The Scientific Temper (2023) Vol. 14 (1): 256-263
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.1.35

E-ISSN: 2231-6396, ISSN: 0976-8653
https://scientifictemper.com/

RESEARCH ARTICLE

Fault analysis in hybrid microgrid for developing a suitable protection scheme

Sangeeta Modi[1*], P Usha[2]

Abstract

Microgrids are emerging as a promising solution to various concerns such as ecological, fiscal, depletion of the resources for fuel availability and power mismatch. A microgrid is an active distribution network that can be connected in islanded or grid-connected modes. Protection of microgrids is one of the main challenges in its implementation because of insufficient short circuit current, reverse power flow and frequent topological changes. Fault analysis is one of the prerequisites for designing the protection scheme of the system under consideration. This paper discusses the protection scheme prerequisites for a photo voltaic (PV) based microgrid topology. Fault analysis on a PV-based hybrid microgrid topology has been carried out and presented to decide the suitable protection algorithm for the controller. Analysis has been conducted assuming that at a given point PV sources supply sufficient power to the load. Fault analysis has been carried out on DC side as well as AC side of the microgrid.

Keywords: Hybrid Microgrid, Microgrid Challenges, Protection Issues, Fault analysis.

Introduction

The conventional power distribution system allows a unidirectional flow of power to the customers. In this system, the magnitude of short-circuit current is directly proportional to the fault current Therefore, a protection scheme is provided with overcurrent-based protection devices. Conventional protection schemes based on overcurrent relays are ineffective in protecting the microgrids due to various reasons such as variation in fault current levels, frequent change in topology, and reverse power flow. Hence there is a need to devise alternative protection schemes for microgrids. A microgrid is a controllable system comprising distributed generators, renewable energy sources, loads, energy storage systems and control devices.

Amandeep, Jitender and Prasenjit (2016) presented a comprehensive review on microgrid controller with the advanced features required for the controller to ensure stability and reliability. The literature also mentioned a research gap in the protection area of hybrid microgrid, which needs to be bridged to utilize the potential of hybrid microgrids.

Augustine *et al.* (2018) analyzed a low-voltage DC microgrid to understand the performance of protection devices available for DC microgrids. Daniel Salomonsson and Ambra Sannino (2009) presented trends in microgrid control.

Sahebkar Farkhani (2020), mentioned that with the advancement in technology and the emergence of microgrids, the conventional distribution system changed to an active network from passive network. This would change the entire operation of the distribution system and the conventional overcurrent-based protection devices can no longer be used. The contribution of fault current to the inverter-based DG source in MGs is only 2 to 3 times the maximum load current as the thermal capabilities of power electronic devices used for converters is low. Therefore, the traditional overcurrent-based protection device can no longer be used as it may not trigger when the fault occurs in islanded mode of operation.

The coordination of different types of relays is a big challenge for protection engineers in distributed generation-based distribution systems. Overcurrent relay

---

[1]Visvesvaraya Technological University, Belagavi, Karnataka, India

[1]People's Education Society University (PESU), Bengaluru, Karnataka, India

[2]Department of Electrical and Electronics Engineering, Dayananda Sagar College of Engineering, Bengaluru, Karnataka, India

***Corresponding Author:** Sangeeta Modi, People's Education Society University (PESU), Bengaluru, Karnataka, India, E-Mail: sangita.sanjna@gmail.com

How to cite this article: Modi, S., Usha, P. (2023). Fault analysis in hybrid microgrid for developing a suitable protection scheme. The Scientific Temper, **14**(1): 256-263.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.1.35

Source of support: Nil

Conflict of interest: None.

Received: 03/12/2022 **Accepted:** 15/12/2022 **Published** : 25/03/2023

coordination is a big challenge in such system as short circuit level of the system will vary according to the configuration of distribution system. An AC microgrid of 4 bus radial system has been considered for relay coordination. A gravitational search algorithm has been applied for the coordination of overcurrent relay in selected AC microgrid system. Time multiplayer settings and plug multiplayer settings of various relays were found out with the help of the gravitational search algorithm. The gravitational search algorithm was proved better than particle swarm optimization algorithm with respect to varying fault current levels.

Developing a robust protection scheme for microgrids proves to be challenging due to the bidirectional power flow, and inherent intermittency of renewable energy resources causing varying dynamics in fault currents. The latter reason also causes the irksome issue of blinding of protection, and sympathetic tripping. Blinding of protection refers to the controller's obliviousness in detecting a fault in the system due to reduced contribution from sources, and failure to recognize uncharacteristic current. Sympathetic or nuisance tripping can be defined as the operation of a protective device in an unfaulted segment or portion of the microgrid due to the presence of fault in another portion of the network. Nuisance tripping in microgrids with renewable resources can also occur due to a sudden change in irradiation, in the case of solar energy, Due to the absence of a frequency component and zero crossing, DC challenges are accompanied with unique challenges. Durgaprasad S., Nagaraja S.& Modi S (2022) mentioned that the challenges associated with DC faults requires high-speed circuit breakers to clear the fault and identify the faulted location in the loop. Mirsaeidi, S., Said, D.M., Mustafa, M.W. (2014) mentioned that challenges are attributed to the direction of fault current, coordination problems of current-based relay, change in the short circuit level, and low fault current capacity of inverters.

A review of research on cooperative control of microgrid with recent developments in wireless communication has been presented, which helps enable agent-based automation in a microgrid practically. The theoretical framework required for corporative control of microgrids has been presented with an example in this paper. Corporate control of microgrids is efficient and fast because of its ability to work in autonomous mode. It is also mentioned that next generation of 5G and IEEE 802.11 will support the corporative method of control for microgrids with deep learning and artificial intelligence techniques.

Microgrid Objectives and Challenges

Objectives of Microgrids

- Remote electrification and Local generation of power
- Reliable supply of power
- Clean sustainable energy

Challenges in Microgrid

- Protection of microgrid: Insufficient level of short circuit current
- Control & protection of microgrids is one of the major challenges.
- During any permanent fault, protection systems or devices should quickly isolate the microgrid from the main grid to protect the microgrid.
- Fault current levels vary as distributed generation units are connected to the grid, affecting the performance of the relays connected in the system.
- The reverse or backward power flow is also one of the main challenges for microgrid operation.
- Topological changes due to connections/disconnections of DG's.

Protection of a microgrid is a major challenge in the development of a renewable energy-based microgrid project. A microgrid is an active distribution network that can operate in grid-connected and islanded mode. It is a cluster of distributed generators. There are various types of protection devices that can be employed for the protection of microgrids.

J. M. Tripathi, Adhishree and R. Krishan(2014) mentioned that regular overcurrent relays cannot be employed to protect the microgrid when changeover from one mode to the other mode occurs. The reason behind this is the difference in short circuit current in both the mode, this will affect the performance of the relay in terms of time of operation and also relay may fail to operate. Therefore, coordination and setting of the relays need to be updated on regular intervals. Most of the DG's are renewable in nature and are grid integrated via power electronic devices in between. Also, there are storage devices integrated to the system to enhance reliability as renewable energy sources are intermittent sources. The low-voltage dc microgrid is employed to integrate Distributed generators and sensitive loads, especially electronic loads.

Modi S and Usha P (2021) discussed the integration of various DG's, storage devices and loads via power electronic interfaces. Integration of distributed generators at various points makes the microgrid to respond to the fault current in a different way. Fault current may change according to the selected device. So, coordination of these devices is very much required. For this purpose, it is required to analyse the system behavior properly against various types of faults. Load flow analysis can be carried out for this purpose. Microgrid configuration plays an important role in deciding the settings of the protective devices. Depending upon the configuration selected fault current may vary in the various devices integrated in the system. One of the important requirements in microgrid protection is of very fast real time communication channel between the protective devices and the master controller unit to ensure security and reliability. Detection and location of fault can be found out with the help of these communication channels based on most sensible standards such as IEC 61850.

As compared to traditional ac distribution systems, microgrid protection has been challenging for a dc system. Lin ZHANG et al(2018) presented effective control strategies and fault characteristics in case of DC microgrid. Grounding issues are also addressed and it is mentioned that ungrounded mode is highly recommended in low volage applications.

Jae-Do Park(2013) mentioned that fault location can be found out by applying the traveling waves concept. This approach has been tailored for ac fault protection as well.

The difference between the two arrival times along with the wave propagation velocity, can identify the fault location. ‘X_f is the distance between the relay and the fault, v is the wave propagation velocity, and t1 and t2 are the arrival times of the traveling waves.

Senarathna TSS (2019) presented review of the adaptive protection scheme. The best part of the developed adaptive protection scheme is that it monitors the microgrid continuously and updates relay fault current immediately according to the conditions in the system but this scheme is not capable of finding the shortest path of isolation.

R. Sitharthan a, M. Geethanjali b, T. Karpaga Senthil Pandy(2016) presented a systematic review on the adaptive protection of microgrids, including a wide range of applicability variants, their strengths, and drawbacks. It also explores the state-of-the-art research that utilize computational intelligence to achieve adaptive protection.

Sahebkar Farkhani (2020) presented the central controller involving multiple features for properly coordinating distributed energy resources to serve the critical and non-critical loads. Initiation of protection techniques at the time of fault occurrence at the grid end or in microgrid ensures stability and reliability in the system.

One of the major challenges in the protection of microgrids under islanded mode is the loss of neutral connection of the transformer. To avoid this situation or overcome this limitation, the transformer is directly earthed by using delta wye connection. The transformer is required to connect DG units to the microgrid for galvanic isolation. It is always advisable to divide the complete microgrid network into number of zones. Point of common coupling (PCC) zone could be the main zone where high-speed CBs with suitable relays are required.

Xiaonang Kang, Carl and Browth (2017) mentioned that protection challenges needing serious care and awareness. This is required for the implementation of microgrid protection schemes.

Features of Protection Scheme Employed for Microgrid

- Faster operation during high voltage dips (by using high speed standard-based communication IEC-61850)
- Adaption capability
- Discrimination: unrequired operation of protective devices should be avoided
- Operation should be reliable.

Block Diagram of the System

Figure 1 and 2 shows the block diagram of system under consideration. On DC side of the bidirectional converter two PV panels are connected along with boost converters to increase the available voltage to the desired level as per the load requirement. On AC side of the bidirectional converter AC load is connected and provision for the utility grid is also given. In order to obtain power balance in the system, the utility grid will supply power to the loads if the renewable sources connected in the system cannot provide sufficient power as they are intermittent.

In this paper microgrid analysis has been carried out for line to ground fault on AC and DC side of the microgrid. Voltage and frequency parameter deviation is observed at various microgrid points under grid and islanded mode of operation and is presented in Table 2.

Line to ground (LG) are the most common fault in the DC side. In AC side, LG faults comprise of 65–70% of the faults. Line to line (LL) and double line to ground fault (LLG) are less frequent. Triple line to ground (LLLG) and triple line (LLL) faults are rare. These faults are also known as balanced faults. In the next section main components of the microgrid are described.

Photo Voltaic (PV) System

Solar Arrays consist of various series-parallel combinations of solar cells. Solar cells in general have efficiency range from 11% to over 20 %. Since power output for PV array is intermittent, DC to DC converter is connected to provide constant DC to the inverter. The maximum power point tracking mechanism is added to the boost converter to

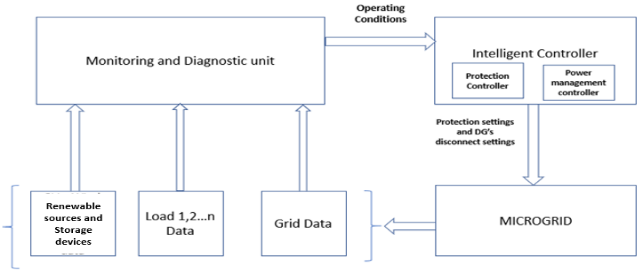


Figure 1: Block diagram of the system under consideration

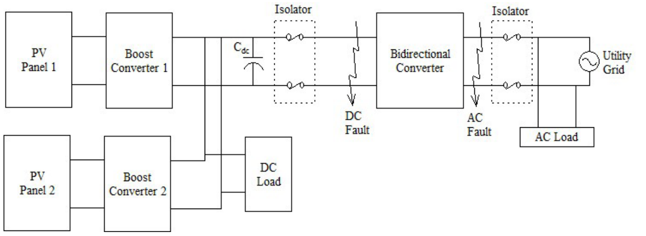


Figure 2: Block diagram of the microgrid (with fault location)

Table 1: Description of the System

Parameter	*Specification*
Utility Grid	230V, 50Hz AC
PV Panel Power Output	250W
Maximum Power Point Voltage	30.23V
Maximum Power Point Current	8.27A
Open Circuit Voltage	37.6V
Short-Circuit Current	8.8A
Inverter rating	2KVA
DC Load	50W, 250W
AC Critical Load	700W, 525VAR (0.8 p.f.)
AC Non-Critical Load	300W, 225VAR(0.8 p.f.)

extract maximum power from the PV array. Describing equations for the selected PV model are shown below:

$$I_d = I_0 * (e^{qV/nkTn} - 1) \quad (1)$$

$$Iph = [Isc + Ki*(T - 298)] * Ir/ 1000 \quad (2)$$

$$I = Iph - I0*(e^{qV / nkT} - 1) \quad (3)$$

Where,
I is the PV output current.
Iph is the photo current.
I_0 is the diode current
Ish is the shunt current.
V is the open circuit voltage;
q is the electron charge (1.6×10^{-19} C)
V is the open-circuit voltage
η is the ideality factor of diode
T is the operating temperature

Boost Converter

Boost converter is a DC-DC converter used to boost the voltage at desired level by stepping up the output voltage of solar panel by switching the switch at a desired frequency. Describing equation of this is shown below:
Voltage Output of boost converter is given by,

$$\frac{V_b}{V_s} = \frac{1}{1-D} \quad (4)$$

where,
V_s is the input to the Boost Converter;
V_b is the output of the Boost Converter;
D is the duty cycle of Boost Converter; In this work, Single-phase Full Bridge Inverter is utilized to convert DC to AC power. Switching is controlled by Sinusoidal Pulse Width Modulation Technique (SPWM). Reference (Sinusoidal) and High-Frequency Carrier signals (triangular or sawtooth) are fed to the comparator to generate pulses of varying amplitude and pulse duration. Modeling equation for the boost converter under open switch as shown in Figure 3 is derived as,

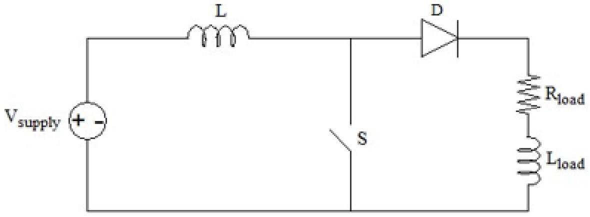


Figure 3: Boost Converter under open switch condition

$$V_{boost} = E + e^{-\left(\frac{R_{load}}{L+L_{load}}\right)(t-t_s)} \left[i(t_s) \left(\frac{L-L_{load}}{L+L_{load}}\right) R_{load} - E + E\frac{L_{load}}{R_{load}} - i(t_s)\left(\frac{L-L_{load}}{L+L_{load}}\right) L_{load} + i'(t_s) L_{load} \right] \quad (5)$$

Method

Power Balance for Power management

Equation 6 and 7 are the power balance equations considered for the system under consideration:

$$\sum_{i=0}^{n} Pgi = Pdi;\ without\ losses\ (6)$$

$$\sum_{i=0}^{n} Pgi = Pdi + Pl_{oss}\text{ ; With Losses} \quad (7)$$

$$Pmin \le Pi \le Pmax \quad (8)$$

Where Pgi is the power generated by ith generating unit, Pdi is the power demanded by the load. is the power lost in heat losses.

If required, the selected microgrid provision has been given for connecting multiple renewable sources (RS). Grid-connected mode (with Utility Grid) and islanded mode of operation are considered for the analysis purpose. DC bus is maintained at 480V and AC bus is maintained at 400V, 50Hz. AC and DC loads are given supply from AC and DC bus, respectively. AC and DC sides are linked together by power-electronic interfaces such as inverters, converters, and bi-directional converters. The controller switches different sources based on input data of power generated and customer demand.

Fault Analysis – Parameters Variation Detection

To devise a suitable protection scheme, one must perform fault analysis. Different faults are created in different region of the system and its responses are analysed.

Flow Chart

Flow chart of the proposed work has been shown in Figure **4.** In this work fault detection and analysis has been carried out for a PV based microgrid is analyzed for LG faults on DC and AC side the microgrid.

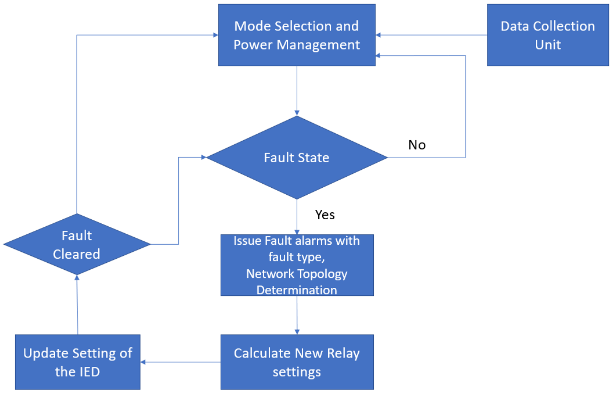


Figure 4: Flow chart for fault detection and relay setting

Fault on DC side under Grid-connected mode

When fault occurs at the DC side at 0.5s, its terminals are shorted; hence, DC terminal voltage and AC load current drops as shown in Figures 5 and 6, respectively. This change in the load current is used to detect the fault by generating a control signal to the breaker which isolates the fault from grid. Generated control signal is shown in Figure 7 which takes 19.5 ms delay from fault occurrence.

Fault on AC side under Grid-connected mode

When fault occurs at AC side at 0.5s, its terminals are shorted and hence AC and DC terminal voltage, AC load current drops as shown in Figure 8 and 9. This change in the load current is used to detect the fault by generating a control signal to the breaker which isolates the fault from grid. The generated control signal is shown in Figure 10 which takes 10.03 ms delay from fault occurrence. Appropriately, we need to set the protective device trip time.

Fault on DC side under Islanded mode

When fault occurs at DC side at 1.5s, DC terminals are shorted and hence AC and DC terminal voltage, AC load current drops as shown in Figures 11 and 12, respectively. This change in the load current is used to detect the fault by generating a control signal to the breaker which isolates the fault from grid. The generated control signal is shown in Figure 13 which takes 5.34ms delay from fault occurrence. Consequently, we need to set the protective device trip time.

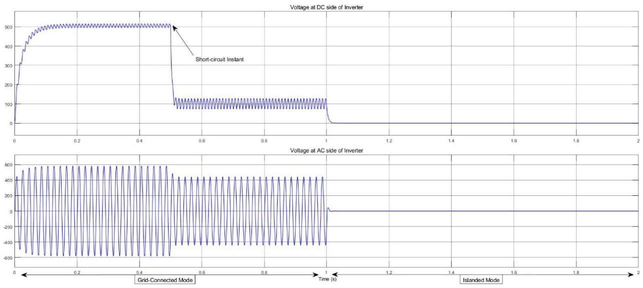


Figure 5: Converter's side DC and AC Voltage

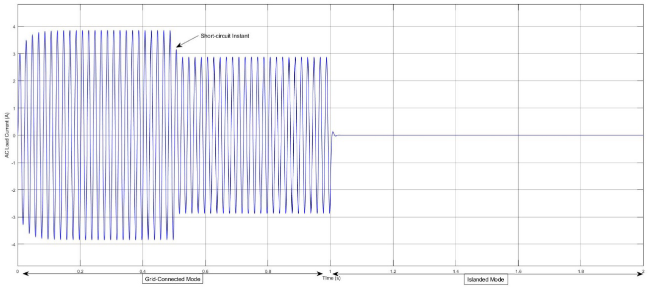


Figure 6: Load current on AC side

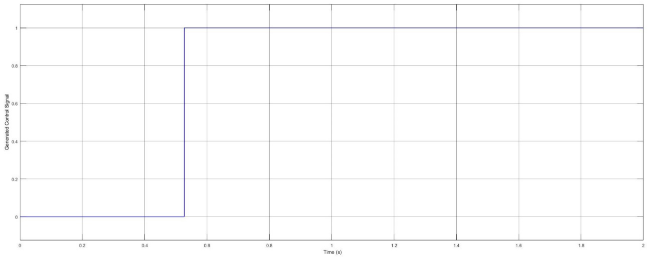


Figure 7: Control signal generated

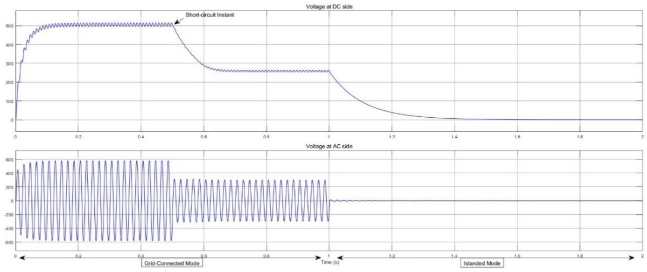


Figure 8: DC and AC voltage of converter

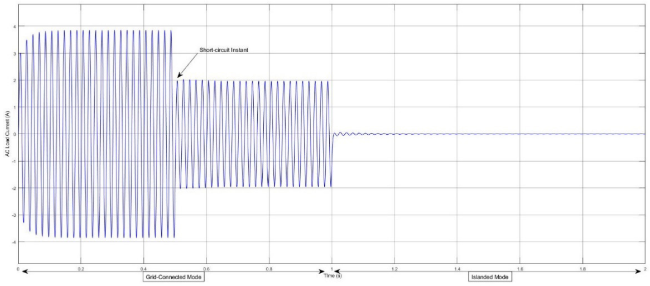


Figure 9: AC Load current

Fault on AC side under Islanded mode

When fault occurs at AC side at 1.5s, AC terminals are shorted and hence AC and DC terminal voltage, AC load current drops as shown in Figures 14 and 15, respectively. This change in the load current is used to detect the fault by generating a control signal to the breaker which isolates the fault from grid. The generated control signal is shown in Figure 16 which takes 5.33ms delay from fault occurrence. Therefore, we need to set the protective device trip time in this section of the circuit.

Breaker tripping time is the sum of breaker sensing time, breaker opening time and arcing time.

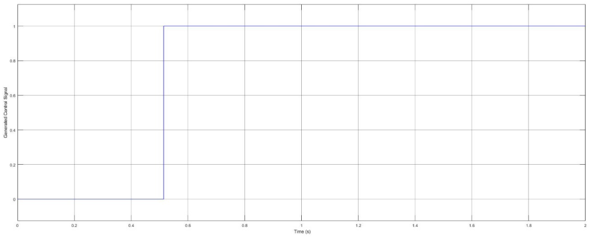


Figure 10: Generated control signal

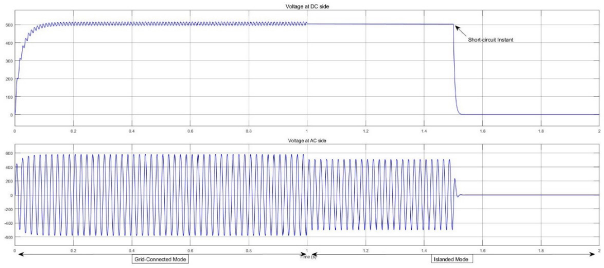


Figure 11: DC and AC Voltage of converter

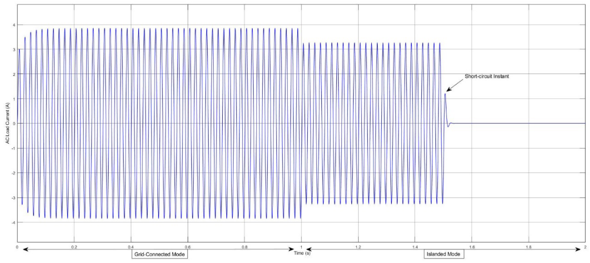


Figure 12: AC Load current

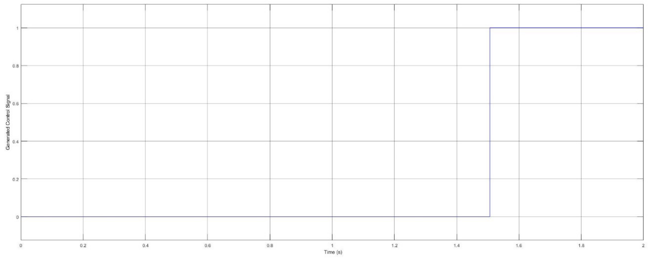


Figure 13: Generated control signal

Fault clearing time

=Relaying time

+Breaker opening time

+Arcing time

where,

Relaying time is the time the relay takes to sense the fault and generate relay signal.

Breaker opening time is the time taken by the breaker to open its contacts after sensing fault.

Arcing time is the time taken from opening circuit breaker contacts to arc extinction.

It is observed that there is a delay between fault occurrence and issue of control signal

generation for the circuit breaker. This relaying time may depend on the type of relay used for operation. Due to the fault, variations in voltage and frequency are observed.

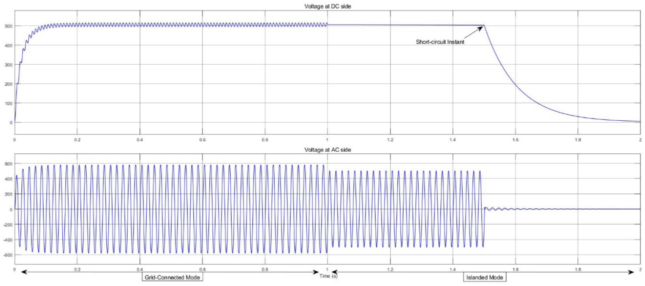


Figure 14: DC and AC voltage of converter

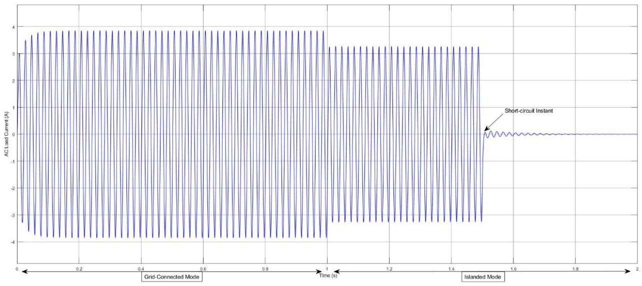


Figure 15: AC Load current

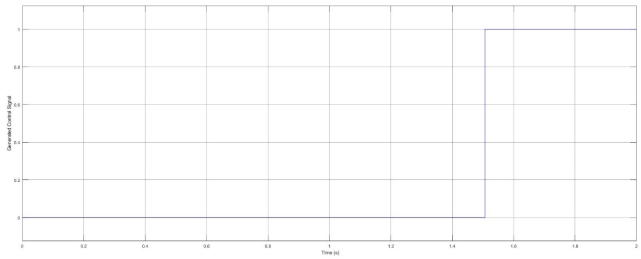
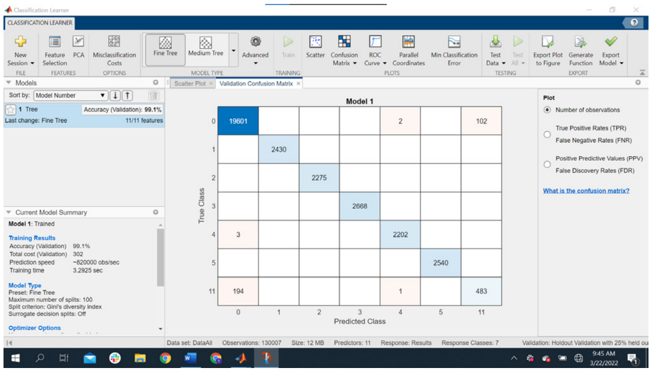


Figure 16: Generated control signal



Sort by: Model Number

1 Tree Accuracy (Validation): 99.1%
Last change: Fine Tree 11/11 features

Current Model Summary

Model 1: Trained

Training Results
Accuracy (Validation) 99.1%
Total cost (Validation) 302
Prediction speed ~820000 obs/sec
Training time 3.2925 sec

Model Type
Preset: Fine Tree
Maximum number of splits: 100
Split criterion: Gini's diversity index
Surrogate decision splits: Off

Optimizer Options

Model 1

True Class \ Predicted Class	0	1	2	3	4	5	11
0	19601				2		102
1		2430					
2			2275				
3				2668			
4	3				2202		
5						2540	
11	194				1		483

● Number of observations
○ True Positive Rates (TPR) False Negative Rates (FNR)
○ Positive Predictive Values (PPV) False Discovery Rates (FDR)

Data set: DataAll Observations: 130007 Size: 12 MB Predictors: 11 Response: Results Response Classes: 7 Validation: Holdout Validation with 25% held ou

Figure 17: Future Scope of the work – Machine Learning Algorithm for detection

Table. 2 result reveals that maximum variation is detected in voltage and frequency parameters under is landed mode of operation compared to grid mode. The frequency oscillations observed were temporary and it was stabilized after few milliseconds. But the variation in voltage was observed to be sustained. This data can be used to set the operating time of relay and circuit breaker to protect the grid and solar panels circuit. Suppose short-circuit fault occurs at DC or AC side of the converter. In that case, relevant faulty section is isolated from with the help of the associated relay connected in the same section. For isolating faults, isolators

Table 2: Variation in Voltage and Frequency

Fault Side	*Mode*	*% Voltage (ΔV)*	*% frequency (Δf)*
DC	Grid	25.1	0.1
AC	Grid	48.9	0.14
DC	Islanded	100	0.56
AC	Islanded	99.84	0.14

or circuit breakers can be used or intelligent electronic devices can be used. The results presented in this paper can be used for setting the desired relay for the specific zone of protection, which will give trip command to the associated circuit breaker.

Application of Machine learning Algorithm

In the future, Fault detection can be carried out by applying machine learning algorithm. The accuracy of the algorithm can be verified by the confusion matrix obtained for various faults as shown in Figure 17.

Discussion

In this study, fault analysis on hybrid microgrid has been carried out. Variation in voltage, current and frequency parameters was observed as shown in Figure 6-16. Percentage deviation in voltage and frequency has been calculated and presented under a microgrid's grid-connected and islanded mode. It was observed that voltage deviation is maximum under islanded mode compared to grid-connected mode. These parameters can be employed for setting the operation time of a relay for protecting the microgrid against various types of faults and

In the literature little attention has been paid in this area. We believe that this work will be a valuable resource for the researchers trying to devise protection scheme for the microgrid. Additionally, the application of machine learning is suggested for fault detection in microgrid. Figure 17 shows machine learning-based fine tree algorithm performance for fault detection. In the future, the performance of various machine learning algorithms can be found out and compared to devise a suitable protection scheme for the modern grid.

Conclusion

In this study analysis of the hybrid microgrid is presented. The results obtained in this work can be applied for setting the desired protective relay for protecting the microgrid. Fault analysis is highly required before devising a protection scheme for the microgrid. Future work may involve an adaptive protection scheme using microcontrollers which can be realized for the microgrid under consideration as a continuation of the work presented here.

Future work may be carried out in devising an accurate and setting less protection scheme for the microgrid by applying machine learning algorithms for the microgrid controller.

Acknowledgements

I would like to express my sincere thanks and gratitude to my guide for her continuous support and guidance. I am also thankful to the PES University, Bengaluru staff for their continuous support during this research work.

Conflicts of Interest

The authors declare that this research was carried out without any financial or commercial ties and there is no conflict of interest with respect to research, authorship and publication of this paper.

Reference

Amandeep Kaur, Jitender Kaushal, Prasenjit Basak(2016).A review on microgrid central controller. Renewable and Sustainable Energy Reviews Volume 55, Pages 338-345

Augustine, Sijo, Quiroz, Jimmy Edward, Reno, Matthew J., and Brahma, Sukumar(2018). DC Microgrid Protection: Review and Challenges. Web. doi:10.2172/1465634.

Daniel Salomonsson, Student Member, IEEE, Lennart Söder, Member, IEEE, and Ambra Sannino, Member, IEEE(2009). Protection of Low-Voltage DC Microgrids.IEEE Transactions on Power Delivery. DOI: 10.1109/TPWRD.2009.2016622 · Source: IEEE Xplore

Durgaprasad S., Nagaraja S., Modi S. (2022). HVDC Fault Analysis and Protection Scheme. Lecture Notes in Electrical Engineering, Springer, Singapore, vol 767. https://doi.org/10.1007/978-981-16-1642-6_18

J.M.Tripathi, Adhishree and R. Krishan(2014).Optimal coordination of overcurrent relays using gravitational search algorithm with DG penetration. 6th IEEE Power India International Conference (PIICON),pp.1-6.doi: 10.1109/POWERI.2014.7117615.

Jae-Do Park, Member, IEEE, and Jared Candelaria, Student Member, IEEE(2013).Fault Detection and Isolation in Low-Voltage DC-Bus Microgrid System.IEEE Transactions On Power Delivery, Vol. 28, No. 2

Kamel, R.M., Chaouachi, A., Nagasaka, K.(2011). Comparison the performances of three earthing systems for micro-grid protection during the grid connected mode. Smart Grid and Renewable Energy, 02(03),206-215.DOI:10.4236/sgre.2011.23024

Lin ZHANG1, Nengling TAI1, Wentao HUANG1, Jian LIU1, Yanhong WANG1(2018).A review on protection of DC microgrids. J. Mod. Power Syst. Clean Energy. 6(6):1113–1127. https://doi.org/10.1007/s40565-018-0381-9

Mirsaeidi, S., Said, D.M., Mustafa, M.W., et al(2014).Progress and problems in micro-grid protection schemes. Renewable and Sustainable Energy Reviews 37, pp.834–839, 10.1016/j.rser.2014.05.044

Modi S., Usha P. (2021). Renewable Energy Source Based Microgrid: Control and Dynamics. Part of Lecture Notes in Electrical Engineering, vol 661. Springer, Singapore. https://doi.org/10.1007/978-981-15-4692-1_12 .

R. Sitharthan a,*, M. Geethanjali b, T. Karpaga Senthil Pandy(2016). Adaptive protection scheme for smart microgrid. with electronically coupled distributed generations. Alexandria Engineering Journal Volume 55, Issue 3, Pages 2539-2550

Sahebkar Farkhani, J.; Zareein, M.; Najafi, A.; Melicio, R.;

Rodrigues(2020). The Power System and Microgrid Protection-A Review. Appl. Sci. 2020, 10, 8271. https://doi.org/10.3390/app10228271

T S S Senarathna and K T M Udayanga Hemapala(2019). Review of adaptive protection methods for microgrids. Department of Electrical Engineering, University of Moratuwa, Moratuwa, Sri LankaAIMS Energy, 7(5): 557–578. DOI: 10.3934/energy.2019.5.557

Xiaoning Kang1, Carl E.K. Nuworklo1, Browh Serge Tekpeti1, Mostafa Kheshti (2017) “ Protection of micro-grid systems: a comprehensive survey” The 6th International Conference on Renewable Power Generation (RPG)