# Induction Motor Equivalent Circuit Parameters

# Problem Definition

The induction generator has 6-phase asymmetric windings as shown below.



In this winding configuration, it can be figured out that there are two separate three phase motors in the same lamination. These separate motors have inherently 30-degree phase difference in their induced voltage.

We can find the speed-torque characteristics of the induction motor using parametric sweep in transient model of Maxwell, but it does not give the equivalent circuit parameters. The deduction of the equivalent circuit parameters from the torque speed characteristics is difficult in transient model, and we can use rmxprt model that gives directly these circuit parameters. However, these models are only valid for 3-phase induction machines. Therefore, we can convert our six-phase induction machine to combined three-phase induction machines. Firstly, we can divide our machine into two windings sequences that are ABC and XYZ, and then we can connect these two motors’ in parallel or series, as shown in below.



Assume that these ABC and XYZ machines have no phase difference at their induced voltage. Since we have two machines in series or parallel, we can calculate different equivalent circuit parameters. While, in series connection, we achieve twice of ABC or XYZ parameters in the combined three-phase machine, in parallel connection, we obtain the half of ABC or XYZ parameters.

Further, converting 6-phase motor to 3-phase motor changes some circuit parameters because we have actually 30-deree phase difference at the induced voltage. It means that actually distribution factor become involved. The equivalent circuit diagram of a phase of an induction motor is shown in below.



Where,

r1 = stator winding resistance

x1 = stator winding leakage reactance

rc = resistance-representing core losses

xm= magnetising reactance

r2'= rotor winding resistance referred to the primary

x2'= rotor winding reactance referred to the primary

## Resistance Calculation in Induction Motor

Winding resistances can be calculated by where, is length, is area, and is resistivity which changes with temperature .

Since mean length of the windings become twice in series connection, which means that we achieve twice of the phase resistance. Besides, in parallel connection, the copper is become twice, which means that we achieve half of the phase resistance.

|  |  |  |
| --- | --- | --- |
| Combined 3-phase series model  (Per phase equivalent) | Combined 3-phase parallel model  (Per phase equivalent) | Six-phase model  (Per phase equivalent) |
|  |  |  |
|  |  |  |

## Stator Rotor Turns Ratio

Turns ratio 

and are winding factors for the stator and rotor respectively. In the combined three-phase and six-phase models, and changes via 30-degree distribution factor.

where q is the number of slots, is angular slot pitch, and is pole pitch.

In our case, winding factor changes with correction factor 0.9659 of . ()

|  |  |  |
| --- | --- | --- |
| Combined 3-phase series model  (Per phase equivalent) | Combined 3-phase parallel model  (Per phase equivalent) | Six-phase model  (Per phase equivalent) |
| 0.9659 | 0.9659 |  |
| 0.9659 | 0.9659 |  |



*F1 = F2*

where N2 is the number of turns of the rotor winding and kw2 is its winding factor.





## Cage Rotor Parameters

A cage rotor is equivalent to a secondary winding having Q2 conductors or bars connected in pairs a pole pitch apart so that there are Q2/p phases.

 where is the rotor phase current referred to primary (stator), m is # of phases.

The current per bar is



In deriving this equation, the rotor is assumed to have Q2/p phases each with p/2 turns and the pitch factor is taken as unity.

Let Rber = resistance of one bar including the end ring. Then,





So, the rotor resistance referred in primary side changes with .

|  |  |  |
| --- | --- | --- |
| Combined 3-phase series model  (Per phase equivalent) | Combined 3-phase parallel model  (Per phase equivalent) | Six-phase model  (Per phase equivalent) |
|  |  |  |

## Leakage Reactance

For a coil of N turns surrounding a magnetic circuit of reluctance R, the flux per ampere is

ϕ = Ni / R = Ni Λ

where Λ is the permeance of the flux path. Now 

where A is the effective area and L is the length of the flux path. The leakage inductance of the coil is Ni ϕ / i = N2 Λ Henries

Then, for the combined system leakage reactance’s are the same. However, rotor reactance referred to primary side changes with .

|  |  |  |
| --- | --- | --- |
| Combined 3-phase series model  (Per phase equivalent) | Combined 3-phase parallel model  (Per phase equivalent) | Six-phase model  (Per phase equivalent) |
|  |  |  |

## Magnetizing Reactance

This reactance in the equivalent circuit determines the current that is drawn by the motor to establish the pole flux ϕ in the magnetic circuit.



We have already shown that for a 3-phase winding of Nph turns per phase and p-poles, the amplitude of the resultant MMF is



where, i is the rms current.

|  |  |  |
| --- | --- | --- |
| Combined 3-phase series model  (Per phase equivalent) | Combined 3-phase parallel model  (Per phase equivalent) | Six-phase model  (Per phase equivalent) |
|  |  |  |