NSCET E-LEARNING PRESENTATION

LISTEN ... LEARN... LEAD...
ELECTRICAL AND ELECTRONICS ENGINEERING

IVth YEAR / VIIIth SEMESTER

EE6009 – POWER ELECTRONICS FOR RENEWABLE ENERGY SYSTEMS

G.Sujitha M.E
Assistant Professor
Nadar Saraswathi College of Engineering & Technology,
Vadapudupatti, Annanji (po), Theni – 625531.
UNIT 02 – Electrical Machines for Renewable Energy Conversion
Education is improving the lives of others and for leaving your community and world better than you found it.

-Marian Wright Edelman
UNIT-2

• Reference theory fundamentals
• Principle of operation and analysis
  ✓ IG
  ✓ PMSG
  ✓ SCIG
  ✓ DFIG
Transformation of three phase electrical quantities to two phase quantities is a usual practice to simplify analysis of three phase electrical circuits.

Polyphase A.C machines can be represented by an equivalent two phase model provided the rotating polyphases winding in rotor and the stationary polyphase windings in stator can be expressed in a fictitious two axes coils.

The process of replacing one set of variables to another related set of variable is called winding transformation or simply transformation or linear transformation.
Evolution of Transformation Technique

- R. H. Park Transformation - 1920 (for synchronous machine)
- H. C. Stanley Transformation - 1930 (for Induction Machine)
- G. Kron Transformation (for Induction Machine)
- D. S. Brereton Transformation (for Induction Machine)
- Krause and Thomas Transformation (after 1965)
- E. Clarke Transformation
The park transform first proposed in 1929 by Robert. H. Park. He referred the stator and rotor variables to a reference frame fixed on the rotor.

From the rotor point of view all the variables can be observed as constant values.

Park’s transformation
- Revolution in machine analysis, has the unique property of eliminating all time varying inductances from the voltage equations of three phase ac machines due to the rotor spinning.
Reference frames
abc/dq Reference Frame Transformation

- The transformation of the abc variables to the dq frames, referred to as abc/dq transformation, can be expressed in a matrix form:

\[
\begin{bmatrix}
  f_{qd0s} \\
\end{bmatrix} = T_{qd0}(\theta) \begin{bmatrix}
  f_{abcs} \\
\end{bmatrix}
\]

\[
T_{qd0s}(\theta) = \frac{2}{3} \begin{bmatrix}
  \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\
  \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\
  \frac{1}{2} & \frac{1}{2} & \frac{1}{2}
\end{bmatrix}
\]
Inverse Park’s Transformation

- the angular displacement $\theta$ must be continuous, but the angular velocity associated with the change of variables is unspecified.
- The frame of reference may rotate at any constant, varying angular velocity, or it may remain stationary.

The inverse of Park’s transformation is given by,

$$
\begin{align*}
[f_{abcs}] &= T_{qd0}(\theta)^{-1} \cdot [f_{qds}]
\end{align*}
$$

$$
T_{qd0}(\theta)^{-1} = \begin{bmatrix}
\cos(\theta) & \sin(\theta) & 1 \\
\cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\
\cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1
\end{bmatrix}
$$
In Electrical Engineering, the alpha-beta Transformation (also known as the Clarke Transformation) is a mathematical transformation. It is a mathematical transformation employed to simplify the analysis of three phase circuits.

- Conceptually, it is similar to the dq0 transformation.
- One very useful application of the \{\alpha-\beta\} transformation is the generation of the reference signal used for space vector modulation control of 3 phase inverters.
He transformed a change of variables associated with the stationary circuits to a variables associated with stationary reference frame. The stationary two-phase variables of Clarke’s transformation are denoted as $\alpha$ and $\beta$ (both are orthogonal).
In order for the transformation to be invertible, a third variable, known as the zero sequence component, is added. The resulting transformation is,

\[ [f_{\alpha\beta0}] = T_{\alpha\beta0}[f_{abc}] \]

Where \( f \) represents voltage, current, flux linkages, or electric charge and the transformation matrix, is given by

\[
T_{\alpha\beta0} = \frac{2}{3} \begin{bmatrix}
1 & -\frac{1}{2} & -\frac{1}{2} \\
0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\
\frac{1}{2} & 1 & \frac{1}{2}
\end{bmatrix}
\]
Inverse Clark’s Transformation

- The inverse transformation is given by

\[
[f_{abc}] = T_{\alpha\beta_0}^{-1}[f_{\alpha\beta_0}]
\]

Where the inverse transformation is given by,

\[
T_{\alpha\beta_0}^{-1} = \begin{bmatrix}
1 & 0 & 1 \\
-\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \\
-\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\
\end{bmatrix}
\]
Commonly Used Reference Frames

Based on speed of reference frame there are four major type of reference frames,

1. ** Arbitrary reference frame**: Reference frame speed is unspecified \(\omega\), variables denoted by \(f_{dq0s}\) transformation matrix denoted by \(K_{s}\).
2. ** Stationary reference frame**: Reference frame speed is zero \(\omega=0\), variables denoted by \(f_{dq0s}^s\) transformation matrix denoted by \(K_{s}^s\).
3. ** Rotor reference frame**: Reference frame speed is equal to rotor speed \(\omega=\omega_r\), variables denoted by \(f_{dq0r}\) transformation matrix denoted by \(K_{s}^s\).
4. ** Synchronous reference frame**: Reference frame speed is equal to synchronous speed \(\omega=\omega_e\), variables denoted by \(f_{dq0e}\) transformation matrix denoted by \(K_{s}^e\).
Introduction

- An induction generator or asynchronous generator is a type of alternating current (AC) electrical generator that uses the principles of induction motors to produce power.

- Induction generators operate by mechanically turning their rotors faster than synchronous speed.

- Induction generators are useful in applications such as mini hydro power plants, wind turbines, or in reducing high-pressure gas streams to lower pressure, because they can recover energy with relatively simple controls.
**Excitation**

- Induction generator is not a self excited machine therefore in order to develop the rotating magnetic field, it requires magnetizing current and reactive power.

- The induction generator obtains its magnetizing current and reactive power from the various sources like the supply mains or it may be another synchronous generator.

- The induction generator can’t work in isolation because it continuously requires reactive power from the supply system.

- However we can have a self excited or isolated induction generation in one case if we will use capacitor bank for reactive power supply instead of AC supply system.
Construction

- Slip-rings (for wound rotor)
- Cooling blades
- Squirrel cage rotor
- Rotor windings
- Shaft
An induction generator is made up of two major components

- **Stator** It consists of steel laminations mounted on a frame so that slots are formed on the inside diameter of the assembly as in a synchronous machine.

- **Rotor** It consists of a structure of steel laminations mounted on a shaft. It is made of solid conducting bars, also embedded in slots in a magnetic core. The bars are connected together at both ends by two conducting end rings. Because of its resemblance, the rotor is called a squirrel cage rotor.
Principle of operation
An induction generator produces electrical power when its rotor is turned faster than the synchronous speed.

In generator operation, a prime mover (turbine or engine) drives the rotor above the synchronous speed (negative slip - difference between synchronous and operating speed is called "slip")

The stator flux still induces currents in the rotor, but since the opposing rotor flux is now cutting the stator coils, an active current is produced in stator coils and the motor now operates as a generator, sending power back to the electrical grid.
Torque-Speed Characteristics

- As the speed of the motor increases the counter torque reaches a max value of torque (breakdown torque) that it can operate until before the operating conditions become unstable.

- Ideally, induction generators work best in the stable region between the no-load condition and maximum torque region.
Permanent Magnet Synchronous Generator (PMSG)

Introduction

- A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil.

- The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature. Synchronous generators are the majority source of commercial electrical energy.
Construction

Types of PMSG rotor Construction

a) Surface mounted  b) inset  c) interior PM motor
SURFACE-MOUNTED PMSG

- The permanent magnets are placed on the rotor surface.
- The permeability of the magnets is very close to that of the non-ferrite materials, the effective air gap between the rotor core and stator is uniformly distributed around the surface of the rotor.
- This type of configuration is known as a non salient-pole PMSG.

INSET PMSG

- The permanent magnets are inset into the rotor surface.
- The saliency is created by the different permeability of the rotor core material and magnets.
INTERIOR PM MOTOR

- Interior permanent magnet motor magnets are buried inside the rotor.
- It provides a much broader region of more or less consistent torque.
- Using a technique called field weakening, designers can apply current to modify performance.
- As speed rises, the permanent magnets and motor generate higher voltage.
**Operation**

- In the majority of designs the rotating assembly in the center of the generator called "rotor" contains the magnet, and the "stator" is the stationary armature that is electrically connected to a load.

- If the load is inductive, then the angle between the rotor and stator fields will be greater than 90 degrees which corresponds to an increased generator voltage. This is known as an **overexcited generator**.

- The opposite is true for a generator supplying a capacitive load which is known as an **under excited generator**.
Advantages

- Light weight and small size in construction.
- Low losses and high efficiency
- No need of external excitation current.
- No need of gearbox.

Disadvantages

- It is useful for small wind turbines, but for large wind turbines the size of the magnet has to be increased.
- Demagnetization of permanent magnet due to atmospheric conditions is a big problem.
Types of IG

- There are two main types of induction generators in the wind energy industry:
  - doubly fed induction generators (DFIGs)
  - squirrel-cage induction generators (SCIGs).
- These generators have the same stator structure and differ only in the rotor structure.
Squirrel Cage Induction Generator

Introduction

- The squirrel-cage induction generator is simple, reliable, cost-effective, and maintenance-free compared to other types of wind generators.

- This is achieved by using a robust squirrel-cage rotor structure, in which the rotor winding is made of copper bars embedded in the rotor magnetic core.

- As a result, slip rings and brushes that are required in the wound-rotor induction and synchronous generators are eliminated.
Constructional feature
- **Stator**
  The stator is made of thin silicon steel laminations. The laminations are basically flat rings with openings disposed along the inner perimeter of the ring. When the laminations are stacked together with the openings aligned, a canal is formed, in which a three-phase copper winding is placed.

- **Rotor**
  The rotor of the SCIG is composed of the laminated core and rotor bars. The rotor bars are embedded in slots inside the rotor laminations and are shorted on both ends by end rings.
The SCIG is a self-excited induction generator where a three-phase capacitor bank is connected across the stator terminals to supply the reactive power requirement of a load.

When such an induction machine is driven by an external mechanical power source, the residual magnetism in the rotor produces an Electromotive Force (EMF) in the stator windings.

This EMF is applied to the capacitor bank causing current flow in the stator winding and establishing a magnetizing flux in the machine.
Principle of operation

- Initially, the induction machine is connected in motoring command such that it generates electromagnetic torque in the same direction as the wind torque.

- In steady-state, the rotational speed exceeds the synchronous speed and the electromagnetic torque is negative.

- This corresponds to the squirrel-cage induction machine operation in generation mode.

- As it is directly connected to the grid, the SCIG works on its natural mechanical characteristic having an accentuated slope (corresponding to a small slip) given by the rotor resistance.
SCIG in wind energy system
The connection of an SCIG to the grid often causes a large inrush current that is 7 ~ 8 times of the rated current and a soft-starter is often needed.

The pole pair number of SCIG used in commercial fixed-speed wind turbines is often equal to 2 or 3, which corresponds to a synchronous speed of 1500 rpm or 1000 rpm for a 50 Hz system.

As a result, a three-stage gearbox is often required in the drive train.

SCIGs are often applied in fixed-speed wind turbine systems directly connected to the grid through a transformer.
Double Fed Induction Generator

Why the term “Doubly Fed”

- Instead of the usual field winding fed with DC, and an armature winding where the generated electricity comes out, there are two three-phase windings, one stationary and one rotating, both separately connected to equipment outside the generator. Thus the term "doubly fed".
- One winding is directly connected to the output, and produces 3-phase AC power at the desired grid frequency.

- The other winding (traditionally called the field, but here both windings can be outputs) is connected to 3-phase AC power at variable frequency.

- This input power is adjusted in frequency and phase to compensate for changes in speed of the turbine.
Schematic diagram of DFIG with wind turbine
• DFIGs are often applied in variable speed wind turbine systems with a multi-stage gearbox.

• The principle is the same as an SCIG-based system but the rotor active power is controlled by the power electronic converters so that a speed range of ±30% around the synchronous speed can be obtained.

• The choice of the rated power for the rotor converter is a trade-off between cost and the desired speed range.
One phase steady state equivalent circuit of the DFIM with different stator and rotor frequencies
The voltage and currents of the stator and the rotor circuits have different frequencies.

The stator frequency ($f_s$) is fixed if the stator is connected directly to the grid.

The rotor frequency voltages and currents is variable ($f_r$) and depends on the speed of the machine.

The impedance $X_{0sr}$ of the rotor will also be dependent on the speed of the machine.
Advantages

- It more fully converts the available wind power over a wider range of wind speeds with less mechanical complexity but more electrical and electronic complexity.

- Only the rotor power needs to be converted. That is typically about 30% of the total power.

- The overall equipment, installation and maintenance cost is apparently lower for DFIG systems for some range of power levels.

- DFIG provides variable speed with a smaller power converter compared to other variable speed generators.
Disadvantages

- A disadvantage of the DFIG compared to the permanent magnet synchronous generator is that the DFIG requires a speed increasing gearbox between the wind turbine and the generator whereas the PMSG can be constructed with a sufficient number of poles to allow direct drive.
Thank you