World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

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Microgrid protection using FACTS controller and machine learning

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World Journal of Advanced Research and Reviews, 2024, 22(03), 1796–1800

Publication history: Received on 17 May 2024; revised on 26 June 2024; accepted on 28 June 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.22.3.1902

Abstract

This research presents a method of machine learning approach for microgrid protection using FACTS Controllers. A Microgrid connected to the Distributed Generators connected with different types of load is very prone to faults. This work uses wavelet transform to predict the failure signals, which is then fed into a machine learning model for real-time identification. These current signals from both ends of the transmission lines are analyzed using wavelet-based multi-resolution analysis, and then compare the results to preset thresholds to generate fault indices. This approach offers a power quality enhanced microgrid protection solution with lower losses and increased dependability.

Keywords: Micro-grid; FACTS; Distributed Generators; Machine Learning; Wavelet Transform

1. Introduction

Microgrid protection is severely protected by FACTS Controllers, which frequently results in fault analysis. STATCOM, DVR and UPFCs, flexible AC transmission systems (FACTS), are main elements of controlling power flow in microgrid. Their addition of reactive and actual power improves voltage stability and grid flexibility. The protective system is made more difficult by their integration of DG. This work is based on a wavelet-based microgrid protection system that uses FACTS and machine learning approaches to increase performance in order to address the failure [1,2].

For the investigation of momentary signals at different frequencies, the wavelet transform (WT) provides an effective tool. Machine learning algorithms use the retrieved features as training data. The trained model shows remarkable precision in detecting and classifying microgrid malfunctions.

2. Mathematical Modelling

The system considered for study is as shown in Figure 1, it is a single-line diagram consisting of 9 zones, where in 3rd zone the FACTS controllers are located. The c grid is 900MVA. Phase angle, impedance, voltage, and other elements that affect power flow in the transmission line are all fully controllable by the FACTS It has the capacity to independently control the actual and reactive power flow in the line[3][6].

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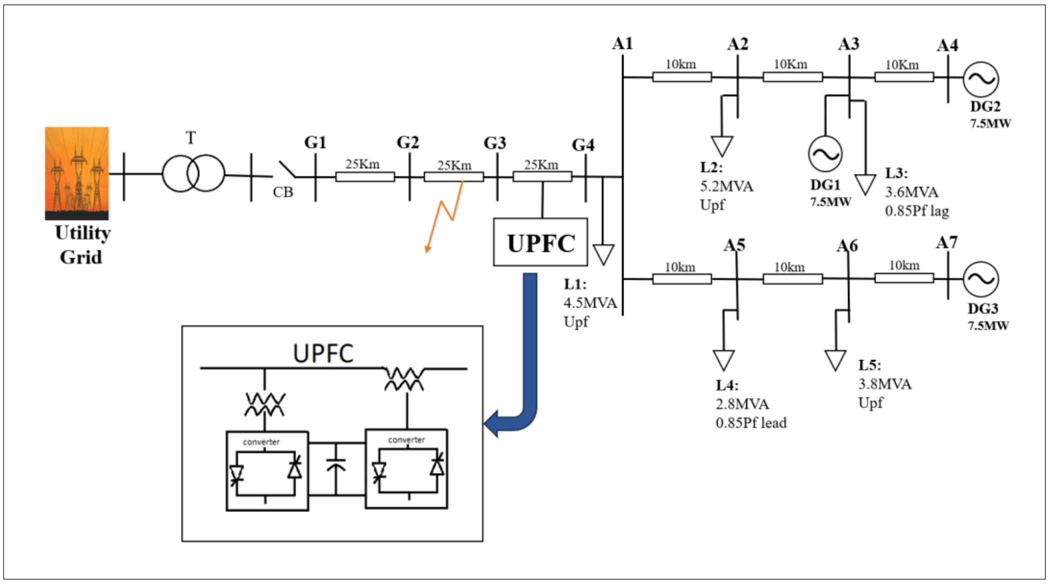

Figure 1 Single Line Diagram of Proposed Network

$$P = \frac{V_2 V_3}{X} \sin \delta,$$
$$Q = \frac{V_2}{X} (V_2 - V_3 \cos \delta)\,. \qquad \text{………………… (1)}$$

The transmission current is controlled by these VSCs. In a transmission line, the current flow is given by

$$I = \frac{V_1 V_2}{X} (V_1 \cos \delta - V_2) \qquad \text{………………(2)}$$

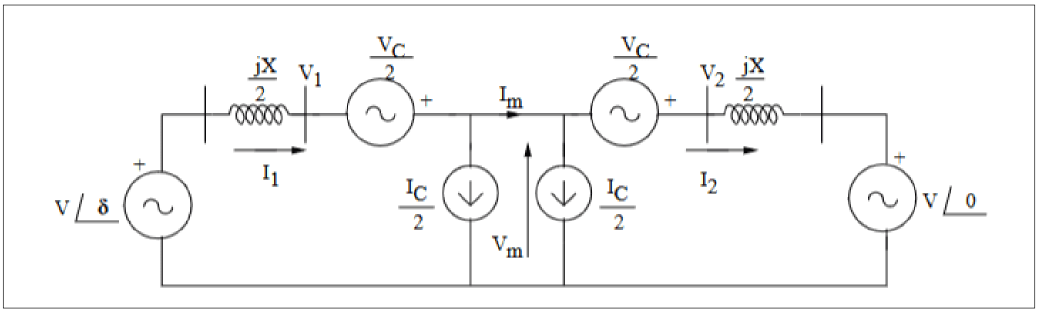

Figure 2 System equivalent circuits

$$V\angle\delta - j\frac{X}{2}\left(I_m + \frac{I_C}{2}\right) + \frac{V_C}{2} = V_m$$
$$V\angle 0 + j\frac{X}{2}\left(I_m - \frac{I_C}{2}\right) - \frac{V_C}{2} = V_m \qquad \text{……………… (3)}$$

The active and passive power outputs at the port 2 of the UPFC are provided by

$$P + jQ = \left(V_m + \frac{V_C}{2}\right)\left(I_m - \frac{I_C}{2}\right)^*$$
$$= V_m I_m^* + \frac{1}{2}\left(V_C I_m^* - V_m I_C^*\right) - \frac{V_C I_C^*}{4} \qquad \text{…………… (4)}$$

The power is maximized when and Pmax is given by

$$P_{\max} = \frac{V^2}{X}\sin\delta + \frac{V_C V}{X}\cos\frac{\delta}{2} + \frac{I_C V}{2}\sin\frac{\delta}{2} \quad \text{............... (5)}$$

3. Machine learning in system protection

Machine learning techniques are used in the third stage to help with defect description and detection. These methods include encoding and decoding of data items, support vector machines (SVM), and wavelet multi-resolution analysis(MRA). Furthermore, non-linear interactions between dependent and independent data items are captured by artificial neural networks (ANN), removing the requirement for intensive statistical data extraction. During the last stage, the system forecasts the result and assesses if the issue has been fixed [4]

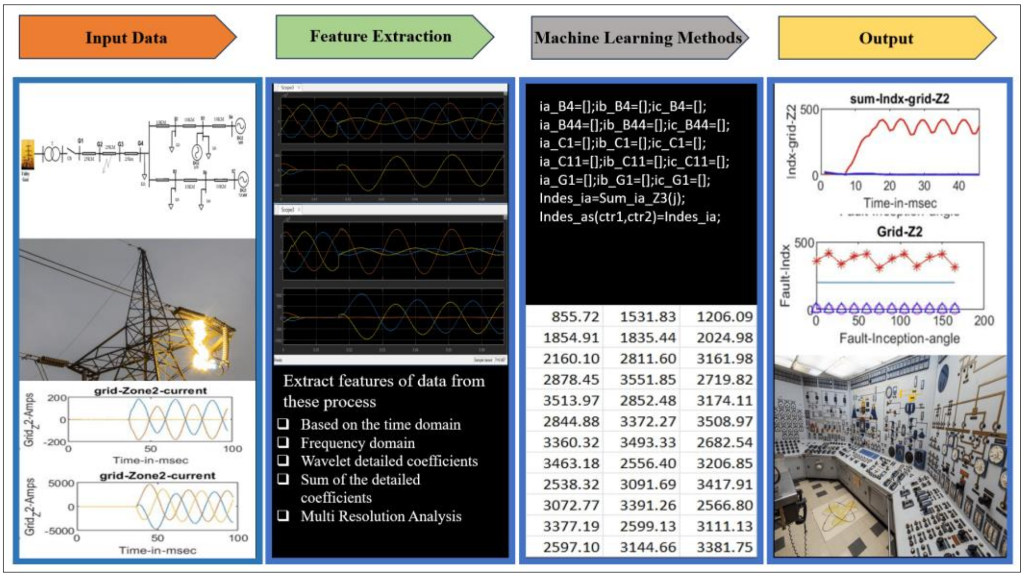

Figure 3 Fault detection using machine learning approach

4. Fault impact analysis in protection scheme

To guarantee the stability and reliability of microgrid systems, it is important to analyze the consequences of errorsin the protection strategy. This means assessing a number of variables, including operational disruptions, equipment damage, system stability, fault detection accuracy, and safety considerations. Through the implementation of a thorough study that encompasses fault implications, vulnerability identification, protective measure optimization, and mitigation, overall microgrid performance can be improved. This allows for smooth functioning while protecting workers and equipment [5].

4.1. Impact Analysis of STATCOM

Data from wavelet enumerated values of multi-resolution analysis of the connected and idle modes of the grid under AG-fault in zone 2 are shown in Table 1. In order to analyze fault situations and diagnose issues inside the microgrid system and enable efficient fault detection and mitigation techniques, this data is an essential resource.

4.2. Impact analysis of SSSC

A distinct threshold value, which is the lowest value of both faulty and healthy line data, is used to credit the faulty phases with analogy to the healthy phase. Wavelet-based diagnosis was utilized to examine four grid operating modes: connected, idle, idle-SSSC, and SSSC connected, for fault investigation.

A zone-2 AG-fault's wavelet enumerated values in the table provided information about the fault conditions and system behavior. It was possible to construct effective fault detection and mitigation strategies by comparing these values across modes.

4.3. Impact analysis of UPFC

A distinct threshold value is used for fault detection, which is obtained from the lowest value between the faulty and healthy line data during an AG-fault in zone 2. This allows the microgrid system to precisely identify and diagnose faults.

Table 1 Fault impact analysis

Impact Analysis of Fault at STATCOM integrated with DG												
FIA	**Fault Index Grid Idle**			**Fault Index Grid Idle-STATCOM**			**Fault Index Grid connected**			**Fault Index Grid-STATCOM Connected**		
	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic
0	1004.07	5.07	5.20	736.45	6.13	5.37	416.12	8.26	6.52	290.21	7.46	5.84
15	1293.30	2.97	2.53	699.02	4.05	3.11	557.81	4.03	3.17	253.56	4.28	5.75
30	1106.40	2.33	2.98	573.70	5.08	2.65	501.49	2.46	2.75	300.77	3.93	4.03
45	1249.29	3.03	2.62	708.14	5.03	3.23	490.58	2.86	2.49	271.56	4.11	3.89
60	1368.49	2.72	2.38	568.59	4.49	3.14	578.26	2.86	2.11	244.08	4.64	5.17
75	1051.37	2.30	3.04	438.10	3.29	2.83	479.65	2.16	2.84	273.31	4.30	3.70
90	1144.37	3.02	2.67	596.19	2.43	4.02	452.90	2.54	2.81	232.83	4.11	3.03
105	1336.94	2.74	2.39	608.35	2.99	3.57	567.33	2.54	2.18	223.44	3.26	4.22
120	1075.37	2.30	3.03	535.67	2.65	4.43	489.60	2.05	2.57	232.73	3.07	2.95
135	1189.56	3.02	2.67	710.95	3.52	4.39	470.39	2.77	2.55	196.98	2.70	3.04
150	1350.42	2.74	2.39	733.80	3.52	3.81	572.35	2.73	2.04	177.16	2.60	3.13
165	1064.82	2.30	3.03	618.94	3.14	4.49	484.95	2.17	2.69	172.45	3.03	1.80
Impact Analysis of Fault at SSSC integrated with DG												
FIA	Fault Index Grid Idle			Fault Index Grid Idle-SSSC			Fault Index Grid connected			Fault Index Grid-SSSC Connected		
	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic
0	1004.07	5.07	5.20	824.28	20.91	11.18	416.12	8.26	6.52	191.34	13.11	16.73
15	1293.30	2.97	2.53	1016.25	16.63	8.49	557.81	4.03	3.17	219.74	9.29	12.93
30	1106.40	2.33	2.98	887.52	13.64	13.34	501.49	2.46	2.75	192.97	9.74	11.74
45	1249.29	3.03	2.62	1070.05	10.99	13.76	490.58	2.86	2.49	258.04	12.25	13.58
60	1368.49	2.72	2.38	1137.58	8.28	11.48	578.26	2.86	2.11	282.52	16.87	10.66
75	1051.37	2.30	3.04	870.63	5.62	9.90	479.65	2.16	2.84	254.36	18.23	14.24
90	1144.37	3.02	2.67	1032.42	5.88	4.07	452.90	2.54	2.81	325.27	18.95	16.46
105	1336.94	2.74	2.39	1161.74	6.23	3.02	567.33	2.54	2.18	357.89	13.45	11.51
120	1075.37	2.30	3.03	931.13	4.81	2.63	489.60	2.05	2.57	303.18	6.59	10.04
135	1189.56	3.02	2.67	1123.71	7.80	6.17	470.39	2.77	2.55	365.50	5.50	6.46
150	1350.42	2.74	2.39	1237.84	9.06	5.39	572.35	2.73	2.04	403.96	4.29	3.24

165	1064.82	2.30	3.03	974.00	10.06	8.05	484.95	2.17	2.69	339.69	4.32	5.03
Impact Analysis of Fault at UPFC integrated with DG												
FIA	Fault Index Grid Idle			Fault Index Grid Idle-UPFC			Fault Index Grid connected			Fault Index Grid-UPFC Connected		
	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic	Ia	Ib	Ic
0	1004.07	5.07	5.20	941.68	4.86	5.19	416.12	8.26	6.52	361.02	6.91	5.50
15	1293.30	2.97	2.53	1145.54	2.98	2.97	557.81	4.03	3.17	416.59	3.71	3.61
30	1106.40	2.33	2.98	943.98	2.49	3.34	501.49	2.46	2.75	334.22	2.29	3.34
45	1249.29	3.03	2.62	1110.77	3.24	2.80	490.58	2.86	2.49	396.49	2.91	2.86
60	1368.49	2.72	2.38	1165.45	2.84	2.75	578.26	2.86	2.11	411.83	2.68	2.60
75	1051.37	2.30	3.04	859.29	2.52	3.33	479.65	2.16	2.84	304.61	2.17	3.31
90	1144.37	3.02	2.67	1027.19	3.21	2.80	452.90	2.54	2.81	374.24	2.89	2.91
105	1336.94	2.74	2.39	1148.51	2.83	2.74	567.33	2.54	2.18	412.74	2.65	2.59
120	1075.37	2.30	3.03	882.97	2.51	3.32	489.60	2.05	2.57	319.02	2.18	3.29
135	1189.56	3.02	2.67	1059.07	3.20	2.80	470.39	2.77	2.55	385.27	2.89	2.89
150	1350.42	2.74	2.39	1150.17	2.83	2.74	572.35	2.73	2.04	412.15	2.68	2.60
165	1064.82	2.30	3.03	865.16	2.50	3.33	484.95	2.17	2.69	311.67	2.20	3.30

5. Conclusion

This method offers an efficient way to secure microgrids by reducing losses and improving system resilience. Additionally, this study advances the technology of microgrids, opening the door for more dependable and effective energy systems in the future.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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