Experiment 13

TRANSMISSION LINE NETWORKS AND THE BUCK-BOOST AND PHASE SHIFT TRANSFORMER

Objectives:

1) To observe the division of power between two transmission lines in parallel
2) To learn the properties of a phase-shift and buck-boost transformer
3) To modify the power division between two parallel lines with a phase-shift/buck-boost transformer

Introduction:

In a practical electric power system there are hundreds of interconnected lines which link the power stations and their widely-dispersed loads. This grid transmission line, of which figure 1 is a simplified example, is far more complex than a simple series parallel circuit. The flow of active and reactive power over the line depends not only upon their impedances, but also upon the relative magnitude and phase angles of the sender and receiver voltages. In such a system, the flow in a particular line may be too high (or too low), bearing in mind the capacity of the line and/or the economics of transmission.

Under this circumstance, the flow of real power can be modified by shifting the phase of either the receiver or the sender-end voltage. Similarly reactive power flow can be modified by raising or lowering one of these two voltages. A tap changing transformer can be used to raise or lower the voltage located at either end of the transmission line. A phase shift can be affected by a rotatable transformer similar to a wound rotor induction motor. However, in most large installations static phase shifting transformers are employed, the degree of shift depending upon the tap settings. The principle of phase shift transformer can be understood by referring to figure 2 which shows the primary windings a1,b1,c1 of a of a three phase wye connected transformed. Secondary windings a2, b2 c2 are also connected in wye, but secondary of a3, b3 and c3 is not connected together. Voltages induced in windings a1, a2, a3 will all be in phase as will be in the voltages induced in the windings b1, b2, b3 and in c1, c2, c3. However, these three groups of voltages are respectively 120 degrees out of phase with each other, as shown in figure 3.

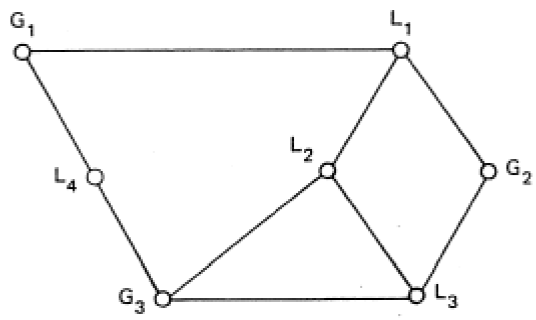

Figure: 1

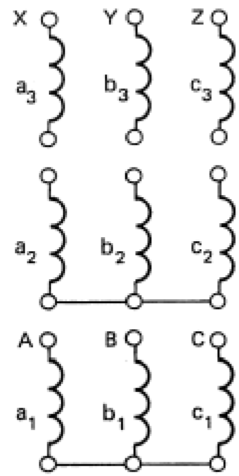

Figure: 2

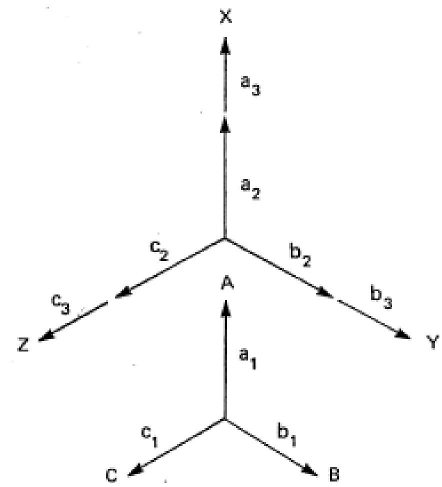

Figure: 3

If windings a2 a3, b2 b3 and c2 c3 are connected in series, the voltage between terminals X. Y and Z will be in phase with the voltage between terminals A, B and C as shown in figure 3. However, if we connect in series windings a2 b3, b2 c3 and c2 a3the phase diagram will be as shown in figure 4, and the voltages between terminals X, Y and Z will be out of phase with the voltage between terminal A, B and C. The degree of phase shift depends upon the relative magnitudes of the voltages a2 b2 c2 and a3 b3 c3. If the voltages are all equal the phase shift will be 60 degrees. With appropriate taps on a three phase transformer, and a selector switch, it is possible to step shift the secondary voltage with respect to the primary as much as 30 degrees. Furthermore, provision can be made so that the phase angle can be progre4ssively changed from lagging to leading and vice versa.

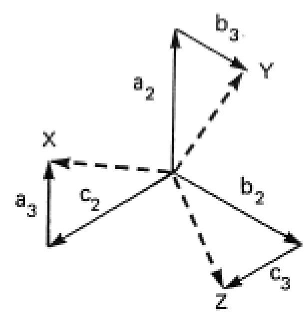

Figure: 4

Referring to figure 1, suppose we wish to modify the power flow in line L2-L3. If we wish to increase the real power, the phase angle between the voltages at L2 and L3 will have to be increased according to equation 1.

$$P = \frac{V_1 V_2}{X} \sin(\delta) \qquad (1)$$

On the other hand, should we wish to reduce the real power to zero, the two voltages will have to be brought in phase. Such phase angle changes can be accomplished by a phase shift transformer located at either end of the line L2-L3. A change in real power over line L2-L3 will affect the real power in the other lines, particularly whose line which coverage at the end points L2 and L3. This is often the reason for modifying the power in line L2-L3 in the first place.

Reactive power can be similarly controlled by boosting (raising) or bucking (lowering) the voltage at either end of the line.

$$Q = \frac{V_1 V_2}{X}\cos(\delta) - \frac{{V_2}^2}{X} \qquad (2)$$

Thus, if the voltage at L2 is raised, reactive power will flow toward L3 the same result will be obtained if the voltage is reduced at station L3. In this regard, we should note that the voltage is only boosted or bucked on the transmission line itself- we must not change the voltage level of the other lines which are connected to points L2 and L3. In the following experiment we shall study the load distribution between two parallel transmission line and how this distribution is modified by a phase shift and buck-boost transformer.

Experiments:

Part 1:

With the variable three phase AC source set at 200V connect the phase shift auto-transformer (EMS 8349) as shown in figure 5. Then fill out Table I.

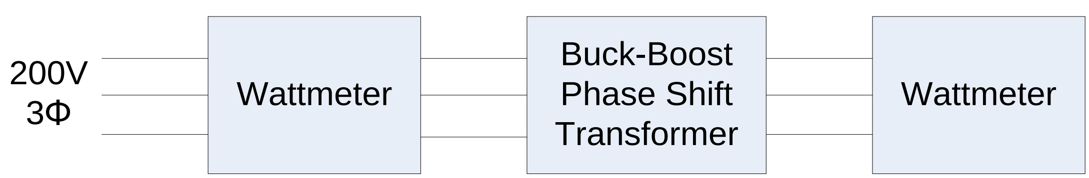

Figure: 5

Table I

Settings		Reading			
Buck-Boost	Phase shift	V1 (V)	V2 (V)	θ (°)	Lead – Lag
0	0°				
0	+15°				
0	-15°				
-15%	0°				
-15%	+15°				
-15%	-15°				
+15%	0°				
+15%	+15°				
+15%	-15°				

Part 2:

Set up the circuit as in figure 6 where two transmission lines in parallel feeding a wye connected resistive load of 300Ω (EMS 8311, representing a heating load) and an Induction motor. Set the transmission line resistances to 60Ω. Set the sending end voltage to 200V, perform the test and fill out Table II.

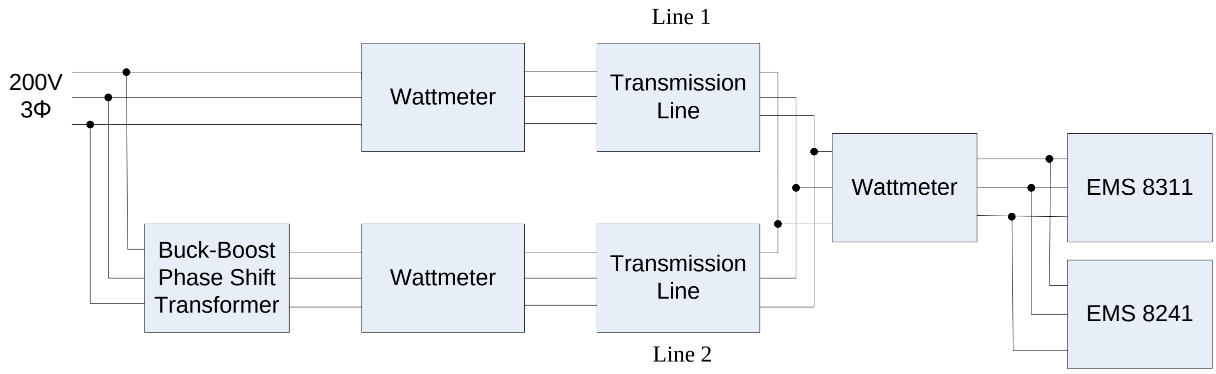

Figure: 6

Table II

Setting				Measurement						
Line 1 impedance (Ω)	Line 2 impedance (Ω)	Buck-Boost	Phase shift	P1 (W)	Q1 (Var)	P2 (W)	Q2 (Var)	V1 (V)	V2 (V)	V3 (V)
60	60	0	0°							
60	60	0	+15°							
60	60	0	-15°							
60	60	+15%	0°							
60	60	+15%	+15°							
60	60	+15%	-15°							
60	60	-15%	0°							
60	60	-15%	+15°							
60	60	-15%	-15°							

Setting				Measurement						
Line 1 impedance (Ω)	Line 2 impedance (Ω)	Buck-Boost	Phase shift	P1 (W)	Q1 (Var)	P2 (W)	Q2 (Var)	V1 (V)	V2 (V)	V3 (V)
0	60	0	0°							
0	60	0	+15°							
0	60	0	-15°							
0	60	+15%	0°							
0	60	+15%	+15°							
0	60	+15%	-15°							
0	60	-15%	0°							
0	60	-15%	+15°							
0	60	-15%	-15°							

Discussion:

1. Discuss the effect of shifting phase in the *buck-boost phase shift* transformer on line power flow.
2. Discuss the effect of changing tap in the *buck-boost phase shift* on line power flow.
3. In figure 7, two transmission lines having reactance per phase of 100 ohms and 200 ohms are connected in parallel. A phase shift transformer T1 is introduced in to the 200 ohm line, close to the receiver, in order that the real power be divided equally between the two lines. If the sender and receiver voltages are both $100kV_{LL}$ calculate the maximum real power delivered and the phased angle needed for the phase shift transformer.
4. If there were no phase shift transformer, what would be the maximum power which could be delivered over both lines?
5. Does the phase shift transformer increase the maximum power which the 200ohm line can deliver?

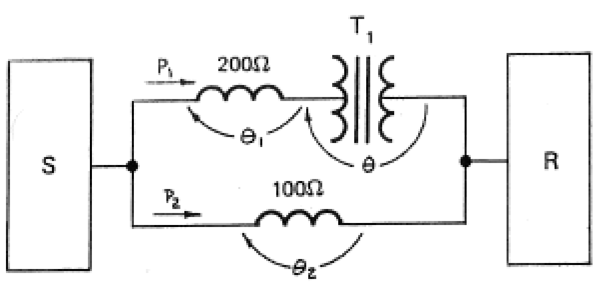

Figure: 7