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A differential current based protection scheme for DC microgrid

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ABSTRACT

A continuous increase in greenhouse emissions has led to more frequent use of renewable energy resources. The increased emergence of DC loads in day-to-day lives has further led to conversion to DC distribution lines. In prospect of getting more environmentally friendly, economical, and reliable power delivery a DC microgrid was developed and has become more common in recent years. The disaster management cell located at the Department of Electrical and Electronics Engineering has designed a DC microgrid which consists of sources provided from the grid, a battery bank, and an array of solar cells supplying to a set of nine loads, which are segregated into three sets of three loads each. This paper presents a protection scheme for the buses present in a microgrid that is based on the differential current principle. It is done with the help of a centralized protection controller that enables fault identification and fault isolation. This protection scheme is further extended to a DC ring-bus microgrid, where the centralized protection controller enables fault identification, fault location, and fault isolation. MATLAB/Simulink is used to obtain the simulation and verify the results.

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1. INTRODUCTION

For the past twenty years, we have seen a clear trend of a shift from conventional power delivery to the use of renewable energy resources. This is mainly due to an increase in the power demand and the requirement for a cleaner, environment-friendly power delivery to be made available [1]. This increase in requirement for environment-friendly power delivery is due to the increase in the greenhouse emissions from electricity generation from fossil fuels and renewable energy resources being capable of providing cleaner generation. Thus, distributed generation units based on renewable energy resources were developed [2], [3]. This led to the development of microgrids which were used to integrate distributed generators more efficiently. So we get AC, DC, and AC-DC hybrid microgrids [4]–[6]. Not only has the increased emergence of DC loads in day-to-day lives such as laptops, mobiles, computers, and LEDs, increased the use of DC microgrids but also DC microgrids have several advantages over AC microgrids. For connecting to a common bus, a DC system requires a lesser number of stages of conversion when compared to an AC system. DC cables aren’t affected by skin effect [7]–[10]. A major challenge of DC microgrids is in regards to their protection. This has been a major advantage for AC microgrids. AC systems have more than 100 years of expertise and have very well-defined standards and guidelines for their protection. All these can be easily implemented on AC microgrids. AC protection consists of circuit breakers that rely on the zero crossing of the AC. DC does not have zero crossings so the same circuit breakers can't be directly implemented. Modification of these circuit breakers can be done but they may not be applicable to certain systems, not only that but this modification will increase the cost of the circuit breaker which is a hindrance when we try to develop cost-efficient systems [11]–[13].

Many studies have been done regarding the protection of DC microgrids and some techniques have been developed which include over current protection, voltage-based protection, localized measurement-based protection, distance protection, differential protection, admittance-based protection, and traveling wave-based protection, and protection based on adaptive techniques [14]. The differential current based-protection scheme is examined. This scheme analyses the difference in the currents coming in and the currents going out of the equipment which is to be protected [15]–[18]. Then, based on whether this difference current exceeds a pre-determined value we decide whether a fault has occurred or not. Some advantages of the scheme are, that they are immune to any voltage variation, it is easier to add more developments or connections to the grid compared to other protection schemes, and they can operate without any prior information regarding fault levels [19], [20].

This paper proposes a differential current-based protection scheme for DC microgrids. Two different cases have been performed. The first one is using this protection system on a DC single-bus microgrid. With the help of a centralized protection controller, we are able to identify and isolate a fault in the DC bus [21]. The second case is performed on a DC ring-bus microgrid. A similar protection scheme is used with slight modifications to adjust for the system used. The centralized protection controller is able to identify, locate, and isolate faults i.e., a faulty bus in this case. The further sections detail the microgrids being used, the protection scheme which is implemented, the results showed, and validation that a safe operation can be accomplished.

2. BLOCK DIAGRAM

The block diagram of the DC single-bus microgrid is shown in Figure 1. This DC single-bus microgrid is present in the disaster management cell located at the Department of Electrical and Electronics Engineering of Jawaharlal Nehru Technological University, Hyderabad. The DC single-bus microgrid consists of a three-phase supply connected to circuit breakers, which are then stepped down with the help of transformers, and then with the help of power converters, it is converted from AC to DC. A battery bank and a PV module are also connected to the DC bus. This is supplied to a set of nine loads. These nine loads are connected to the DC bus in groups of three loads each. The three loads in a group are namely, a DC motor load, a light load, and a heater load [22]–[25].

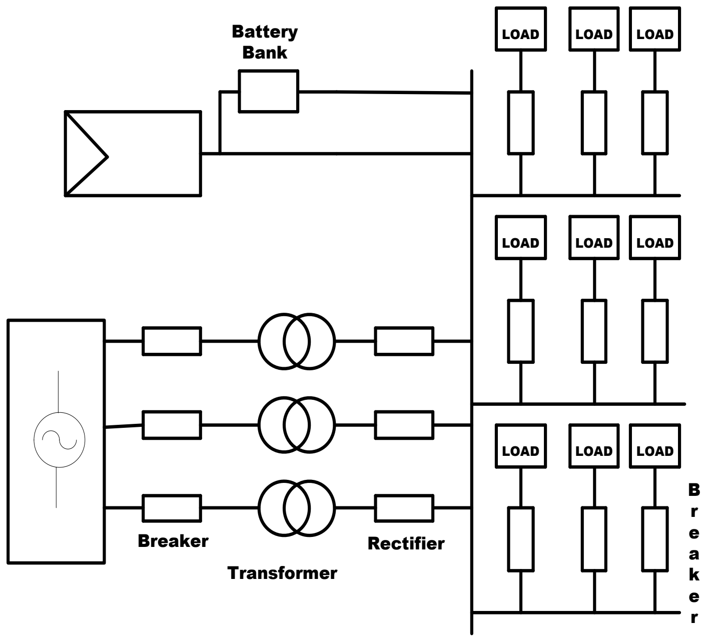

Figure 1. Block diagram of DC single-bus microgrid

The block diagram of the DC ring-bus microgrid is shown in Figure 2. This DC ring-bus microgrid is done by altering the already present DC single-bus microgrid [26], [27]. So, all the nine loads, the grid, PV module, and the battery bank used here are the same except for the configuration of the bus. MATLAB/Simulink is used to obtain simulation for these models and the proposed protection scheme based on differential current is implemented to protect the microgrid from possible bus faults.

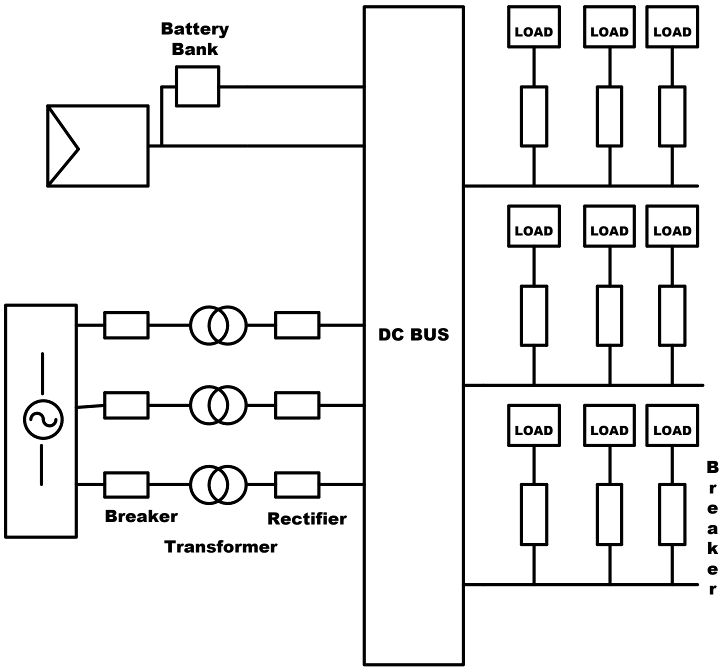

Figure 2. Block diagram of DC ring-bus microgrid

3. PROPOSED PROTECTION SCHEME

The proposed protection scheme implemented here is based on the differential current principle. This scheme analyses the difference in the currents coming in and the currents going out of the bus. Then, with the help of a pre-determined value it decides whether a fault at the bus has occurred or not.

3.1. Operating principle

For DC single-bus microgrid, we implement the proposed protection scheme which is based on differential current with the help of controllable switches. These controllable switches are placed in strategic locations to protect the microgrid from potential possible bus faults. As this is intended to protect the microgrid from bus faults, the controllable switches are to be placed at the lines going into the bus and those leaving the bus. These switches are also provided with equipment to measure current. This gives the currents those enter and currents those leave the bus. These currents are then sent to a centralized protection controller. The centralized protection controller is nothing but a controller, but for MATLAB/Simulink usage it is represented with the help of a MATLAB function block. The centralized protection controller then analyses the current inputs to it with the help of a function and then determines whether a fault has occurred at the bus or not. If a fault has occurred, it proceeds to give a trip signal to the controllable switches present to turn the switches OFF, thus isolating the fault i.e., the bus. For DC ring-bus microgrid, a similar approach is done. There are seven buses and similar controllable switches are provided near all entry and exit lines of the buses. This ring-bus configuration has an advantage over the single-bus configuration such that if a single bus, that is present in it has a fault occurred on it, isolation of the faulty bus ensures that the system is still running. Here, the centralized protection controller checks for fault at each and every bus individually, and if a fault occurs gives a trip signal to the respective switches of the faulty bus, leading to isolation of the faulty bus and safe running of the microgrid after the fault has occurred [12].

3.2. Fault detection

The protection logic used is described in Figure 3. As shown in (1) shows all the currents entering the DC bus in DC single-bus microgrid. As in (1), i_{s1}, i_{s2}, and i_{s3} denote the currents coming from the grid and entering the Bus. And i_{s4} denotes the current from the PV module. Thus, i_1 is the sum of all the currents entering the bus in the case of the DC ring-bus microgrid, each bus has a single current entering the bus. This current itself is denoted as i_1. As in (2), $i_{l1,}$ i_{l2}, and i_{l3} denote the currents leaving the bus and being supplies to each set of loads. Thus, i_2 is the sum of all currents leaving the bus. In the case of the DC ring-bus microgrid, each bus has a single current leaving the bus [15]–[18]. This current itself is denoted as i_2. As in (3), i_{diff} is the differential current. It is the difference between all currents entering the bus i_1, and all currents leaving the bus i_2. As in (4), i_{pd} is the predetermined current used to detect if a fault has occurred. If i_{diff} is greater than the predetermined value of current, then it is understood that a fault has occurred in the bus. The predetermined current i_{pd}, is found out by the method of trial and error and running the simulation to understand how the circuit behaves both under normal circumstances and in the case of a fault occurring. By running the simulation, we find out the lowest value of the differential current that we could get when the fault occurs. Thus, the lowest value of current that the differential current could reach is found to be 0.0006 amperes.

$$i_{s1} + i_{s2} + i_{s3} + i_{s4} = i_1 \quad (1)$$

$$i_{l1} + i_{l2} + i_{l3} = i_2 \quad (2)$$

$$i_{diff} = |i_1 - i_2| \quad (3)$$

$$i_{diff} > i_{pd} \quad (4)$$

3.3. Fault isolation

From the protection logic, when the condition is satisfied, and the central protection controller has detected a fault in the bus, it will send the necessary trip signals to the controllable switches to isolate the system from the bus [22], [23]. In the case of the DC ring-bus microgrid. When a fault occurs in a bus, the centralized protection controller detects the fault and locates on which bus the fault has occurred. Once the faulty bus has been recognized, the centralized protection controller sends trip signals to the controllable switches present at the faulty bus. Thus, isolating the faulty bus.

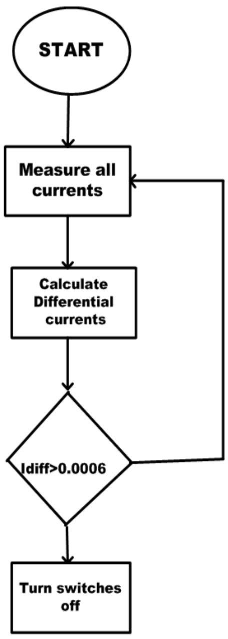

Figure 3. Flowchart of protection logic

4. SIMULATION RESULTS

The simulation model used is shown in Figure 4. This model contains an 11 kV substation that is connected via a medium voltage breaker to a three-phase transformer. The three-phase transformer steps down the voltage from 11 kV to 230 V (L-N). This is further stepped down to 48 V with the help of another transformer and then it is converted from AC to DC with the help of a rectifier [25]–[27]. The outputs from the rectifier are used as supply along with the output of the PV module. If in case the grid is no longer able to supply power, the PV module is present to run in the islanded mode of operation. Three groups of three loads each i.e., nine loads in total are connected.

For the simulation model, the protection is implemented by adding controllable switches in strategic locations. Figure 5 shows the location where the controllable switches have been added to give protection from possible bus faults. A bus fault is simulated as a short circuit between the positive and the negative lines of the bus. This fault is given at T = 1 s.

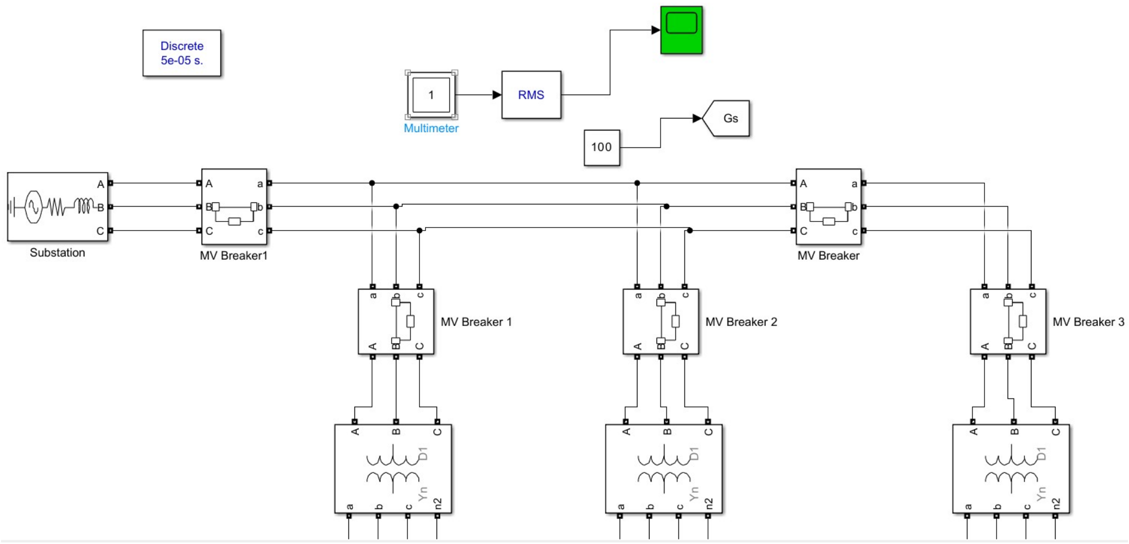

Figure 4. Simulation model

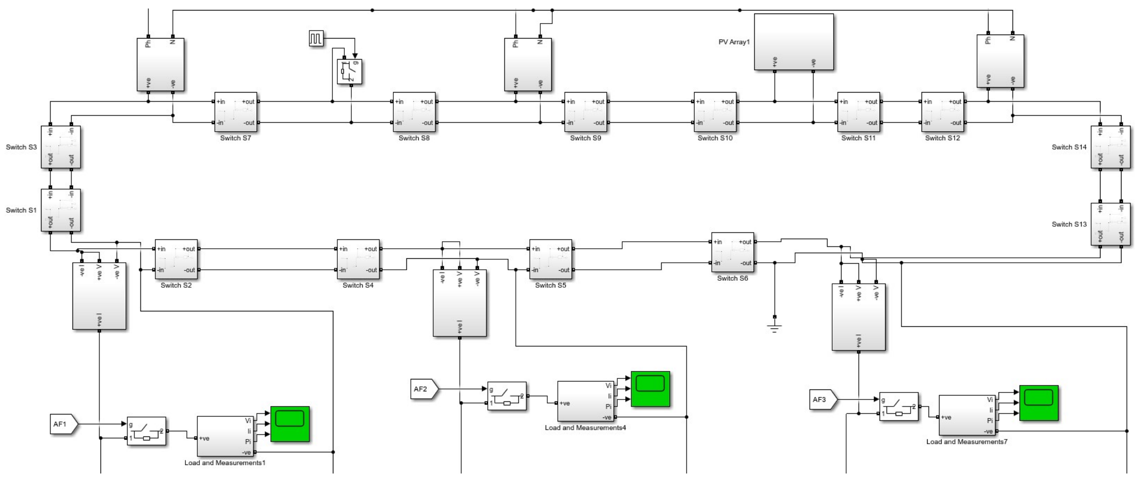

Figure 5. Controllable switches added to the simulation model

For a DC ring-bus microgrid, we modify the simulation model shown in Figure 4. The bus configuration is modified to represent a ring-bus configuration. Figure 6 represents the modified simulation model for a DC ring-bus microgrid along with the controllable switches provided for protection from possible bus faults. A short circuit fault is provided to a bus (say bus 1) at T=1s. This implies all the other 6 buses are in fault-free condition i.e., isolation of the faulty bus ensures that the safe operation of the system continues without the faulty bus.

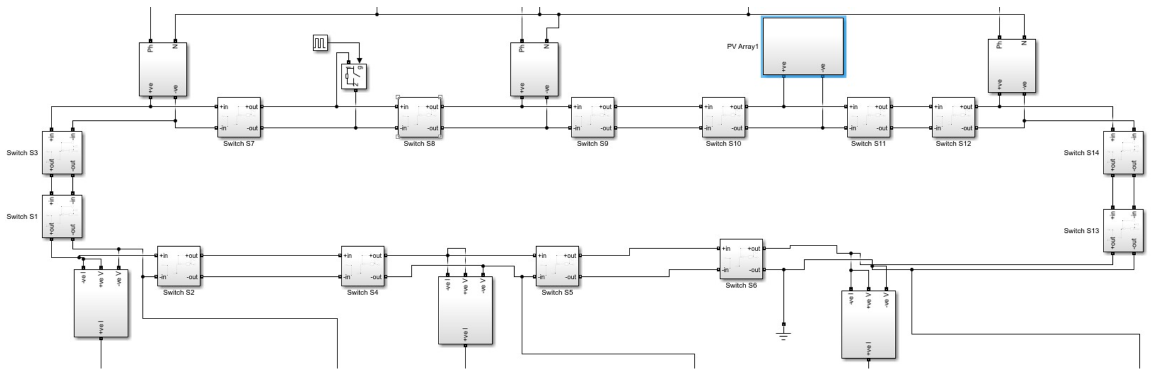

Figure 6. Ring-bus model with controllable switches

4.1. Protection scheme

The interior of the controllable switch is shown in Figure 7. Controllable switch consists of a measurement device that is used to measure the current and a switch that is used for isolating a fault. The measured current is sent to the centralized protection controller. Figure 8. Shows the centralized protection controller.

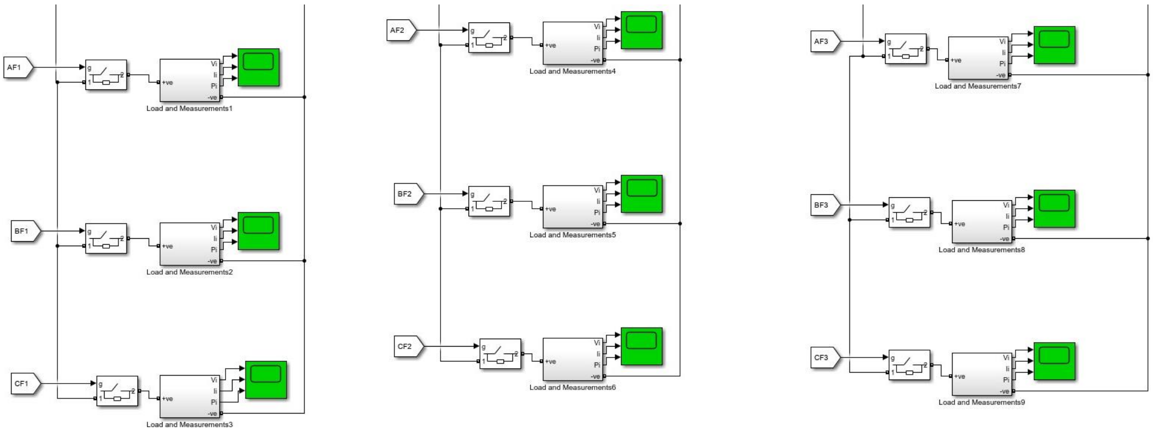

Figure. 7. Controllable switch

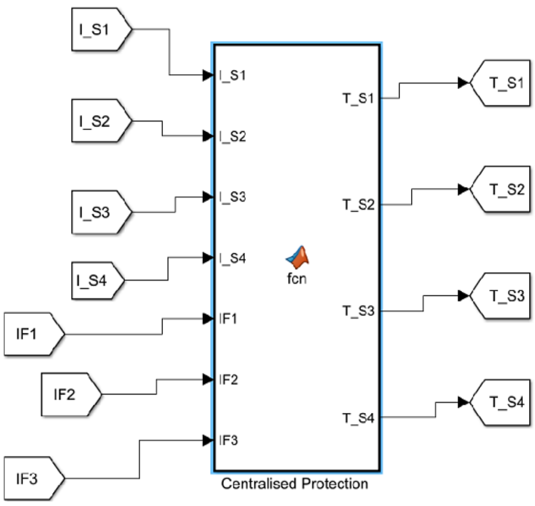

Figure 8. Centralized protection controller

4.2. Simulation results

For DC single-bus microgrid case, a short circuit fault is applied at T = 1 s. The voltage, current, and power at a load are shown in Figure 9. The switching states of the switches are shown in Figure 10. It is clear from Figure 9, that the voltage, current, and power drop to 0 right after the fault has occurred at T = 1 s. This can further be confirmed in Figure 10. Which Shows the switch condition showing OFF-state right after the fault has occurred at T = 1 s.

For DC ring-bus microgrid case, a short circuit fault is applied to a bus (say bus-1) at T = 1 s. The voltage, current, and power at a load are shown in Figure 11. The switching states of switches provided at a faulty bus are shown in Figure 12. The switching state of a switch provided at a fault-free bus is shown in Figure 13. It is clear from Figure 11, that the voltage, current and power don't drop even after a fault has occurred to bus-1 at T = 1 s. This can further be confirmed in Figure 12. Which shows the switch condition showing Off-state right after the fault has occurred at T = 1 s and from Figure13. Switch showing to be in ON-state even after the fault has occurred at T =1 s.

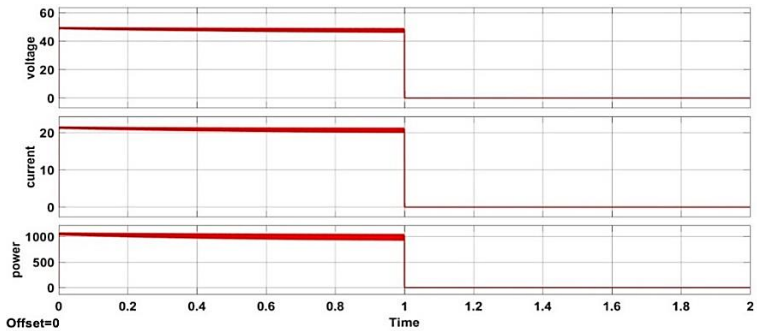

Figure 9. Voltage, current and power at a load

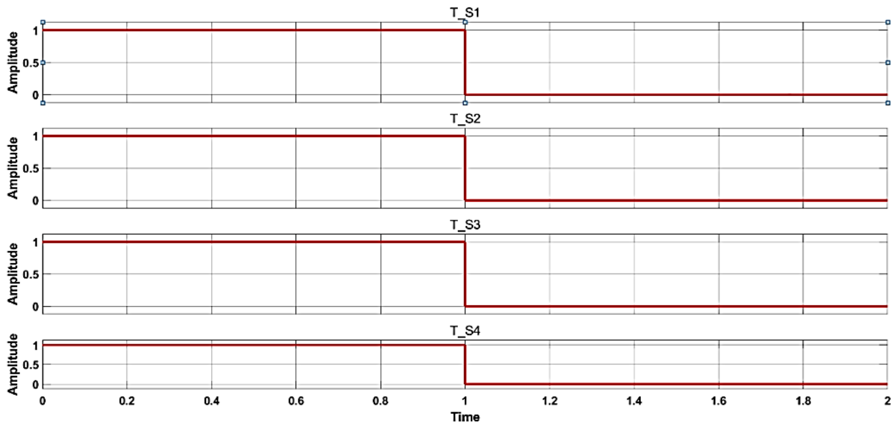

Figure 10. Switch states for controllable switches

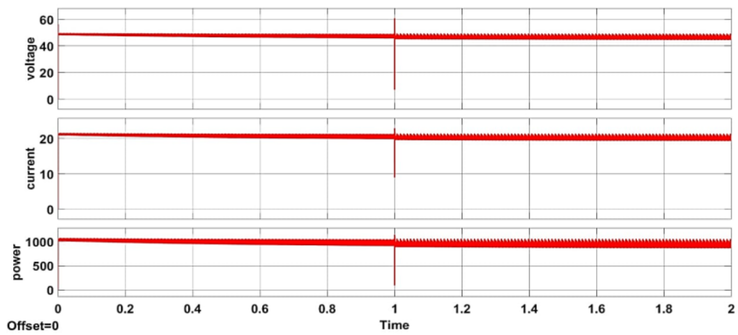

Figure 11. Voltage, current and power at a load

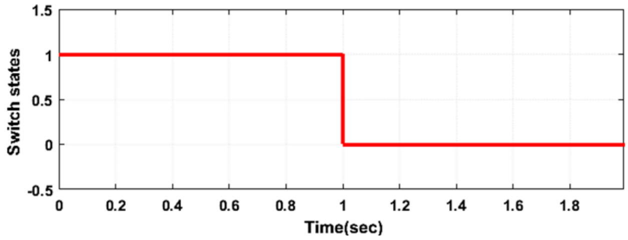

Figure 12. Switch states for switches at faulty bus

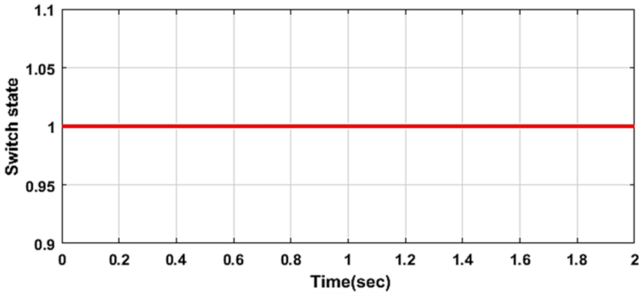

Figure 13. Switch state for the switch at fault-free bus

5. CONCLUSION

This paper proposes a primary protection scheme for the buses present in a DC microgrid. Two systems were considered, which were DC single-bus microgrid and DC ring-bus microgrid. The protection system employs differential current as a protection principle. Differential protection was applied with the help of a centralized protection controller, which enables fault detection and fault isolation. The results show that the protection scheme is effective in providing a reliable and safe operation of the DC microgrid and also demonstrates high levels of sensitivity in providing protection for possible bus faults.

REFERENCES

[1] R. M. Cuzner and G. Venkataramanan, "The status of DC micro-grid protection," in *Conference Record - IAS Annual Meeting (IEEE Industry Applications Society)*, Oct. 2008, pp. 1–8, doi: 10.1109/08IAS.2008.382.

[2] K. Chenchireddy and V. Jegathesan, "ANFIS based reduce device count DSTATCOM," *Journal of Applied Science and Engineering (Taiwan)*, vol. 26, no. 11, pp. 1657–1666, 2023, doi: 10.6180/jase.202311_26(11).0014.

[3] T. Dragičević, X. Lu, J. C. Vasquez, and J. M. Guerrero, "DC Microgrids - Part II: A Review of power architectures, applications, and standardization issues," *IEEE Transactions on Power Electronics*, vol. 31, no. 5, pp. 3528–3549, May 2016, doi: 10.1109/TPEL.2015.2464277.

[4] M. Saeedifard, M. Graovac, R. F. Dias, and R. Iravani, "DC power systems: Challenges and opportunities," in *IEEE PES General Meeting, PES 2010*, Jul. 2010, pp. 1–7, doi: 10.1109/PES.2010.5589736.

[5] D. Salomonsson, L. Söder, and A. Sannino, "Protection of low-voltage DC microgrids," *IEEE Transactions on Power Delivery*, vol. 24, no. 3, pp. 1045–1053, Jul. 2009, doi: 10.1109/TPWRD.2009.2016622.

[6] P. van Gelder and J. A. Ferreira, "Zero volt switching hybrid DC circuit breakers," in *Conference Record - IAS Annual Meeting (IEEE Industry Applications Society)*, 2000, vol. 5, pp. 2923–2927, doi: 10.1109/IAS.2000.882581.

[7] S. S. Rath, G. Panda, P. K. Ray, and A. Mohanty, "A comprehensive review on microgrid protection: Issues and challenges," in *3rd International Conference on Energy, Power and Environment: Towards Clean Energy Technologies, ICEPE 2020*, Mar. 2021, pp. 1–6, doi: 10.1109/ICEPE50861.2021.9404520.

[8] K. Chenchireddy and V. Jegathesan, "CHB multilevel inverter with sliding mode controller for DSTATCOM applications," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 4, p. 2195, Dec. 2023, doi: 10.11591/ijpeds.v14.i4.pp2195-2203.

[9] R. Ramaschi, S. Leva, A. Gobessi and M. Mauri, "Fuse-based protection system in a DC-microgrid for fast-charging applications: sizing and implications," 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, 2023, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194895.

[10] H. Miller, J. Burger, N. Fischer, and B. Kasztenny, "Modern line current differential protection solutions," in *2010 63rd Annual Conference for Protective Relay Engineers*, Mar. 2010, pp. 1–25, doi: 10.1109/CPRE.2010.5469504.

[11] D. G, B. Mangu, and M. H. Khan, "A capacitor-based boost nine-level inverter with less switching device count," in *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*, May 2023, pp. 1–5, doi: 10.1109/resem57584.2023.10236133.

[12] M. A. Kumar and A. Jaya Laxmi, "Power restoration based on intentional islanding algorithm for distributed energy resources in disaster management," *International Journal of Modelling and Simulation*, vol. 38, no. 3, pp. 189–206, Jul. 2018, doi:

10.1080/02286203.2017.1409686.
[13] M. Dewadasa, A. Ghosh, and G. Ledwich, "Protection of microgrids using differential relays," in *2011 21st Australasian Universities Power Engineering Conference, AUPEC 2011*, 2011.
[14] S. K. Prince, S. Affijulla, and G. Panda, "Protection of DC microgrids based on complex power during faults in On/Off-grid scenarios," *IEEE Transactions on Industry Applications*, vol. 59, no. 1, pp. 244–254, Jan. 2023, doi: 10.1109/TIA.2022.3206171.
[15] K. Chenchireddy and V. Jegathesan, "Cascaded H-bridge multilevel inverter-based DSTATCOM with an artificial neural fuzzy inference systembased controller," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 32, no. 1, p. 43, Oct. 2023, doi: 10.11591/ijeecs.v32.i1.pp43-51.
[16] G. K. Rao and P. Jena, "Unit protection of tapped line DC microgrid," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 10, no. 4, pp. 4680–4689, Aug. 2022, doi: 10.1109/JESTPE.2022.3143525.
[17] S. Yu, X. Wang, and C. Pang, "A pilot protection scheme of DC lines for MMC-HVDC grid using random matrix," *Journal of Modern Power Systems and Clean Energy*, vol. 11, no. 3, pp. 950–966, 2023, doi: 10.35833/MPCE.2021.000435.
[18] G. Dhasharatha, N. R. Varma, A. Spandana, P. A. Kumar, B. Venumadhav, and B. P. Kumar, "Design and implementation of three-phase three level NPC inverter," in *7th International Conference on Trends in Electronics and Informatics, ICOEI 2023 - Proceedings*, Apr. 2023, pp. 106–110, doi: 10.1109/ICOEI56765.2023.10125979.
[19] G. Kesava Rao and P. Jena, "Fault detection in DC microgrid based on the resistance estimation," *IEEE Systems Journal*, vol. 16, no. 1, pp. 1009–1020, Mar. 2022, doi: 10.1109/JSYST.2020.3046054.
[20] S. Roy and H. N. V. Pico, "Transient stability and active protection of power systems with grid-forming PV power plants," *IEEE Transactions on Power Systems*, vol. 38, no. 1, pp. 897–911, Jan. 2023, doi: 10.1109/TPWRS.2022.3165704.
[21] H. Yu, Z. Jin, H. Zhang, and V. Terzija, "A phasor estimation algorithm robust to decaying DC component," *IEEE Transactions on Power Delivery*, vol. 37, no. 2, pp. 860–870, Apr. 2022, doi: 10.1109/TPWRD.2021.3073135.
[22] R. Rajan, V. Rao, and G. V. N. Kumar, "Influence of static VAR compensator for undervoltage load shedding to avoid voltage instability," *International Journal of Applied Power Engineering (IJAPE)*, vol. 3, no. 2, pp. 124–129, 2014, doi: 10.11591/ijape.v3.i2.pp124-129.
[23] D. Tzelepis, S. M. Blair, A. Dysko, and C. Booth, "DC busbar protection for HVDC substations incorporating power restoration control based on dyadic sub-band tree structures," *IEEE Access*, vol. 7, pp. 11464–11473, 2019, doi: 10.1109/ACCESS.2019.2892202.
[24] S. Jena, S. Paladhi, and A. K. Pradhan, "Bus protection in systems with inverter interfaced renewables using composite sequence currents," *International Journal of Electrical Power and Energy Systems*, vol. 136, p. 107665, Mar. 2022, doi: 10.1016/j.ijepes.2021.107665.
[25] S. Baidya and C. Nandi, "A comprehensive review on DC Microgrid protection schemes," *Electric Power Systems Research*, vol. 210, p. 108051, Sep. 2022, doi: 10.1016/j.epsr.2022.108051.
[26] G. Dhasharatha, R. Varma, B. V. Ramana, K. Madhu, J. Chandra Shekar, and G. Nithin, "Z-source inverter for standalone application," in *Proceedings of the 8th International Conference on Communication and Electronics Systems, ICCES 2023*, Jun. 2023, pp. 26–31, doi: 10.1109/ICCES57224.2023.10192666.
[27] P. M. Anderson, C. Henville, R. Rifaat, B. Johnson, and S. Meliopoulos, "Line commutated converter HVDC protection," in *Power System Protection*, Wiley, 2022, pp. 973–1019.

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