International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org



IJIEMR Transactions, online available on 06th Mar 2023. Link :http://www.ijiemr.org/downloads.php?vol=Volume-12&issue=Issue 03

**DOI: 10.48047/IJIEMR/V12/ISSUE 03/05**

Title **An adaptive virtual impedance fault current limiter for islanded microgrid protection coordination**

Volume 12, ISSUE 03, Pages: 32-45

Paper Authors
**B V Ramana, Dr. I. Prabhakar Reddy**

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

# An adaptive virtual impedance fault current limiter for islanded microgrid protection coordination

**B V Ramana[1], Dr. I. Prabhakar Reddy[2]**

[1]Research Scholar, EEE department, JNT University, Ananthapuramu, AP, India

[2]Professor, Department of Electrical Engineering, NBKRIST, Nellore, Andhra Pradesh, India

**Abstract:** Fault currents of inverter-interfaced distributed generators (IIDGs) depend on inverter controllers. Thus, IIDGs fault currents are different than those of synchronous-based DGs, both from the magnitude and waveshape perspectives. In the event of short-circuit faults, droop-based IIDGs switch between a voltage source and a current source, which increases the complexity and non-linearity of short-circuit current calculation (SCC). This paper proposes a new SCC algorithm that incorporates virtual impedance-fault current limiters (VI-FCLs) to enable modelling droop-based IIDGs as a voltage source behind an impedance. The VI-FCL was implemented as an additional control loop in the inverter control scheme to limit IIDG fault currents and achieve optimal protection coordination (OPC). Further, the VI-FCL is adaptively adjusted to enhance overcurrent protection sensitivity. A two-stage OPC algorithm for directional overcurrent relays (DOCRs) is developed. In Stage I, an optimal value for the adaptive VI-FCLs and relay currents are calculated. Stage II aims at obtaining optimal DOCRs settings. Time-domain simulations are used to demonstrate the effectiveness of the proposed adaptive VI-FCL and the accuracy of the proposed SCC algorithm. The proposed SCC algorithm and the OPC program are successfully validated using an islanded microgrid that is part of a Canadian distribution system.

**Keywords:** Renewable energy, Hybrid Microgrid, Battery Energy Storage, Particle Swarm Optimization.

## I. Intoduction

Renewable energy technology advances and government incentives allow distribution systems to include RESs like solar and wind. Microgrids can maintain active distribution networks (ADNs) with bidirectional power flow [1]. Grid connected and islanded microgrids operate. Droop-based control can operate an islanded microgrid without communication [2]. If unprotected against short-circuit faults, islanded microgrids could be at risk. ADNs and microgrids use DOCRs for bidirectional fault currents. Time-coordinated DOCRs reliably isolate failures and minimise load interruption. Distributed generators (DGs), whether synchronous-based or inverter-interfaced, contribute differentially to microgrid fault currents. Inverter-interfaced DGs (IIDGs) connect RESs with microgrids. Islanded microgrids use IIDGs as droop-controlled voltage sources to distribute load. SBDGs affect fault current more than IIDGs, which have a restricted short-circuit capacity. To coordinate DOCRs, use shortcircuit current computation (SCC). Because they exclude inverter controllers, SBDG fault analysis methods cannot be used to assess IIDG microgrids. A model must represent IIDG behaviour during faults and be used in fault analysis to obtain DOCR short-circuit currents [3, 4]. [3] used a superposition theorem-based SCC approach for IIDGs. Photovoltaic (PV) source fault current was modified based on terminal voltage in Ref. [5]. [6] developed a sparsity-based IIDG SCC algorithm. Droop-based IIDG SCC algorithms were developed by [7]. The algorithm ignored current reference saturation.

A decoupled sequence control analytical fault analysis model for grid-connected IIDGs was proposed in [8]. The model examined IIDG fault currents. The transient behaviour of IIDG fault currents was modelled in [9] using IIDG controller saturation. The point of common coupling (PCC) voltage was used to construct a domain of attraction (DOA) that accurately assesses PI controller state. [10] modelled grid-connected IIDGs as voltage-controlled current sources and considered fault ridethrough (FRT). With restricted modulation signals, the model transitions from a voltage-controlled current to a voltage source. The IIDG secondary control was modified to limit inherent fault current in [11]. (FCL). In [12], a central controller determined DOCR settings for adaptive protection. A dynamic virtual impedance-fault current limiter (VI-FCL) [13] limits downstream fault currents and protects a dynamic voltage restorer (DVR). Parallel synchronous generators (SGs) in islanded microgrids limited inverter current with a virtual impedance. [14, 15] reviewed virtual impedance control techniques for current and voltage source converters. The power flow algorithm for droop-based islanded microgrids incorporated virtual impedances, but the IIDG output voltage referenced the internal inverter voltage [16]. Ref. [17] proposes a more accurate model that accounts for voltage loss across the virtual impedance. [18, 19] investigated using physical FCLs in sequence with the ADN to reestablish protection coordination in grid-connected and islanded modes of operation. [20] employed dual-setting DOCRs with a low-bandwidth communication link to operate forward and backward. The scheme preserved protection coordination. Communication channels are expensive despite minimal bandwidth. [21] solved the OPC as a non-linear programming (NLP) issue using a hybrid symbiotic organism search method (HSOSA). Ref. [22] solved protection coordination for an N-1 contingency. All studies [19–22] considered solely SBDGs. VI-FCLs limited IIDG fault currents in an islanded microgrid with multi-IIDGs [23]. [24] presented a harmonic-DOCR-based microgrid protection method (HDOCRs). The IIDG control system was updated to inject an nth-order harmonic current produced by the HDOCRs in islanded mode. The scheme uses IIDG primary current controllers, which are control signal-saturable.

Although the IIDGs have little contribution to fault currents, built-in current hard limiters may suffer from reference \scurrent saturation. The saturation block hard limiter limits IIDG output current after a grid disruption. Controlling the reference values of the IIDG active and reactive current components in the dq-reference frame restricts the IIDG fault current to a maximum. The IIDG fault current may saturate at its threshold regardless of fault location. The IIDG model may switch between droop-based voltage and constant current sources.This complicates the SCC and makes outer control loops unstable [14].

Physical FCLs limited fault currents [18, 19], but they are expensive, bulky, and require maintenance. VI-FCLs limit IIDG fault currents in a reasonable way. Controlling the IIDG as a voltage source behind a virtual impedance during faults saves inverter switches from overcurrent or thermal damage and assures islanded microgrid stability and reliability. VI-FCLs are inexpensive, keep IIDGs connected during faults, and increase transient stability.

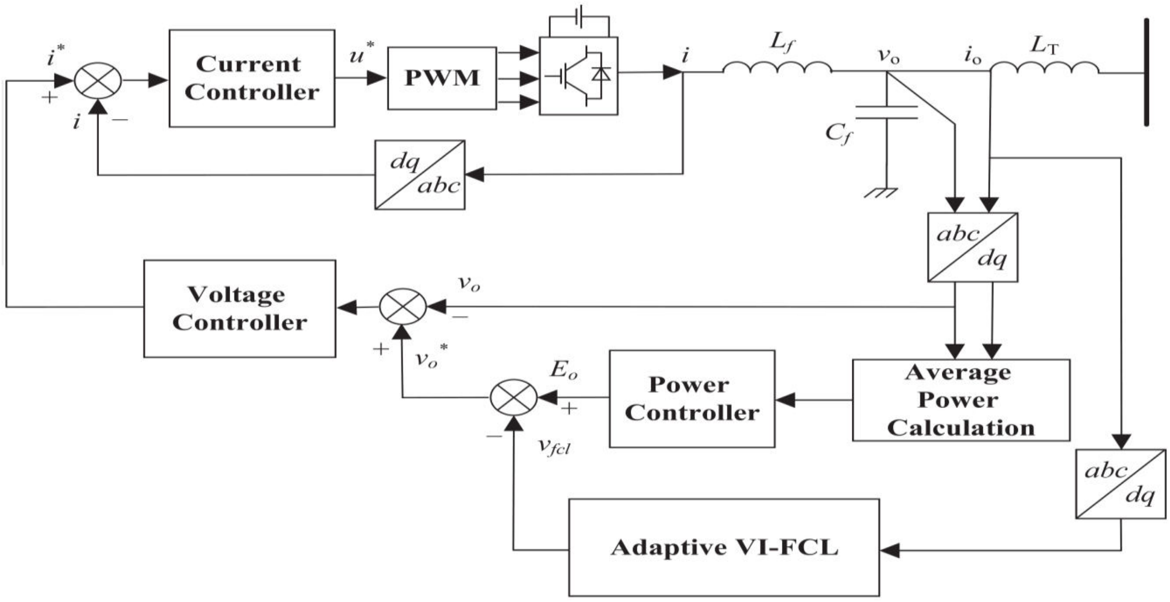


Figure 1 Droop-controlled IIDG control scheme with VI-FCL

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

Previous studies used VI-FCL for non-OPC goals. This study presents a novel OPC framework with an SCC algorithm for islanded microgrids: A VI-FCL limits IIDG fault currents below their threshold. Unlike SCC approaches in the literature, the VI-FCL is adaptively modified and integrated in the SCC algorithm. A two-stage algorithm is suggested for islanded microgrids' OPC formulation. At the second stage, the algorithm calculates relay currents and sizes the adaptive VI-FCL.

Figure 1 depicts the generic control block diagram for a droop-based IIDG with a VI-FCL, in which a cascaded structure has an innermost current control loop that provides control over its output current io. The outer control loop is a power control loop that achieves power-sharing by generating a voltage reference, Eo, which is subtracted from the voltage drop across a VI-FCL, vfcl, to provide a voltage reference, v o, for the output voltage vo. By generating a reference signal for a current controller, a voltage controller regulates the voltage across the filter capacitor. The current controller is located in the innermost loop and controls the filter inductor current by generating the inverter reference voltage u, also known as gating signals.

This paper is structured as follows. Section 1 provides an introduction of Islanded HMGS. Section 2 describes the mathematical model of hybrid microgrid system. Section 3 and 4 briefly introduces power management scheme and particle swarm optimization algorithm respectively. Design considerations of islanded HMGS explain in Section 5. Section 6 and 7 presents economic analysis and simulation results.

## II. The VI-FCL design

When using hard limiters in the current control loops of IIDGs, the inverter's output currents may saturate following fault initiation. As a result, the IIDG model may alternate between a constant current source and a droop-based voltage source, complicating the SCC. The VI-FCLs model IIDGs as a voltage source behind an impedance similar to that of SGs. As a result, it keeps the voltage source model of IIDGs intact during faults. As a result, a control method was developed to incorporate a VI-FCL as an additional control loop in the inverter control scheme to protect the IIDG switches from overcurrent and reduce the complexity of SCC.

The VI-FCL is implemented in the IIDG control circuit and only activated during faults to act as a high impedance. The VIFCL can be viewed as a transient impedance that is engaged only during faults. It is added virtually by subtracting the voltage. The constant VI-

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

FCL limits the IIDG fault current regardless of fault severity, limiting the range of fault scenarios considered for protection coordination. Using an adaptive VI-FCL, on the other hand, provides a more gradual fault current profile that accommodates a wider range of fault resistances.

It is worth noting that the proposed adaptive VI-FCLs offer the following benefits:

(i) Unlike constant VI-FCLs, the proposed adaptive VI-FCL improves protection sensitivity by allowing sensible fault current levels to be set based on fault severity.

(ii) During faults with hard limiters, the reference current may saturate, resulting in poor dynamic performance in the outer control loops [14]. As reported in [25], VIFCLs, on the other hand, prevent current saturation and contribute to microgrid transient stability.

(iii) IIDGs with VI-FCLs behave similarly to SGs. The higher the fault current, the closer the fault location to the IIDG. This behavior improves the selectivity of protection coordination.

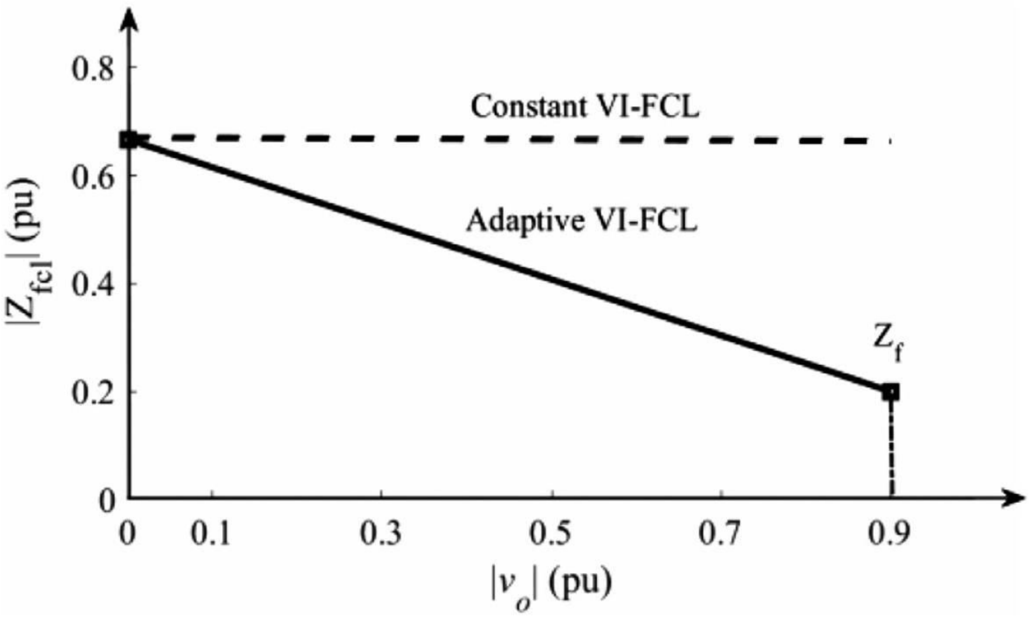


Figure 1 Proposed topology of HMGS for study

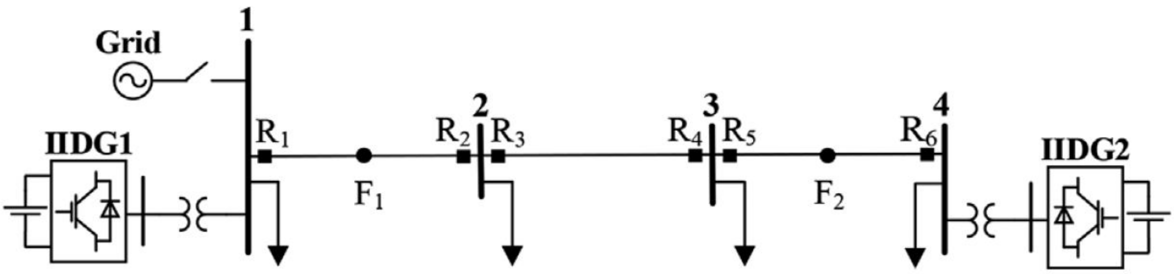


Figure 2 Load profile consumption per day for 15 houses

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

Figure 2 depicts a schematic diagram of a typical micro-grid integrated with a resistive SFCL, with the SFCL installed at the point of common coupling (PCC) between the micro-grid and the main network. All of these DG units, including the energy storage device, photovoltaic (PV) plant, and wind farm, are connected to the micro-grid via inverters [9], [10]. It should be noted that the energy storage device will function as a master DG, which is used to stabilise the microgrid. The maser DG has two control patterns in general, known as the P-Q control and the V-f control.

When the micro-grid is connected to the grid, each of the DG units will use the P-Q control. If a short-circuit fault occurs in the main network, the micro-grid can be configured to operate in the islanded state. The master DG's goal is to keep the micro-frequency grid's and voltage as stable as possible, and its control pattern will shift from the original P-Q control to the V-f control. Because reasonably controlling the master DG is a fundamental method of ensuring transient performance, employing the resistive type SFCL is expected to affect the control mechanism more actively and smooth out the transition process. Because of the SFCL's rapid quenching characteristics, it can be used as a control trigger if the fault current is detected to be greater than its critical value in a timely manner. That is, the SFCL's trigger signal generated by the superconducting-normal (S-N) transition will be sent to a collection system and used to activate the master DG's control switching.

A feasible method for effectively implementing the master DG's control switching is presented below. Figure 3 depicts the energy storage device's control strategy in relation to the resistive SFCL's trigger signal.

The bulk Bi series and YBa2Cu3Ox(YBCO) second-generation (2G) are currently the primary high temperature superconducting (HTS) materials for electric power applications [13], [14]. Given that commercial YBCO 2G tapes may have a high resistivity matrix with a linear resistance of 0.354/m, the transition to the normal-conducting state may occur between 2 and 4 ms after the start of fault current. Furthermore, YBCO 2G tapes with stainless steel reinforcement have good mechanical properties, such as tensile strength greater than 250 MPa at room temperature. Because the YBCO 2G components may actuate faster than the Bi-2212 components [15], [16], and the expected current-limitation for the YBCO 2G components after the S-N transition is higher for the YBCO 2G components, the YBCO 2G tapes may be more suitable for making the resistive SFCL.

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

In some ways, the AC loss will have a significant impact on the engineering application of the SFCL. Its alternating current loss can be measured using standard electrical techniques and calculated using finite-element simulations. In theory, the electrical properties of a superconductor can be modelled using a nonlinear power law in which voltage varies.The measured DC current-voltage characteristics can be used to calculate the critical current density Jc and the power index n.

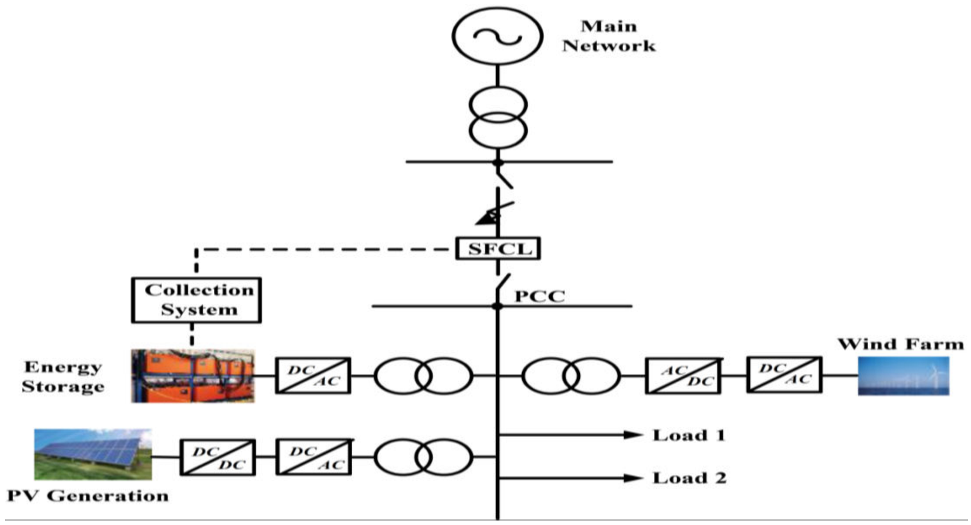


Figure 3 Schematic diagram of a typical micro-grid integrated with the SFCL

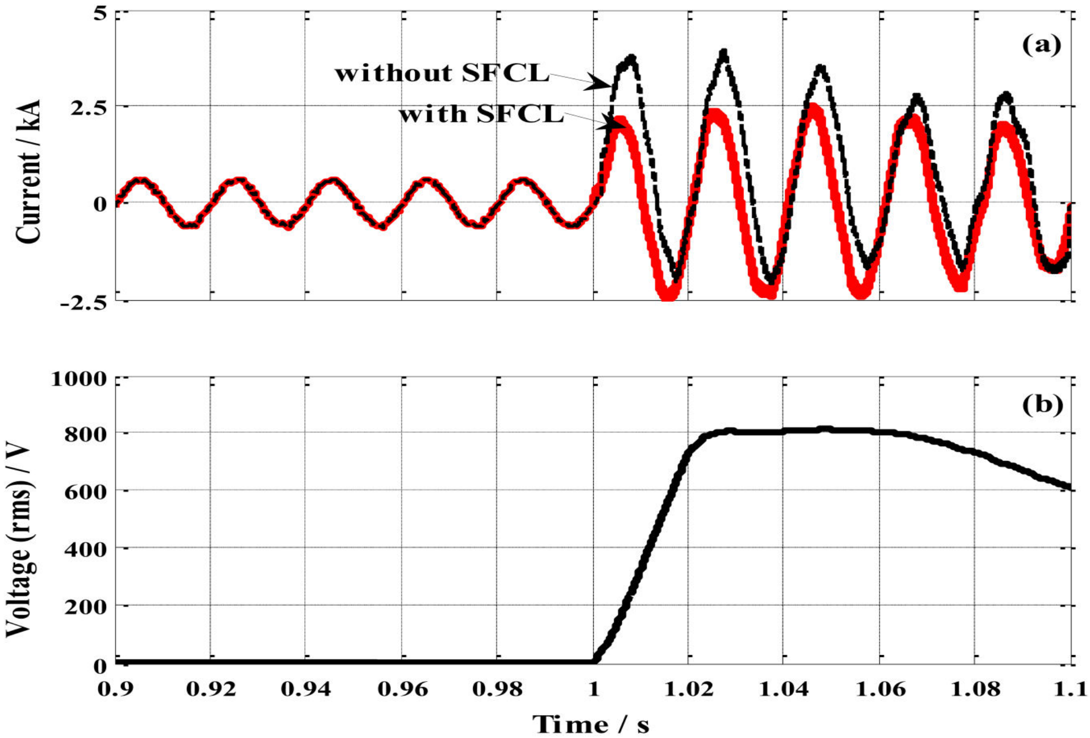


Fig. 4. Operating characteristics of the suggested resistive type SFCL. (a) fault current at the PCC and (b) RMS voltage across the SFCL's two terminals.

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

TABLE I MAIN SIMULATION PARAMETERS OF THE SYSTEM MODEL

| Proposed Microgrid System | |
|---|---|
| Energy Storage | ( 800 V / 1000 Ah ) X5 |
| PV Plant | 100 kW X 10 |
| Wind Farm | 260 kW X 10 |
| Load 1 | 0.2 MW |
| Load 2 | 0.1 MW + j0.05 Mvar |
| Voltage / Frequency | 3 kV / 50 Hz |
| **Resistive type SFCL** | |
| Normal - state Resistance | 1Ω |

To quantitatively evaluate the resistive type SFCL's effects on a micro-grid system's transient performance, the simulation model corresponding to Fig. 2 is built in MATLAB/ SIMULINK, and parts of simulation parameters are indicated as Table I. The access voltage of the demonstrated micro-grid system is selected as 3 kV, and the short-circuit fault is supposed to happen at the middle of the connecting line. During the simulation analysis, it is set that the fault occurs at t0 = 1 s and lasts for 100 ms. Further, the static-state switch will be operated at t=1.1 s, and the micro-grid system will carry out the transition from its grid-connected mode to islanded mode. Herein two different simulation cases are considered and respectively reordered as case I and case II. For the former, the SFCL is not applied, and the control switching will be implemented after the fault is cleared. Regarding the latter, the resistive SFCL is employed, and this suggested device will be used for current-limitation and control trigger.Before the fault happens, the micro-grid is connected to the main network, and a certain power exchange between them is generated. There are about 1.8 MW active power and 0.05 Mvar reactive power exporting to the main network. For example, the DG units in the micro-grid can not only meet the power requirements of the two local loads, but also provide energy to the accessed main network. The resistive SFCL will play its role in time after the fault. The operating characteristics of the resistive type SFCL are depicted in Fig. 4. The maximum value (root-meansquare, RMS value) of the SFCL's terminal voltage can be up to 800 V due to the increased fault current. Given that the fault current will be quickly detected to be greater than the critical value, it is assumed that the master DG's control transition will be activated once the terminal-voltage is detected to be greater than 200V and can last for 5 ms (a quarter of the power-frequency cycle).

The characteristics of the fault currents provided by the wind farm and the PV plant are shown in Fig. 5, and the effects of the SFCL are also considered. The detailed data results are presented in Table II. According to Figs. 4 and 5, the resistive SFCL's current-limiting characteristics can be confirmed, and the reduction of overcurrent inrush will have a positive effect on the micro-grid.

Figures 6-7 depict the micro-bus grid's voltage, exchange power, and frequency characteristics during control switching. It can be seen that the use of resistive SFCL can make significant contributions to the performance of the micro-grid. Using SFCL can keep the micro-PCC grid's voltage at 0.5 pu, whereas without SFCL, the PCC voltage drops to 0.08 pu, and the expected increase rate is approximately 84%. Furthermore, using the resistive SFCL can make the micro-grid achieves a smooth transition, where power supply reliability can be increased to some extent, and the SFCL's current-limiting resistance can effectively absorb surplus power, thereby limiting frequency variations.

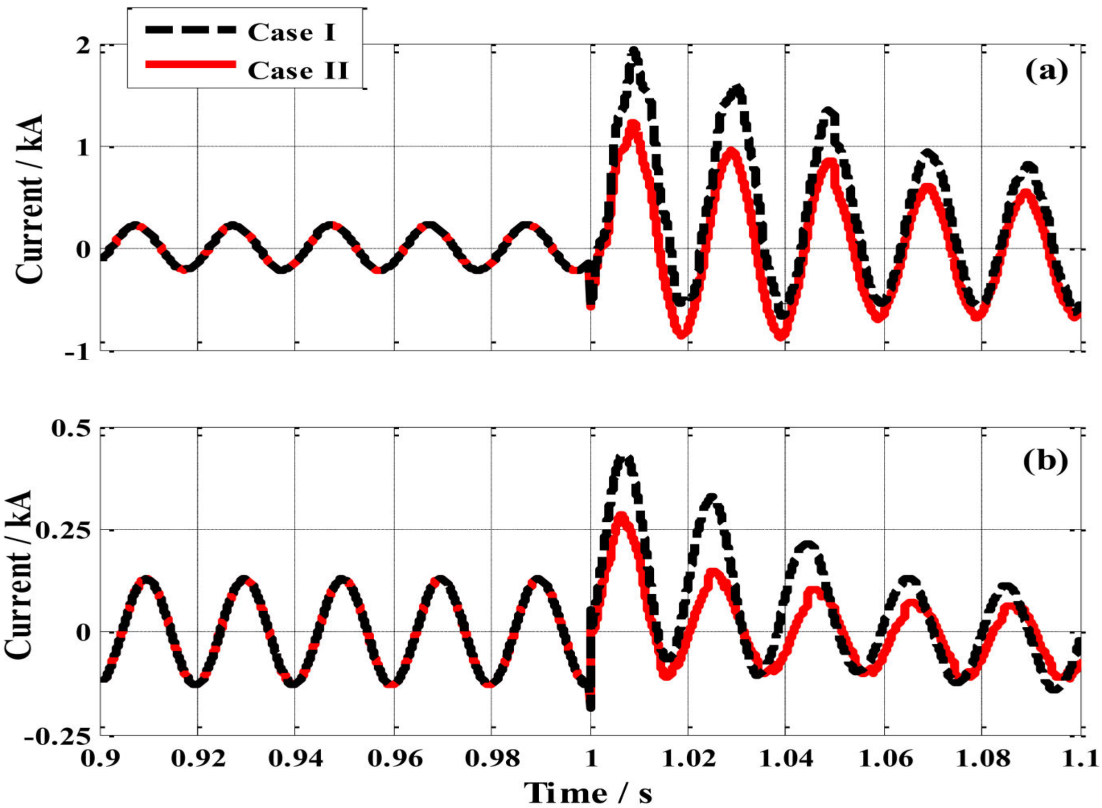


Figure 5 Waveforms of the fault current provided by the DG included in the micro-grid with and without the SFCL. (a) wind farm and (b) PV plant.

Because the power quality of the micro-grid is a critical assessment index, the SFCL's effects on the system frequency are investigated. Without FCL, the maximum deviation of the frequency is about 0.3 Hz, and when SFCL is present, the fluctuating margin is less than 0.1 Hz. As a result, improving frequency quality will aid in the stabilisation of power sources and local loads.

TABLE II FIRST PEAK OF THE FAULT CURRENT AT DIFFERENT LOCATIONS

| **Measuring point** | **Without FCL** | **With the SFCL** | **With Proposed FCL** | **Current limiting ratio of SFCL** | **Current limiting ratio of Proposed FCL** |
|---|---|---|---|---|---|
| PCC | 3.8 KA | 2.1 KA | 2.0 KA | 44.7 % | 47.36% |
| Wind farm | 1.9 KA | 1.1 KA | 1.01 KA | 42.1 % | 46.8% |
| PV plant | 0.4 KA | 0.255 KA | 0.225 KA | 36.2 % | 43.75% |

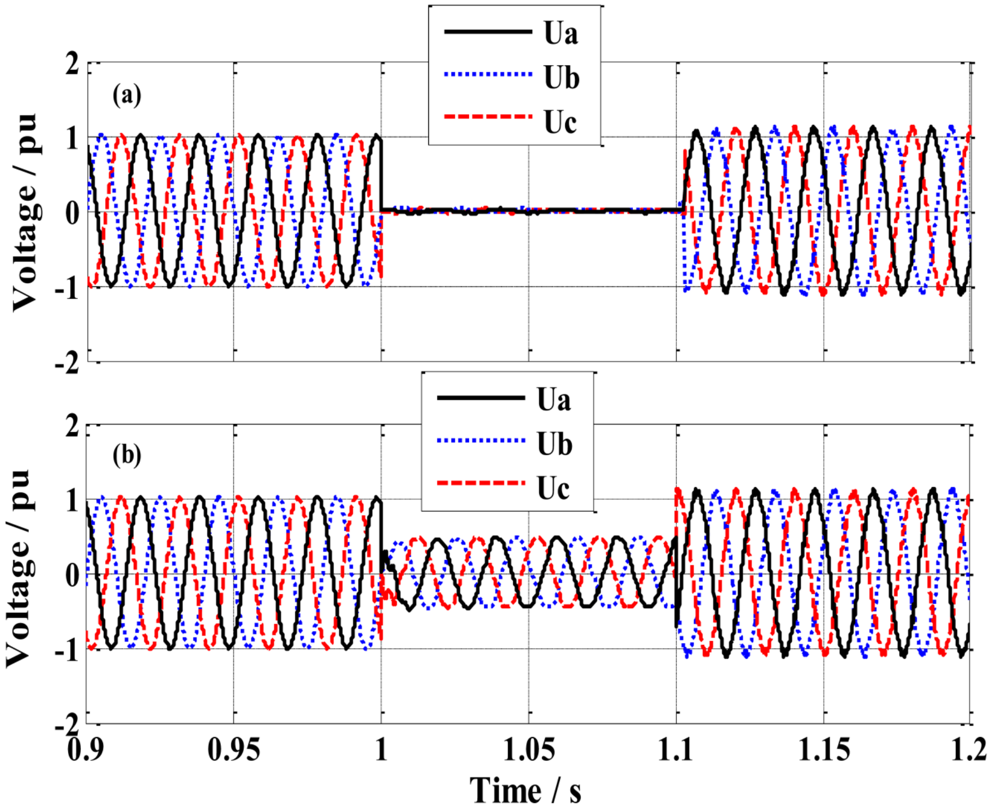


Fig. 6. Waveforms of the micro-grid's PCC voltage during the fault. (a) case I

International Journal for Innovative
Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

and (b) case II.

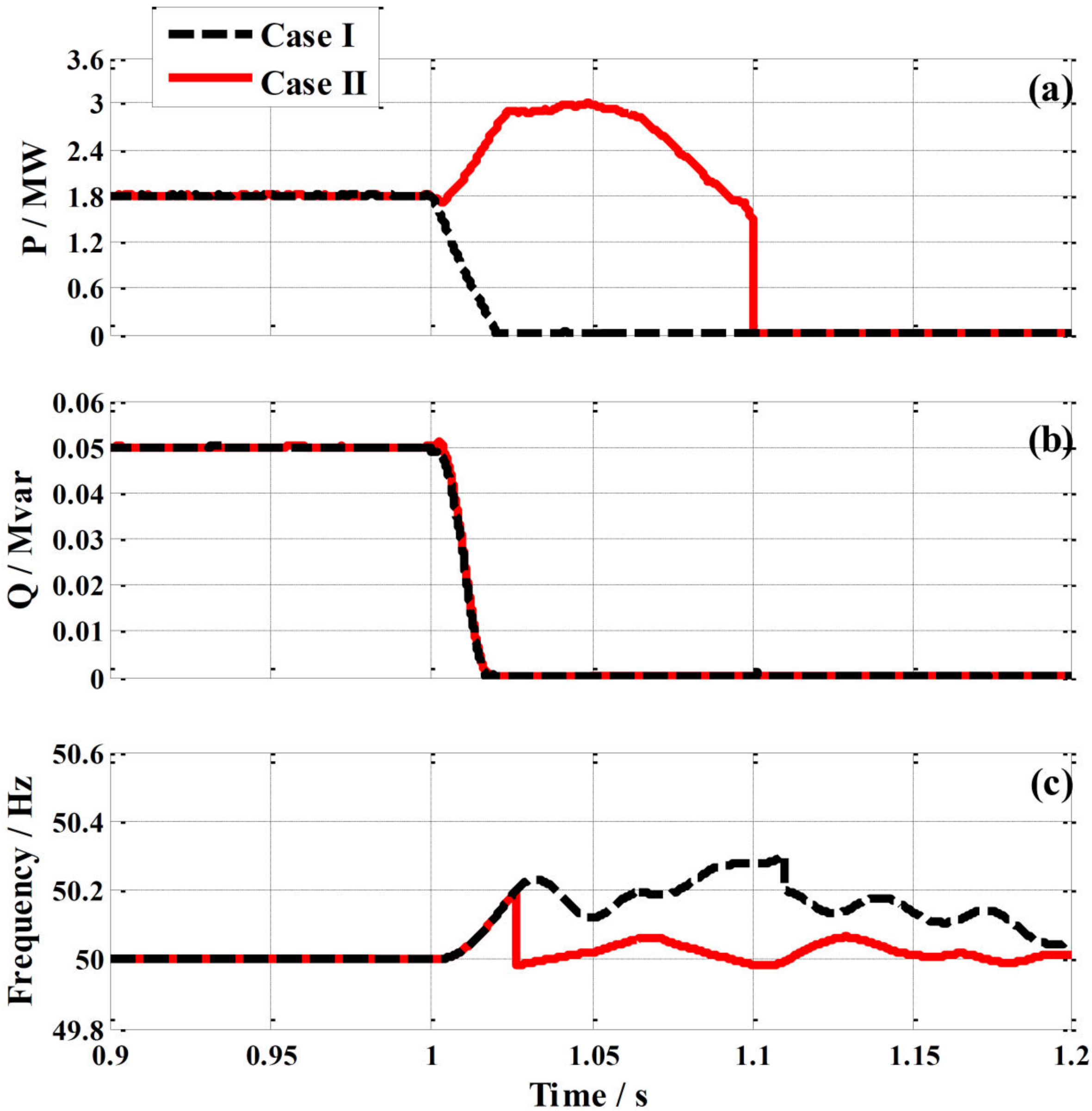


Fig. 7. Transient characteristics of the micro-grid system during the fault. (a) active power exchange, (b) reactive power exchange and (c) system frequency

**CONCLUSION**

In this paper, a resistive type superconducting fault current limiter is proposed to play the role of transient performance enhancement of a micro-grid system during a fault. Theoretical derivation, technical discussion, and simulation analysis are all performed. According to the findings, using resistive SFCL can effectively limit the transient current rush, ensure power balance, and improve the voltage and frequency stability of the micro-grid system.

In the near future, a small-scale prototype of the resistive type SFCL will be built and tested in a real microgrid system. The findings of the study will be reported in subsequent articles.

## VII. REFERENCES

[1] Mark D. Ainslie, Jumpei Baba, Valerio Salvucci, Tanzo Nitta, Takao Fukunaga, Masatoyo Shibuya, Shinji Torii, Toshiro Matsumura, and Toshiya Kumagai, ―Superconducting Fault Current Limiter Design Using Parallel-Connected YBCO Thin Films,‖ IEEE Trans. Appl. Superconduct., vol. 19, no. 3, pp.1918–1921, June 2009.

[2] Steven M. Blair, Campbell D. Booth, Graeme M. Burt, and Chris G. Bright, ―Application of Multiple Resistive Superconducting FaultCurrent Limiters for Fast Fault Detection in Highly Interconnected Distribution Systems,‖ IEEE Trans. Power Del., vol. 28, no. 2, pp. 1120–1127, Apr. 2013.

[3] Carlos A. Baldan, Jérika S. Lamas, André A. Bernardes, Carlos Y. Shigue, and Ernesto Ruppert, ―Fault Current Limiter Using Transformer and Modular Device of YBCO Coated Conductor,‖ IEEE Trans. Appl. Superconduct., vol. 23, no. 3, June 2013, No. 5603804.

[4] Chien-Liang Chen, Virginia Polytech, VA Blacksburg, Yubin Wang, Jih-Sheng Lai, Yuang-Shung Lee, and D. Martin, ―Design of Parallel Inverters for Smooth Mode Transfer Microgrid Applications,‖ IEEE Trans. Power Electron., vol. 25, no. 1, pp. 6–15, Jan. 2010.

[5] Jaehong Kim, J.M. Guerrero, P. Rodriguez, R. Teodorescu, and Nam Kwanghee, ―Mode Adaptive Droop Control With Virtual Output Impedances for an Inverter-Based Flexible AC Microgrid,‖ IEEE Trans. Power Electron., vol. 26, no. 3, pp. 689–701, Mar. 2011.

[6] M.A. Zamani, A.Yazdani, and T.S. Sidhu, ―A Control Strategy for Enhanced Operation of Inverter-Based Microgrids Under Transient Disturbances and Network Faults,‖ IEEE Trans. Power Del., vol. 27, no. 4, pp. 1737–1747, Oct. 2012.

[7] Jong-Fil Moon, and Jin-Seok Kim, ―Voltage Sag Analysis in Loop Power Distribution System with SFCL,‖ IEEE Trans. Appl. Superconduct., vol. 23, no. 3, June 2013, No. 5601504.

[8] C.A. Baldan, J.S. Lamas, C.Y. Shigue, and E.R. Filho, ―Fault Current Limiter Using YBCO Coated Conductor—The Limiting Factor and Its Recovery Time,‖ IEEE Trans. Appl. Superconduct., vol. 19, no. 3, pp. 1810–1813, June 2009.

[9] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho, ―Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays,‖ IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1198–1208, May 2009.

[10] Maurizio Cirrincione, Marcello Pucci, and Gianpaolo Vitale, ―Neural MPPT of Variable-Pitch Wind Generators With Induction Machines in a Wide Wind Speed Range,‖ IEEE Trans. Ind. Applicat., vol. 49, no. 2, pp. 942–953, Apr. 2013.

[11] Frede Blaabjerg, Remus Teodorescu, Marco Liserre, and Adrian V. Timbus, ―Overview of control and grid Synchronization for Distributed Power Generation Systems,‖ IEEE Trans. Ind. Electron., vol. 53, no. 5, pp. 1398–1409, Oct. 2006.

[12] J. A. Peças Lopes, C. L. Moreira, and A. G. Madureira. ―Defining Control Strategies for MicroGrids Islanded Operation,‖ IEEE Trans. Power Syst., vol. 21, no. 2, pp. 916–924, May 2006.

[13] S. Elschner, A. Kudymow, S. Fink,W. Goldacker, F. Grilli, C. Schacherer, A. Hobl, J. Bock, and M. Noe, ―ENSYSTROB—Resistive fault current limiter based on coated conductors for medium voltage application,‖ IEEE Trans. Applied Superconduct., vol. 21, no. 3, pp. 1209–1212, Jun. 2011.

[14] W. T. B. de Sousa, A. Polasek, F. A. Silva, R. Dias, A. R. Jurelo, and R. de Andrade, Jr., ―Simulations and tests of MCP-BSCCO-2212 superconducting fault current limiters,‖ IEEE Trans. Applied Supercond--uct., vol. 22, no. 2, Apr. 2012, No. 5600106.

[15] W. T. B. de Sousa, R. Dias, F. A. da Silva, A. Polasek, and R. de Andrade, Jr., ―Comparison Between the Fault Current Limiting Performance of Bi-2212 Bifilar Components and 2G YBCO Coils,‖ IEEE Trans. Appl. Superconduct., vol. 23, no. 3, Jun. 2013, No. 5602204.

[16] L. Ying, J. Sheng, B. Lin, L. Yao, J. Zhang, Z. Jin, Y. Li, and Z. Hong. ―AC Loss and Contact Resistance of Resistive Type Fault Current Limiter Using YBCO Coated Conductors,‖ IEEE Trans. Appl. Superconduct., vol. 22, no. 3, June 2012, No. 5602204.

[17] Francesco Grilli and Stephen P. Ashworth, ―Quantifying AC Losses in YBCO Coated Conductor Coils,‖ IEEE Trans. Appl. Superconduct., vol. 17, no. 2, pp. 3187–3190, June 2007.

[18] Hyoungku Kang, Jin Bae Na, Yoon Do Chung, and Tae Kuk Ko, ―Experimental Study on the Barrier Effects in Gaseous Helium for the Insulation Design of a High Voltage SFCL,‖ IEEE Trans. Appl. Superconduct., vol. 21, no. 3, pp.1328–1331, June 2011.

[19] Jin Bae Na, Hyoungku Kang, and Tae Kuk Ko, ―Numerical Analysis and Electrical Insulation Design of a Single-Phase 154 kV Class NonInductively Wound Solenoid Type Superconducting Fault Current Limiter,‖ IEEE Trans. Appl. Superconduct., vol. 22, no. 3, June 2012, No. 5602104