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Research Article

Voltage Sag Source Location Using Artificial Neural Network

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Abstract

Voltage sag is one of the most severe power quality disturbances to be dealt with by the industrial sector, as it can cause severe process disruptions and results in substantial economic loss. A short-term decrease in voltage lasting anywhere from milliseconds up to a few seconds is called voltage sag. The most severe voltage sags are caused by faults in the power system. Sag originating due to faults propagates through the system affecting loads connected far away from the sag source. Therefore, the accountability for the generation of disturbances on the system must be assessed and the sag sources must be analyzed and located. Locating sag source in a complicated power system network is a difficult task. Conventional methods for locating sag source needs measurement of sag voltage and current. This paper introduces an alternative method for voltage sag source location based on voltage information using Artificial Neural Network (ANN). The source is located considering the sag magnitude at the primary and secondary side of a transformer. The performance of the proposed method is validated using PSCAD /EMTDC on a model of a regional network including transmission and sub-transmission levels. The set of measurements taken from the regional network during a one year sag survey is used as training data for ANN. The results show the good performance of the new method and its unique applicability in cases where only voltages are recorded, such as the sag survey presented.

Keywords: *Voltage sag, ANN, Source Location, Power quality*

1. Introduction

Voltage sags cause several problems on end-users' equipments. These problems have been quantified and for instance, sensitive industrial load malfunction costs billions of rupees every year (Mc Granagh *et al*,2002). The most severe voltage sags are caused by faults in the power system. Unfortunately the sags are not confined nearby the fault location; they propagate through the system affecting loads connected far away from the sag source (Bollen.M.H.J *et al*,1999). Therefore, the accountability for the generation of disturbances on the system must be assessed and the sag sources must be analyzed and located. One of the first works aiming to locate the source of voltage sags defined the concepts of "disturbance power and disturbance energy". This concept was applied to locate the source of disturbances caused by capacitor switching and faults in the network (Parsons A.C *et al*, 2000). Later, a second work introduced the concept of "slope of the system trajectory" to locate the source of voltage sags (LiC, Tayjasanan *et al*, 2003). This method was generalized to a new approach using the sign of an estimated resistance to locate the source of voltage sags (Tayjasanant.T *et al*, 2005). Meanwhile, another approach using the variation of the real current component was introduced. This method uses the real part of the complex current to locate the sag source (Hamzah.N *et al*, 2004). Another method was motivated by the increasing use of digital relays and their applicability for power quality analysis. The distance relay algorithms can be used for the location of the voltage sag source based on the magnitude and angle of the measured impedance before and during a fault (Pradhan.A.K *et al*, 2005). These methods have been tested for symmetrical and asymmetrical faults and most of them have not been very accurate especially for asymmetrical faults (Leborgne.R.C *et al*, 2006). Moreover, the previous methods need both the current and the voltage measurements to locate the source of the sag. However, during several voltage sag surveys, it has been observed that it is a common practice to register and save voltage information only. Therefore, a method to locate the sag source based on the voltage sag magnitude obtained at two voltage levels of a substation is proposed in (Roberto Chouhy Leborgne *et al*, 2008). The method shows a remarkable accuracy for the location of the source of sags observed at transmission networks. In order to reduce the complexity in computations, this paper proposes ANN for location of voltage sag. The location of the sag source as observed from a monitored bus is defined as upstream or downstream, using the steady state power flow direction as reference. Upstream is the region against the flow of power and downstream is the region following the flow of power, as shown in Figure 1.

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2. Sag Location Based on Voltage Measurement

A method based on the analysis of the voltage sag magnitude and phase-angle jump was proposed to classify the source at the connection point of sensitive customers (Gomez.J *et al*, 2005). For a typical industrial installation the sags generated in the utility grid and the sags generated inside the industrial grid will follow different phase-angle jump vs. sag magnitude relation. Unfortunately, this method is not suitable for classifying sags at the interconnection point of two utilities at transmission levels because it is not expected to observe such a phase-angle jump vs. magnitude characteristic when there are transmission networks at both sides of the monitoring point.

An alternative simple approach to locate the sag source based on voltages sag magnitude at both sides of the transformer that interconnects two grids, as shown in Figure 2. The idea is to compare the voltage sag magnitudes in per unit with respect to pre-fault voltages at both sides of the transformer:

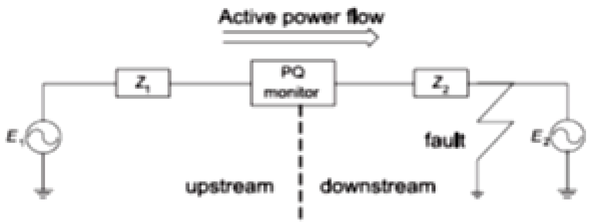

Fig. 1 Location of sag source

$$V_1 = \frac{V_{1-sag}}{V_{1-prefault}} \quad (1)$$

$$V_2 = \frac{V_{2-sag}}{V_{2-prefault}} \quad (2)$$

where $V_{i\text{-}sag}$ is the during sag voltage in kV and $V_{i\text{-}prefault}$ is the pre-fault voltage in kV. The voltage drop at each side of the transformer is given by:

$$\Delta V_1 = Z_1 I_{fault} \quad (3)$$

$$\Delta V_2 = Z_1 + Z_{TRAFO} \; I_{fault} \quad (4)$$

where, Z_{TRAFO} is the transformer impedance and I_{fault} is the fault current.

The voltage drop is higher on the side where the fault is located. Therefore, if $\Delta V_2 > \Delta V_1$ ($V_1 > V_2$) the fault is downstream, otherwise the fault is upstream. If the downstream system does not include generation units, V_1 and V_2 are expected to be equal during upstream faults. This method is intended to locate sag source at the interconnection point of transmission utilities. At this level the influence of loads is not so evident. And the effect of constant power loads may not affect the performance of the method because other loads such as induction machines will supply the extra current demanded by the constant power loads during short sags. Another concern is when unbalanced voltage sags propagate through a delta/star transformer. The relation of the voltage sag magnitudes at both sides of the transformers will depend on the sag type (Leborgne.R.C *et al*, 2004).

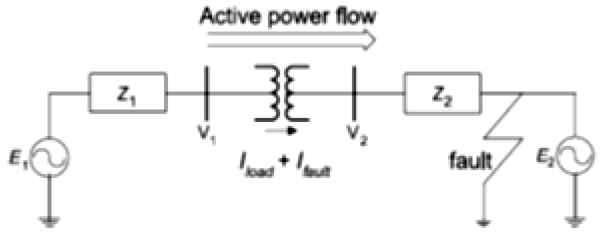

Fig. 2 Location of sag source using sag magnitude

3. Artificial Neural Network for Locating Sag Source

The voltage sag magnitude, estimated in terms of the prefault voltage, at both sides of a power transformer (230/138KV) is used as input to ANN. The output of ANN is sag source location which is either upstream (US) or downstream (DS). Hence the output neuron of ANN should yield binary output which is either 1 (US) or 0 (DS). The neural network used for locating sag source is full-connected, three layer, feed-forward, perceptron neural network. “Fully connected” means that the output from each input and hidden neuron is distributed to all of the neurons in the following layer. “Feed forward” means that the values only move from input to hidden to output layers; no values are fed back to earlier layers (a Recurrent Network allows values to be fed backward). The input layer has two neurons which receives V_{sag} at 230KV side and V_{sag} at 138KV side as input. There are two hidden layers with three and two neurons respectively. The output layer has only one neuron. If the input to the output neuron exceeds threshold limit it produces a output of ‘1’ otherwise ‘0’. Output ‘1’ indicates US (upstream) and output ‘0’ indicates DS (downstream). Back propagation training algorithm is used for training the neural network.

4. Test System

The method to locate the sag source is tested using a model of a regional network including transmission and sub-transmission levels, as well as meshed and radial system configurations. The network contains 67 power lines (69, 138, and 230 kV) with a total length of 6619 km. There are 93 substations with an installed transformer capacity of 2076 MVA. The generation capacity is larger than the present demand. The excess of generated power is exported to other regional grids through the RVD substation. A schematic network diagram is shown in Figure 3.

5. Training data for ANN

Voltage sags have been measured during a one year period in several buses of the system shown in Figure 3. During this sag survey only voltage information was registered.

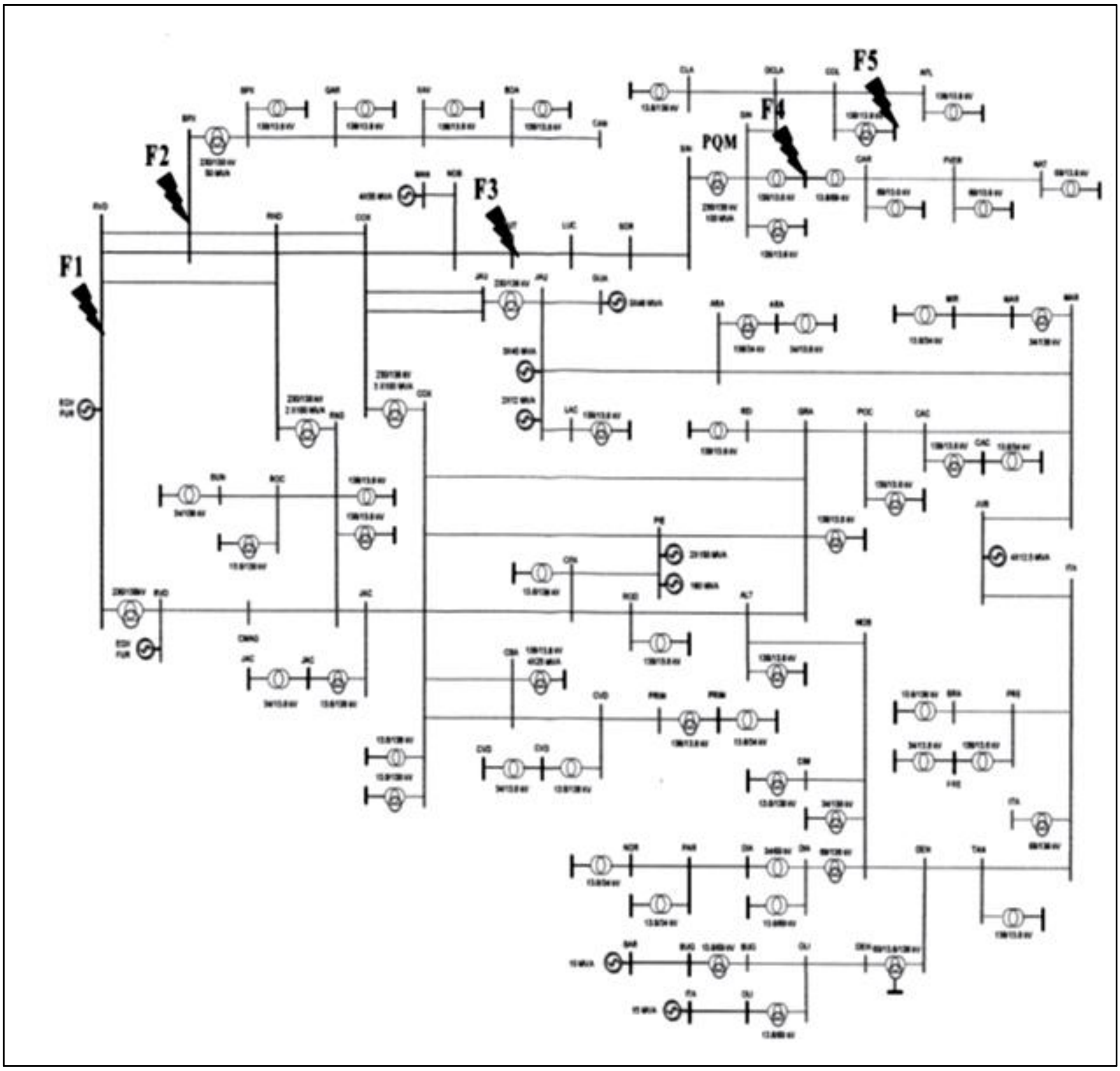

Fig. 3 Network diagram

Fortunately also the fault location has been obtained for events at the 230 kV and 138 kV lines. Therefore, it is possible to use this data as training data for ANN. Table 6 shows the voltage sag magnitude registered at both buses in the substation during the identified faults. Not all the measured sags are used because to test the method the fault location must be previously known. Therefore, only fault that happened at the 230 kV and 138 kV networks are identified and used for the method. The downstream events are highlighted with gray. In all the downstream cases the sag magnitude is lower at the 138 kV bus. There are some events where the sag magnitude is slightly lower (0.01 per unit) at the 138 kV bus, but these events were upstream.

6. Simulation Results

A substation that interconnects two utilities is chosen for PQ-monitoring (PQM). The 230 kV and the 138 kV grids are operated by two different utilities. Therefore, it is relevant to locate the source of the sag taking into account the boundaries between the two utilities. The faults are simulated at both utility networks, in upstream and downstream locations referred to the monitored buses. At each fault location 4 types of faults are simulated (LLLG, LL, LLG, and LG). At the monitored bus the active power always flows from the 230 kV to the 138 kV bus due to the lack of generation units at the downstream network. The simulated fault locations are named in Table 2. The results for the simulations are organized in Table 3 –6, one for each type of fault (LLLG, LL, LLG, LG). The first row of the table indicates the fault position as shown in Figure 3; the second and the third rows show the sag magnitude at the 230 kV and 138 kV buses; and the fourth row shows the location assessed by the test.

Table 1 Measurement results used as training data

Fault type	Fault location	Relative Location	Vsag 230kV	Vsag 138kV
LL	COL/ALF	DS	0.67	0.60
LG	COX/JAU	US	0.65	0.66
LG	NOB/DEN	US	0.97	0.97
LG	COL/ALF	DS	0.71	0.63
LG	COX/JAU	US	0.90	0.89
LG	BPX/RND	US	0.92	0.92
LG	JAC/COX	US	0.90	0.90
LG	COX/JAU	US	0.88	0.88
LG	COL/ALF	DS	0.68	0.63
LL	CBA/CVD	US	0.87	0.86
LLL	CMAG/RND	US	0.94	0.93
LLL	JUB/MAR	US	0.96	0.95
LLL	DEN/TAN	US	0.96	0.96
LLG	JAC/COX	US	0.90	0.89
LG	GRA/POC	US	0.93	0.93
LG	JUB/MAR	US	0.97	0.97
LG	DCLA/COL	DS	0.58	0.46
LG	JUB/MAR	US	0.97	0.97
LG	NOB/DEN	US	0.97	0.97
LG	RVD/RND	US	0.93	0.92
LLG	DCLA/COL	DS	0.50	0.37
LLL	PRE/ITA	US	0.92	0.92
LL	ITA/JUB	US	0.93	0.93
LLL	NOB/MUT	US	0.00	0.00
LL	JUB/MAR	US	0.93	0.93
LLL	DCLA/COL	DS	0.38	0.23
LL	DEN/TAN	US	0.96	0.96
LL	DEN/TAN	US	0.96	0.96
LLG	MAR/CAC	US	0.97	0.96
LL	JAC/COX	US	0.89	0.90

Table 2 Fault location used for simulations

F1	F2	F3	F4	F5
RVD 230	BPX 138	MUT 230	SIN 13.8	AFL 138
US	US	US	DS	DS

Note: US: upstream, DS: downstream

Table 3 Source location for symmetrical fault

Fault	V_{sag} 230KV	V_{sag} 138KV	Location
F1	0.93	0.93	US
F2	0.92	0.92	US
F3	0.01	0.01	US
F4	0.78	0.73	DS
F5	0.66	0.57	DS

Note: US: upstream, DS: downstream

Table 4 Source location for LL fault

Fault	V_{sag} 230KV	V_{sag} 138KV	Location
F1	0.93	0.93	US
F2	0.92	0.92	US
F3	0.5	0.5	US
F4	0.81	0.77	DS
F5	0.74	0.69	DS

Note: US: upstream, DS: downstream

Table 5 Source location for LLG fault

Fault	V_{sag} 230KV	V_{sag} 138KV	Location
F1	0.94	0.94	US
F2	0.93	0.93	US
F3	0.07	0.07	US
F4	0.74	0.69	DS
F5	0.67	0.6	DS

Note: US: upstream, DS: downstream

Table 6 Source location for LG fault

Fault	V_{sag} 230KV	V_{sag} 138KV	Location
F1	0.98	0.98	US
F2	0.97	0.97	US
F3	0.11	0.11	US
F4	0.72	0.67	DS
F5	0.72	0.67	DS

Note: US: upstream, DS: downstream

Conclusion

Conventional methods for locating sag source needs measurement of sag voltage and current. In this paper an alternative method for voltage sag source location based on voltage information using Artificial Neural Network (ANN) is explained. The voltage sag magnitude, estimated in terms of the prefault voltage, at both sides of a power transformer is used to find the relative location of the sag source. The method was successfully applied to simulated voltage sags on a model of a regional network comprising both the transmission and the distribution levels.

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