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Differential Relaying Protection of Transmission Line Interconnecting DG and UPFC using Discrete Wavelet Transform

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***Abstract*—This paper presents an approximate level Discrete Wavelet Transform (DWT) based differential relaying scheme for a transmission line in the presence of Unified Power Flow Controller (UPFC), Wind farm and Photo voltaic (PV) module. The fault current signals are obtained from respective buses and pre-processing it with the help of approximate level DWT to derive fourth level approximate coefficients (CA4). Further, the RMS value is extracted to compute operating and restraining values for fault detection in such a complex transmission system. The proposed relaying scheme has been extensively tested for wide variations in parameters and operating conditions, and the performance shows that the proposed scheme is highly reliable.**

***Index Terms*—Discrete Wavelet transform (DWT), Photo Voltaic Module, Unified Power Flow Controller (UPFC), Wind-farm.**

I. INTRODUCTION

Each and every day the demand for electricity is increasing. The transmission networks are pushed to their physical limits to optimize the operation aspects of generation, transmission and distribution of electric power. Utilities are forced to rely on the already existing networks to meet the electric demand. Flexible AC Transmission systems (FACTS) [2] play an important role to reduce the stress involved in the transmission lines. The concept of FACTS refers to a family of power electronic based devices to enhance AC system controllability and stability thus increasing power transfer capability. UPFC has the ability to independently control three important parameters of power system such as bus voltage, line active and reactive power [11]. Even though UPFC is capable of improving the power transfer capability of transmission network, it creates a certain problem regarding transmission line protection greatly in reach of distance relay. When a fault occurs in the presence of UPFC, the voltage and current signals are greatly affected in both steady and transient state, which significantly varies the performance of distance relay scheme. When UPFC controls the active and reactive power of the transmission network it significantly varies the transmission line impedance, which greatly affects the distance relay to under reach or over reach.

In recent years, integration of renewable energy sources to the grids at different levels of voltage has been increased and the share of such sources in the transmission system is increasing day by day. The generation of electricity from renewable energy sources includes technologies such as hydropower, wind power, solar power, tidal and wave power, geothermal power and power from renewable biomass. The variability created by renewable sources produces distinct challenges for integration into the larger power system. Wind and solar are relatively mature for use in large capacities and in wide areas, and have a significant impact on the power grid that is likely to increase over time. Even though integration of renewable sources meets the demand to an extent, the challenges that power system encounter due to this integration is more. When a wind farm and PV is integrated to the transmission system, there will be an under/over voltage condition due to the variation in wind speed and temperature. Thus, protection is a serious concern when a transmission line is connected to renewable energy sources [5]. Further, when UPFC is also integrated to such a system conventional distance relaying scheme fails to operate.

II. WAVELET TRANSFORM

Wavelet transform is a very effective tool for analysing power transients. WT introduces several applications in the field of fault detection, fault location, high impedance fault etc. A wavelet is a waveform of which have limited duration and with an average value of zero. The original signal known as mother wavelet is dilated and shifted in order to produce daughter wavelets. Wavelet analysis allows the use of both long time intervals and shorter regions in order to cover irregular low frequency and high frequency information. The wavelet transform are of two types continuous wavelet transform (CWT) and discrete wavelet transform (DWT).

Continuous Wavelet Transform (CWT) has been developed as an alternative to Short Term Fourier Transform (STFT) to overcome the resolution problem. The CWT of a signal x(t) is given by,

$$CWT(x,b,a) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} x(t)\varphi\frac{(t-b)}{a}dt \qquad (1)$$

where,

$\varphi\frac{(t-b)}{a}$ is the mother wavelet

a = dilation parameter (scale factor)

b = translation parameter.

Discrete Wavelet Transform (DWT) is another special case of WT. It is considerably easier to implement compared to CWT. Even though the idea of computation is same as that of CWT, the time-scale representation of digital signal is obtained using digital filtering techniques. The continuous wavelet transform was computed by changing the scale of the analysis window, shifting the window in time, multiplying by the signal, and integrating over all times. In the discrete case, filters of different cut-off frequencies are used to analyse the signal at different scales. The signal is passed through a series of high pass filters to analyse the high frequencies, and it is passed through a series of low pass filters to analyse the low frequencies.

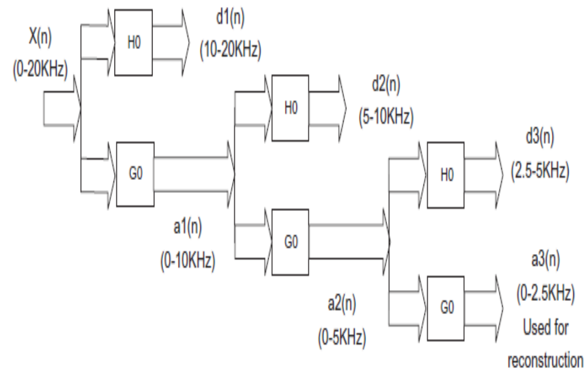

Fig: 1 An example of three level decomposition

The equation to derive the high pass and low pass wavelet coefficients is given by:

$$H_i = \sum_{n=0}^{k-1} x_{2i-n} \times S_n(z) \qquad (2)$$

$$G_i = \sum_{n=0}^{k-1} x_{2i-n} \times t_n(z) \qquad (3)$$

where,

$S_n(z)$ and $t_n(z)$ are called *wavelet filters*

k is the length of the filter

i = 0,1, … [n/2]-1

In this paper, the current features are extracted by pre-processing the current signals from each of the different substations using wavelet transform. The Daubechies-4 (db4) mother wavelet is selected to produce the daughter wavelets as it is well suited for fault and transient analysis. In the proposed scheme a sampling frequency of 20 kHz (400 samples in a 50Hz system) is considered. The current signal is decomposed into four levels resulting in “a-1 (0-10kHz) and d-1 (10-20kHz)” at level 1, “a-2 (0-5 kHz) and d-2 (5-10 kHz)” at level 2, “a-3 (0-2.5 kHz) and d-3 (2.5-5 kHz)” at level 3 and “a-4(0-1.25 kHz) and d-4 (1.25-2.5kHz)”at level 4. The rms value of the re-constructed signal is used to compute the operating and restraining values.

III. SYSTEM STUDIED

A 500 kV, 50 Hz transmission system is considered for studying the proposed scheme. The model is illustrated in Fig:2. Here we can see three substations and a UPFC is located at the middle of the transmission line. Wind farm is connected as substation-2 and PV is connected as substation-3.

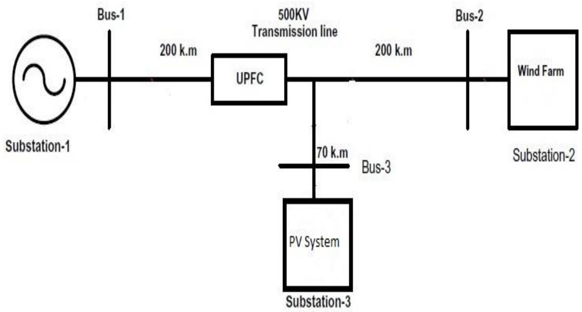

Fig: 2 Simulated transmission system.

The parameters used for modelling the proposed system are given below:

Transmission line parameter:

R_1 = 0.01537(Ω/km): Positive sequence resistance

R_0 = 0.04612(Ω/km): Zero sequence resistance

L_1 = 0.8858× 10^{-3} (H/km): Positive sequence inductance

L_0 = 2.654× 10^{-3} (H/km): Zero sequence inductance

C_0 = 13.06× 10^{-9} (F/km): Positive sequence capacitance

Source parameter:

V_1 = 500 kV (substation-1), 50 Hz, short-circuit level 1500 MVA, ∂_1= 12°

V_2= 500 kV (substation-2), 50 Hz, 60MW

Wind-farm is connected through a 575 V/500 kV, 70 MVA transformer, ∂_2= 8°.

V_3 = 500 kV (substation-3 voltage), 50 Hz, short-circuit level 1500 MVA, ∂_3=0.

UPFC is installed in the middle of the transmission line of length 200 km which have a rating of 100 MVA. In the proposed scheme UPFC is operated in automatic control mode since it is the most common mode of operation. The UPFC has two 48-pulse voltage source inverters which are connected with the help of two 2500µF common dc capacitors. The first inverter is STATCOM, which is connected to the transmission system with the help of a Δ/Y shunt transformer of rating 500/20kV. STATCOM helps to inject or consume reactive power to the transmission line and hence regulating the voltage at the connected point. Another inverter Static Synchronous Series Compensator (SSSC) is connected to the transmission system with the help of a Y/Y series transformer of rating 20 kV/60 kV to regulate the voltage and power flow through the line.

Wind farm of capacity 60 MW (40 numbers of wind turbines each of capacity 1.5 MW). Wind turbines uses Doubly-Fed induction generator which allows extracting maximum energy from the wind by optimizing the turbine speed, also it minimizes the mechanical stress in turbine during gust of wind.

Solar insolation and cell temperature are the main two parameters that determine the output characteristics of the PV module. A 36W PV module is taken as the reference module for simulation. The other parameters are as given below,

Rated power	= 36W
Total number of cells in series	= 36
Total number of cells in parallel	= 1
Voltage at maximum power (V_{mp})	= 18 V
Current at maximum power (I_{mp})	= 4 A

The proposed concept is tested for wide variations in fault parameters and operating conditions as given below:

- Different types of fault: Single line fault, Double line fault, Line to ground fault, three phase fault.
- Variation in fault resistance(R_f) 0-100 Ω
- Variation in wind speed: 5-25m/sec
- Variation in temperature: 30-150° C

IV. PROPOSED METHOD

The fig:3 illustrates the proposed relaying scheme. The fourth level reconstructed current signal (a-4) is derived from each substation and the rms value of the reconstructed current signal is computed to calculate the operating (E_{op}) and restraining (E_{ref}) quantity.

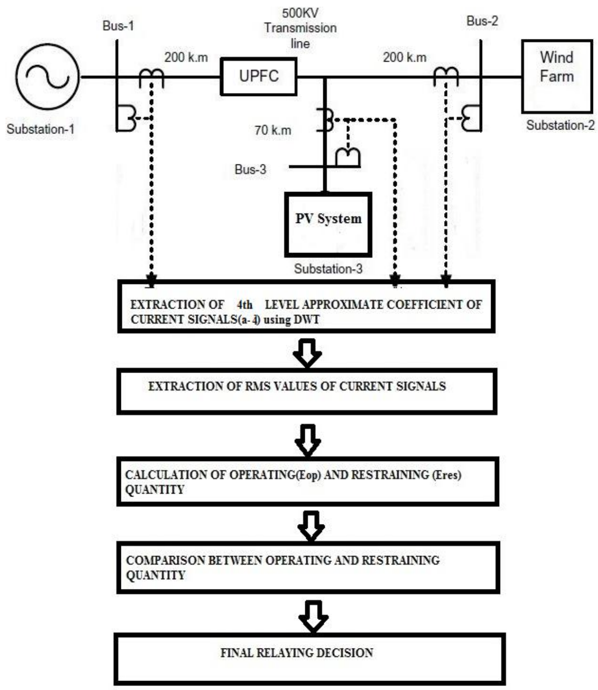

Fig 3: Proposed relaying scheme

The operating and restraining quantity of the differential relay can be calculated as follows:

$I_{op} = (I_{a1} - I_{a2} - I_{a3})$ (4)

$I_{res} = (I_{a1} + I_{a2} + I_{a3})$ (5)

where I_{a1} , I_{a2} , I_{a3} are the reconstructed current signals of a-phase of substation-1, 2 and 3, respectively. The operating E_{op}) and restraining quantity (E_{ref}) is calculated by:

$E_{op} = \sum_N I_{op}^2$ (6)

$E_{ref} = \sum_N I_{res}^2$ (7)

where N is the number of samples.

V. RESULTS AND DISCUSSION

Sim-Power Systems is used to model the proposed system. The performance is observed under different fault conditions and also varying parameters.

A. Internal fault

Different types of faults are simulated on the transmission system and the proposed scheme is validated. Fig:4 shows the current waveform when a fault is applied on substation-1 at 0.3 sec.

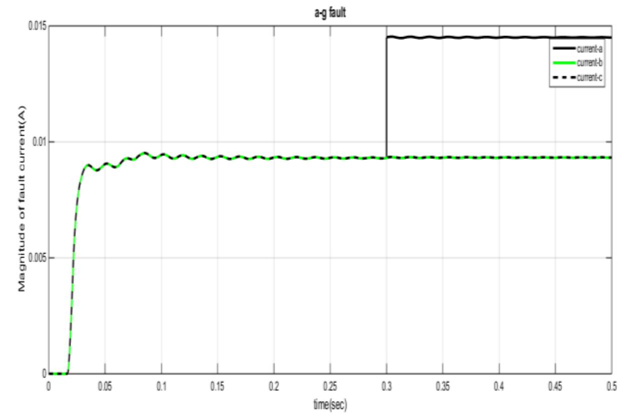

Fig:4 Current waveform when fault is applied at 0.3sec

Table:1 shows the operating and restraining values obtained for various internal fault conditions. The result shows that E_{op} is at higher level compared to E_{ref}.

Table:1 Internal fault conditions.

Faults	E_{op}(A)	E_{ref}(A)
AG	1292	291.9
ABG	386.6	375.6
AB	2279	840.7
ABC	2284	845.4

B. Varying fault Resistance

Faults with high resistance generally affect the performance of the conventional relaying scheme (distance relaying scheme). In order to test the effect of the change in fault resistance (R_f), the validation is carried out for an AG fault with different values of R_f (R_f= 0-100Ω). Table:2 confirms that the magnitude of both E_{ref} and E_{op} are changing as R_f is increasing from 0 to 100 Ω. However, E_{op} stays at much higher level compared to E_{ref} for each fault resistance and thus, makes the relaying scheme reliable. It has been found that the impact of high resistance fault (R_f= 0-100Ω) has no significant effect on the performance of the proposed relaying scheme.

Table:2 Effect of varying fault resistance.

Fault resistance(Ω)	E_{op}(A)	E_{ref}(A)
20	2410	1542
40	2412	1540
60	2398	1538
100	2410	1545

C. Varying Wind speed and Temperature

The output power of a wind farm and PV system has a non-linear relationship with the wind speed and temperature respectively which greatly affect the conventional relaying scheme. The proposed relaying scheme is tested under different wind speed (varies from 5 m/s to 25 m/s) and temperature (varying from 30°C to 150°C) during faulted condition. It is observed that the operating and restraining quantities vary with respect to wind speed as shown in table 3 & 4.

Table 3: Effect of varying wind speed.

Wind speed(m/sec)	E_{op}(A)	E_{ref}(A)
5	2410	1525
10	2411	1534
15	2432	1520
20	2430	1511
25	2405	1525

Table 4: Effect of varying temperature

Temperature(° C)	E_{op}(A)	E_{ref}(A)
30	1.9×10^5	968
60	1.95×10^5	972
90	1.88×10^5	1000
100	1.89×10^5	962
150	1.96×10^5	985

VII. CONCLUSION

A Discrete wavelet based differential relaying scheme which uses a-4 coefficient of db-4 signal for transmission line protection including UPFC, wind-farm and PV is proposed. The scheme works on the computed operating and restraining signals to issue or suppress the tripping signal. The proposed differential scheme is validated for detecting and classifying faults including wide variations in different faults, faults resistance, PV and wind-farm parameters. It is observed that the relaying scheme is highly effective in detecting fault.

REFERENCES

[1] Xiaoyao Zhou, Haifeng Wang, Aggarwal RK, Beaumont Phil, "Performance evaluation of a distance relay as applied to a transmission system With UPFC". *IEEE Trans Power Del* 2006;21(3):1137–47.

[2] Dash PK, Pradhan AK, Panda G, Liew AC, "Adaptive relay setting for flexible AC transmission systems (FACTS)". *IEEE Trans Power Del* 2000;15(1):38–43.

[3] El-Zonkoly AM, Desouki H, "Wavelet entropy based algorithm for fault detection and classification in FACTS compensated transmission line". *Int J Electr Power Energy Syst* 2011;33(8):1368–74.

[4] Ghorbani Amir, Mozafari Babak, Ranjbar Ali Mohammad, "Digital distance protection of transmission lines in the presence of SSSC". *Int J Electr Power Energy Syst* 2012;43(1):712–9.

[5] Pradhan AK, Joos Geza, "Adaptive distance relay setting for lines connecting wind farms". *IEEE Trans Energy Convers* 2007;22(1).

[6] Dash PK, Pradhan AK, Panda G, "Distance protection in the presence of unified power flow controller." *Int J Electr Power Energy Syst* 2000;54(3):189–98.

[7] Ito H, Shuto I, Ayakawa H, Beaumont P, Okuno K, "Development of an improved multifunction high speed operating current differential relay for transmission line protection". *Int Conf DPSP IEE Conf* 2001;479:511–4.

[8] Silveira PM, Seara R, Zurn HH, "An approach using wavelet transform for fault type identification in digital relaying". *IEEE-PES Summer Meeting* 1999;2:937–42.

[9] Megahed I, Moussa AM, Bayoumy AE. "Usage of wavelet transform in the protection of series-compensated transmission lines". *IEEE Trans Power Del* Jul 2006;21(3):1213–21.

[10] Badri ram, D N Vishwakarma, "Power system protection and switch gear".

[11] Hingorani NG, Gyugyi L. "Understanding FACTS concepts and technology of flexible AC transmission systems". New York: IEEE Press; 2000.

[12] M.Veerachary,"Power Tracking for Nonlinear PV Sources with Coupled Inductor SEPIC Converter," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 41, No. 3, July 2005.