Transmission Loss Allocation Based on Circuit Theories and Orthogonal Projection

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Abstract: ***The introduction of deregulation and subsequent open access policy in electricity sector has brought competition in energy market. Allocation of transmission loss has become a contentious issue among the electricity producers and consumers. A closed form solution for transmission loss allocation does not exist due to the fact that transmission loss is a highly non-linear function of system states and it is a non-separable quantity. In absence of a closed form solution different utilities use different methods for transmission loss allocation. Most of these techniques involve complex mathematical operations and time consuming computations. A new transmission loss allocation based on circuit theory and orthogonal projection has been developed and presented in this thesis. The orthogonal projection computes loss allocation much faster than other methods. A relatively short execution time of this method makes it a suitable candidate for being a part of a real time decision making process. Most independent system variables can be used as inputs to this method which in turn makes the loss allocation procedure responsive to practical situations. In this method we calculate A) Review of the Calculations for the Share on Branch Current. B) Current Projection Component C) Power Flow Decomposition D) Branch Loss Allocation***

Keywords: Matlab, Circuit theory, Loss Allocation

1. Introduction

Electricity, one of the most widely used form of energy, has been discovered little more than a century ago. After the discovery of Edison's electric bulb, electricity has been commercially produced and marketed in USA. Thomas Alva Edison, regarded as the pioneer of electric power system, first established "The Pearl Street Power Station" in New York, USA in 1882. Later more companies were established. In early days there was no regulation in electric power industries. Small companies operated small generators in municipal areas and sold power to industries and other users in that area. These companies were somewhat inefficient and redundant in the services they provided. Separate companies provided electricity for different needs such as street illumination, industrial power, residential lighting and street car service. They frequently operated under non exclusive franchises, often in competition with one another. In 1896, Westinghouse pioneered the use of alternating current to deliver electricity over a long distance from its hydroelectric plant at Niagara Falls. This generating and delivery system was far more efficient and quickly became the national standard. This development quickly led to the formation of large "public utility" companies. Today, electric power systems have become common entities all over the world. Thousands of electric utility and companies are supplying power to billions of consumers. People cannot imagine living without electricity. It has become an essential commodity in our everyday life and billions of equipment and accessories are being used in the world today that are solely dependent on electric power.

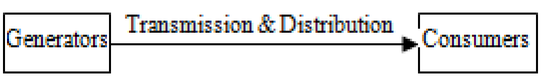

Figure 1.1: Schematic diagram of traditional power industry

2. Transmission Loss

Transmission loss in electric power system is a natural phenomenon. Electric power has to be moved from generation place to the consumer's place through some wires for consumption. All wires have some resistance, which consume some power. The power consumed in this way is referred to as "loss". Most of this loss is attributable to the heating of the power lines by the electrical current flowing through them. The loss (i2R) is then lost to the surrounding of the power lines. Transmission loss represents about 5% to 10% of total generation, a quantity worth millions of dollar per year. In Alberta alone, total transmission loss costs about 200 million dollars per year. Power loss in a Transmission and Distribution network is influenced by a number of factors such as:

- The location of generating plant and load connection points and the energy associated with each;
- Types of connected loads;
- Network configuration;
- Voltage levels and voltage unbalance;
- Dynamic factors associated with the operation of large alternating current networks (e.g. Power factor, harmonics and the control of active and reactive power);
- The length of the lines - this is an almost linear relationship (e.g. Doubling the line length would double the line loss);
- The current in the line - this is a square law relationship where doubling the line current would quadruple the line loss;
- The design of lines, particularly the size, material and type of cables; and the types of transformers and their loadings.

In a traditional power system, total transmission loss is optimized while keeping the running cost at the minimum. In a deregulated power system, due to the competition in the generation sector, transmission loss has to be allocated to individual generators.

3. Related Circuit Theory

Consider a n -bus power system and a solved power flow of the system exists, defining the vector of complex bus power injections S, and the vector of complex bus voltages, V. Convert S into the bus current injection vector,

I, as Ik= diag(V*)^(-1) S* (1)

Where diag(V*) is a diagonal matrix with n x n dimension, whose elements are the complex conjugates of bus voltages. Then use the superposition principle to derive the contributions of each current injection to the bus voltages and the branch currents. Take the current injection at busk(Ik) for example. Its contributions to the bus voltages (Vk) can be computed as

$$V^k = [V_1^k, \ldots, V_i^k, \ldots, V_n^k]^T = ZeI_k \quad (2)$$

Where Z is the bus impedance matrix;e is a n x 1 dimension vector with value of 1 at position k and all the others equal 0.

The contribution of to the voltage drop across branch (Vrk) is computed as

$$\Delta V_r^k = V_{rf}^k - V_{rt}^k \quad (3)$$

where the subscripts rf, rt represent the "from" bus and the "to" bus of branch r , respectively.

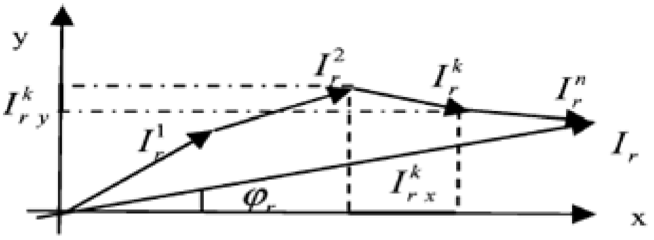

Figure 3.1: Illustration for the contributions of individual current injections to the current through branch r.

The contribution of Kite the current through branch r (Irk)can be computed as

$$I_r^k = \Delta V_r^k / z_r \quad (4)$$

zr = rr+ixr where is the complex serial impedance of branch r. Here the shunt elements of lines are not taken into account because we only focus on active loss allocation. The reactive loss allocation could be derived in a similar way. According to the superposition principle, the branch current contributions due to each current injection satisfy

$$I_r = \sum_{k=1}^{n} I_r^k. \quad (5)$$

The above derivation is totally based on the circuit theories.

4. Orthogonal Projection

In this we use the solutions to similar physical application problems for reference. For example, doing work by the force, the basic solution to this problem is orthogonal decomposition. Only the component of the force in the direction of the motion does work. This solution totally conforms to the general physical principles, and it is founded on the explicit mathematical concept, i.e., orthogonal projection. In a similar way, the orthogonal projection concept could be applied to determine the shares of each current injection on the branch currents.

Taking the total branch current Ir as the reference vector, decompose all the branch current contributions due to current injections into two components, one vertical to Ir, the other parallel to Ir , as shown in Fig. As doing work, analogously, only the components in the direction of Ir take shares of Ir. While for the components vertical to Ir , their addition equals to zero and they take no shares

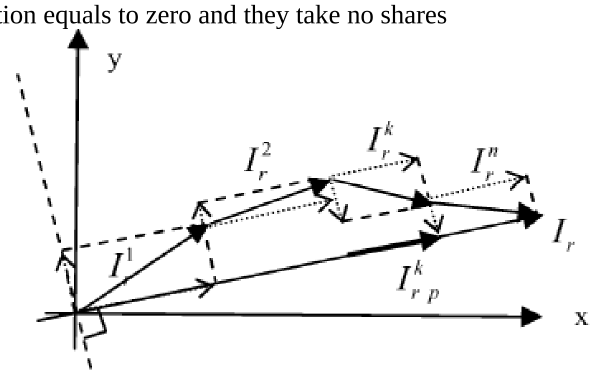

Figure 3.2: Orthogonal decomposition of the branch current contributions due to individual current injections.

The components in the direction of the total branch current accord with the concept of orthogonal projection exactly. Let Irkp denote the orthogonal projection vector of Irk in the direction of Ir, which is defined to be the current projection component of branch r produced by the current injection at bus k , and it is calculated as

$$I_{r\,p}^k = \frac{I_r^k \cdot I_r}{|I_r|} e^{j\varphi_r} = \left|I_r^k\right| \cos\left(\varphi_r^k - \varphi_r\right) e^{j\varphi_r}. \quad (6)$$

The current projection components satisfy:

$$\sum_{k=1}^{n} I_{r\,p}^k = I_r. \quad (7)$$

Then the share of the current injection at bus k on total branch current will be:

$$\frac{I_{r\,p}^{k}}{I_r} = \frac{\left|I_r^k\right| \cos\left(\varphi_r^k - \varphi_r\right) e^{j\varphi_r}}{\left|I_r\right| e^{j\varphi_r}} = \frac{\left|I_r^k\right| \cos\left(\varphi_r^k - \varphi_r\right)}{\left|I_r\right|}. \tag{8}$$

From above it can be seen that the share is a real number. And the share would keep stable when the voltage reference bus changes since it is relative to the difference of the two phase angles, and which is independent on the choice of the voltage reference bus.

5. Results

Branch Power Flow Decomposition for Generators

Line	G1 (p.u.)	G4(p.u.)
1-2	0.20879+0.06245j	0.03161+0.00945j
	0.20460+0.04273j	0.03097+0.00647j
1-3	0.15389+0.05023j	-0.03142-0.01025j
	0.15182+0.04065j	-0.03099-0.00830j
3-2	0.01569+0.00117j	0.06998+0.00523j
	0.01552+0.00068j	0.06926+0.00303j
4-2	0.00698+0.00274j	0.23538+0.09251j
	0.00680+0.00190j	0.22928+0.06395j
4-3	-0.00387-0.00289j	0.26150+0.19518j
	-0.00387-0.00248j	0.26180+0.16767j

Branch Active Loss Allocation to Generators

Line	G1 (p.u.)	G4(p.u.)
1-2	0.00397	0.00060
1-3	0.00227	-0.00046
3-2	0.00013	0.00058
4-2	0.00017	0.00575
4-3	-0.00000	0.00000

6. Conclusion

A circuit-based method for branch loss allocation is presented by applying the orthogonal projection concept. Theoretical analysis and numerical results show that the proposed method has the following characteristics.

- It combines the circuit theories and the concept of orthogonal projection to yield the loss allocation of branches.
- The obtained branch loss allocation has the same expression as the loss allocation principle in [4]. Compared with the method in [4], the proposed method gives intuitively clear explanation of the obtained branch loss allocation.
- The obtained shares of the buses on the currents and power flows through branches accords with general physical principles, and are independent to the choice of the voltage reference bus.

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