TRANSFER OF POWER BY USING TWO INDUCTION MACHINES

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Abstract
The main reason for interconnection of different power grids is to reduce the overall economic costs as well as increase reliability and security of supplying electricity services. This paper describes the flow and distribution of power within the two asynchronous grids connected by the twin stator induction machine. The two machines are made to run at predetermined operating speed. The system works with no restriction on the grid frequency. The simulation results based on two nominally identical wound rotor induction machines are presented.
Keywords: Power system interconnection, transfer of power, cascaded induction machine.

I. INTRODUCTION

The interconnections of electric power supply systems are done for economic reasons, to reduce the cost of electricity and to improve reliability of power supply. Thus, for electrical power flow from one power system or grid to another power system or grid a simple, reliable and low cost interconnection is needed. There are some methods in which two AC systems are connected like in FACTS, HVDC and VFT to transfer the power between two grids. The connection can be through an AC link (tie line), a power electronic system (HVDC), or via VFT. Connecting two grids has certain advantages and disadvantages. The difficulty increases if the two grids have different frequencies. It is essential to maintain systems to be stable during the power transfer. The current way of connecting two asynchronous grids using HVDC link and another system to transfer power based on a wound rotor induction motor, is called Variable Frequency Transformer VFT. VFT connect two grids of the same frequency or frequencies of close value. The stator is connected to one grid and the rotor is connected to the other grid through slip rings. The VFT is new technology in the field of power transfer. The disadvantage is that it connect the two grids of nearly same frequency. The VFT technology is in use between United States and Mexico to transfer power from one grid to the other grid. The major problem occurs when the two grids work on different frequencies. This drawback can be overcome by using twin induction machines and connecting them to the different frequency grids. Two induction machines provide asynchronous power transmission between two independent power generating networks. The
cascaded connection of induction motor is utilized. This paper presents link for power transfer between the two grids, without restriction on the grid frequencies. The difference in the frequency of two grids can be of small value or large value. The link is based on a twin stator induction machines. Simulation and results are presented with typical example.

II. THEORY OF OPERATION

The system consists of two induction motors, connected in cascade for power transfer between the two grids. The stators of the two machines are connected to different values of frequency (grids) and the rotors are connected mechanically on a common shaft to a driving motor to control the speed and direction. The rotors are also connected electrically for power transfer between the two grids. The system contains two wound rotors induction machines in twin stator configuration. The power is transferred between two generating networks through the electrical connection provided between the rotors. Fig. 1 shows the connection of rotors. In this system machine A is connected to one generating network and machine B is connected to another generating network. The machine A rotor has an induced voltage and magnetic field of frequency f_{rA} due to its stator field. Similarly for machine B, the rotor induced voltage and magnetic field have a frequency f_{rB} due to its stator field. The rotors of the two machines are mechanically coupled and the rotor windings are connected in reverse sequence so as to produce contra rotating fields. The rotating fields produced by two rotors will rotate in opposite direction to each other. The two rotors frequencies must be of the same value to obtain power transfer. Two rotors must be connected electrically to satisfy this condition.

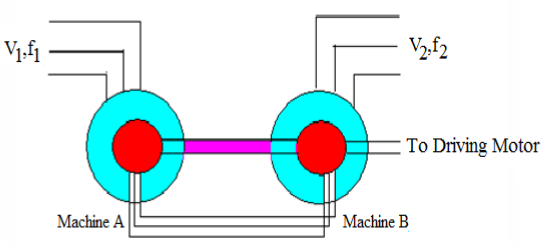

Fig. 1 Electrical and Mechanical connection of combined rotor

The rotors of two induction machines are connected to common driving motor for control of speed and direction. In this connection, two magnetic fields are produced in the air gap one by stator magnetic field and other by the rotor magnetic field. The stators magnetic field rotates with synchronous speed and it depends on number of poles and supply frequency of the machines ($N_s=120f/P$). The rotor magnetic field of each machine depends on machine number of poles and rotor frequency. The rotor frequency depends on the relative speed of the rotor to the stator magnetic field, which is slip of the machine. In the twin stator configuration, there are two currents in each rotor. The first current is due to the induced voltage generated by the stator rotating field that rotates relative to the rotor with a slip value. These current components circulate in both rotors due to the way of connecting them electrically. The second current comes from the other rotor. The power transferred from AC power system 1 to AC power system 2 is carried by current i_A and it is calculated from the equation,

P = average power = $1/T \int e_B(t).\ i_A(t)\ dt$ (1)

To obtain average power, the frequencies of $e_B(t)$ and $i_A(t)$ must be equal otherwise the integration evaluates to zero. It is necessary to obtain the condition at which the frequencies of the two rotors become equal.

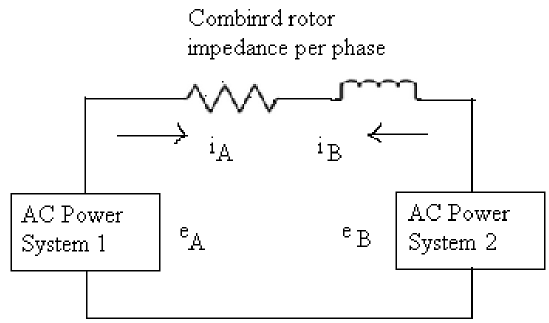

Fig. 2 Power transfer between two generating system

III. POWER FLOW

In the cascade connection, two similar wound rotor induction machines are used. In this connection shown in fig. 3, the corresponding rotor phases of the two machines are connected in reverse sequence. The two stators are supplied with voltage V_1 for machine A and V_2 for machine B, of the same phase sequence, generating rotating fields in the machine air gaps, in the same direction of rotation. If machine B has a frequency lower than the machine A frequency, then rotor 2 will start running opposite to the field direction of rotation with an angular velocity that equals to the angular velocity difference of the machine 2 stator voltage V_2 and the common rotor voltage V_r . Fig. 3 shows the power flow between two asynchronous grids.

Where,

V_1, f_1- voltage and frequency of Grid 1

V_2, f_2- voltage and frequency of Grid 2

ω_r - driving motor speed, rad/sec

f_{rA}, f_{rB} - rotor frequency of machine A and machine B, Hz

ω_1, ω_2 – stator rotating field (speed) of machine A and machine B, rad/sec

ω_{m1}, ω_{m2} – rotor rotating field (speed) of machine A and machine B, rad/sec

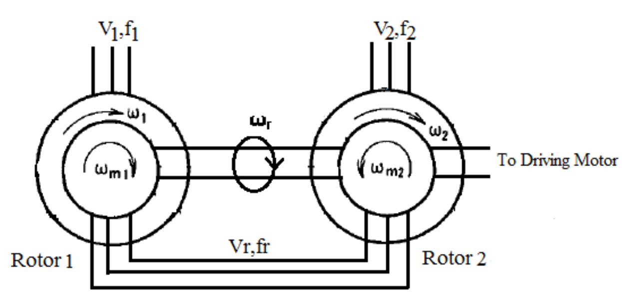

Fig. 3 Power flow between cascaded induction machines

The configuration of fig. 3, is considered, for $\omega_1 > \omega_r > \omega_2$. The rotating field in the air gap, developed by the machine A, has an angular velocity ω_1,

$$\omega_1 = 2\pi f_1 / p \qquad (2)$$

Where p is the number of pole pairs.

The voltage V_1 induced in the machine A rotor windings by the air-gap rotating field has an angular velocity ω_r equal to the difference between the air-gap field angular velocity ω_1 and (machine A) rotor angular velocity ω_{m1}. In this case ω_{m1} has the same (clockwise) direction as machine A field rotation.

$$\omega_r = \omega_1 - \omega_{m1} \qquad (3)$$

The corresponding rotor frequency is,

$$f_r = [p(\omega_1 - \omega_{m1}) / 2\pi] \qquad (4)$$

Machine B is doubly fed with the voltage V_r from the rotor, having rotor frequency f_r and with the voltage V_2 from the stator, having the frequency f_2. The machine B air gap rotating field angular velocity ω_2 determined by the voltage V_2 is,

$$\omega_2 = 2\pi f_2 / p \qquad (5)$$

Thus, in order to maintain synchronization, the machine B rotor is forced to turn with an angular velocity ω_{m2}, so that the rotating field developed by the rotor supply, superimposed on the rotor 2 angular velocity ω_{m2}, gives a rotating field of angular velocity equal to ω_2.

$$\omega_2 = \omega_r + \omega_{m2} \qquad (6)$$

Since $\omega_2 < \omega_r$, from equation (6) it is concluded that the machine B rotor angular velocity ω_{m2} has a negative value and rotates in a direction opposite (anticlockwise) to the machine B stator rotating field ω_2.
From equation (3) and (6),

$$\omega_{m1} - \omega_{m2} = \omega_1 - \omega_2 \qquad (7)$$

From equation (7) it can be seen that the two rotor angular velocities ω_{m1} and ω_{m2} may take various values, however the value $\omega_{m1} - \omega_{m2}$ should be constant and equal to the difference of the two stator angular velocities $\omega_1 - \omega_2$.
The differential drive speed control may be obtained by varying the frequency difference $f_1 - f_2$, of the voltage phasors supplying the machine stators. The difference $\omega_{m1} - \omega_{m2}$ of rotor angular velocities increases, when the frequency difference increases.

For machine A slip is S_A,

$$S_A = \omega_r / \omega_1 \qquad (8)$$

For machine B slip is S_B,

$$S_B = \omega_r / \omega_2 \qquad (9)$$

When $\omega_1 > \omega_r > \omega_2$, the cascaded machine operate in forward direction (clockwise). Then according to equation [8] machine A slip is $S_A < 1$ and rotor 1 rotates in rotating field direction, giving machine A forward (clockwise) direction. For machine B, according to equation [9], slip is $S_B > 1$ and rotor 2 rotates opposite to its rotating field direction, giving reverse (anticlockwise) machine direction.

ω_1 has the same direction as ω_r while ω_2 has an opposite direction of rotation to ω_r,

$$f_{rA} = f_1 [(\omega_1 - \omega_r)/\omega_1] \qquad (10)$$

$$f_{rB} = f_2 [(\omega_2 + \omega_r)/\omega_2] \qquad (11)$$

The condition of power transfer between the rotors is,

$$f_{rA} = f_{rB} \qquad (12)$$

The driving motor speed becomes,

$$\omega_r = 60 [f_1 - f_2 / P_A + P_B] \qquad (13)$$

Equation (13) gives driving motor speed and same speed is applied to rotor of two induction machines. The operating speed of two rotors is same, hence frequency is same.

The rotor slip power P_r may be expressed as function of mechanical power P_{m1} and slip S_1 for machine A, P_{m2} and slip S_2 for machine B.

$$P_{rA} = P_{m1}.S_A / (1 - S_A) \qquad (14)$$

$$P_{rB} = P_{m2}.S_B / (1 - S_B) \qquad (15)$$

Where P_{m1} and P_{m2} are Mechanical powers given as,

$$P_{m1} = -(1 - S_A) P_1 \qquad (16)$$

$$P_{m2} = -(1 - S_B) P_2 \qquad (17)$$

Where P_1 and P_2 are stator electrical powers.
The slip power P_{rA} is negative for machine A and P_{rB} is positive for machine B.
Thus power is transferred from machine B to Machine A. The power transferred within the rotor circuit is given by,

$$P = [S_A * E_{rA} * S_B * E_{rB} / (S_A * X_{rA}) + (S_B * X_{rB})] \sin \alpha \quad (18)$$

Where S_A, S_B are slips, E_{rA}, E_{rB} are the rotor induced EMFs and X_{rA}, X_{rB} are the rotor reactances of machine A and machine B respectively. α is the angle between E_{rA} and E_{rB}.

IV. SIMULATION AND RESULTS

The simulation of the system is carried out using Simulink software package. Two induction machines are mechanically coupled and made to rotate at a predetermined speed. The machine A is 2 pole connected to 50 Hz frequency grid and machine B is 2 pole connected to 36 Hz frequency grid. The two machines are driven at calculated speed of 210 rpm. The voltage at machine A is 1000 V with an angle of -240° and voltage at machine B is kept 1000 V with an angle of 0°. The angles of these two voltages cannot be related to each other due to the difference in the frequencies of grid. The rotors of two induction motors are made to run at the predetermined speed, so that they have same rotor frequency. The slips of the two machines are fixed as the system runs under fixed speed. So to increase the power transfer for the same angle α stator to rotor turns ratio must be maximized for both machines.

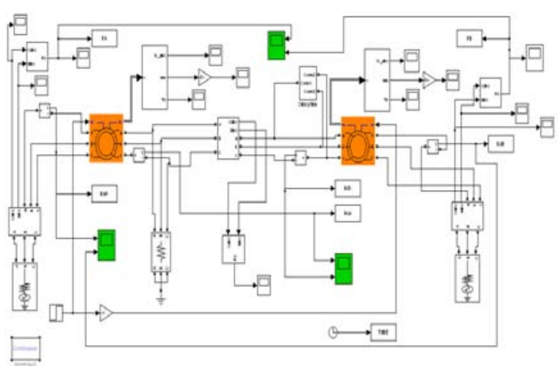

Fig. 4 Simulink model of system

Figure 5 shows the steady state power at the system terminals. The system power at machine A (50 Hz) is about -7.134 KW and the system power at machine B (36 Hz) is around +7.135 KW. The power is transferred from the 36 Hz to the 50 Hz i.e. from machine B to machine A. The simulation result shows that the power has a constant value at steady state. Fig. 6 shows two rotor currents. The default direction of the rotor current is from rotor to the external circuit. Both currents have the same frequency. The two rotor currents contain no harmonics. Even that the two stator currents have different frequencies, the two rotor currents have equal frequencies. Hence the condition for power transfer is satisfied at the calculated speed.

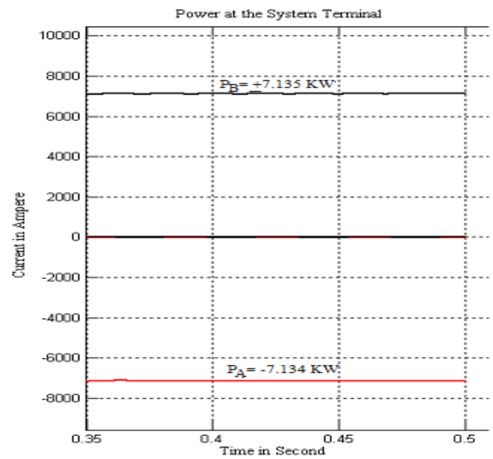

Fig. 5 Power at the systems terminals

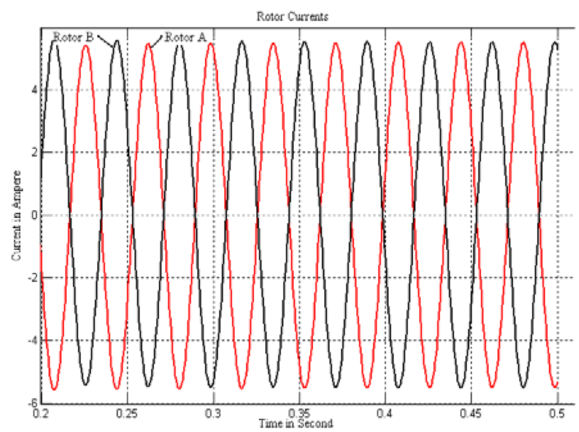

Fig. 6 Rotor currents

V. CONCLUSION

The system can be used to transfer the power between two asynchronous grids. The system does not restrict to the frequency of grid. It used to connect the grid between any two values of frequency.

This system does not require slip-rings as the two rotors are mechanically coupled with direct electrical connections. The calculated speed operate two rotors at same speed and it leads to generate same rotor frequency from either machine and rotor current contains no harmonics. The speed is fixed at the calculated value and the change in the power transferred will depend upon the two voltages V_1 and V_2, and angle α.

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