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Research paper

Location of fault in a hybrid power system using impedance based method

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Abstract

Fault analysis is a major and complex task for the power system engineers. It requires models, which determine the distance of the fault in the transmission line. By the use of mathematical models, we determine the behavior of faults and their locations, which help in preventing the transmission lines from heavy damage. Determining the fault location and their distance to buses is the sole objective of this paper. The method used for the fault location detection is impedance-based technique. For analysis, various faults at various locations of the system were modeled and simulated using MATLAB/SIMULINK. The results and applications are stated in this paper and it is found that this method is easier and most widely used.

Keywords: *Hybrid System (HS); Micro Turbine Generator (MTG); Wind Turbine (WT) Semicolon.*

1. Introduction

In an integrated electrical system, the electricity generated by the generating stations is transmitted to the consumer end with the help of transmission lines. The system is said to be in a balanced state when it is working in normal operating condition and in a state of unbalanced in case of faults. There are many factors responsible for the fault occurrence in power system such as mechanical failures of equipment's, natural events such as excessive wind, rain, falling of trees, etc. By considering the values of voltages and currents in balanced and unbalanced conditions the analysis of fault can be done [1]. Occurrence of faults affects the equipment's connected due to the large current flow. The voltage level will change drastically due to the fault current which can cause in failure of the insulation. The purpose of this paper is to provide an idea about impedance based method of fault location on the hybrid system [5].

The power sector is a very significant part of every nation. It generally consists of power industries in which the generated power is supplied to the consumers with the means of transmission lines. The protection of transmission line from the occurrence of faults is very challenging. The factors such as lightning, storm, freezing, rain, snow and damage of insulation are the main reason for failure of transmission line. Mostly the faults which take place in the transmission line are phase to ground faults, three phase faults, line to line faults etc. For smooth power flow the fault should be cleared as quickly as possible. If we will able to detect the location of the fault then we could reduce the total operating cost of the system as well as provide the better system performance [2].

This paper sectionalized into three categories. Firstly, it describes about the proposed technique with some other techniques for fault calculation in section-2, then the hybrid system comprises of wind and micro turbine system in section-3 and finally analysis of simulation and results in section-4 as follows. The paper is concluded in section-5.

2. Impedance based method

The impedance base technique is one of the methods for locating faults in transmission line. Fault currents and voltages from both ends are used in this method. At both the ends of transmission line fault recorder are placed which gives fault currents and voltages provided that both ends are not synchronized [2]. One-edged impedance based fault location technique is the modified version of impedance based technique. Here, Location of fault is estimated from one end only. It is very simple to implement, provide proper location estimation and only one end data is needed. An advantage is that it needs no communication channel. The drawbacks of one-edged impedance method are corrected by using a technique called Takagi technique [2]. In this method, by using superposition theorems the load current is subtracted from the total current to split the fault into a pre-fault and post fault-network. In modified Takagi technique, to avoid the fault current the zero sequence current for a single-line to ground fault is used [1,9]. The distance to fault is calculated by using this following expression:

$$m=\frac{\mathrm{Im}\,g\left(V_G\times 3I_{GO}^{*}\right)}{\mathrm{Im}\,g\left(Z_{L1}\times I_G\times 3I_{GO}^{*}\right)} \tag{1}$$

In order to calculate the distance to a fault , a new technique called Erikson technique is introduced in which source impedance parameter are used to solve the reactance errors due to fault resistance [5]. The current distribution factor is substituted to give:

$$V_G=mZ_{L1}I_G+R_F\left(\frac{Z_{G1}+Z_{L1}+Z_{H1}}{(1-m)Z_{L1}+Z_{H1}}\right)\Delta I_G \tag{2}$$

By simplifying and rearranging:

$$m^2 - K_1 m + K_2 - K_3 R_F = 0 \tag{3}$$

The constants K1, K2 and K3 are the complex multiplications of voltage, current, line impedance and source impedance are as follows:

$$K_1 = a + jb = 1 + \frac{Z_{H1}}{Z_{L1}} + \left(\frac{V_G}{Z_{L1} \times I_G} \right) \tag{4}$$

$$K_2 = c + jd = \left(\frac{V_G}{Z_{L1} \times I_G} \right) + \left(1 + \frac{Z_{H1}}{Z_{L1}} \right) \tag{5}$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{H1} + Z_{G1}}{Z_{L1}} \right) \tag{6}$$

Separation of real and imaginary parts gives the solution of distance to fault using the following equation:

$$m = \frac{\left(a - \frac{eb}{f} \right) \pm \sqrt{\left(a - \frac{eb}{f} \right)^2 - 4\left(c - \frac{ed}{f} \right)}}{2} \tag{7}$$

"M" should lie between 0 and 1 per unit. The location estimate resistance can be calculated as:

$$R_F = \frac{d - mb}{f} \tag{8}$$

Novosel et. al., Technique is the modification of Erikson technique which helps in spotting the fault on a short radial transmission line [4]. The lines feed the loads which are combined at the feeder end by evaluating the load impedance from the current and the pre-fault voltage as:

$$Z_{load} = R + jX = \frac{V_{G1R2}}{I_{G1R2}} - Z_{L1} \tag{9}$$

$$K_1 = a + jb = 1 + \frac{Z_{load}}{Z_{L1}} + \left(\frac{V_G}{Z_{L1} \times I_G} \right) \tag{10}$$

By using equation (7), we can obtain the per unit distance to the fault and the constants are defined as:

$$K_2 = c + jd = \frac{V_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{load}}{Z_{L1}} \right) \tag{11}$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{load} + Z_{G1}}{Z_{L1}} \right) \tag{12}$$

A location estimate is chosen for the value of m, which lies between 0 and 1 per unit. Due to the fault resistance and load this method is rugged to any reactance error. A two-edged impedance based fault-location technique is used to determine the location of fault by using current and voltage waveforms during a fault from both the ends of a transmission line. Any reactance error caused by the load resistance or load current is estimated by additional measurements from the far end of the transmission line. For the fault location, three symmetrical components are used and the negative sequence components are not affected by load current [5]. The zero, positive and negative sequence currents are expressed as:

$$I_a^0 = \frac{1}{3}\left(I_a + I_b + I_c \right) \tag{13}$$

$$I_a^+ = \frac{1}{3}\left(I_a + \alpha I_b + \alpha^2 I_c \right) \tag{14}$$

$$\mathrm{I_a^-} = \frac{1}{3}\left(\mathrm{I_a} + \alpha^2 \mathrm{I_b} + \alpha \mathrm{I_c} \right) \tag{15}$$

Similarly, the zero, positive and negative sequence voltages are expressed as:

$$V_a^0 = \frac{1}{3}\left(V_a + V_b + V_c \right) \tag{16}$$

$$V_a^+ = \frac{1}{3}\left(V_a + \alpha V_b + \alpha^2 V_c \right) \tag{17}$$

$$V_a^- = \frac{1}{3}\left(V_a + \alpha^2 V_b + \alpha V_c \right) \tag{18}$$

In matrix form the equation can be expressed as:

$$\begin{bmatrix} V_a^0 \\ V_a^+ \\ V_a^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{19}$$

3. Hybrid system

The combination of renewable source of energy with a conventional source of energy to form a virtual grid is generally considered as a hybrid generation system. This kind of configuration gives rise to two major issues. One is higher emission due to conventional generation technique and the other one is the high cost of generation of renewable source of energy [4]. As the wind energy system has no emission, but high capital cost and the micro turbine energy system have relatively lower cost with low emission hence these two systems can be combined together to model a hybrid system. With the help of power electronic interface this hybrid system can be operated in isolated mode or in grid connected mode. The parameters of the hybrid generation system for voltage, frequency etc. should be maintained by the power electronic interface [3-6].

3.1. Wind turbine system

Wind energy is the most promising source of renewable energy. The wind energy available is seized by the wind turbine and converted into electrical energy. The functional structure of wind turbine system depends upon two schemes of operation called constant speed wind turbine and variable speed wind turbine. Previously the average size of the commercial turbine was about 300 kW but presently the machines are of the largest capacity up to 5 MW have been developed. For electrical power generation self-excited generator is used in this system [3]. Wind turbine modeling is a complex system which converts wind energy to rotational energy and then to electrical energy [6]. Several factors such as wind speed, size and shape of the turbine help to determine the output power of the turbine. The wind turbine system has both input and output variables which help to extract power from the air stream. The input and output variables are namely wind speed, turbine speed, rotor blade tilt, rotor blade pitch angle and torque or power respectively. With the help of the input and output variable of the wind turbine we can derive a relation between wind speed and power [3].

The kinetic energy in the air of mass m moving with the velocity V is given by:

$$\textit{Kinetic}\ \text{energy} = \frac{1}{2} m V^{2} \tag{20}$$

The power in the moving air flow is the flow rate of kinetic energy per second

$$\textit{Power} = \frac{1}{2}(\textit{mass}\ \text{flow rate per sec}) V^{2} \tag{21}$$

The difference between the upstream and downstream of wind power gives the actual power extracted.

$$\textit{Power} = \frac{1}{2}(\textit{mass}\ \text{flow rate per sec})(V^{2} - V_{0}^{2}) \tag{22}$$

Where,

P = mechanical power extracted by rotor

V= upstream wind velocity of the rotor blade in m/sec

V_0 = downstream wind velocity in m/sec

$$\text{Mass flow rate} = \rho A.\frac{V + V_0}{2} \tag{23}$$

Where

ρ = air density in kg/m^3

A = area swept by the rotor blade

After rearranging the terms, we have:

$$P = \frac{1}{2} \rho A V^{3} C_p$$

Where

$$C_p = \frac{\left(1 + \frac{V_0}{V}\right)\left(1 - \left(\frac{V_0}{V}\right)^{2}\right)}{2}$$

CP = power coefficient of rotor which has a maximum value of 0.59

3.2. Micro turbine system

The objective of micro turbine generation system is to present a generating unit which is able to act as a backup to maintain the continuity of supply when renewable source alone is insufficient to meet the load. Micro turbines produce a growing interest in its applications since these units can start quickly and are also useful to supply the peak load for grid support [7]. There are several other applications such as remote power and combined heat and power systems. The range of MTGs is from 30 to 400 kW, while conventional gas turbines are from 500 kW to 300 MW. Micro turbines are capable of burning a number of fuels at high low pressure levels. They have a low marginal electrical efficiency. Based on their simple design and relatively few moving parts they possess a greater reliability, lower maintenance, reduce noise, lower capital cost, and easier installation. Their emission capability is eight times lower than the diesel generators. So now a day's micro turbines are gaining popularity. Mainly micro turbines are categorized in two types. One is single shaft models, and another one is two shaft models [8]. There is a single expansion turbine, which rotates both compressor and generator. Due to this they operate at an ultra-high speed and generate electrical power at high frequency. In a single shaft design, since a generator supplies a high frequency AC voltage so there is a need of a power electronic interface between the micro turbine generation system and the load. But in case of two shaft design, there is no need of the interface system. Compressor, turbine, recuperator, high speed generator and the power electronic interface system are the basic components of the micro turbine generation system [7]. The high speed generator usually employs the permanent magnet synchronous generator and the power electronics interfacing is a component generally used for handling transient and voltage spikes. These are the major components which we should consider for the modeling of gas turbine systems.

4. Simulation results and analysis

The transmission line of length 100 km is modeled using MATLAB\SIMULINK. Table-1 provides the location calculation for faults at various distances from the source end. The error is more in wavelet transform method. The proposed scheme calculates the fault location from the source point.

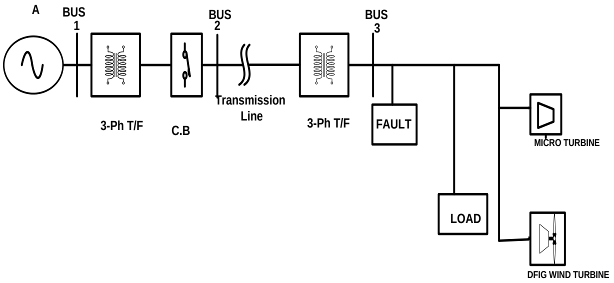

Fig. 1:

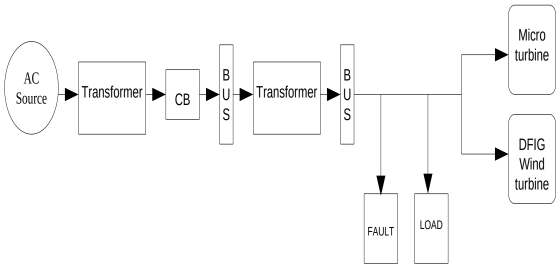

Fig. 2:

The fault calculated at different locations. The fault location is estimated at different fault points. Faults are calculated at 10km, 20km, 30km, 40km, 50km, 60km, 70km, 80km and 90km using impedance based method For a fault at a distance of 20 km the error value is only 1.23 %, whereas for a fault at a distance of 60km from the source the error decreases to 0.32 %.

Table 1: Calculation of Fault Distance Using Impedance Method

Actual Fault Distance in Km	Estimated fault location in (Km)	Error in (%)
10	9.82	1.82
20	19.75	1.23
30	29.75	0.85
40	39.72	0.69
50	49.76	0.47
60	59.8	0.32
70	69.84	0.23
80	79.88	0.16
90	89.91	0.097

From the analysis of the fault distance calculation using our proposed technique, it is clearly perceptible that as the fault distance from the source increases the error in the estimation fault location decreases significantly.

5. Conclusion

In the transmission line, the fault should be cleared as quickly as possible for better reliability. If the fault clearing time is smaller, lesser the threat of damaging equipment's, less the interruptions, etc. If we get the accurate location of faults then the restoration of system will be faster. Many research workers have proposed many different methods to calculate the distance of fault in the system network. This paper provides a basic idea of the calculation of the fault using impedance method. It is a cost effective method. It also does not require any information exchange between the relays. As we have very limited measurement this method gives the result, which contains some error. However, it provides the accurate and error free result if the fault is available for a couple of cycles. This method is not proficient for the high voltage transmission line where the fault presents for less than two cycles.

Thus, further future research should be done for an adaptable impedance based technique to calculate the fault location if the fault persists less than two cycles.

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