EFFECTS OF DSTATCOM ON MEASURED IMPEDANCE AT SOURCE NODE OF DISTRIBUTION FEEDER

A. Kazemi S. Jamali H. Shateri
Centre of Excellence for Power Systems Automation and Operation, Iran University of Science and Technology, Iran
kazemi@iust.ac.ir sjamali@iust.ac.ir shateri@iust.ac.ir

ABSTRACT

Distance protection is not utilized in distribution networks, unlike the transmission systems, due to the inherent characteristic of the distribution networks and the additional required facilities of the distance protection, compared with over-current protection, which is in use in the distribution systems. This paper studies the measured impedance at the source node of a distribution feeder in the presence of Distribution STATic COMpensator (DSTATCOM,), one of the distribution version of FACTS devises. The ideal tripping characteristic is presented for the distribution feeder with DSTATCOM. The variation of this tripping characteristic is investigated as a function of the power system conditions. The especial case of the absence of the fault resistance is highlighted.

INTRODUCTION

The measured impedance at the relaying point is the basis of the distance protection operation. There are several factors affecting the measured impedance at the relaying point. Some of these factors are related to the power system parameters prior to the fault instance, which can be categorized into two groups. First group is the structural conditions, while the second is the operational conditions. In addition to the power system parameters, the fault resistance could greatly influence the measured impedance, in such a way that for zero fault resistance, the power system parameters do not affect the measured impedance. In other words, power system parameters affect the measured impedance only in the presence of the fault resistance, and as the fault resistance increases, the impact of the power system parameters becomes more severe.

An adaptive distance protection is introduced to solve the problems caused by the presence of the fault resistance [2]. Since the fault resistance is an unknown quantity, [2] presented an ideal tripping characteristic for distance relays, for a definite range of the fault resistance, e.g. 0-200 ohms.

References [3]-[5] discuss the adaptive distance protection from various points of view. For example, [4] presented a fixed quadrilateral characteristic according to the ideal tripping characteristic. Applying the artificial intelligent techniques, [5] tried to identify the boundaries of the ideal tripping characteristic presented in [2].

The mentioned efforts are about the transmission lines, since distance relays are normally used on the transmission lines, at HV, EHV, and UHV levels. Just an effort [6] discusses about the distance relay application in the distribution networks at MV level for a feeder without any lateral and with a lumped load at the far end. Distribution networks are somehow different from the transmission networks. The lines in the transmission systems are two-end lines with the lumped loads at the ends, but in the distribution networks there are many laterals, the loads are distributed all over the network. Therefore, the inherent characteristics of distribution and transmission systems are different, and consequently the measured impedance would be different in these two systems.

In the recent years FACTS devices are introduced to the power systems to increase the transmitting capacity of the lines and provide the optimum utilization of the system capability. It is well documented in the literature that the introduction of FACTS devices in a power system has a great influence on its dynamics. As power system dynamics changes, many sub-systems are affected, including the protective systems. In addition to the transmission version of FACTS devices, some distribution version of FACTS devices are introduced for application in distribution networks. DSTATCOM is one of the proposed distribution FACTS devices.

This paper studies the measured impedance at the source node of a distribution feeder in the presence of DSTATCOM. The ideal tripping characteristic is presented for the distribution feeder. The tripping characteristic variation caused by variation in the power system conditions is studied. Special attention is paid to the measured impedance at the source node in the case of zero fault resistance.

DSTATCOM AND ITS MODELLING

Shunt connected FACTS devices are usually utilized to regulate the voltage of their connection point. Static Var Compensator (SVC) is an early type of the shunt connected FACTS devices, which controls its connection point voltage by adjusting its susceptance in order to supply or absorb the required reactive power. Advancement in the power electronic devices, such as Gate Turn Off (GTO) devices, introduced the so-called advanced Static Var Systems (SVS). STATCOM is an example of the advanced SVS, consisting of three-phase sets of several GTO based valve and a dc link capacitor and the associated control system. The control system operates in such a way that its connection point voltage is being regulated according to its controlling strategy within its operational limits. STATCOM consists of a converter which is connected to the line via a shunt coupling transformer [7].

STATCOM can be modelled as a shunt branch consisting of an impedance, due to the coupling transformer, and a voltage source, which is in phase with the voltage of its connection point, so it can only inject or absorb reactive power according to the magnitude of voltage source. DSTATCOM can be modelled the same as STATCOM.

MEASURED IMPEDANCE

In the case of zero fault resistance and for a lumped load at far end of the feeder, the measured impedance at the source node is the actual impedance of the line section between the fault point and the source node. According to Fig. 1 this impedance is equal to pZ_{1L}, where p is per unit length of the line section between the fault point and the source node, and Z_{1L} is the distribution feeder positive sequence impedance in ohms.

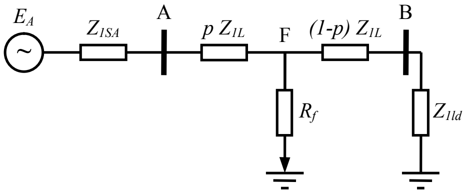

Fig. 1. Equivalent circuit for a single phase to ground fault

For a non-zero fault resistance, the measured impedance at the source node is not equal to the impedance of the mentioned line section. In this case, the structural and operational conditions of the distribution network affect the measured impedance at the source node. The structural condition is evaluated by short circuit level at the source node, S_{SA}. The operational conditions prior to the fault instance can be represented by the impedance of the lumped load, Z_{1ld} and Z_{0ld}. With respect to Fig. 1 and Fig. 2, the measured impedance at the source node can be calculated by the following equations, which are driven by following the impedance calculation procedure of [2].

$$Z_{1A} = Z_{1SA} + p\,Z_{1L} \tag{1}$$

$$Z_{1B} = Z_{1ld} + (1-p)Z_{1L} \tag{2}$$

$$Z_{0A} = Z_{0SA} + p\,Z_{0L} \tag{3}$$

$$Z_{0B} = Z_{0ld} + (1-p)Z_{0L} \tag{4}$$

$$Z_\Sigma = 2\frac{Z_{1A}Z_{1B}}{Z_{1A}+Z_{1B}} + \frac{Z_{0A}Z_{0B}}{Z_{0A}+Z_{0B}} \tag{5}$$

$$C_1 = \frac{Z_{1B}}{Z_{1A}+Z_{1B}} \tag{6}$$

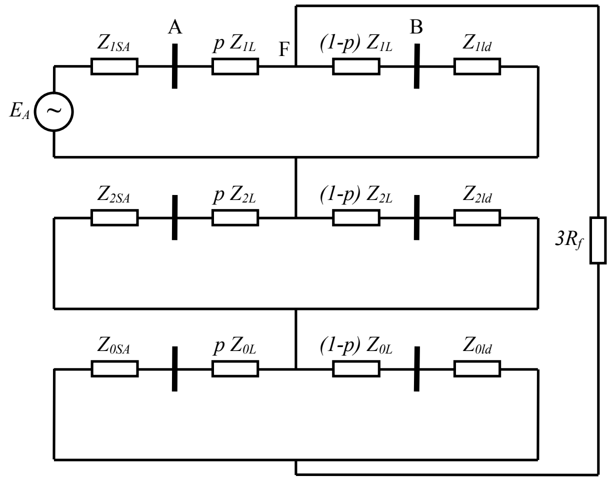

Fig. 2. Equivalent circuit of phase A to ground fault

$$C_0 = \frac{Z_{0B}}{Z_{0A}+Z_{0B}} \tag{7}$$

$$K_{0L} = \frac{Z_{0L}-Z_{1L}}{3Z_{1L}} \tag{8}$$

$$C_{ld} = \frac{1}{Z_{1B}}(Z_\Sigma + 3R_f) \tag{9}$$

$$Z_A = p\,Z_{1L} + \frac{3R_f}{C_{ld}+2C_1+C_0(1+3K_{0L})} \tag{10}$$

It can be seen that for zero fault resistance, the measured impedance at the source node is equal to the impedance of the line section between the source node and the fault point. As it can be seen from (10), power system conditions only affect the measured impedance in the presence of the fault resistance.

Depending on DSTATCOM exclusion or inclusion in the fault loop, the measured impedance at the relaying point would change. Here, DSTATCOM is installed at the length of i per unit from the relaying point. The following equations introduced due to DSTATCOM presence on the line, independent of its exclusion or inclusion in the fault loop.

$$Z_{1AI} = Z_{1SA} + iZ_{1L} \tag{11}$$

$$Z_{1BI} = Z_{1ld} + (1-i)Z_{1L} \tag{12}$$

$$Z_{1AF} = Z_{1SA} + pZ_{1L} \tag{13}$$

$$Z_{1BF} = Z_{1ld} + (1-p)Z_{1L} \tag{14}$$

$$Z_{1IF} = |i-p|Z_{1L} \tag{15}$$

$$Z_{0AI} = Z_{0SA} + iZ_{0L} \tag{16}$$

$$Z_{0BI} = Z_{0ld} + (1-i)Z_{0L} \tag{17}$$

$$Z_{0AF} = Z_{0SA} + pZ_{0L} \tag{18}$$

$$Z_{0BF} = Z_{0ld} + (1-p)Z_{0L} \tag{19}$$

$$Z_{0IF} = |i-p|Z_{0L} \tag{20}$$

DSTATCOM out of fault loop

Once DSTATCOM is out of the fault loop, (1)-(4) and (9) should be modified and some new equations are introduced:

$$Z_{1A} = Z_{1AF} \tag{21}$$

$$Z_{1B} = Z_{1IF} + \frac{Z_{Sh} Z_{1BI}}{Z_{Sh} + Z_{1BI}} \tag{22}$$

$$Z_{0A} = Z_{0AF} \tag{23}$$

$$Z_{0B} = Z_{0IF} + \frac{Z_{Sh} Z_{0BI}}{Z_{Sh} + Z_{0BI}} \tag{24}$$

$$Den = Z_{1BI}\,[\,Z_{1AF} E_{Sh} + Z_{1IF}\,] + Z_{Sh} Z_{1BF} \tag{25}$$

$$K_{ld} = Z_{1BI}\,[\,1 - E_{Sh}\,] + Z_{Sh} \tag{26}$$

$$C_{ld} = (\,Z_{\Sigma} + 3R_f\,)K_{ld} \,/\, Den \tag{27}$$

It can be seen that in the absence of the fault resistance, the measured impedance at the source node is equal to the actual impedance of the line section between the source node and the fault point.

DSTATCOM in fault loop

Once DSTATCOM is in the fault loop, (1)-(4) should be modified, (9) is changed to (26)-(27), and some new equations are introduced:

$$Z_{1A} = Z_{1IF} + \frac{Z_{Sh} Z_{1AI}}{Z_{Sh} + Z_{1AI}} \tag{28}$$

$$Z_{1B} = Z_{1BF} \tag{29}$$

$$Z_{0A} = Z_{0IF} + \frac{Z_{Sh} Z_{0AI}}{Z_{Sh} + Z_{0AI}} \tag{30}$$

$$Z_{0B} = Z_{0BF} \tag{31}$$

$$C_{1A} = \frac{Z_{Sh}}{Z_{Sh} + Z_{1AI}} \tag{32}$$

$$C_{0A} = \frac{Z_{Sh}}{Z_{Sh} + Z_{0AI}} \tag{33}$$

$$Den = Z_{1AI} Z_{1BF} E_{Sh} + Z_{Sh} Z_{1BF} \tag{34}$$

$$K_{ld_{\Delta}} = Z_{1AI} E_{Sh} - Z_{1BI}\,[\,1 - E_{Sh}\,] \tag{35}$$

$$C_{ld_{\Delta}} = (\,Z_{\Sigma} + 3R_f\,)K_{ld} \,/\, Den \tag{36}$$

$$C_{Sh} = Z_{1IF} \begin{bmatrix} C_{ld_{\Delta}} + 2C_1(\,1 - C_{1A}\,) + \\ C_0(\,1 - C_{0A}\,)(\,1 + 3K_{0L}\,) \end{bmatrix} \tag{37}$$

$$Z_A = p\,Z_{1L} + \frac{C_{Sh} + 3R_f}{C_{ld} + 2C_1 C_{1A} + C_0 C_{0A}(\,1 + 3K_{0L}\,)} \tag{38}$$

It can be seen that in the absence of the fault resistance, the measured impedance at the source node is not equal to the actual impedance of the line section between the source node and the fault point.

EFFECTS OF DSTATCOM ON IDEAL TRIPPING CHARACTERISTIC

Knowing the structural and operational conditions, the ideal tripping characteristic can be defined. The ideal tripping characteristic has four boundaries. First boundary is the measured impedance for zero fault resistance; fault location varies from source node up to load node. In the second boundary, the fault location is at load node; fault resistance varies between 0 and 200 ohms. Third boundary is the result of the fault point variation along the feeder for the fault resistance of 200 ohms. Forth boundary is achieved by variation of the fault resistance between 0 and 200 ohms for the faults on the source node.

The ideal tripping characteristic for a distribution feeder is presented for a practical system. A 20 kV distribution feeder with the length of 30 km has been utilized in this study. By utilizing the Electro-Magnetic Transient Program (EMTP) [8] various sequence impedances of the feeder are evaluated according to its physical dimensions. The calculated impedances of the feeder for various sequences are:

$Z_{1L} = 0.2712 + j\ 0.3357$ Ω/km
$Z_{0L} = 0.4158 + j\ 1.5840$ Ω/km

Fig. 3 shows the ideal tripping characteristic, in the absence of DSTATCOM, when the short circuit level at the source node is 200 MVA; the supplied active load is equal to 5 MW, and the supplied reactive load is 3 MVAR.

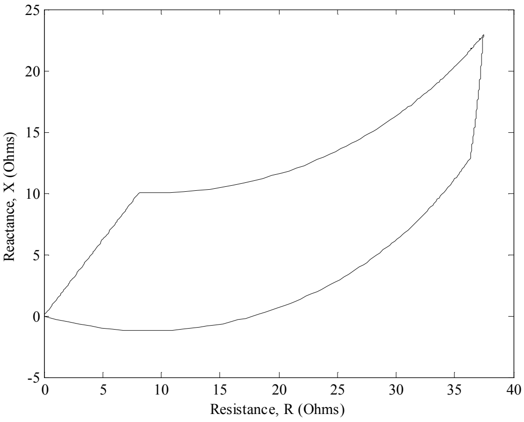

Fig. 3. Ideal tripping characteristic in the absence of DSTATCOM

It can be seen that in the absence of the fault resistance, the measured impedance at the source node is the actual impedance of the line section between the source node and the fault point. The measured impedance deviates from its actual value only in the presence of the fault resistance.

Once DSTATCOM is connected to the distribution feeder, a fraction of the required reactive power by the distribution feeder is supplied from DSTATCOM and the rest of the required load is supplied through the source node.

Fig. 4 shows the effect of the presence of DSTATCOM at the mid-point of the feeder on the measured impedance at the source node. Here, the rated reactive power of STATCOM is 2 MVAR and it is fully loaded. Tripping characteristic without DSTATCOM is also shown in the dotted form for comparison.

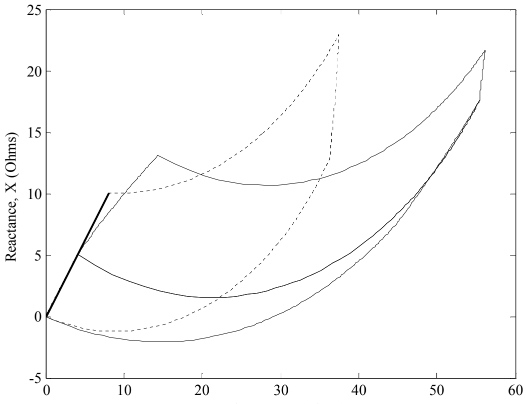

Fig. 4. Ideal tripping characteristic in the presence of DSTATCOM

It can be seen that in the presence of DSTATCOM at the mid-point of the feeder, the tripping characteristic varies. The measured impedance for zero fault resistance is not equal to its actual value in the case of the faults between the mid-point and the far end of the feeder.

Fig. 5 shows the effect of the variation of DSTATCOM compensation current on the measured impedance. Here, DSTATCOM current is 1.0, 0.5, and 0.0 pu in both leading and lagging modes. Tripping characteristic without DSTATCOM is also shown in the dotted form.

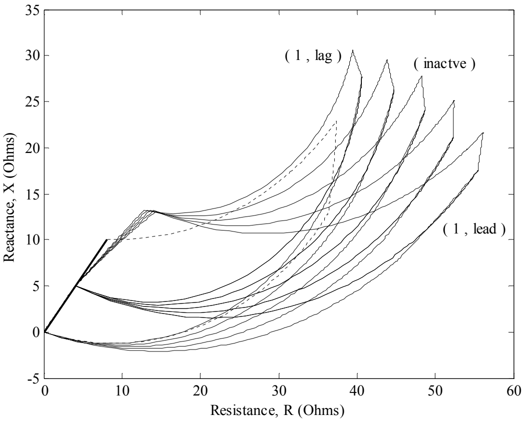

Fig. 5. Ideal tripping characteristic variation

It can be seen that as DSTATCOM compensation degree varies, the ideal tripping characteristic changes considerably. In the case of the inactive DSTATCOM, the compensation current of zero, the tripping characteristic changes considerably, in spite of there is no reactive power exchange between DSTATCOM and the distribution network.

CONCLUSION

This paper has presented the measured impedance at the source node of a distribution feeder with DSTATCOM. The measured impedance, and consequently the ideal tripping characteristic, depends on DSTATCOM structural and controlling parameters and the power system operational and structural conditions.

The installation point of DSTATCOM as well as its compensation current influences the measured impedance and consequently the distance relay ideal tripping characteristic considerably.

In the case of the absence of the fault resistance, the measured impedance is equal to the actual impedance of the line section between the source node and the fault point for the faults on the line section between the source node and DSTATCOM, and it deviates from its actual value in the case of the faults on the line sections between DSTATCOM and the load node. The amount of the measured impedance deviation is a function of DSTATCOM parameters and the power system conditions.

REFERENCES

[1] Zhang Zhizhe and C. Deshu, 1991, "An adaptive approach in digital distance protection", *IEEE Trans. Power Delivery*, vol. 6, no. 1, 135-142.

[2] Y. Q. Xia, K. K. Li, and A. K. David, 1994, "Adaptive relay setting for stand-alone digital distance protection", *IEEE Trans. Power Delivery*, vol. 9, no. 1, 480-491.

[3] S. Jamali, 2001, "A fast adaptive digital distance protection", *Proceedings of IEE 7th International Conference on Developments in Power System Protection, DPSP2001*, 149-152.

[4] Chang-Ho Jung, Dong-Joon Shin, and Jin-O Kim, 2000, "Adaptive setting of digital relay for transmission line protection", *Proceedings of IEEE International Conference on Power System Technology*, *PowerCon2000*, vol. 3, 1465-1468.

[5] K. K. Li, L. L. Lai, and A. K. David, 2000, "Stand alone intelligent digital distance relay", *IEEE Trans. Power Systems*, vol. 15, no. 1, 137-142.

[6] I. Chilvers, N. Jenkins, and P. Crossley, 2005, "Distance relaying of 11 kV circuits to increase the installed capacity of distributed generation", *IEE Proc. Generation, Transmission and Distribution*, vol. 152, no. 1, 40-46.

[7] A. T. Johns, A. Ter-Gazarian, and D. F. Warne, 1999, *Flexible ac transmission systems (FACTS),* Padstow, Cornwall: TJ International Ltd.

[8] H. W. Dommel, 1997, *EMPT reference manual,* Microtran Power System Analysis Corporation, Vancouver, British Columbia, Canada.