Wind Turbine Electricity Generation

D. Induction Generator

DESIGN FEATURES

STATOR WITH MULTIPLE WINDINGS

ROTOR – CONDUCTING BARS

POWER EXTRACTED FROM STATOR

ALTERNATIVE DESIGNS

- ROTORS ARE WOUND ALSO
- POWER IS TAKEN FROM BOTH ROTOR & STATOR (DFIG)

DOUBLY FED INDUCTION GENERATOR

DESIGN CHALLENGES

- ENSURE CONSTANT FREQUENCY SOURCE TO CONTROL ROTATION SPEED
- EXTERNAL SOURCE OF REACTIVE POWER
- OFTEN OPERATE WITH POOR POWER FACTOR → CAN BE OVERCOME WITH CLEVER ELECTRICAL DESIGN

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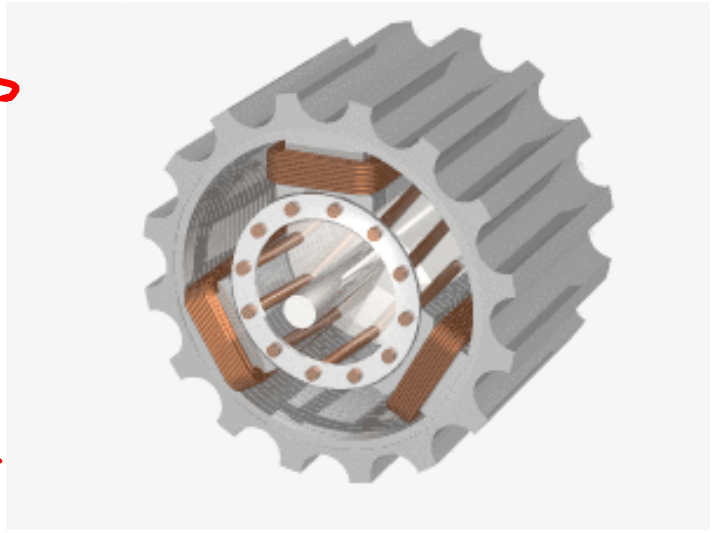
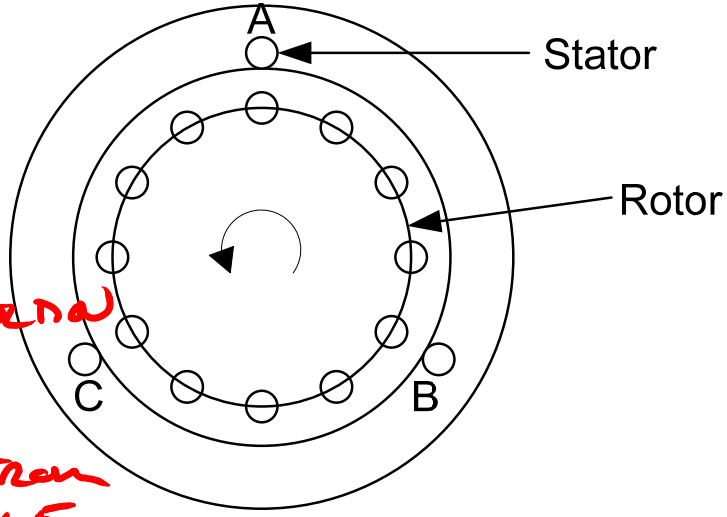
INDUCTION ELECTRIC MACHINES HAVE BEEN WIDELY USED AS MOTORS

USE AS GENERATORS IS MORE RECENT



CURRENTLY, INDUCTION GENERATOR DESIGNS ARE MOST COMMON GENERATOR IN WIND INDUSTRY



WHY WOULD INDUCTION MOTORS DOMINATE IN WIND TURBINES?

SIMPLE DESIGN → ALLOWS FOR RUGGED CONSTRUCTION

RELATIVELY INEXPENSIVE

CONNECTION & DISCONNECTION FROM GRID IS RELATIVELY SIMPLE

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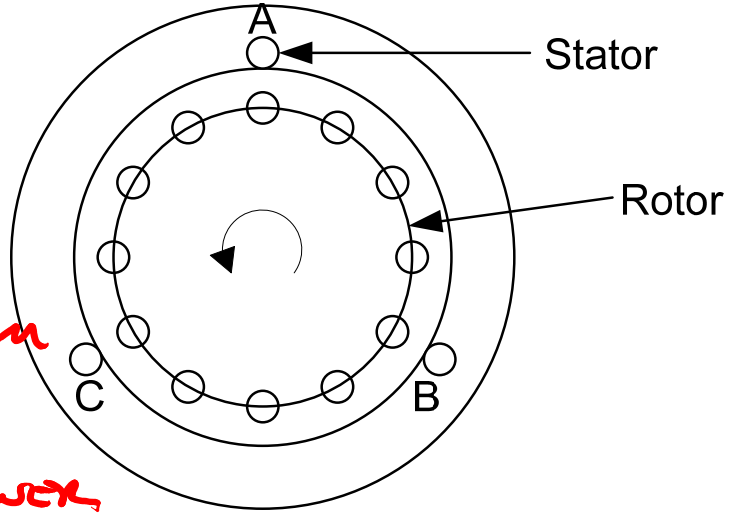

DUE TO LIMITATIONS, APPLICATION IS PRIMARILY FOR LARGE, GRID CONNECTED SYSTEMS

AN OUTSIDE ELECTRICAL SYSTEM (GRID)
- SETS FREQUENCY
- PROVIDES REACTIVE POWER

CAN BE USED FOR DISTRIBUTED OR NON-GRID CONNECTED SYSTEMS IF ISSUES ARE ADDRESSED
- REACTIVE POWER SUPPLY
- AIDS FOR FREQUENCY STABILITY
- SPIN UP ASSISTANCE (IN SOME CASES)

START-UP OF GENERATOR
- RUN GENERATOR AS A MOTOR → USES ENERGY
- USE WIND TO START → ONLY CONNECT TO GRID WHEN IT IS GENERATING

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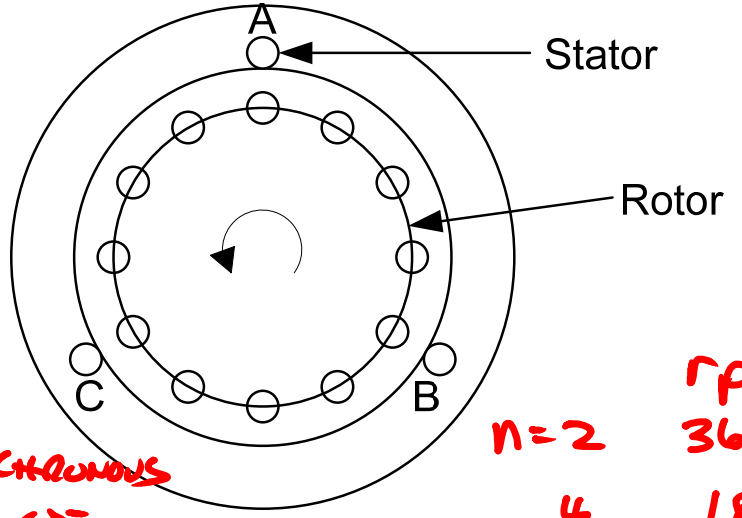
THEORY OF OPERATION



- STATORS PRODUCE A ROTATING MAGNETIC FIELD
  - → SUPPLY AC CURRENT TO WINDINGS W/ PHASE OFFSET
  - → FIELD ROTATES AT SYNCHRONOUS SPEED, DEPENDS ON # OF WINDINGS

	rpm
n=2	3600
4	1800
6	1200

- ROTOR SPINS AT A SPEED DIFFERENT THAN SYNCHRONOUS SPEED
  - → RELATIVE MOTION BETWEEN ROTOR & STATOR FIELDS
  - → SINCE ROTOR IS PASSING THROUGH A CHANGING MAGNETIC FIELD, THE BARS WILL HAVE INDUCED CURRENT
  - → INDUCED CURRENT PRODUCES A MAGNETIC FIELD ASSOCIATED WITH ROTOR
  - → INTERACTION BETWEEN ROTOR & STATOR FIELDS CAUSES ELEVATED VOLTAGE AT STATOR TERMINALS → CURRENT

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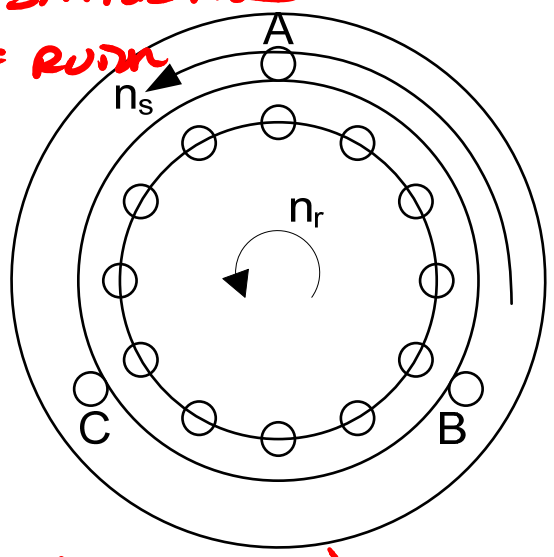
n_s - SPEED OF STATOR FIELD

n_r - SPEED OF ROTOR

THEORY OF OPERATION



PARAMETER GOVERNING INDUCTION MACHINE OPERATION IS SLIP S

$$S = \frac{n_s - n_r}{n_s}$$

NORMALIZED SPEED DIFFERENCE

QUOTED IN %

TYPICAL SLIP VALUES ARE ~2% (FOR GENERATION)

SELDOM DOES SLIP EXCEED 3% (DURING GENERATION)

GENERATOR WILL EXPERIENCE A WIDE RANGE OF S DURING START UP

$n_r = 0$ INITIALLY

CONVENTION

$S > 0$ MOTOR - STATOR FIELD SPINS FASTER THAN ROTOR

$S < 0$ GENERATOR - ROTOR SPINS FASTER THAN THE STATOR

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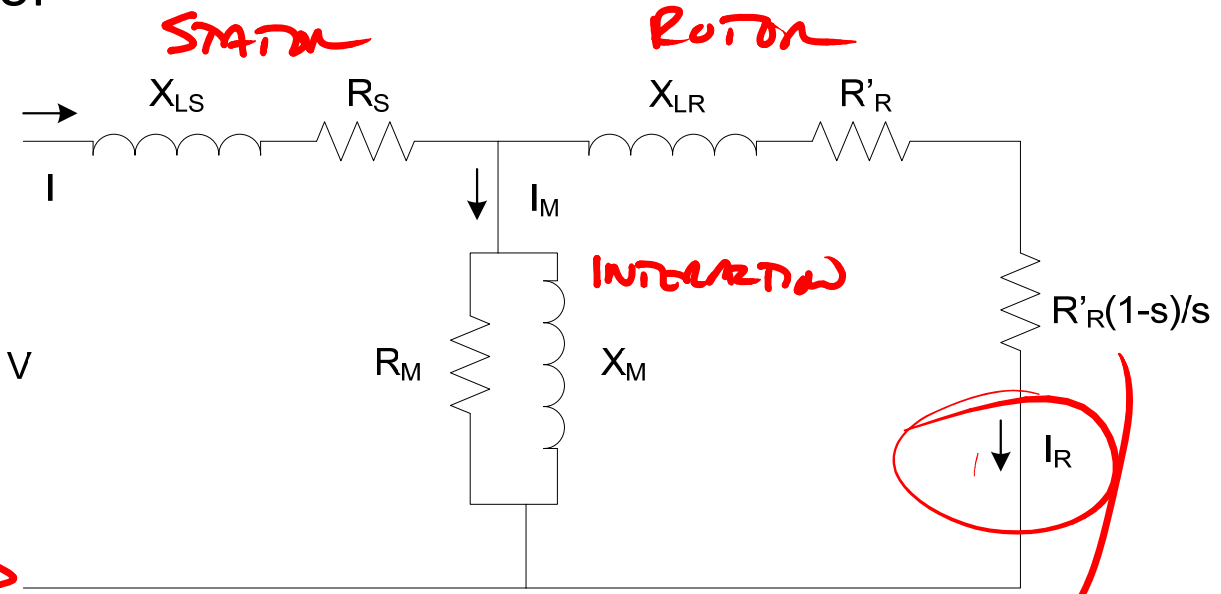
INDUCTION GENERATOR CAN BE REPRESENTED BY AN EQUIVALENT CIRCUIT



MOTOR/GENERATOR CAN BE CHARACTERIZED IN TERMS OF THESE QUANTITIES

$X_m >> X_{LS}$ OR X_{LR}

$R'_R \frac{(1-s)}{s}$ POSITIVE $s<1$ INTEGRATE $s>1$

VARIABLE RESISTOR

← CHECK!

R_m IS TYPICALLY LARGE ↑ IGNORE

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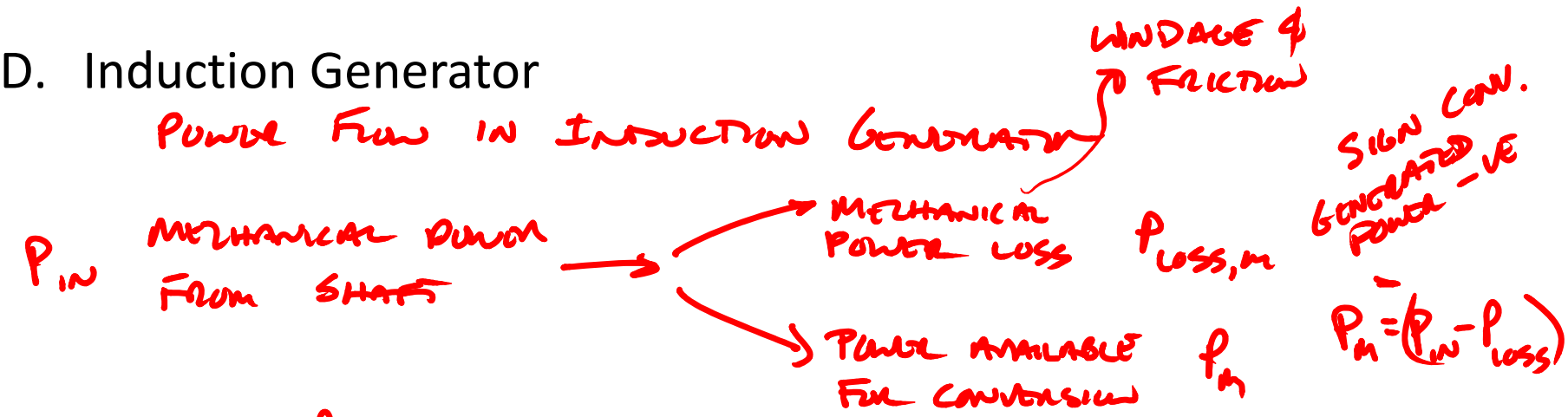

THIS POWER P_M IS TRANSFORMED INTO ELECTRICAL POWER

$$P_m = I^2 R'_R \frac{1-s}{s}$$ ← POWER GENERATED IN ROTOR

SOME POWER LOST IN ROTOR → NET POWER ONLY IS TRANSFERRED

$$P_g = P_m - P_{loss,R} = I^2 R'_R \frac{1-s}{s} + I_R^2 R'_R$$

SIMPLIFY $$P_g = \frac{P_m}{1-s}$$

SOME POWER LOST IN STATOR $I_s^2 R_s = P_{loss,s}$

SO NET POWER DELIVERED AT TERMINALS $P_{out} = P_g - P_{loss,s}$