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민감도지수를 기반한 적응형 거리계전방식

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Adaptive Distance Relaying Based on Sensitivity Factors

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Abstract - An unwanted trip of backup distance relays often lead to a blackout. This paper presents investigation report on involvement of backup distance relays in the past blackouts and sensitivity-factor based algorithm to make a distinction between a fault and overload caused by line tripping. A preliminary idea to prevent deterioration of the situation due to unwanted trip of distance relays by utilizing the proposed algorithm is presented.

1. Introduction

With interconnection of power system, power utility networks are becoming larger and transmission linesare now operating closer to their limit than ever before. As a result, power system ismore vulnerable to disturbance which thus increases a possibility of stability problem. Studies of several large blackouts during the past decays indicate that protective relays are involved in most of them, especially backup protection relays [1].

In this paper, several previous blackout cases are investigated and its summary is described in Sec. 2. Then in Sec. 3, a sensitivity factor-based algorithm to distinguish a fault from overload due to line tripping is proposed. Sec. 4 gives the simulation results. Finally, a conclusion is given in Sec. 5.

2. Backup Relays in Blackout

EHV transmission lines are usually protected by duplicated main protection scheme with time delayed backup protection. Main protection is used to trip the line in less than two cycles by processing information measured at terminal buses when a fault occurs. Backup protection provides time delayed cover to the main protection, and is required to trip only when the main protection fails to clear the fault. In KEPCO, a main protection applies a current differential protection and a backup protection applies a three-step distance protection. Zone-3 unit is devoted to the backup protection so its reach is quite long. Because of this long reach, sometimes a heavy load results in its tripping. Overload is sometimes caused by tripping of other lines diverting its load flow to other lines. Many such cases can be found in previous blackout cases as described below.

Study of significant disturbances indicates that protective relays are involved in one way or another in 75 percent of major disturbances [2]. Blackouts are usually caused by a sequence of low-probability disturbances which is generally not planned by the system designers and is not expected by operators, making power system more susceptible to blackout. These types of events most likely occur following sequential outages on a stressed system, when the system is operated marginally in compliance with planning criteria. For example, some generators and/or lines for maintenance, line trips due to fault, which makes other lines get overloaded. If some other disturbance occurs, like another line touching a tree and tripped, it will make the system into a more serious state, which may result into blackout.

The Northeast blackout on November 9, 1965, resulted in the loss of over 20,000 MW of load and affected 30 million people. This event resulted in fundamental changes in utility operation and planning led to the foundation of the North American Electric Reliability Council (NERC) and associated regional reliability councils. The initiation of the disturbance was the faulty setting of a relay and the resulting tripping of one of five heavily loaded 230-kV transmission lines. The flow of power on the disconnected line was thus shifted to the remaining four lines, causing them to become overloaded and to trip successively in totally 2.5 seconds. Then cascading tripping of additional lines began and resulted in blackout [1,5].

On July 13,1977, New York City experienced a blackout that resulted in 6,000 MW loss of load and affected 9 million people in New York City. At 8:37 p.m., flashes of lightning knocked out two 345-kV lines connecting Buchanan South to Millwood West, which cut off all the electricity from the 900-MW Indian Point facility. 18.5 minutes later, an additional lightning strike caused the loss of two 345-kV lines, which connect Sprain Brook to Buchanan and Sprain Brook to Millwood West. The resulting surge of power from the Northwest caused the loss of the Pleasant Valley to Millwood West line by relay action. 23 minutes later, the Leeds to Pleasant Valley 345-kV line sagged into a tree due to overload and tripped out. Within a minute the 345-kV to 138-kV transformer at Pleasant Valley overloaded and tripped. Within 3 minutes the Long Island Lighting Co. system operator manually opened the Jamaica to Valley Stream tie. About 7 minutes later, the tap-changing failure resulted in the loss of the Linden-to-Goethals tie to PJM, which was carrying 1,150 MW to Consolidated Edison. The two remaining external 138-ties to Consolidated Edison tripped on overload, which isolated Consolidated Edison system and eventually caused it to collapse [1,6].

On July 2, 1996, West Coast Blackout resulted in the loss of 11,850 MW of load and affected 2 million people in the West. The outage began when a 345-kV transmission line in Idaho sagged into a tree and tripped out. A protective relay on a parallel line also detected the fault and incorrectly tripped a second line. Other relays tripped two of four generating units at Jim Bridger plant. About 23 seconds later, the Mill Creek to Antelope 230-kV line tripped by zone 3 relay. Remedial action relays separated the system into five pre-engineered islands and the islands collapsed due to stability problems [1].

On August 10, 1996, West Coast Blackout resulted in the loss of over28,000 MW of load and affected 7.5 million people in the West. Tree faults put three 500-kV line sections out of service. At 15:48 p.m., Keeler-Allston 500-kV line sagged into a tree and tripped, which caused the loss of 1300 MW of loading. The transmission line outages overloaded parallel lower-voltage lines in Portland area. About 5 minutes later, a relay failure tripped a 115-kV line, and a 230-kV line sagged into a tree and also tripped. About the same time generators at the McNary hydroelectric plants started tripping because of faulty relays. Increasing oscillations soon caused synchronous instability and the ensuing cascading tripping of transmission lines broke the interconnection into four electric islands [1].

On August 14, 2003, the latest blackout resulted in resulted in the loss of 70,000 MW of load and affected about 50 million people. 13:31 Eastlake 5 generation unit tripped and 14:02 Stuart-Atlanta 345-kV line tripped off due to contact with tree. 15:05-15:57 3 345-kV lines tripped due to contact with trees. 15:39-16:08 16 138-kV lines tripped due to overloading. 16:05-16:10 many key lines operated on Zone 3 impedance relays (or Zone 2 relays set to operate like Zone 3s), which eventually led to cascading trips and total blackout [1]. Note that all of these events involve protection relay tripping due to line overload, which played a critical role in blackout development. So if such relay tripping can be avoided, it might prevent a large blackout and in the next section, sensitivity factor-based algorithm that can discriminate a fault from overload will be presented.

3. Fault Discrimination Based on Sensitivity Factors

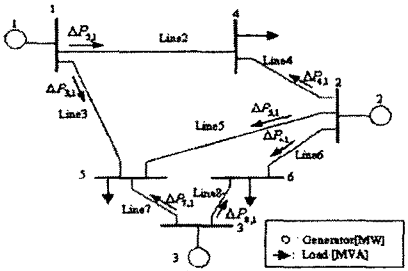
It is assumed in this study that a fault and line tripping does not happen simultaneously, which is quite true in a real situation. If load diverted to other lines is estimated using sensitivity factor and then each line flow can be calculated and compared with its measured load flow, discrimination can be made using Eq. (1).

$$\left|\hat{P}_k^M - \hat{P}_k^E\right| < \varepsilon * \hat{P}_k^M \qquad k = 1,2,3,\ldots \tag{1}$$

Where $\hat{P}_k^M$ represents on-line measured post-fault line flow, and $\hat{P}_k^E$ represents estimated post-fault line flow. ε is a constant which take some margin and error into account. The value of ε should satisfy following requirements.

- The power loss on line caused by ignoring line resistance in DC load flow from which sensitivity factors is deduced.
- The maximum error resulting from voltage magnitude change on the bus after line removed.
- The margin for guarantee of criterion validity

$\hat{P}_k^E$ can be obtained using a sensitivity factor which need be calculated in normal state. Fig. 1 explains how to compute the estimated line flow $\hat{P}_k^E$ *using sensitivity factors.*



<Fig 1> Line flow redistribution

According to power conservation and superposition principle, the estimated post-fault line flow can be considered as the addition of pre-fault flow and power flow change. Pre-fault flow can be measured on-line and the flow change can be calculated using sensitivity factors. Then, estimated flow $\hat{P}_k^E$ can be obtained by:

$$\hat{P}_k^E = P_k^M + \Delta P_{k,1} \tag{2}$$

Where P_k^M represents pre-fault flow which can be measured and recorded and $\Delta P_{k,1}$ represents flow change which is the effect from line 1 to line k after line 1 is removed.

For a given topological network whose parameters are known, the flow change $\Delta P_{k,1}$ can be regarded as a variable only related to pre-fault flow on line 1, P_1^M, which can be measured on-line and was recorded after line 1 removed. So, flow change can be computed as:

$$\Delta P_{k,1} = d_{k,1} * P_1^M \tag{3}$$

Where $d_{k,1}$ is defined as one of two basic types of sensitivity factors, line outage distribution factor (LODF) from line 1 to line k after line 1 is removed. Note that line outage distribution factors are dependent on network topology and parameters, and can be calculated in normal state and given as

$$d_{l,k} = \frac{\Delta f_l}{f_k^0} = \frac{x_k}{x_l}\left(X_{in} - X_{jn} - X_{im} + X_{jm}\right)/\left[x_k - \left(X_{nn} + X_{mm} - 2X_{nm}\right)\right] \tag{4}$$

Where $d_{l,k}$ is LODF from line k to line l when line k is tripped out. x_k and x_l represents reactance of line k and line l, respectively. f_k^0 is original flow on line k and Δf_l is the flow change on line l after line k is tripped out.

Substituting $\Delta P_{k,1}$ into equation (2), estimated post-fault flow can be calculated as follow:

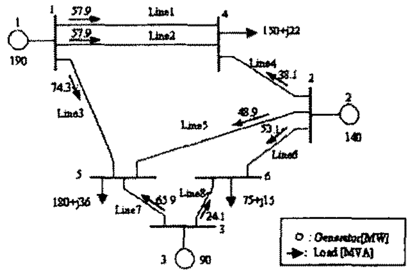
$$\hat{P}_k^E = P_k^M + d_{k,1} * P_1^M \tag{5}$$

Note that LODF matrix between all lines in the network is given as follow:

$$d_{N*N} = [d_{l,k}] = \begin{bmatrix} -1 & d_{1,2} & \cdots & d_{1,n} \\ d_{2,1} & -1 & \cdots & d_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n,1} & d_{n,2} & \cdots & -1 \end{bmatrix}$$

4. Case Study

The simulation of electric system using MATLAB/Simulink has been performed for the system in Fig. 2, in which pre-fault power flow of each line is displayed. Suppose a three-phase fault occurs on one of the parallel lines between bus 1 and bus 4, and the protection relay trips the line correctly. After line 1 is removed from the system, the flow on line 1 will be mostly transferred to line 2.



<Fig 2> 6-bus Simulation System

According to the line parameters and topology of system shown in Fig. 2, the LODF matrix of pre-fault network can be calculated beforehand and they are listed as follow:

$$d_{8*8} = \begin{bmatrix} -1.00 & 0.74 & 0.26 & 0.26 & -0.15 & -0.11 & -0.11 & 0.11 \\ 0.74 & -1.00 & 0.26 & 0.26 & -0.15 & -0.11 & -0.11 & 0.11 \\ 0.50 & 0.50 & -1.00 & -1.00 & 0.57 & 0.43 & 0.43 & -0.43 \\ 0.50 & 0.50 & -1.00 & -1.00 & 0.57 & 0.43 & 0.43 & -0.43 \\ -0.22 & -0.22 & 0.44 & 0.44 & -1.00 & 0.56 & 0.56 & -0.56 \\ -0.19 & -0.19 & 0.38 & 0.38 & 0.62 & -1.00 & -1.00 & 1.00 \\ -0.19 & -0.19 & 0.38 & 0.38 & 0.62 & -1.00 & -1.00 & 1.00 \\ 0.19 & 0.19 & -0.38 & -0.38 & -0.62 & 1.00 & 1.00 & -1.00 \end{bmatrix}$$

In LODF matrix, row index represents the removed line Id number and column index represents affected line Id number. From the above matrix, it can be easily seen that the sumof each row is equal to zero, that is to say the total effect of the line removing on the whole system is zero, which is as the result of power conservation law.

After line 1 is removed by protection relay, according to Eq. (2), the estimated post-fault line flow can be calculated with pre-fault line flow of the removed line and the line Id number. The flow on line 2 become high enough to operate the relay, but by checking Eq. (1) as |103.2-100.8|=2.4(MW) < 0.2*103.2=20.64(MW), the relay operation can be blocked.

5. Conclusion

Cascading trip caused by backup relay due to line overload could become a severe threat to power system stability and security. A sensitivity-based algorithm could be useful in preventing operation of distance relay in case of overload caused by line tripping. The simulation of six-bus system shows effectiveness of the proposed algorithm.

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