Impact of Distribution Pole Configuration on Power Transfer and Shielding Characteristics

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Abstract

The current system of rural distribution conductors comprises of underslung earth conductors. This system is prone to conductor clashing and other inherent issues relating to the reliability of operation. This paper investigates the impact of shifting the earth conductor above the phase conductors as this is expected to minimise the safety issues associated with the current one. Both the systems have been compared based on maximum power transferred and shielding provided by the overhead conductors to the telecommunication lines. Power flow has been used to plot the Power curve and the shielding factor is calculated theoretically based upon the mutual impedances between the conductors. The shielding factor has been evaluated for steady state condition and unbalanced fault condition. The results obtained from the evaluation show that the new pole configuration will not affect the power transfer limits and the shielding characteristics. Furthermore this paper also discusses about the procedure involved in the study of steel based conductors in the distribution network and categorising them according to their risk of failure due to corrosion. Corrosion degradation and subsequent breakage of steel conductors is a substantial issue for Western Power which will have both safety and reliability implications.

1. Introduction

The rural distribution system of Western Power comprises mainly of 33 kV, 22kV and 11kV distribution lines. In the current distribution pole configuration, the earth conductor is below the phase conductors. The earth conductor serves not only as a return path for the fault current to the substation but also acts as a shield in minimising the Low Frequency Induced (LFI) Voltage on telecommunication lines which are at close proximity to the power lines. Low frequency induced voltage is the voltage induced by a power line on a parallel circuit like a telecommunication line due to the flux generated by it (AS CJC4 2000).

The main issue with the current system has been the phenomenon of conductor clashing between the phase and earth conductors. There have been incidents when this has led to sparking and consequent ground fires causing human life and property damage. Also the current system limits the distances between intermediate poles to 135 metres. This means that more poles have to be installed on the rural lines, which in turn increases the installation cost as well as the cost of maintenance of distribution assets. Western Power is assessing the possibility of modifying the pole configuration in which the earth conductor will be placed above the phase conductor.

1.1. Objectives

The primary objective of this project is to compare the current and the proposed pole configuration based on the following parameters

- The line impedance and maximum power transfer through the distribution line.
- The shielding effect provided by the earth conductor electromagnetic interference to telecommunication lines.

The findings and recommendations from this project will help Western Power make a decision on whether to go ahead with the proposed method of installing earth conductor above phase conductors.

The second part of this project deals with the study of the condition of steel based distribution conductors in the network and categorising them according to their risk of failure. Steel conductors make up nearly 40% of the Western Power distribution network.

The findings and recommendations from this project will improve the safety of the distribution network by decreasing the number of wires down incidents and the conductor faults per km. It will also help Western Power in prioritising its condition based conductor replacement strategy. This will result in reduced maintenance costs and a more effective capital expenditure program.

1.2 Power Transfer Curves

The power transfer for distribution lines is limited by the voltage magnitude at the ends, the reactance between the two lines and the phase angle (Wadhwa 2004). In order to ensure safe operation of the power system, the operating voltage at the nodes must be kept as far as possible from the critical values (Machowski et al. 1997). The two widely used methods for determining maximum power transfer are PV curves and VQ curves. PV curves can be readily calculated using power flow programs. In this case, the load demand at the buses is increased in steps at a constant power factor while the generator's terminal voltage is held at a nominal value. It must be ensured that the reactive power outputs are within limits; if a generator's reactive power limit is reached, the corresponding generator bus is treated as another load bus. The PV relation can then be plotted by recording the MW demand level against the node voltage at the corresponding bus (ed. Grisby 2007).

1.3 Electromagnetic coupling

In general the earth does not act as an electromagnetic shield thus an inductive coupling is formed between power lines and telecom cables both above ground and those buried underground. The coupling between the power line and the telecommunication cable exists under both steady state and faulted condition. The shielding factor is directly dependant on this electromagnetic coupling (Popovic 1991). The coupling is dependent on the length of the exposure and the position of the telecom cable. There is a difference in mutual coupling depending upon if the cables are placed above ground or buried underground. This has a direct impact on the shielding factor.

1.4 Corrosion of steel conductors

Previous studies conducted on steel wires (Nakamura & Suzumara 2004) have shown the relation between Relative Humidity (RH) of the atmosphere, sodium chloride concentration and the age of the conductors. Factors such as industrial pollution also contribute to corrosion but within the region under study, they only have a minimal effect. The wind speeds of the region and rainfall have also been considered in this study for more accuracy as they are correlated to the factors listed above.

2. ANALYSIS

2.1 Evaluation of impedance and maximum power transfer

In order to evaluate the maximum power transferred through the line, the first step is evaluation of the impedance of the transmission line. The impedance is calculated using line parameter software (Available at The University of Western Australia). The co-ordinate model of the pole configuration is constructed from the pole structure with the ground level as reference. The data required for the calculation of the parameters are as follows: Position of the conductor in the tower, diameter and resistance of the phase and earth conductors and the sag of the conductor in the mid span.

The line length between the two nodes has been considered to be 10 km. The phase conductors are assumed to be of 19/3.25 AAAC type and 7/1.60 FE is used for the steel conductor. Power Flow Software has been used to evaluate the P-V curve of the system. The single phase model of the line is used which is derived from the positive phase sequence model. The first node is considered as a slack node and the second one as a load node with varying load of P + j Q. The line connecting these nodes is the distribution line under study.

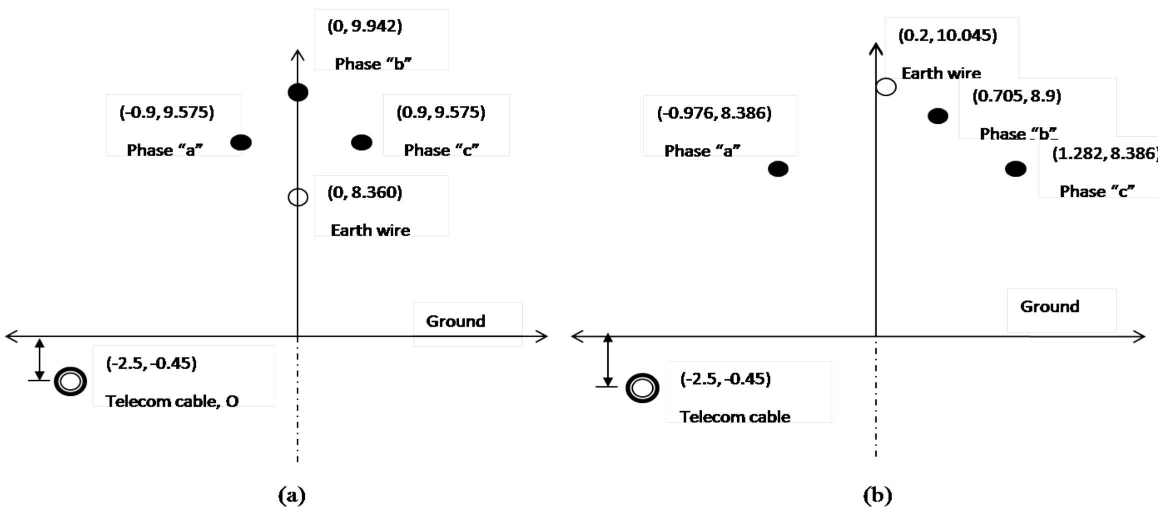

Figure 1: Co-ordinate axis model of the distribution pole configuration (a) current configuration, (b) Proposed configuration

2.2. Shielding factor calculation

The shielding provided by the earth conductor can be represented using a factor called shielding or screening factor { **k** }.The shielding factor can be defined as:

$$k = \frac{\text{Voltage induced in the presence of shielding conductors}}{\text{Voltage induced in the absence of shielding conductors}} \quad (1)$$

k is a complex value so generally the modulus or the magnitude is used.

The shielding factor is mainly dependent on the mutual impedance (coupling) between the phase and earth conductors and the mutual impedance between the telecommunication cable and the phase conductors.

The shielding factor in steady-state case is obtained from the following set of equations:
Voltage induced in the absence of shielding conductors,

$$V_{C1} = Z_{OA}I_A + Z_{OB}I_B + Z_{OC}I_C \tag{2}$$

Voltage induced in the presence of shielding conductors (Tlies,2008):

$$V_{C2} = \left(Z_{OA}I_A + Z_{OB}I_B + Z_{OC}I_C \right) + Z_{OE}I_E \tag{3}$$

$$I_E = \frac{-1}{Z_{EE}}(Z_{EA}I_A + Z_{EB}I_B + Z_{EC}I_C) \tag{4}$$

Shielding factor,

$$k = \frac{V_{c2}}{V_{c1}} = 1 - \frac{Z_{OE}}{Z_{EE}} \frac{(Z_{EA}I_A + Z_{EB}I_B + Z_{EC}I_C)}{(Z_{OA}I_A + Z_{OB}I_B + Z_{OC}I_C)} \tag{5}$$

In the above equations;
Z_{EA}, Z_{EB}, Z_{EC} : Mutual impedance between the earth wire and the corresponding phase conductor.
Z_{EE} : Self impedance of the earth conductor
Z_{OA}, Z_{OB}, Z_{OC} : Mutual impedance between the earth wire and the telecom cable
I_A, I_B, I_C : Current flowing through phases "a", "b", and "c" respectively.

For balanced condition,
$I_A = I < 0^o$, $I_B = I< -120^0$, $I_C = I< +120^0$

For shielding factor in the case of an unbalanced case, we consider a single phase to earth fault in phase "a" of the 3-phase system. The induced current will be maximum in this case due to the proximity of phase "a" and the telecom cable with respect to other phases.

The shielding factor in this case can be calculated by the equation:

$$k = 1 - \frac{Z_{EA}}{Z_{EE}} * \frac{Z_{OE}}{Z_{OA}} \tag{6}$$

2.3 Corrosion assessment of conductors

For assessing the risk of failure due to corrosion, the conductors have been grouped according to the Distribution feeders they belong to. The criteria for classification were: Relative Humidity, Rainfall, Distance from the coast, Age of conductors and Wind speed. Each assessment criteria is weighted in terms of their contribution to corrosion. Also an intra category weighting is given within each category highlighting its contribution. A score is obtained by multiplying the weighting multiplier with the corresponding intra category weighting. Based on the score, the conductors have been classified as 'Low', 'Medium', 'High' and 'Extreme' risk.

3. RESULTS AND DISCUSSION

The maximum power transfer limits for the current configuration and the new configuration have been evaluated and the results are presented in the table in Table 1. The shielding factors have been evaluated in both steady state and unbalanced fault conditions. The shielding factors for both conductor configurations are shown in Fig 2 .The shielding factors have been evaluated using earth conductor of different resistances.

From the results, we can infer that the maximum power that can be transferred in both the cases are nearly equal and hence the new system will not affect the power transfer limits. This is because there is only a small difference in the value of impedance for the two cases. In steady state condition, the shielding factor is better for the new configuration compared to the current configuration. Thus if we use 7/1.60 FE type conductor as the earth conductor in the new configuration, the shielding factor of the earth conductor will be better for the new configuration. In case of an unbalanced fault, the shielding factors are nearly the same. The shielding factor improves with decrease in resistance.

Since the new configuration will have lesser safety issues and also does not affect the shielding characteristics of the earth conductor, it will be beneficial to modify the conductor configuration.

Corrosion assessment has been completed for most of the feeders using the above methodology, and conductor samples have been selected for testing from various risk categories. These samples will be tested for tensile strength and visual assessment of corrosion in order to confirm the accuracy of the methodology used.

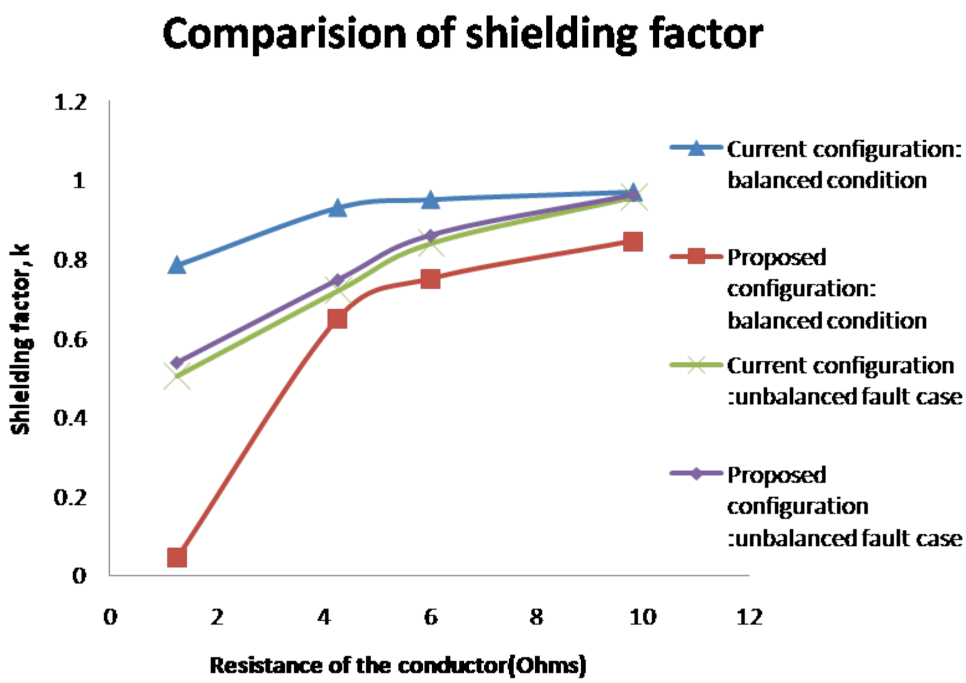

Figure 2: Shielding factors in both cases for balanced condition and unbalanced fault.

	Current tower configuration	Proposed tower configuration
Maximum Power Transferred(MW)	29.28 at 0.5319 p.u voltage	28.73 at 0.5053 p.u. voltage
Power Transferred at 0.9 p.u. voltage(MW)	11.3	11.07

Table 1: Power transfer limits obtained from PV curve of the system.

4. CONCLUSION

The performance of the current and proposed distribution pole configuration has been compared in terms of their power transfer capability and shielding factors. The condition assessment of the steel conductors will be completed once the results from the testing of samples have been obtained.

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6. REFERENCES

Grisby, Leonard L; 2007, *Power System Stability and Control*, Taylor & Francis Group

Jan Machowski, Janusz WB, & James RB, 1997, *Power Systems Dynamics and Stability* John Wiley & Sons, New York

Popovic, LjM, 1991,'Analytical Expressions for Evaluating Screening effect of transmission line earth wires' *IEE Proceedings*, Vol.138, No.4, July 1991

Standards Australia, CJC 4 2000, *Co-ordination between Power and Telecommunication,* Available from: Standards Australia Online

Suzumara,K & Nakamura,S ,2004,'Environmental Factors Affecting Corrosion of Galvanised Steel Wires', *Journal of Materials in Civil Engineering*

Tlies, Nasser D; 2008, *Power System Modelling and Fault Analysis,* Elseiver Ltd.

Wadhwa, CL; 2004, *Electric Power Systems,* New Age Publishers, 4th edition