite fault clearance before reclosing. If BESS is considered to remain connected under fault conditions and supplies power to a healthy phase, the outage time can significantly reduce, and thus will improve the reliability of power supply. In addition, the BESS can also be used for frequency regulation and peak load shaving.

The conventional reclosing technique experiences a problem of synchronism in the distribution network because the BESS will not be disconnected from the distribution system even under fault conditions and will maintain the power supply to healthy phase. Conventional reclosing schemes do not consider a synchronism problem between the utility and the BESS when reclosing is attempted. Due to the existence of both sources at the sending and receiving ends, the synchronism should be checked using the information of voltage, phase angle, and frequency. Hence, proposed adaptive reclosing technique can be used to overcome this problem of synchronism, as the BESS and loads are completely dis-connected from the system. Thus, they can form a small micro-grid if voltage, frequency and phase angle remain within steady state limit.

As already discussed in previous section, with BESS included in the system, the current from the BESS side continues to flow to the faulted point. Therefore, travelling wave gets developed due to switching event at the instant of fault clearance, leading to distortion of voltage and current wave-forms. These are because of harmonics and the high frequency oscillations. The total harmonic distortion (THD) and individual harmonic can be considered for analysis purposes. Figure 6 shows the THD value of the current supplied by the BESS at the instant of fault clearance when the single line-to-ground (SLG) (AG) fault occurs.

It is clear that THD of the faulted phase as compared to healthy phase increases rapidly at the instant of fault clearance. As such, calculation of THD value of current signal from the BESS of faulted phase can be utilized to detect the fault clearance instant.

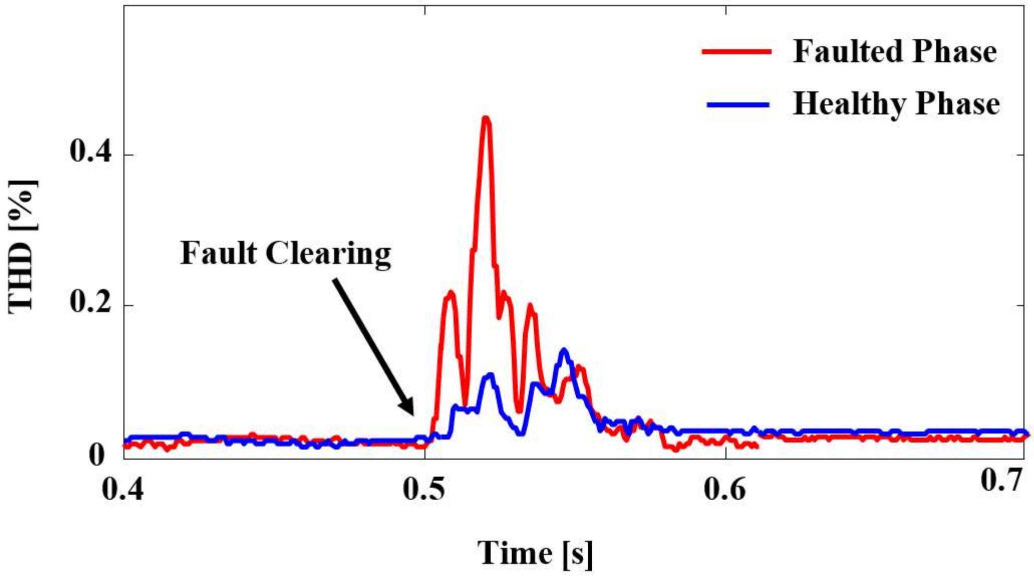


Figure 6. THD of current supplied by BESS at the instant of fault clearance when SLG fault occurs

3.1 Review on conventional reclosing technique

The conventional reclosing adopts a fixed dead time, irrespective of fault type whether a fault is temporary or permanent in nature. The drawback of conventional reclosing has a large dead time despite fault clearance before reclosing [2]-[4]. For example, the operation sequence of a recloser in the distribution system of the Korea Electric Power Corporation (KEPCO) has the fixed dead times of 0.5 s and 15 s. If the hybrid DG-BESS is connected under fault conditions and supplies power to a healthy phase, the outage time can be significantly reduced, and thus it will improve the reliability of the power supply. The BESS can also be used for frequency regulation and peak load shaving.

The conventional reclosing technique experiences a problem of synchronism in the distribution network because the BESS does not get disconnected from the distribution system even under fault conditions and will maintain the power supply to a healthy phase. Conventional reclosing schemes do not take into account a synchronism between the utility and the BESS when reclosing is attempted. However, due to the existence of both sources at the sending and receiving ends, the synchronism can be considered using voltage, phase angle, and frequency. Hence, proposed adaptive reclosing technique can be used to overcome this problem of synchronism, as the BESS and loads get completely dis-connected from the grid system. Thus, they can form a small micro-grid, if voltage and frequency are maintained within steady state limit.

3.2 Review on monitoring of ARTUPS technique

The electric power industry is currently facing historical and significant restructuring of its conventional vertically integrated configuration. Specifically, the BESS has been widely applied in power distribution systems along with renewable energy sources to ensure uninterruptible power supply. As BESSs are increasingly adopted in power distribution networks, utilities will have to adapt or change their practices and procedures. Accordingly, research has increasingly gained focus on BESS connected to grid. These studies have focused on the power quality, operation, control strategy of the BESS, integration with renewable energy, and energy management [1–14]. However, only a small number of protection studies in power systems with BESSs have been reported. Among the various protection issues, this study focuses on reclosing with incorporation of BESSs in the system.

The recloser is a circuit-interrupting device for distribution systems due to which the magnitudes of fault currents are limited. The operation sequence of a recloser in the distribution system of KEPCO has the fixed dead times of 0.5 s and 15 s. Distinguishing permanent faults from temporary faults in reclosing sequences is very important. However, conventional reclosing adopts a fixed dead time, irrespective of whether a fault is temporary or permanent in nature [15]. This leads to have dead time despite fault clearance before reclosing, which is a disadvantage of conventional reclosing. In transmission systems, various schemes have been proposed to detect fault clearance and reduce dead time [16–20]. However, these methods cannot be applied to distribution systems and only a small number of studies have examined the fault clearance in distribution systems [21]. In addition, the BESS can be used for frequency regulation and peak load shaving.

The distribution system must be operated at a steady state without faults to use the BESS for frequency regulation and peak load shaving. If the BESS is connected under fault conditions and supplies power to a healthy phase, the outage time will get significantly reduced, and thus it will improve the reliability of the power supply. In this case, however, the distribution system experiences a new challenge in reclosing because the BESS will not be disconnected from the distribution system even under fault conditions and will maintain the power supply to a healthy phase. Conventional reclosing schemes do not consider a synchronism problem between the utility and the BESS when reclosing is attempted. Due to the existence of both sources at the sending and receiving ends, a reclosing in distribution systems with BESS is very similar to reclosing in a transmission line, and thus the synchronism problem including voltage, phase angle, and frequency must be considered. This study proposes a novel adaptive reclosing technique in distribution systems with the BESS as a UPS. The proposed technique includes a method of fault clearance detection using THD of current from the BESS at fault conditions to provide the adaptive dead time. The proposed algorithm is also tested for various switching events like load switching of active as well as reactive power load and capacitor switching operation. The proposed algorithm has been divided into following sections as shown below:

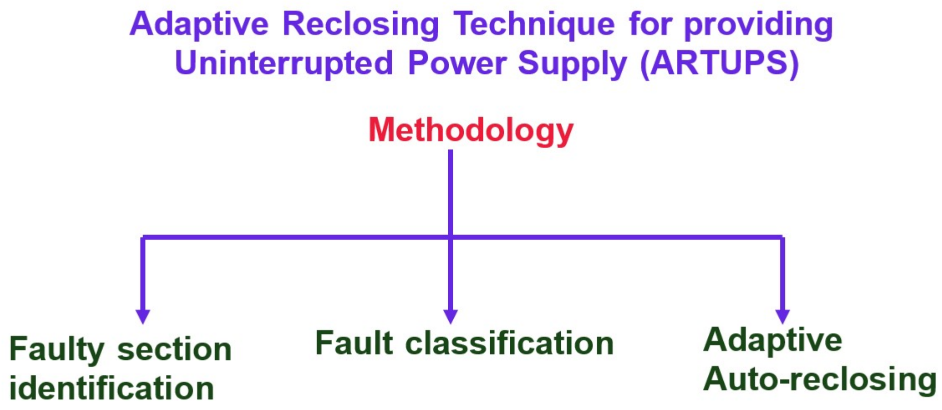


Figure 7. ARTUPS algorithm methodology

4 Executed Tests and Experiments

4.1 Test Plan

In the offline set-up for validation of proposed algorithm, two converters are used to emulate the behaviour of DGs connected. Converter 1 operates in voltage control mode as BESS and Converter 2 in Current control mode as Photovoltaic System. The grid operates at 230 V, 50 Hz. The line impedance and isolation transformer are used to connect it to microgrid system at point of common coupling (PCC). Two independent control systems are used to control the operation of both power converters:

A. Control level: Primary control

- Local control implemented in the inverters (Fr-P & V-Q droop).
- The frequency signal allows instantaneous sharing of load among the generators in the microgrid.
- Key control for grid connected to island transition and island operation.

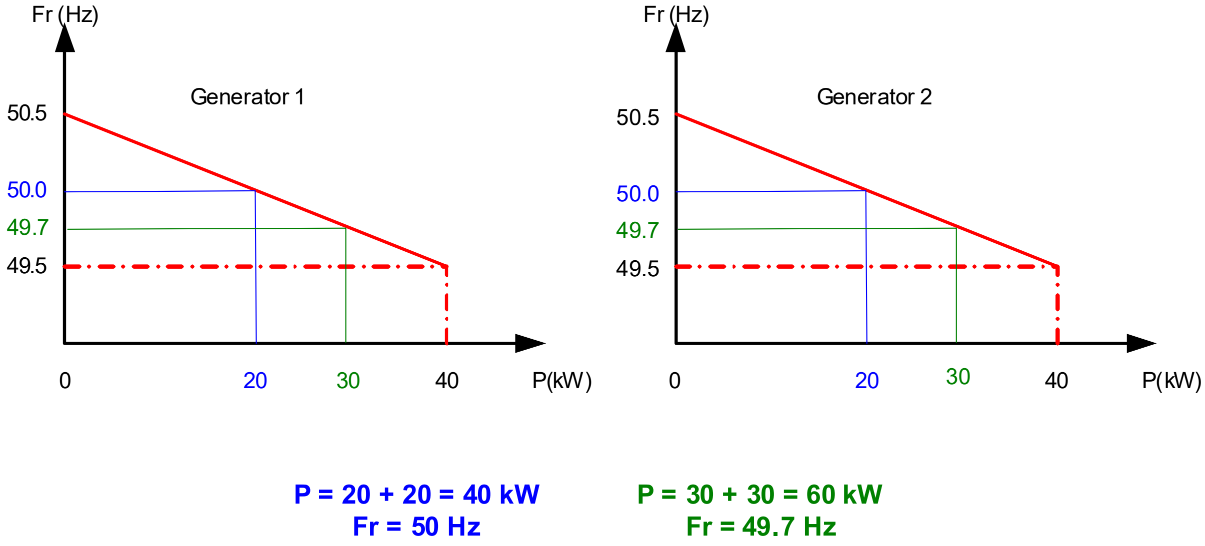


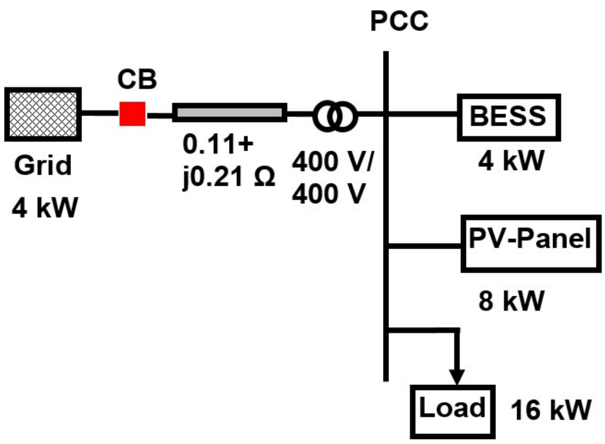
Figure 8. Droop characteristics at the inverters

B. Control level: Secondary control

- Microgrid Energy Management System: Real time visualization of data (P/Q/Fr/V), Historical data storage, Setting of predefined power schedules for distributed energy resources (DER), Secondary control in grid-connected and islanded modes
- Implementation based on Multi Agent technologies: Modular, Plug&Play, Distributed
- Real time economic operation: each controllable device provides its operating costs (generation costs, deviation costs, DSM strategies etc), supply and demand are matched and a microgrid price is obtained, each device is assigned a power set point according to the microgrid price
- Functions of the secondary control: grid-connected operation: Maintains the power exchange with the main grid to predefined values, islanded operation: Recovers the reference frequency (50 Hz)

Different switching operations are performed in a stepwise manner to observe its effect on the power management from the grid as well as DG sides. The test cases are performed in both grid as well as islanded mode of operation:

1. Load switching in grid-connected mode



Case 1: Active load is increased to 18kW.

Case 2: Reactive load is increased to 2.5kVAR and PV power to 10kW.

Case 3: Reactive load is increased to 7.5kVAR and PV power to 12kW.

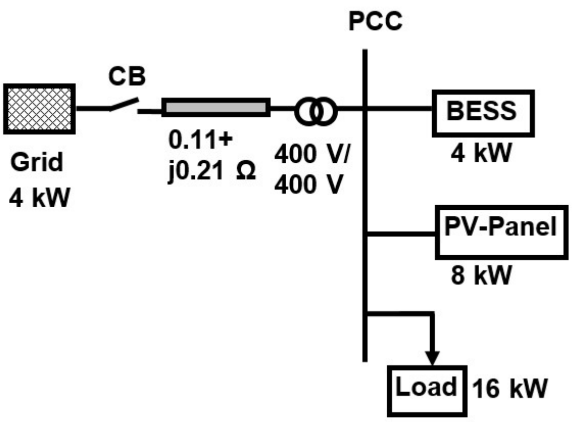
Case 4: Capacitor switching of 2.5 kVAR is performed to improve the power factor.

Figure 9. Single line diagram of set-up in grid-connected mode

Figure 10. Monitoring of active power, reactive power and frequency plots for grid, BESS and PV system in grid-connected mode

Figure 11. Monitoring of active power, reactive power and frequency plots for grid, BESS and PV system in isolated mode

2. Load switching in isolated mode



Case 1: Active load is increased to 18kW.

Case 2: Reactive load is increased to 2.5kVAR and PV power to 10kW.

Case 3: Reactive load is increased to 7.5kVAR and PV power to 12kW.

Case 4: Capacitor switching of 2.5 kVAR is performed to improve the power factor.

Figure 12. Single line diagram of set-up in isolated mode

3. *Fault identification and classification*

The fault detection algorithm is based on the angular differences between the sequence components of the fundamental current signal. The logic diagram for the proposed fault classification technique is shown in Figure 13. In the proposed algorithm, the positive and negative sequences of the postfault current are considered.

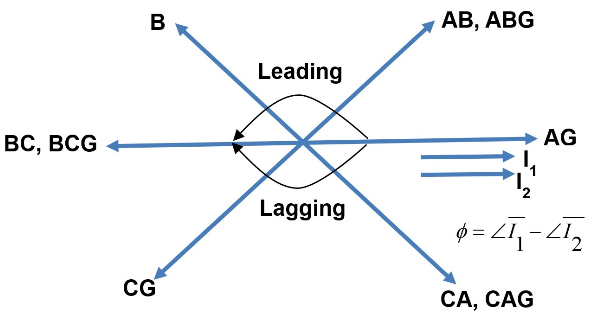


Figure 13. Logic Diagram of Fault Detection Algorithm for Microgrid System

Fault type	Leading angle Range	Lagging angle Range
AG	330<Φ<30	330<Φ<30
AB or **ABG**	30<Φ<90	270<Φ<330
BG	90<Φ<150	210<Φ<270
BC or **BCG**	150<Φ<210	150<Φ<210
CG	210<Φ<270	90<Φ<150
CA or **CAG**	270<Φ<330	30<Φ<90

Table 2. Angle differences for each fault type

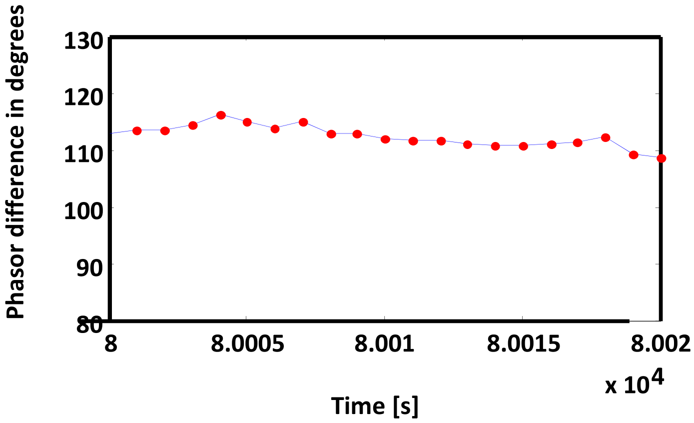


Figure 14. Angular difference plot for CG fault, φ = 115.56º

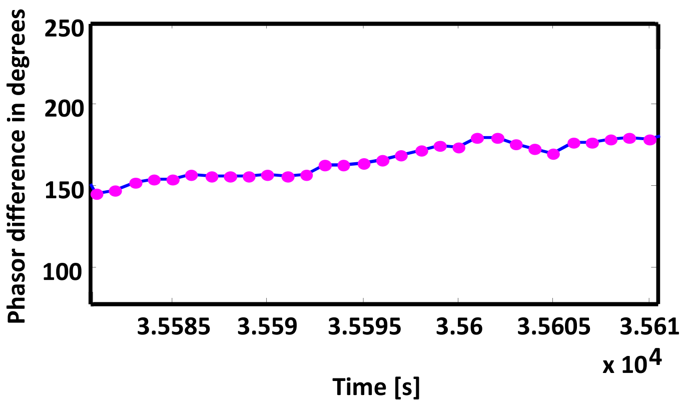


Figure 15. Angular difference plot for BCG fault, φ = 180.90º

4.2 Standards, Procedures, and Methodology

The standards, procedure and methodology which has been followed is tabulated in Table 3.

Standards	Procedures	Methodology
• The voltage and current signals are streamed according to IEEE C37.118.2-2011 compliance with a specific host ID (TCP/IP), port and device ID code.	• The overall procedure is discussed in previous section.	• Load switching operation and capacitor switching • Faulty section identification • Fault classification based on logic • Fault clearance detection • *Synchronism check operation*

Table 3. Standards, procedure and methodology

4.3 Test Set-up(s)

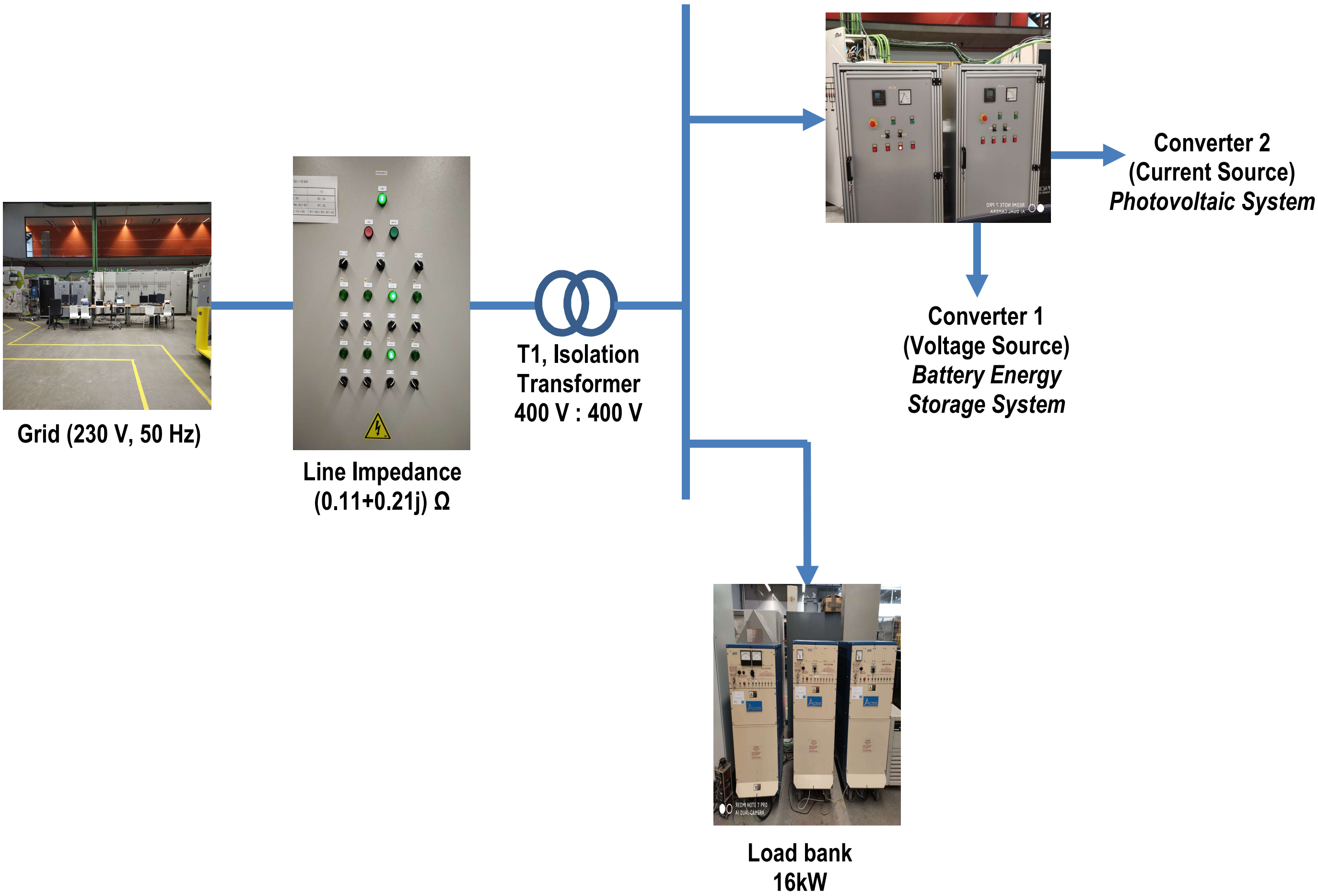


Figure 16. Experimental set-up for offline testing

4.4 Data Management and Processing

The data is managed to store in workspace of *MatLab* as discussed in section 4.1. Then from workspace, it is saved in the computer as ".mat" file. The data quality is good and has no measurement errors therefore the data pre-processing is not required. The algorithm can directly consume the signal to process it to produce the results. The algorithm is written in such a way that whatever be the type of fault, it will classify it based on the angular difference analogy .The stored data in workspace can also be analysed later for other monitoring information or application.

5 Results and Conclusions

5.1 Results

As mentioned before, the testing of ARTUPS has been done for offline validation of proposed adaptive reclosing operation and fault classification

The main goal is the validation of ARTUPS for reduction of outage time and improvement of reliability of power supply. The real-time monitoring of the test signals for voltage and current allows the identification of faulty section and its isolation from the healthy part. The synchronism check is performed by comparing the values of frequency, voltage and phase angle for both the sides including grid as well as BESS side as shown in Figure 3 –Figure 5. The fault clearance detection is observed successfully by measuring the second order harmonic current of faulty and healthy phase from BESS side as shown in Figure 6. Also, the fault classification algorithm based on logic diagram is performing accurately under different test condition adapted as shown in Figure 13 -Figure 15. Also, the proposed algorithm is giving correct outputs for load switching and capacitor switching operation in grid and islanded mode of operation. The snapshot of the measurements of active and reactive power, frequency is also shown in the Figure 10 andFigure 11. An abrupt increase in second order harmonic current values for faulty phase clearly indicates the fault clearance time which is shown in Figure 17 – Figure 18.

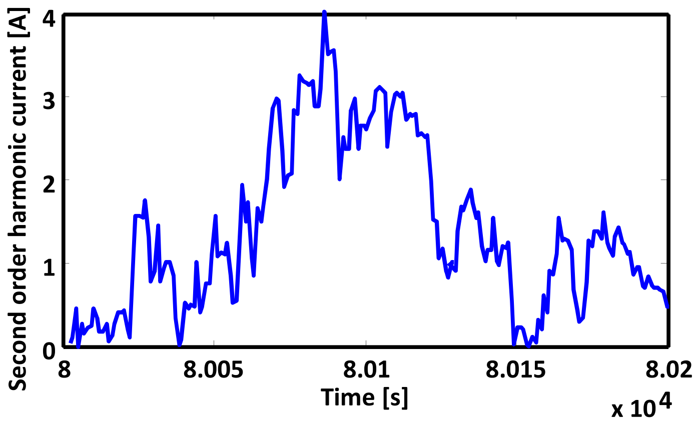


Figure 17. Second order harmonic current of faulty phase, I_{2THD} (faulty phase)

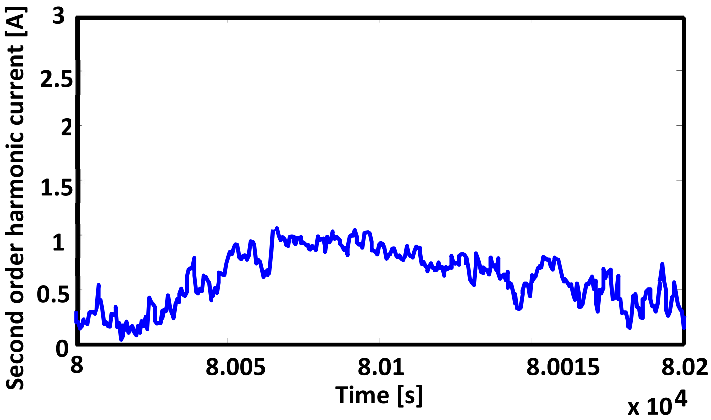


Figure 18. Second order harmonic current of healthy phase, I_{2THD} (healthy phase)

5.2 Conclusions

- ARTUPS is effective and accurate in detection of fault and fault classification.
- The algorithm accurately verifies the fault clearance detection and synchronism check process using frequency and phase angle.
- ARTUPS operation is found to be accurate during various switching operation and different system configuration including islanding as well as grid connected modes.
- Further improvement is needed in ARTUPS algorithm to increase its speed of operation of circuit breaker to reduce the transients occurring due to single pole operation.

6 Open Issues and Suggestions for Improvements

An open issue is the time taken to execute the algorithm. The computational burden associated with the algorithm may restrict it to get implemented in real-time power system.

Suggestions for improvements are:

- Appropriate selection of the parameters to achieve fast monitoring maintaining the accuracy.
- Execution time for algorithm can be minimized by reducing the window size and by looking into many other factors involved in the coding.
- Pre-fault and post-fault data can be taken separately for each fault cases.
- Multiple load switching operation can be monitored simultaneously to observe the effect on the DG system.

7 Dissemination Planning

Writing research paper in collaboration with the TA user group manager and other group members after making improvements.

8 References

[1] H. Jeong-Yong, O. Yun-Sik, S. Hun-Chul, K. Chul-Hwan, "An adaptive autoreclosure scheme with reference to transient stability for transmission lines," *J Electr Eng Technol,* vol. 10, no. 3, pp. 795-803, 2015.

[2] B. Keyvani, Z. M. Karbalaye, L.Hamid, " Stability enhancement of multi-machine systems using adaptive reclosing of transmission lines," *Int J Electr Power Energy Syst,* vol. 62, pp. 391-397, Nov. 2014.

[3] K. Hassan, Li.Zuyi, " Design of a novel phasor measurement unit-based transmission line auto reclosing scheme," *IETGener,Transm Distrib, IET Renew Power Gener,* vol. 5, no. 8,pp. 806-813, Aug.2011.

[4] A.A. Montanari, T. M. Cristina, P. Carlos, "Adaptive single phase auto reclosing based on secondary arc voltage harmonic signature," In: *International conference on power systems transient,* Kyoto, Japan, 2009.

[5] Z. Haihua, T. Bhattacharya, T. Duong, S. T. Terence, K.Ashwin, "Composite energy storage system involving battery and ultracapacitor with dynamic energy management in microgrid applications," *IEEE Trans Power Electron,* vol. 26, no. 3. pp. 923-930, 2011.

[6] L. Ju, W. Jinyu, Y. Wei, L. Yao, "to short-term frequency response of wind farms by using energy storage systems," *IET Renew. Power Gener.,* vol. 10, no. 5, pp. 669-678, 2016.

[7] M. H. Moradi, M. Eskandari, H. S. Mahdi, "Cooperative control strategy of energy storage systems and micro sources for stabilizing microgrids in different operation mode," *Int J Electr Power Energy Syst*, vol. 78, pp. 390-400, 2016.

[8] G. Josep M, L. P. Chiang, L. Tzung-Lin, C. Mukul, "Advanced control architectures for intelligent microgrids—part II: power quality, energy storage, and AC/DC microgrids," *IEEE Trans Indust Electron*, vol. 60, no. 4, pp. 1263–1270, 2013.

[9] R.Ehsan, S. Saeed, R. Roose, M. Marc, "Energy management at the distribution grid using a Battery Energy Storage System (BESS)," *Int J Electr Power Energy Syst,* vol. 77, pp. 337-344, 2016.

[10] B. Maryam, C. Rachid, P. Mario,"Decentralized voltage control of clustered active distribution network by means of energy storage systems," *Electric Power Syst Res*, vol. 136, pp. 370-382, 2016.

[11] L. Xiangjun, H.Dong, L. Xiaokang, " Battery energy storage station (BESS)based smoothing control of photovoltaic (PV) and wind power generation fluctuations," *IEEE Trans Sustain Energy,* vol. 4, no. 2, pp. 464–473, 2013.

[12] S. Ravi, C. Kalyan, B. Ravi, "Impact of energy storage system on load frequency control for diverse sources of interconnected power system in deregulated power environment," *Int J Electr Power Energy Syst*, vol. 79, pp. 11-26, 2016.

[13] X. Yixing, S.Chanan, "Power system reliability impact of energy storage integration with intelligent operation strategy," *IEEE Trans Smart Grid*, vol. 5, no. 2, pp. 1129–1137, 2014.

[14] S. Ioan, M. Corneliu, "Control strategy of three-phase battery energy storage systems for frequency support in microgrids and with uninterrupted supply of local loads," *IEEE Trans Power Electron*, vol. 29, no. 9, pp. 5010–5020, 2014.

[15] W.Peng, G.Zhiyong, B.Lina, “Operational adequacy studies of power systems with wind farms and energy storages,” *IEEE Trans Power Syst,* vol. 27, no. 4, pp. 2377–2384, 2012.

[16] H. Ioannis, P. Andreas, E. Venizelos, “Overview of current and future energy storage technologies for electric power applications,” *Renew Sustain Energy Rev*, pp. 1513-1522, 2009.

[17] D. Wang, G.Shaoyue, J.Hongjie, W. Chengshan, Z.Yue, L. Ning, et al., “A demand response and battery storage coordination algorithm for providing microgrid tie-line smoothing services,” *IEEE Trans Sustain Energy,* vol. 5, no. 2, pp. 476-486, 2014.

[18] B. Ted KA, Y. Alex, J.A. von, Y. Zuan Z, H.H. Max, H. Douglas, “Optimal energy storage sizing and control for wind power applications,” *IEEE Trans Sustain Energy*, vol. 2, no. 1, pp. 69-77, 2011.

[19] S. Hun-Chul, “New reclosing technique in distribution system with battery energy storage system,” *J Kor Inst Illumin Electr Instal En,* vol. 30, no.1, pp. 21–27, 2016.

[20] Q. Hao, “A high-efficiency grid-tie battery energy storage system [Ph.D. thesis],” *Virginia Polytechnic Institute and State University*, 2011.

[21] KEPCO. Technical standard for interconnecting distributed generation with distribution system; 2015.

9 Annex

9.1 List of Figures

9.2 List of Tables