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Transmission line fault identification and classification with integrated FACTS device using multiresolution analysis and naïve bayes classifier

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ABSTRACT

This paper is present a novel approach for solving the pending under-reach problem encountered by distance relay protection scheme in the 3rd zones protection coverage for a midpoint STATCOM compensated transmission lines. The propose transmission line model is develop in Matlab for analyzed feature extraction using Discrete Wavelet multiresolution analysis approach. Extracted feature from standard deviation and entropy energy contents of SLG transient faults current at location beyond the integrated STATCOM used for machine learning algorithm model building using WEKA software. The Naïve Bayes classifier model perform best with robustness prediction and detection of faults with quick convergence even with less training data. The outperformance of the proposed classifier has been 100 % for the relay algorithm modification for under-reach problem elimination in 3rd zones protection coverage.

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1. INTRODUCTION

Distance relays protection on high voltage transmission line have become a great challenge for power system protection engineers due to some limitation encountered in the operational compromise as currently encountered in a compensated transmission line protection scheme [1-5]. The distance relay operational characteristic is based on either impedance, admittance, reactance, resistance or quadrilateral operational characteristics. The admittance characteristic (referred to as the mho) is commonly applied in distance relay protection zones adopted for transmission line protection as seen in the Mho numerical relays operation [6]. The distance relay measured the transmission line apparent impedance based on estimated faults voltages and currents between the relay locations to the fault point to determine whether the calculated impedance falls within the pre-set impedance value under normal operation [7]. The integration of compensation devices like the shunt static compensation (STATCOM) on transmission line system is to help in the effective power transfer from the sources end to the load terminal and maintaining the voltage at the midpoint of the line by injecting reactive power during the capacitive mode into the utility grid or absorbing reactive power from the grid during the inductive operational mode. This injected current affects the estimated impedance seen by the protective relay especially with fault after the mid-point location of the compensation device leading to much higher estimation of the fault impedance outside the 3rd zone protection coverage of the relay for adjacent faulted line leading to under-reach effect. Such faults are undetected by the relay and may cause serious dame to lives, installations and safety compromise [8-10]. In view of this operational challenge in distance relay to provide reliable and secure power system protection on STATCOM compensated transmission line, an adaptive relaying algorithm with the adoption of synchronized measurement on PSCAD EMTDC simulation model for shunt compensated line using the wide area network measurement and monitoring approach for relay performance suitability, with the adoption of high speed communication link proposed earlier [11]. Another innovation on synchronised measurement using two ends information for the protection compromise problem eradication with the adoption of Phasor measurement unit (PMU) alongside with pilot protection scheme through communication link proposed on shunt compensated line to eliminate distance relay protection problems [12, 13].

A three zones protection model for internal and external fault discrimination for effective power flow capability improvement on the western Nanjing power grid with integrated unified power flow controller (UPFC) based on transmission line parameters model conducted [14]. The adoption of a layer peeling algorithm for power system accurate network mapping using probing measuring impulses from post-fault information was developed for fault location determination on overhead transmission lines [15]. Research on zone 3 backup protection compromise elimination in distance relay during load encroachment with the adoption of synchro phasor measurements obtained from PMU at both end of the transmission line network[16]. The complexity involved in the handling of the two-end faults data for accurate analysis, the high cost of communication device are some limitations of these proposed methods. In view of these limitations, the current study propose a fault data signature extraction from just one end protection location and machine learning using MATLAB and Waikato Environment for Knowledge Analysis (WEKA) software for effective single line to ground (SLG) fault detection, and classification on the STATCOM compensated transmission line in order to eliminate under-reach effect encountered in the 3rd zone protection coverage of distance relay element.The article is structured into five section consisting of introduction, research methods, result / discussion, and conclusion for in-depth divulgence of relevant and related information for future work emulation. The study proposes a novel advanced signal processing approach and machine learning approach to solving the pending protection compromise in distance relay to current existing body of knowledge as presented.

2. RESEARCH METHOD

The paper present a Libya compensated power grid line of 300 km, rated 400 kV,and 50 Hz frequency as depicted in Figure 1.The study system is a 4 -bus system with A, B, C and D buses for the 3 protection zones coverages for relay at the end bus A. The system contains two-source system with Generator in the sending end and Load at the receiving end. On this study model, various types of fault beyond the STATCOME locations are simulated in Matlab software for fault voltage and current signals signature data extraction for each scenario.

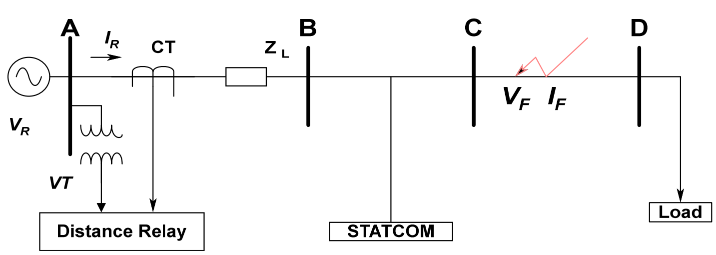


Figure 1. STATCOM compensated transmission line

The flow for the applied method for this study is display in Figure 2 for the SLG fault detection and classification on the STATCOM compensated transmission line to address the under-reach challenges faced by the distance relay protective element in the 3rd zone protection region as earlier explained. Initially (Pre-processing Stage), the three-phase current signal obtained from the SLG fault Mathlab simulation of the transmission line power system with and without integrated STATCOM were analysed using wavelet analysis to obtain the feature extraction or data for onward intelligent machine learning. In the second stage

(Classification), the several algorithms in WEKA machine learning software were deployed for the intelligent training of several algorithm for effective classification and fault detection model building. This is finally followed by the deployment of trained model for effective trip decision making to eliminate the pending misclassification currently encountered in conventional distance relay protection scheme. Figure 2 by a simple block diagram describing the various stages and which is explained and described in detail below.

– Simulate the two models scenarios to obtain fault current signatures from models of the system as seen in Figure 3 -5.
– In second stage entail the feature extraction from each extracted voltage and current fault signals from noise by decomposing the signal using discrete wavelet transform (DWT) based multi revolution analysis at various levels.
– Pre-processing stage: Collation of extracted features across all faults instances to obtain signal standard deviation (SD) and entropy energy values (EV) across all sampled signals using DWT.
– Training stage**:** The extracted features (SD and EV) data at various instances deployed for training AI algorithm training.
– Classification Model building**:** Train model deployment for fault detection, classification and accurate trip decision making across both model architectures.

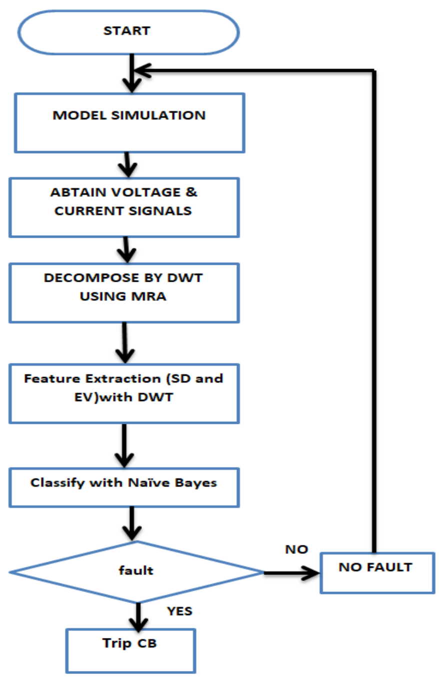
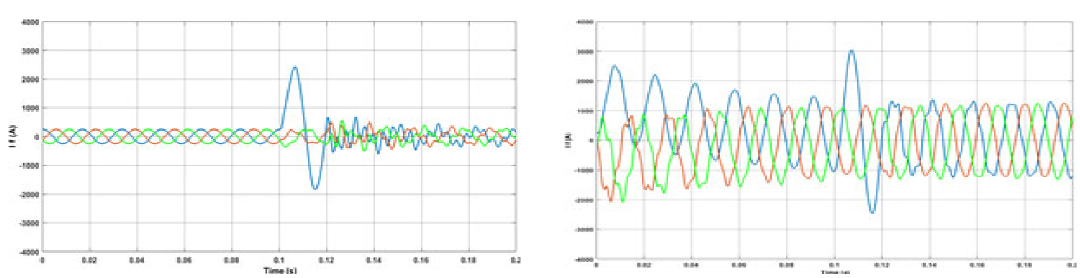
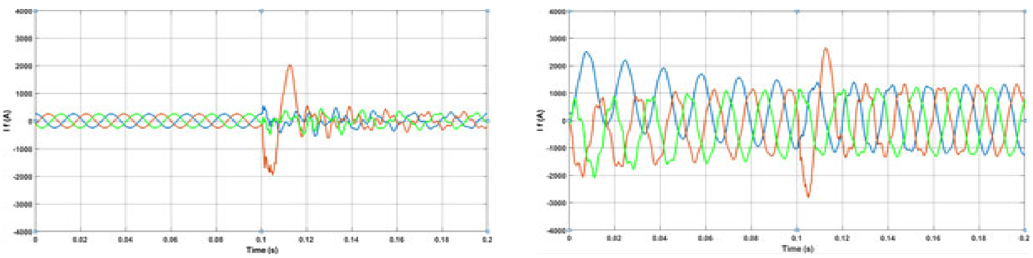


Figure 2. Flow Chart



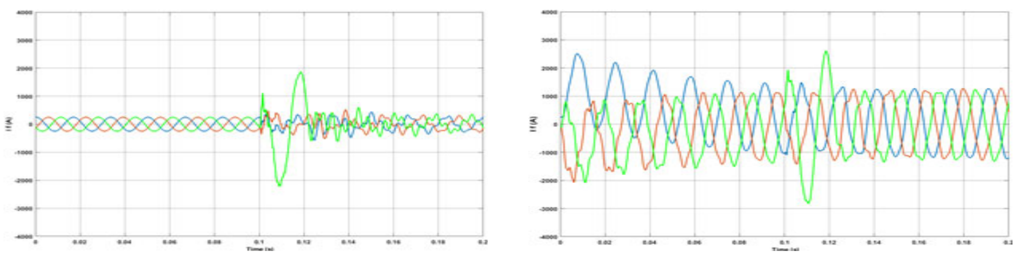
(a) (b)

Figure 3. Phase A SLG fault at 200km (a) without (b) integrated STATCOM compensation



(a) (b)

Figure 4. Phase B SLG fault at 200km (a) without (b) integrated STATCOM compensation



(a) (b)

Figure 5. Phase C SLG fault at 200km (a) without (b) integrated STATCOM compensation

2.1. Discrete wavelet transform

The DWT is a powerful tool for time-frequency signal analysis of sampled localized transients' 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, 18-24]. 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 (1) and (2) for decomposed signal [25-26].

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

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

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 (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.

2.2. Features Extraction and WEKA Machine learning

The SD for both model scenarios before and during STATCOM integration on the high voltage transmission line extracted and analysed accordingly. The under-reach effect occurs only for extracted fault signals at different locations beyond the connected STATCOM 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 in two model scenarios.

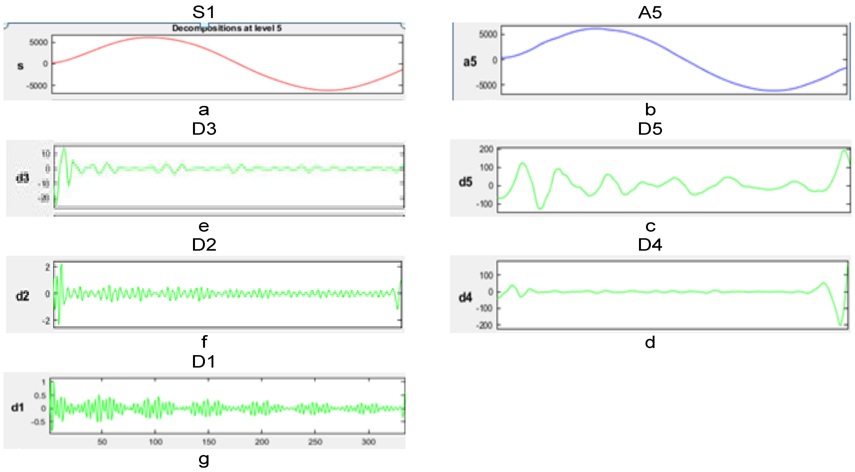


Figure 6. Decomposed transient fault current to 5 levels

3. RESULTS AND ANALYSIS

The extracted analyzed result on Table 1 display the standard deviation for SLG faults for each faulted phase for both scenarios with and without integration of compensation device as propose. The result displayed no variation under normal operation condition in the measured current magnitude. However, after the integration of STATCOM compensated device, the SD across each faulted phase condition is much greater compared to those of healthy lines as an indication of fault presence. Similarly, there is much differences in the obtained values for integrated scenarios with higher analyzed values of SD for each faulted phases as compared with non-integration scenarios of compensation devices as display in Table 1.

Table 1: Extracted SD values from analyzed transient currents

			Without STATCOM			with STATCOM		
Condition	Type of fault	Location/km	STD- A	STD-B	STD- C	STD- A	STD-B	STD- C
Normal	No Fault	100	177.35	177.13	177.06	875.0	877.0	866.0
		200	177.35	177.13	177.06	875.0	877.0	866.0
LG	AG	100	**3087.0**	166.0	204.0	**3394.0**	800.0	797.0
		200	**1460.0**	154.45	196.0	**2046.0**	825.0	817.0
	BG	100	300	**3170.0**	267.0	793.0	**3490.0**	835.0
		200	238.11	**1367.63**	189.37	821.0	**2110.0**	836.0
	CG	100	263.0	299.0	**2660.0**	854.0	811.0	**3305.0**
		200	187.16	236.74	**1136.06**	852.0	831.0	**1888.0**

Furthermore, the entropy energy result in Table 2 display the similar information for the normal conditions without variations in the SD 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 STATCOM condition as compared to non-integration as highlighted on red on the result display.

Table 2: Extracted Entropy energy values from analyzed transient currents

			Without STATCOM			with STATCOM		
Condition	Type of Fault	Location / km	E-A 10^8	E-B 10^8	E-C 10^8	E-A 10^8	E-B 10^8	E-C 10^8
Normal	No Fault	100	1.25	0.49	0.40	22.7	6.25	13.1
		200	1.25	0.49	0.40	22.7	6.25	13.1
LG	AG	100	**94.6**	0.56	0.51	**128**	5.36	11.4
		200	**25.9**	0.56	0.51	**56.5**	5.62	12.1
	BG	100	1.64	**57.1**	0.51	21.3	**70.7**	13.2
		200	1.44	**15.3**	0.41	25.8	**27.5**	12.3
	CG	100	1.39	0.76	**72.9**	21.7	5.74	**97.1**
		200	1.33	0.60	**18.80**	21.2	6.22	**38.6**

The analyses performances of the SLG fault classification models developed in WEKA to address the pending under-reach challenges encountered by distance relay for 3rd zones fault detection on a STATCOM compensated lines indicated effective model performance with the deployment of the propose Naive Bayes algorithm as compared to other intelligent algorithm with 100 % accuracy for all SLG fault detection and discrimination as observe in Table 3. This model effectively generalized after tested with new set of SD and EV data that was not deployed for the model training. The display Figure 7 shows the accuracy rate of the best algorithm

Table 3: Trained machine learning models performance analyses

Scenarios	Performance	Naive Bayes algorithm (%)	MLP algorithm (%)
Case 1 model with SD	Correct classification	100	80
	Misclassification	0	20
Case 2 model with EV	Correct classification	100	80
	Misclassification	0	20

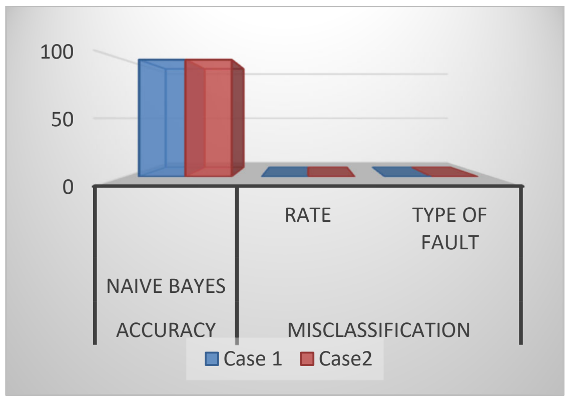


Figure 7. Accuracy rate and Misclassification rate

4. CONCLUSION

The implication of the above result indicated the effective developed model that harnesses the pending under-reach challenges encountered on integrated STATCOM compensated transmission lines, using unique extracted signal features from advanced signal of SLG transient faults. Both features from SD and EV data have proven to contained useful hidden information that could be deploy for SLG fault discrimination and detection models under STATCOM integration. Naïve Bayes classifier model algorithm present a novel modification in distance relay algorithm performance to eliminate under-reach fault detection in the 3rd zone protection coverage for a distance relay backup operation performance.

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