مجلة غريان للتقنية / المعهد العالي للعلوم والتقنية غريان
Gharyan Journal of Technology, High Institute of Science & Technology Gharian
Issue (10), September- 2024-العدد العاشر، سبتمبر

A shunt Compensation Impact on UHVTL Distance Relay using Machine Learning in Discrete Wavelet Classifier

Elhadi Emhemed Aker[1], Mohamed.M.Almelian[2] , Mohammad A Omran[3] and Osaji Emmanuel[4].

1- Department of Electrical Engineering, Higher Institute of Science and Technology Gharian, Libya
2- Department of Electrical Engineering, Higher Institute of Science and Technology Mezdah, Libya
3- Faculty of Engineering, College of Technical Sciences, Ben-Walid, Libya
4- Department of electrical and electronics Engineering, Federal University Lokoja, Nigeria.

E-Mail: hadi.aker@yahoo.com

الخلاصة:

تقدم هذه الورقة نهجًا ذكيًا لاستخراج البيانات لتطوير نموذج تصنيف أخطاء ترحيل المسافة التكيفي للتعلم الآلي (ML–ADR)، باستخدام تحليلات الموجات الهجينة المنفصلة متعددة الحلول وخوارزمية التعلم الآلي (ML– DWMRA) على الجهد العابر للدائرة القصيرة المستخرج ذو الدورة الواحدة. والإشارات الحالية لاكتشاف المعرفة المفيدة المخفية التي يتم نشرها في تعديل ADR الحالي. يتم تشغيل نظام خط النقل، حيث يقوم عنصر المنطقة 3 بالحماية من خطأ الطرف البعيد، مع وبدون نقطة منتصف جهاز تعويض التحويلة المتكاملة على طول الخط. يتم نشر الميزات الـ 29 المستخرجة بشكل فريد عبر 2560 مصدر خطأ من كل من الخطوط المحمية الخاطئة والسليمة لتطوير نموذج تصنيف خطأ ML–ADR من أجل الكشف الفعال عن أخطاء الدائرة القصيرة وتصنيفها وتقليل وقت اتخاذ قرار الرحلة لعنصر الحماية للمنطقة –3. إن النتيجة السابقة من نموذج

مختبر Mat لمرحل المسافة العددية التكيفي المتصل بنظام خط النقل المتكامل لمعوض التحويلة في منتصف النقطة تثبت بالفعل أن وجود تأثير تحت الوصول لخطأ الدائرة القصيرة البعيدة للمنطقة 3 يؤدي إلى تقدير غير صحيح للمقاومة. يوفر ML–ADR أفضل نموذج لمصنف الأخطاء المتكامل مع أدنى متوسط لقيمة الخطأ المطلق وهو 0.0009، وهذا النموذج راضٍ ويحقق أخيرًا أهداف ADR المطلوب.

Abstract

This paper presents an intelligent data mining approach for the Machine Learning-Adaptive Distance Relay (ML-ADR) fault classification model development, using hybrid discrete wavelet multiresolution analyses and machine learning (DWMRA-ML) algorithm on extracted 1-cycle short circuit transient voltage and current signals to discover the hidden useful knowledge that is deployed in the modification of existing ADR. The transmission line system, where the zone-3 element is protecting against the far-end fault is run with and without an integrated shunt compensating device midpoint along the line. The uniquely extracted 29 features across 2,560 fault sources from both faulty and healthy protected lines to build a historical fault database that is deployed for ML-ADR fault classification model development for effective short circuit fault detection, classification, and trip decision time reduction of the zone-3 protective element. The prior result from the Mat lab model of the adaptive numerical distance relay connected on midpoint- shunt compensator integrated transmission line system does indeed establish that the existence of the under-reach effect for zone-3 far-end short circuit fault causes wrong impedance estimation.

The ML-ADR provides the best integrated fault classifier model with the lowest mean absolute error value of 0.0009, this model satisfied and finally meets the objectives of the desired ADR.

Keywords : *Distance Relay, UHV Transmission Line, Discrete Wavelet Transform, Shunt compensation, Zone.*

Introduction

There has been a constant global increase in the amount of electric power energy demands in recent years, these have necessitated the commissioning of new power generation stations, alongside with the expansion of the transmission and distribution grids in meeting these new trends [1] ,[2]. The quest for electrical power energy sustainability solution resulted in the integration of mixed energy generation sources with a high penetration level of renewable energy resources (RERs) in the form of photovoltaic (PVs) and wind turbines (WTs) generation sources on currently existing electric systems to create balances between energy generations and demands [3],[4],[5]. The concerns of evacuations of all generated power from mixed sources to the end load terminals through the transmission and distribution lines are also affected by drops in the voltage values (voltage-sags) at the midpoint of the long-distance transmission lines. These challenges encourage the introduction of Flexible Alternating Current Transmission System (FACTS) devices like the Static Synchronous Series Compensator (SSSC) [6], Static VAR compensator (SVC) [7] , Static Synchronous Compensators [8], and composite compensator like the unified power flow controller (UPFC) [9], for maximum electric power delivery from the generation sources to end-terminal substations at UHV level with minimal power losses, and voltage variation [10]. These connected FACTS elements on the transmission lines are associated with misoperation challenges to the distance protection relays, by wrong tripping operations due to under-reach and over-reach protection coverage phenomena [11],[12]. Figure 1 displays the transmission line power transfer capability parameters to be considered for optimal transfer of electrical power energy from the source to the load.

Impact of FACTS Devices on Power System Protection

Protection relays are very significant flexible devices used protect the transmission lines and considered as cost-effective, fast response speed and highly reliable [13].

The bottom line of protection devices is discriminating between the normal operating conditions of the power system networks from the abnormal conditions within the allowable limits as stipulated by operating standard to isolate only affected sections from other healthy sections [14], [15]. Transmission line impedances, voltages and currents are the parameters required for protective relay settings and operations. These parameters are, however, significantly affected by FACTS devices installed in the power system. The presence of FACTS devices, therefore, necessitates further investigations on their impacts on the protection scheme layout [16].

FACTS controller’s impacts on the performance of distance relays have been a subject of research for the past two decades [17],[18],[19]. Authors in [20], [21], [22] reported that the UPFC and the TCSC have a significant impact on the performance of distance relay in terms of overreach. A general study regarding the influence of

SVC and midpoint shunt compensators on distance relays performance was performed and results were summarized [23].

Research Method

This paper presents a compensated transmission line of 300 km, rated at 400 kV with 50 Hz frequency as depicted in Figure 1. The system under study is a 4-sections system with (A, B, C and D buses) for the 3 protection zones coverage for relay at the sending end bus (A). The system contains generation and load at sending and receiving ends as ulstrated in Figure (1). On this study model, various types of faults beyond the compensation device locations are simulated in Matlab software environment for fault voltage and current signals. Valuable data were extracted from each scenario.

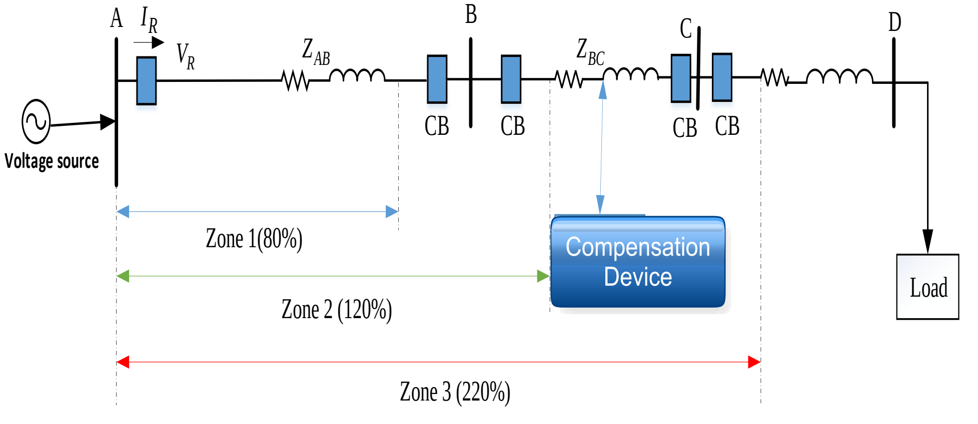

Figure (1): Shunt compensation transmission line

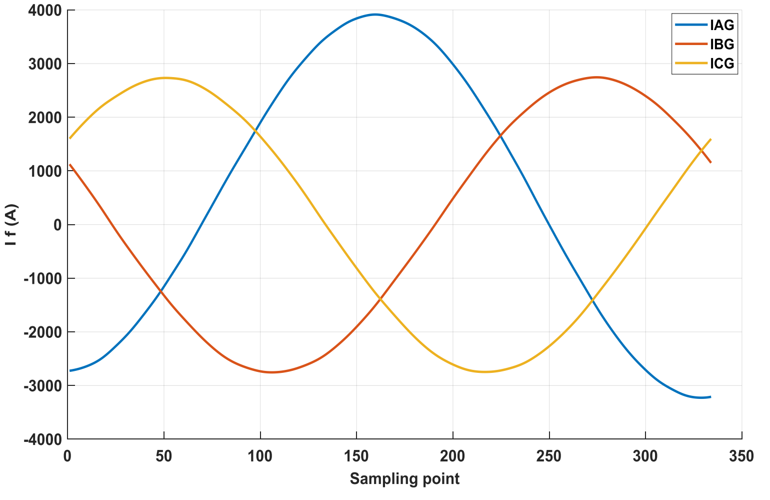

Figure (2): Current waveform for an A-G fault at 200 km
Without integrated shunt compensation

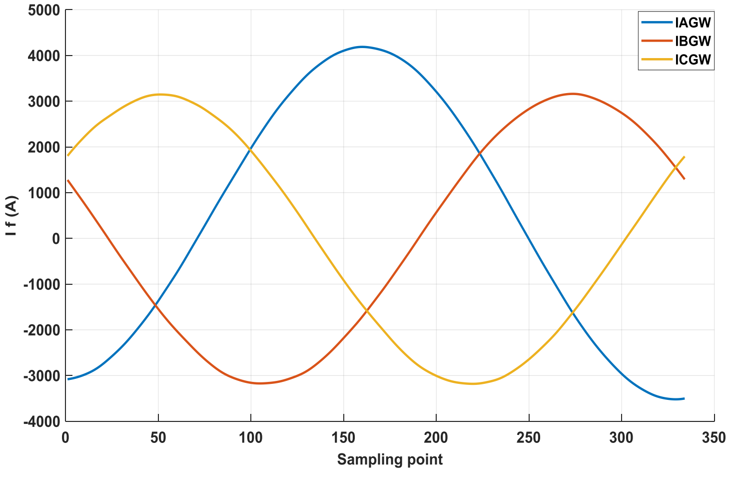

Figure (3): Current waveform for an A-G fault at 200 km
With integrated shunt compensation

Result of Fault Signal Decomposition (DWMRA)

Result from the two proposed power system networks topologies with and without midpoint integrated shunt compensation subjected to ten different fault types from 150 km distance location with the midpoint integrated compensator at 10 km interval to the end of the, under two fault angles (0^o C & 30^o C), and four fault resistances (0.001 Ω, 10 Ω, 50 Ω, & 100 Ω). This produced a three phase-fault transient voltage and current signals across both faulty and healthy lines for short circuit simulations across ten different fault types for a simulation period of 0.2 sec.

The sample of the extracted fault transient current waveform comparison for the phase A-G fault at 200 km far-end fault location without and with integrated midpoint shunt compensation integration on the utility transmission line as displayed in Figures 4 and 5 respectively.

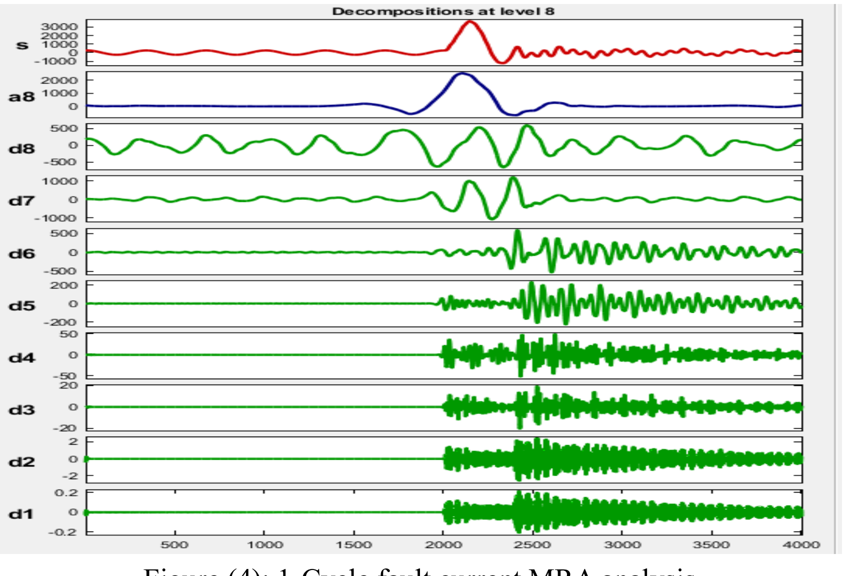

Figure (4): 1-Cycle fault current MRA analysis
Without shunt compensation

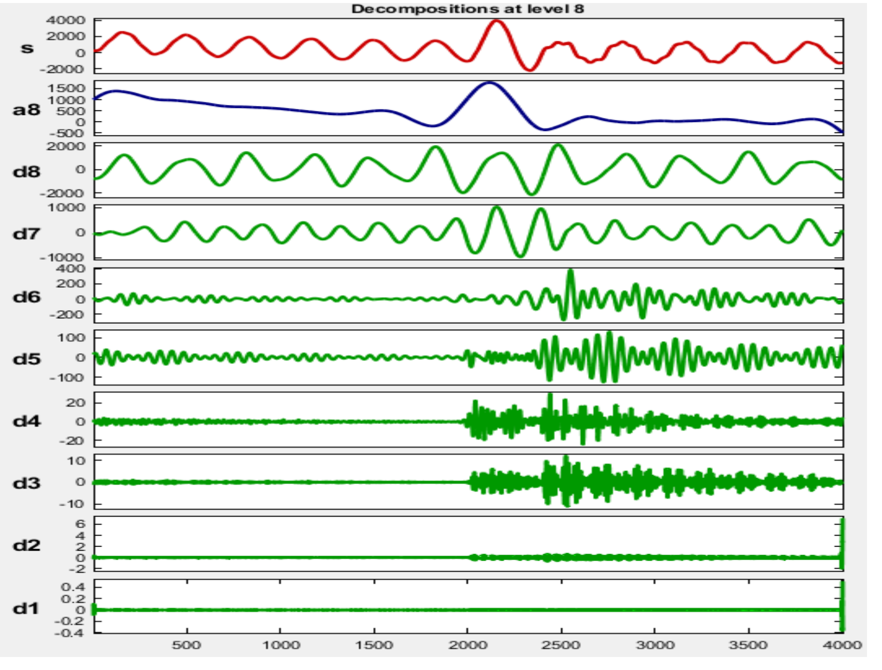

Figure (5): 1-Cycle fault current MRA analysis with shunt compensation

Extracted Features Decomposition Analyses

The hidden useful knowledge of fault signal decomposed parameters are mined for Extraction like the standard deviation (STD), entropy energy value (EE), minimum (min).

The extracted fault transient signals from both voltage and current signals are subjected to 8-levels decomposed DWMRA to extract the useful unique hidden information that may be used in the ML-ADR model development. The samples of the extracted 1-cycle fault transient current decomposition from far-end fault at 200 km are executed for unique feature extraction like the STD, EE, and magnitude with and without midpoint integrated compensation are showed in Figures (2) and (3).

The Discrete Wavelet Transform is a powerful tool for time-frequency signal analysis of sampled localized transient's current signal to produce non-redundant restoration of signal. Moreover, it produces better spatial and spectral localization of signal. In recent decades, such advanced powerful tool has been used for designing the protective relays [17-23]. In DWT, the fault current signal x (t) is decomposed into low and high frequency components such as approximation (A) and detailed coefficients (D) which is mathematically expressed in Equation (1) and (2) for decomposed signal.

$$x(t) = \sum_k cA_1 \Phi_{j-1,k}(t) + \sum_k cD_1 \Phi_{j-1,k}(t) \quad (1)$$

$$x(t) = A_1(t) + D_1(t) \quad (2)$$

The low frequency component of the signal also referred to as the approximation coefficients undergoes series levels of the decomposition up to N level to extract the original information from the noise and for regeneration of the decomposed signal as expressed in Equation (3).

$$x(t) = A_N(t) + D_N(t) + D_{N-1}(t) + \cdots D_1(t) \quad (3)$$

Where N = 5 is the decomposition level for extracted fault current signals as seen in Figure 6.

WEKA Machine learning and Features Extraction

The Standard Deviation for both model scenarios with compensation device integration or without on the UHV transmission line extracted and analysed accordingly. The under-reach effect occurs only for extracted fault signals at different locations beyond the connected compensation device element for the 3rd zone protection coverage of the distance relay. Other features include the entropy energy of the transient fault signal with hidden related information for fault detection study. All extracted features from transient faults signal are deployed for the onward model building in the WEKA machine learning algorithm for intelligent detective and classification model building scenarios as seen in Figure 6.

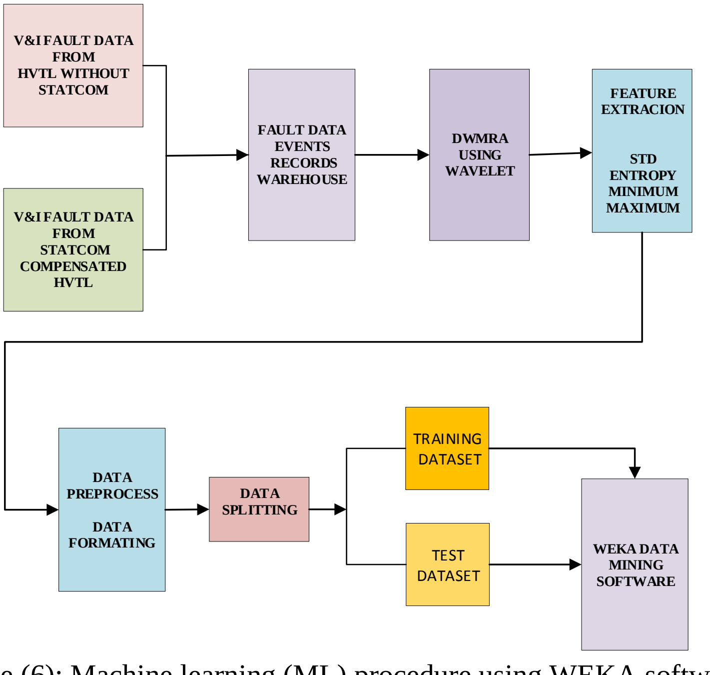

Figure (6): Machine learning (ML) procedure using WEKA software

Results and Analysis

The extracted analyzed result on Table 1 displays the standard deviation for all types of faults, each faulted phase for one scenario without integration of compensation device as proposed. The results displayed no variations under normal operation conditions in the measured current magnitude as showing in figure 2. However, after the integration of compensation, the faulted phase condition as showing in figure 3 is much greater compared to those of healthy lines, thus, indicating a presence of fault. Similarly, there are much differences in the obtained values for integrated scenarios with higher analyzed values of currents for each faulted phases as compared with non-integration scenarios of compensation devices as display in Table 2.

Table (1): Current magnitude during normal conditions and faults at different locations without shunt compensated power system.

		Without shunt compensator					
Fault Distance	**Type of Fault**	**Minimum Current**			**Maximum Current**		
		Ia kA	**I b kA**	**I c kA**	**Ia kA**	**I b kA**	**I c kA**
	No fault	−0.205	−0.205	−0.205	0.205	0.205	0.205
100 km	LG	−2.57	−0.34	−0.46	6.95	0.28	0.25
	LL	−4.11	−12.5	−0.25	12.6	4.05	0.25
	LLG	−4.19	−12.0	−0.71	1.34	4.3	0.65
	LLLG	−3.88	−12.0	−12.4	1.52	6.76	4.3
200 km	LG	−1.23	−0.27	−0.39	3.67	0.19	0.18
	LL	−2.19	−7.01	−0.25	7.06	2.16	0.25
	LLG	−2.1	−6.78	−0.45	7.56	2.34	0.38
	LLLG	−1.97	−7.06	−7.16	8.32	3.78	2.82
300 km	LG	−0.78	−0.294	−0.37	2.49	0.185	0.19

	LL	−1.56	−4.78	−0.25	4.93	1.47	0.25
	LLG	−1.51	−4.85	−0.51	5.08	1.62	0.37
	LLLG	−1.31	−5.17	−4.97	5.72	2.62	2.16

Table (2): Current magnitude during normal conditions and faults at different locations with shunt compensated power system.

Fault Distance	Type of Fault	With shunt compensator					
		Minimum Current			Maximum Current		
		I a kA	I b kA	I c kA	I a kA	I b kA	I c kA
	No f	−1.22	−2.07	−2.08	2.51	1.26	1.21
100 km	LG	−3.36	−1.04	1.17	6.95	1.23	0.8
	LL	−4.57	−11.7	−1.24	11.8	4.58	1.07
	LLG	−4.74	−11.4	−1.3	1.26	4.82	1.18
	LLLG	−4.57	−11.5	−1.1.9	1.43	7.02	4.91
200 km	LG	−2.20	−1.12	−1.23	3.97	1.23	1.08
	LL	−2.80	−6.3	−1.25	6.38	2.71	1.07
	LLG	−2.85	−6.25	−1.36	6.76	2.99	1.09
	LLLG	−2.72	−6.47	−6.46	4.49	4.06	3.3
300 km	LG	−1.85	−1.19	−1.28	3.18	1.22	0.84
	LL	−2.22	−4.56	−1.27	4.61	2.22	1.07
	LLG	−2.33	−4.61	−1.38	4.88	2.41	1.17
	LLLG	−2.22	−4.84	−4.79	5.32	3.24	2.68

Furthermore, the entropy energy result in Table 2 displays the similar information for the normal conditions without variations in the current values under both simulation scenarios. The faulted phase entropy energy value is higher across all faulted phases as an indication of fault presence. The comparison study also indicated a much higher value in entropy energy under integrated compensation device condition as compared to non-integration as highlighted in red on the displayed results.

The analyses performances of the fault classification models developed in WEKA to address the pending under-reach challenges encountered by distance relay for 3rd zone's fault detection on a compensation device line indicated effective model performance with the deployment of the propose Naive ML-ADR algorithm as compared to other intelligent algorithm with 100% accuracy for all most fault detection and discrimination as observe in Table 3.

ML-ADR Classifier Model Validation

The evaluated ML-ADR model addresses the impeding zone-3 element trip operation compromise is further validated by deploying into the new set of extracted real-life simulation data that was not used in the model training and testing. To validate all developed fault classifier models to determine the performance generalization of the model with the new fault scenarios data acquisition from different fault types different from those applied in the model training and testing across both proposed models. Several random sampled transient short circuit faults were deployed for the validation study. The summary of the new extracted and validation dataset that are pre-processed similarly as the training and test dataset deployed in the ML-ADR classification model at different faults in Table 3.

Table (3): ML-ADR classifier model validation result

Fault Classifier Models	Faults Instance Record	Correctly Classified	Incorrectly Classified	Model Performance (%)	Mean absolute error	ROC Area (%)
ML-ADR-LG	194	194	0	100	0	1
ML-ADR-LLG	192	188	4	97.91	0.0069	1
ML-ADR-LL	190	190	0	100	0	1
ML-ADR-LLLG	62	60	2	96.77	0.0277	1
Integrated ML-ADR	638	632	6	99.06	0.0009	1

Conclusion

The adoption of an appropriate machine learning (ML) intelligent algorithm model studies the adaptive distance relay (ADR) modelling that should eliminate the zone-3 protective element compromise during far-end fault due to under reach effect from midpoint integrated shunt compensator on transmission lines. This has been successfully achieved. The study has addressed the impending distance relay zone-3 element backup protection compromise due to under reach effect caused by the infeed contribution of the short circuit current from the shunt compensator into the faulty section of the transmission lines.

The deployed integrated ML-ADR fault classifier model is successfully deployed using decomposed extracted 2,560 historical fault database records from 1-cycle fault voltage and current signal in combination with network topology variations.

References

[1] Petinrin, J. and M. Shaabanb, Impact of renewable generation on voltage control in distribution systems. Renewable and Sustainable Energy Reviews, 2016. **65**: p. 770-783.

[2] Hariadi, T.K., et al., Energy efficiency and policy analysis for household in DI Yogyakarta (Yogyakarta Special Region) Indonesia. International Journal on Advanced Science, Engineering and Information Technology, 2016. **6**(3): p. 329-333.

[3] Liserre, M., T. Sauter, and J.Y. Hung, Future energy systems: Integrating renewable energy sources into the smart power grid through industrial electronics. IEEE industrial electronics magazine, 2010. **4**(1): p. 18-37.

[4] Naserian, M., A. Karimi, and S.E. Mirabdolahi, Robust Optimal Controller Design for Induction Generator Driven by Variable-Speed Wind Turbine with STATCOM Using Immune Algorithm. International Journal on Advanced Science, Engineering and Information Technology, 2011. **1**(5): p. 481-486.

[5] Samir, A., et al., Efficient PV-grid system integration with PV-voltage-source converter reactive power support. The Journal of Engineering, 2018. **2018**(2): p. 130-137.

[6] Zellagui, M. and A. Chaghi, Effects of shunt FACTS devices on MHO distance protection setting in 400 kV transmission line. Electrical and Electronic Engineering, 2012. **2**(3): p. 164-169.

[7] Khoa, N.M. and D.D. Tung, Locating fault on transmission line with static var compensator based on phasor measurement unit. Energies, 2018. **11**(9): p. 2380.

[8] Rabie, S. and H. Afrakhte, Optimal determination of island boundaries besides the optimal placement of D-STATCOM devices and DG units. Turkish Journal of Electrical Engineering and Computer Sciences, 2017. **25**(2): p. 1508-1521.

[9] Al-Behadili, A.K.L., Performance Analysis of Distance Relay on Shunt/Series Facts-Compensated Transmission Line. 2015.

[10] Moravej, Z., M. Pazoki, and M. Khederzadeh, New smart fault locator in compensated line with UPFC. International Journal of Electrical Power & Energy Systems, 2017. **92**: p. 125-135.

[11] Gupta, O.H. and M. Tripathy. Relaying scheme for STATCOM compensated transmission line. in 2016 IEEE 6th international conference on power systems (ICPS). 2016. IEEE.

[12] Ilango, R., Impact Analysis of midpoint Connected STATCOM on Distance Relay Performance. TELKOMNIKA Indonesian Journal of Electrical Engineering, 2015. **13**(2): p. 257-263.

[13] Yadav, A. and Y. Dash, An overview of transmission line protection by artificial neural network: fault detection, fault classification, fault location, and fault

direction discrimination. Advances in Artificial Neural Systems, 2014. **2014**(1): p. 230382.

[14] Purohit, M. and V. Gohokar, Effects of series compensation on distance protection of high voltage transmission lines under fault conditions. International Journal of Electrical Engineering & Technology (IJEET) Volume. **9**: p. 57-66.

[15] Gopakumar, P., M.J.B. Reddy, and D.K. Mohanta, Transmission line fault detection and localisation methodology using PMU measurements. IET Generation, Transmission & Distribution, 2015. **9**(11): p. 1033-1042.

[16] 16.Ghorbani, A., B. Mozafari, and A.M. Ranjbar, Digital distance protection of transmission lines in the presence of SSSC. International Journal of Electrical Power & Energy Systems, 2012. **43**(1): p. 712-719.

[17] 17.Behera, S., P. Raja, and S. Moorthi. Modelling and simulation of the impact of SVC on existing distance relay for transmission line protection. in 2015 International Conference on Condition Assessment Techniques in Electrical Systems (CATCON). 2015. IEEE.

[18] 18.Gupta, O.H. and M. Tripathy, An innovative pilot relaying scheme for shunt-compensated line. IEEE transactions on power delivery, 2015. **30**(3): p. 1439-1448.

[19] 19.Chandan, A., et al., Advance distance protection of transmission line in presence of shunt compensator. International Research Journal of Engineering and Technology (IRJET), 2015. **2**(3): p. 751-757.

[20] 20.Reyes-Archundia, E., E. Moreno-Goytia, and J. Guardado, An algorithm based on traveling waves for transmission line protection in a TCSC environment. International Journal of Electrical Power & Energy Systems, 2014. **60**: p. 367-377.

[21] 21. Hemmati, R., M. Nikzad, and S.S.S. Farahani, Investigation of UPFC performance under system uncertainties. International Journal of Electrical Power & Energy Systems, 2012. **43**(1): p. 1137-1143.

[22] 22. Mehrjerdi, H. and A. Ghorbani, Adaptive algorithm for transmission line protection in the presence of UPFC. International Journal of Electrical Power & Energy Systems, 2017. **91**: p. 10-19.

[23] Hemasundar, D., M. Thakre, and V. Kale. Impact of STATCOM on distance relay-Modeling and simulation using PSCAD/EMTDC. in 2014 IEEE Students' Conference on Electrical, Electronics and Computer Science. 2014. IEEE.

