

Appendix A

The method proposed in Chapter 3 is also validated on large system. A modified IEEE-14 bus DC microgrid given in [131] is considered, and modified to a 1200-V bipolar DC microgrid. Fig. A.1 shows the schematic of the test system. The line length and parameters are given in Table A.1. Conventional DC loads are connected at bus numbers 5, 7, 9, 11, 12, and 14.

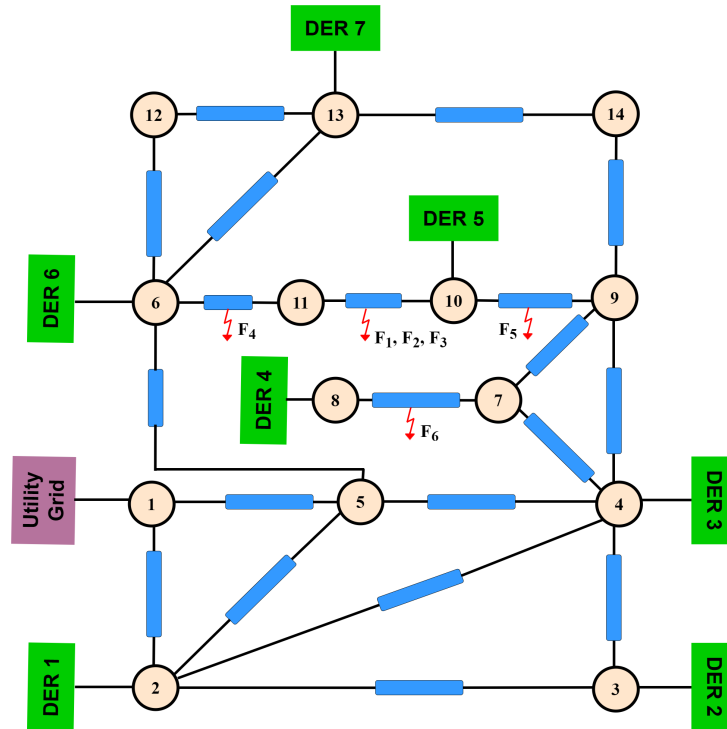


Figure A.1: Modified IEEE-14 bus system for a 1200-V bipolar DC microgrid.

Currents in the line section between bus-10 and bus-11 are considered for analysis, and any fault in the line section between bus-10 and bus-11 is considered as internal fault. The fault inception time is 0.1 sec.

Different internal faults, positive pole-to-ground (PGF), negative pole-to-ground (NGF), and pole-to-pole (PPF), F_1 , F_2 , and F_3 , respectively, in Fig. A.1, are simu-

Table A.1: Line lengths of the modified IEEE-14 bus DC microgrid.

From	To	Length (km)	From	To	Length (km)
1	2	2.25	6	11	7.58
1	5	8.5	6	12	9.75
2	3	7.5	6	13	4.95
2	4	6.7	7	8	6.7
2	5	6.63	7	9	4.2
3	4	6.5	9	10	3.22
4	5	1.6	9	14	1.03
4	7	1.0	10	11	7.31
4	9	4.95	12	13	7.62
5	6	4.95	13	14	1.33

Branch Parameters: $R=10 \text{ m}\Omega/\text{km}/\text{conductor}$, $L=100 \text{ }\mu\text{H}/\text{km}/\text{conductor}$.

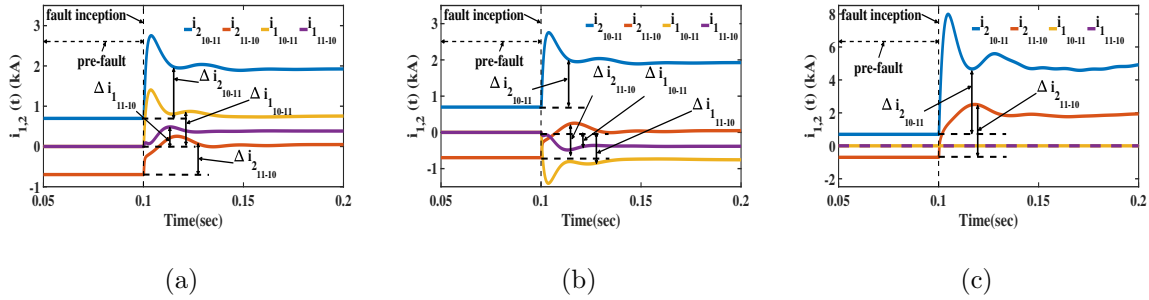


Figure A.2: Balance and unbalance Components for internal faults (a) F_1 (b) F_2 (c) F_3 .

lated, and the results are given in Fig. A.2. Refer to Fig. A.2, $i_{2_{10-11}}$ and $i_{1_{10-11}}$ are the symmetrical domain balance and unbalance currents, respectively, at bus-10. Similarly, $i_{2_{11-10}}$ and $i_{1_{11-10}}$ are the symmetrical domain balance and unbalance currents, respectively, at bus-11. Further, $\Delta i_{2_{10-11}}$, $\Delta i_{1_{10-11}}$ are the superimposed balance and unbalance components, respectively, at bus-10, and $\Delta i_{2_{11-10}}$, $\Delta i_{1_{11-10}}$ are the superimposed balance and unbalance components, respectively, at bus-11.

It is clear from Fig. A.2 that, for internal faults, $\Delta i_{2_{10-11}}$ and $\Delta i_{2_{11-10}}$, both are positive. Further, $\Delta i_{1_{10-11}}$ and $\Delta i_{1_{11-10}}$ are positive for PGF, Fig. A.2(a), negative for NGF, Fig. A.2(b), and zero for PPF, Fig. A.2(c), which clearly classify the internal faults.

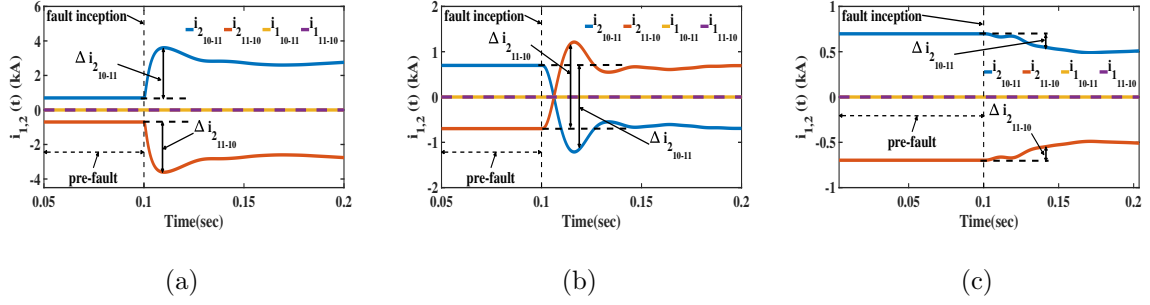


Figure A.3: Balance and unbalance Components for external faults (a) F_4 (b) F_5 (c) F_6 .

Fig. A.3 shows the simulation results for external faults. As shown in Fig. A.3(a), for a PPF in the line section between bus-6 and bus-11 (F_4), $\Delta i_{2_{10-11}}$ is positive and $\Delta i_{2_{11-10}}$ is negative. For a PPF in the line section between bus-9 and bus-10 (F_5), $\Delta i_{2_{10-11}}$ is negative and $\Delta i_{2_{11-10}}$ is positive, as shown in Fig. A.3(b). Fig. A.3(c) shows the simulation results for a PPF in the line section between bus-7 and bus-8 (F_6), and the value of $\Delta i_{2_{10-11}}$ is negative and $\Delta i_{2_{11-10}}$ is positive. The trajectory of Δi_2 in the Δi -plane for different

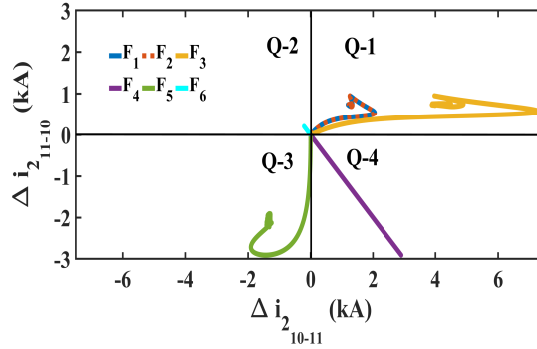


Figure A.4: Δi_2 in Δi -plane for internal and external faults.

internal and external faults is shown in Fig. A.4.

It is worth mentioning that, **the proposed method is a unit protection scheme that operates for any internal faults and does not respond to external disturbances, including faults. Therefore, the proposed scheme is independent of the size and topology of the system.**

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Publications Related to this Work

Journals

1. **A. Pandey**, and S. R. Mohanty, “Graph Convolutional Network Based Fault Detection and Identification for Low-voltage DC Microgrid,” *Journal of Modern Power Systems and Clean Energy*, vol. 11, no. 3, pp. 917-926, May 2023, doi: 10.35833/MPCE.2022.000251.
2. **A. Pandey**, S. R. Mohanty and R. Mohanty, “A Cyber Resilient Protection Scheme for Bipolar DC Microgrids using Symmetrical Component Decomposition,” *IEEE Transactions on Industrial Informatics*, vol. 20, no. 3, pp. 4481-4491, March 2024, doi: 10.1109/TII.2023.3325003.
3. **A. Pandey**, R. Mohanty and S. R. Mohanty, “Time-Domain Backup Protection for Converter Dominated Hybrid AC-DC Microgrids,” *IEEE Transactions on Industrial Informatics*, vol. 21, no. 9, pp. 7076-7085, Sept. 2025, doi: 10.1109/TII.2025.3574424.

Conference

1. **A. Pandey**, D.N. Kamath, and S. R. Mohanty, “Real-time simulation of Blockchain-Enabled Protection Scheme for DC Microgrids,” *2024 IEEE 11th Power India International Conference (PIICON)*, JAIPUR, India, 2024, pp. 1-6, doi: 10.1109/PI-ICON63519.2024.10995021