Wavelet Based Protection Scheme for Multi Terminal Transmission System with PV and Wind Generation

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Abstract: A hybrid generation is a part of large power system in which number of sources usually attached to a power electronic converter and loads are clustered can operate independent of the main power system. The protection scheme is crucial against faults based on traditional over current protection since there are adequate problems due to fault currents in the mode of operation. This paper adopts a new approach for detection, discrimination of the faults for multi terminal transmission line protection in presence of hybrid generation. Transient current based protection scheme is developed with discrete wavelet transform. Fault indices of all phase currents at all terminals are obtained by analyzing the detail coefficients of current signals using bior 1.5 mother wavelet. This scheme is tested for different types of faults and is found effective for detection and discrimination of fault with various fault inception angle and fault impedance.

Keywords: Multi terminal transmission System, Wavelets, Hybrid energy sources.

I. INTRODUCTION

An electrical power system consists of utility grid and hybrid energy sources like wind and photovoltaic. The heavy short circuit currents are likely to cause damage to equipment if suitable protective relays and circuit breakers are not provided for the protection of each section of the power system. A fault in a power system can lead to abnormal currents and voltages[4,6]. During a three phase short circuit, the currents may become excessively large and the voltages may go to zero. The system must be protected against such occurrences, and steps must be taken to remove a fault as quickly as possible[10]. An integration scheme of solar photovoltaic combination with a wind energy system of large capacity doubly excited induction generator is described in this paper. Protection must required to respond both utility grid and renewable energy sources. If the fault is on the utility grid, the desired response may be to isolate the hybrid energy sources from the main utility as rapidly as possible to protect the system[5]. If the fault is within the hybrid source, the protection scheme isolates the energy source section of the system to eliminate the fault. In order to cope with the bi-directional energy flow due to large numbers of sources new protection schemes are required[7].

Reliable protection schemes can reduce costs for distributed generation, providing for more options in the overall mix of power sources. Mixed communications, different terminal arrangements, and accommodation of communication failure provides protection engineers with necessary options to improve overall system operation.

The proposed algorithm describes the general operating principle of multi terminal transmission line protection[1] with hybrid energy source using wavelet analysis. An operating...
current signals are identified and then sum of the detailed coefficients are calculated by make use of bior1.5 mother wavelet at each terminal. This is compared to a threshold value of current signal in order to provide security against external faults. The protection scheme is simple if all the information is available at each terminal in order to provide high-speed tripping of each faulty terminal[3]. The test results can clearly shows that the variation in the value of fault index of the healthy phase in the presence of hybrid energy sources in the path along one terminal towards the other terminal with variations in fault inception angle and resistance.

II. HYBRID ENERGY SYSTEM
Distributed generation technologies applicable for hybrid energy sources may include emerging technologies such as wind turbine, solar PV, micro-hydropower, diesel generators. Hybrid generation consists of low voltage distribution systems with distributed energy resources, such as wind turbine and photovoltaic power systems, together with storage devices[9]. Solar PV generation involves the generation of electricity from solar energy. Due to enormous improvement in inverter technologies, PV generation is now preferred worldwide as Distributed Energy Resources. Solar energy can be utilized by collecting and converting it directly into electrical energy using photovoltaic system. Rapid progress in increasing the efficiency and reducing the cost of PV cells has been made over the past few decades[8]. Their terrestrial uses are now widespread, particularly in providing power for communications, lighting and other electrical appliances in remote locations where a more conventional electricity supply would be too costly.
Wind turbine converts kinetic energy of winds motion into electrical energy using the energy conversion systems. Usually doubly fed induction generators are used in WECSs[2]. The main part of the wind turbine is the tower, the rotor, and the nacelle. The nacelle provides the mechanical transmission and the generator. Wind velocities between 4 m/s and 30 m/s are used for driving wind turbine generator shaft and producing electrical energy. Turbine captures the wind energy flow through rotor blades and transfers the energy to the induction generator through the gearbox. The generator shaft is driven by the wind turbine to generate electric power.

III. SYSTEM MODELING AND ANALYSIS
Single line diagram of Four terminal transmission line with hybrid Energy source of wind and PV generation included in the system as illustrated in Figure 1 and description about the details of the system are represented in table1.

Fig.1: Single line diagram of multi terminal transmission system with hybrid Energy source.
Table 1: Parameters of the Power System and Details of Wavelet

| Terminal | Generator | Voltage (kV) | Power (MVA) | Transformer Ratio | Phase Angle |
|----------|-----------|--------------|-------------|------------------|-------------|
| 1        | 1         | 500          | 9000        | Y-g              | 0°          |
| 2        | 2         | 500          | 9000        | Y-g              | 20°         |
| 3        | Wind      | 10.5         |             |                  |             |
| 4        | Photovoltaic | 1.25       |             |                  |             |

Transmission line (Distributed):
- Resistance: $R = 0.01273 \, \Omega/Km$, $R_0 = 0.3864 \, \Omega/Km$
- Inductance: $L = 0.9337 \, \text{H/Km}$, $L_0 = 4.1264 \, \text{H/Km}$
- Capacitance: $C = 12.74 \, \text{F/km}$, $C_0 = 7.751 \, \text{F/km}$

Mother Wavelet: Bior 1.5
Sampling frequency: 216 KHz
Information Analyzed: Detail at 1, D1
Frequency band: 108 KHz - 54 KHz
Number of Samples per cycle: 21600
Occurrence of Fault: Second cycle
Data window length: One cycle/17.7 ms

IV. RESULTS AND DISCUSSIONS

The wavelet-based fault classifier modules are tested using data sets consisting of fault cases. Fault index, fault inception angle, distance, and fault resistance were changed to investigate the effects on the performance of the proposed algorithm.

A. Test results of single phase to ground faults (LG)

The network was tested by presenting different single phase to ground fault cases with varying fault inception angles from 0° to 180° with steps of 20. Figure 1 shows the detection of LG fault at Phase A of the wavelet-based fault classifier module at terminal 1. Figure 2 illustrates the analysis of detailed coefficients of Single Phase to ground fault at Phase A and is observed that the faulty phase detailed coefficient values are greater than the threshold value. The variation of Fault distance from 0 to 100 km in steps of 10 with constant Fault Inception angle (FIA) at 60° and Fault Inception angle with constant distance at 40 km for fault inception time 15 ms ($\Phi_1 = 60°$) and fault resistance $R_f = 5 \Omega$ of Single Line to Ground (SLG) fault at terminal 1 is shown in fig 3.

Fig 2: Detection of LG fault at Phase A.
Fig 3. Analysis of detailed coefficients of Single Phase to ground fault at Phase A.

Fig 4. Varying Fault distance with constant FIA 60° and Fault inception with constant distance at 40km of SLG fault at terminal1.

B. Test results of phase to phase faults (LL)

The network was tested by presenting different single phase to ground fault cases with varying fault inception angles from 0° to 180° with steps of 20. Figure 5 shows the detection of LL fault at Phase A&B of the wavelet based fault classifier module at terminal 2. Figure 6 illustrates the analysis of detailed coefficients of Double line (DL) fault at Phase A&B and is observed that the faulty phases detailed coefficient values are greater than the threshold value. The variation of Fault distance from 0 to 100 km in steps of 10 with constant Fault Inception angle (FIA) at 60° and Fault inception angle with constant distance at 40km for fault inception time 15ms (Φ1 = 60°) and fault resistance Rf = 5Ω of Double Line (DL) fault at terminal 2 is shown in fig 7.

Fig 5. Detection of LL fault at Phase A&B.

Fig 6. Analysis of detailed coefficients of Double line fault at Phase A&B.
Fig 7. Varying Fault distance with constant FIA $60^0$ and Fault inception with constant distance at 40km of DL fault at terminal2.

C. Test results of double phase to ground faults (LLG)
The network was tested by presenting different single phase to ground fault cases with varying fault inception angles from $0^0$ to $180^0$ with steps of 20 . Figure 8 shows the detection of LLG fault at Phase A&B of the wavelet based fault classifier module at terminal3. Figure 9 illustrates the analysis of detailed coefficients of Double line to ground (DLG) fault at Phase A&B and is observed that the faulty phases detailed coefficient values are greater than the threshold value.

Fig 8. Detection of LLG fault at Phase A&B.

Fig 9. Analysis of detailed coefficients of Double line to ground fault at Phase A&B.
The variation of Fault distance from 0 to 100 km in steps of 10 with constant Fault Inception angle (FIA) at $60^\circ$ and Fault inception angle with constant distance at 40km for fault inception time 15ms ($\Phi_1= 60^\circ$) and fault resistance $R_f = 5\Omega$ of Double Line to ground (DLG) fault at terminal3 is shown in fig10.

**D. Test results of Three phase fault (LLL)**

The network was tested by presenting Three phase fault case with varying fault inception angles from $0^\circ$ to $180^\circ$ with steps of 20. Figure11 shows the detection of LLLG fault at Phase A,B&C of the wavelet based fault classifier module at terminal4. Figure12 illustrates the analysis of detailed coefficients of Three phase fault at Phase A,B&C and is observed that the faulty phases detailed coefficients values are greater than the threshold value. The variation of Fault distance from 0 to 100 km in steps of 10 with constant Fault Inception angle (FIA) at $60^\circ$ and Fault inception angle with constant distance at 40km for fault inception time 15ms ($\Phi_1= 60^\circ$) and fault resistance $R_f = 5\Omega$ of Three Phase fault at terminal4 is shown in fig13.

**Fig 10. Varying Fault distance with constant FIA  60$^\circ$ and Fault inception with constant distance at 40km of DLG fault at terminal3.**

**Fig 11. Detection of LLL fault at Phase A,B&C.**
V. CONCLUSION
The accuracy and reliability of algorithm and wavelet analysis for fault classification for shunt faults on multi terminal transmission line fed from sources with two end terminals and hybrid energy sources like wind and PV system at other two terminals is presented in this work. The online data sheet used to input to the algorithm employs the fundamental components of three phase currents of each section measured at all end terminals, thus require less communication and data acquisitions. The wavelet detailed coefficient based classification algorithm provides automatic detection and discrimination of fault type, faulted phases less than half cycle from the inception of fault at any fault resistance. The variation of fault parameters such as line distance, fault inception angle and fault resistance on multi terminal transmission with hybrid energy system protection scheme is effectively done. The performance of the proposed protection scheme has been investigated by a number of classified short circuit fault conditions are analyzed. The complexity of the possible types of faults of transmission line, varied fault inception angles from 0 to 180°, fault resistance (0-50Ω) are identified and tested at different distances.

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