INVERTER CONTROLLER USING SYNCHRONOUS GENERATOR MATHEMATICAL MODEL

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CHAPTER 1

1.1 Introduction

DC-AC converters are knows as inverters. An inverter is an electrical device that converts direct current (DC) to alternating current (AC), and this alternated power can be maintained in any frequency or voltage with the use of appropriate transformers, circuits and switches. Follow the lines to know about the advantages of inverters in our day to day life. The function of the inverter is to change a DC input to a symmetric AC output of desired magnitude and frequency. The output could be fixed or variable at a fixed or variable frequency. Variable output can be obtained by varying the input DC and maintaining the gain of the inverter constant. The inverter gain may be defined as the ratio of the AC output voltage to DC input voltage.

The output waveforms of ideal inverters should be sinusoidal. However, the waveform of practical inverter are non-sinusoidal and contain certain distortion for low and medium power application, square wave or quasi wave may be acceptable such as powering a car radio to that of backing up a building in case of power outage. Inverters can come in many different varieties, difference in price, power, efficiency and purpose. The purpose of a DC-AC power inverter is typically to take DC power supplied by a battery, such as a 12 volt car battery, and transform it into a 120 volt AC power source operating at 50 or 60 Hz, emulating the power available at an ordinary household electrical outlet; and for high applications, low distorted sinusoidal waveforms are required. With the availability of high speed power semiconductor devices the distortion contents of output voltage can be minimized or reduced significantly by switching techniques.

Inverter can be broadly classified into types. First single phase inverter and second three phase inverter. Also can be classified depending on the kind of the source of the feeding to voltage source inverters (VSI) and current source inverters (CSI).

Three phase inverters are normally used for high power applications. Three signal phase half or full bridge can be connected a three phase output can be obtained from a configuration of six transistors two types of the control signals can be applied to the transistors 180^{o} conduction or 120^{o} conduction. The 180^{o} conduction has better utilization of the switches and is the preferred method.

There are many controller systems use in the inverter controller such as Proportional-Integral controller (PI controller), Proportional, Integral, and Derivative (PID controller) and fuzzy logic. The proposed of PI controller is to improve the performance of the soft switched inverter. The duty ratio of the inverter is controlled by PI controller. To provide optimal performance at all operating conditions of the system PI controller is developed to control the duty ratio of the inverter.

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change [4]. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

The fuzzy logic controller is a control system based on fuzzy logic a mathematical system that analyses analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively) [3].

The alternator is a machine which produces alternating electricity. It is a kind of generators which converts mechanical energy into electrical energy. It is also known as synchronous generator (SG). Synchronous machines include alternators and motors which run at a constant speed in synchronism with the alternating current supply to which is connected. An alternator is a machine which has a stationary conductor system called stator and a rotating field system called rotor. The arrangement is very helpful to collect heavy currents at high voltages from stationary terminals.

Synchronous machine has two mechanical parts; a rotor and a stator. There are also have two electrical parts to the machine; a field source and an armature winding. These basic fundamentals of an electric machine are like those for a DC machine, with one significant difference. The field source of a synchronous machine is on the rotor, the armature winding of a synchronous machine is on the stator. Like DC machines, the field source creates a magnetic field the armature winding has a voltage induced in it by the field. Also like DC machines, the field can be produced using either a field winding or by using permanent magnets. Permanent magnet (PM) machines are common in small sizes, whilst large machines are usually made with field windings. Permanent magnet (PM) synchronous motors are widely used in low and mid power applications such as computer peripheral equipments, robotics and adjustable speed drives.

In this project, propose a control strategy based on the synchronverter technology. Controller is run as synchronverter, which are mathematically equivalent to the conventional synchronous generators. The rotor-side converter is responsible for maintaining the DC link voltage and the load side converter. The dynamic equations are the same, only the mechanical power exchanged with the prime mover (or with the mechanical load, as the case may be) is replaced with the power exchanged with the DC bus. It has been called such an inverter (including the filter inductors and capacitors) and the associated controller a synchronverter.

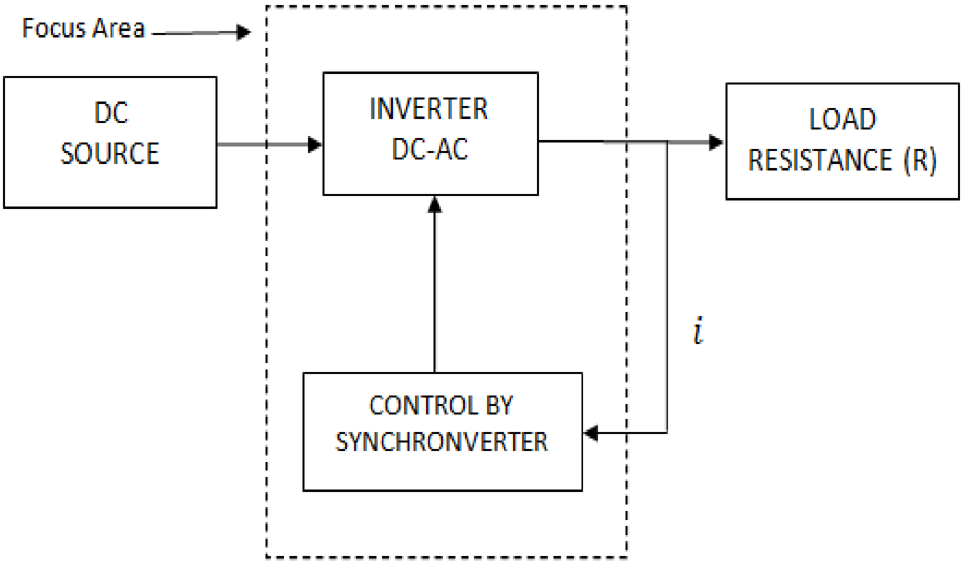


Figure 1.1: Project block diagram

1.2 Problem Statement

Inverters are used in many applications in power systems. Power electronics and machine drives fields required DC-AC conversion in example, motor control and renewable energy where the DC source will be inverted to AC output to suit the motor rating. The speed of the AC can be controlled by controlling the output voltage frequency and amplitude. So this DC-AC inverter is designed to achieve these tasks. The key problem in this project is how to control the inverter in distributed power generation. There are two options. The first is to redesign the whole power system and to change the way it is operated (e.g., establish fast communication lines between generators and possibly central control) and the second is to find a way so that these inverters can be integrated into the existing system and behave in the same way as synchronous generators. When the inverters connected with the load, the synchronoverter will be control on the current and power generation as been hoped.

1.3 Project objectives

The objectives of this project are:

1- To design the inverter control using synchronous generator model.
2- To develop the current control for inverter control.
3- To investigate the current response at the load connection.

1.4 Scope of project

This project primarily development a new control strategy using mathematical model of SG in the inverter (DC-AC). In order to achieve these scopes of this project are:

1- The synchronous inverter control using synchronous generator equation will be designed in the MATLAB.
2- The modelling of current controller that suitable for DC-AC in order to control the current output is designed using MATLAB.
3- The connection between the inverter and load connection must be established using MATLAB.

CHAPTER 2

LITERATURE REVIEW

2.1 Synchronous Generator

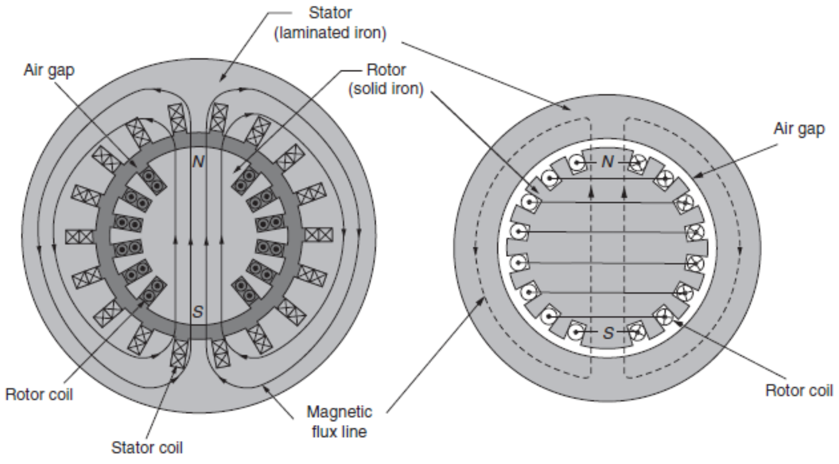
Synchronous generators are the primary source of all the electrical energy. It is known as synchronous machines because it operates at synchronous speed where the speed of rotor always matches supply frequency. These machines are the largest energy converters in the world. Where if converts mechanical energy into electrical energy.

The magnetic field created by the armature currents rotate at the same speed as that created by the field current on the rotor, which is rotating at the synchronous speed and a steady torque results. Synchronous machines are principally used as alternating current (AC) generators. They supply the electric power used by all sectors of modern societies such as industrial, commercial, agricultural and domestic. Synchronous machines are sometimes used as constant speed motors or as compensators for reactive power control in large power systems. In this chapter will be explains to the constructional and operating principles of the synchronous machine and generator performance for stand-alone and load applications. The effects of load and field excitation on the synchronous motor are investigated [13]. With power electrical devices such as variable voltage variable frequency (VVVF) power supplies, synchronous engines, particularly those with permanent magnet rotors, are widely utilised for variable hasten drives. If the stator excitation of an enduring magnet engine is controlled by its rotor position such that the stator area is habitually 90^{o}(electrical) ahead of the rotor, the motor presentation can be very close to the accepted scrubbed DC engines, which is very much highly rated for variable hasten drives. The rotor place can be either noticed by utilising rotor place sensors or deduced from the induced emf in the stator windings. Since this type of motors does not need paint brushes, as are known as brushless DC engines [5].

2.2 Synchronous Machine Structures

2.2.1 Stator and Rotor

Armature winding of alternators is different from that of DC machines. Basically three phase alternators carry three sets of windings arranged in the slots in such a way that there exists a phase difference of 120^{o} between the induced e.m.f.s in them. In a DC machine, winding is brought out. In three phase alternators winding is open to two ends of each of set of winding is brought out. All the coils used for one phase must be connected in such a way that their e.m.f.s help each other. And overall design should be in such a way that the waveform of an induced e.m.f is almost sinusoidal wave form.



(a) (b)

Figure 2.1: Schematic illustration of Synchronous machines of
(a) Round or cylindrical rotor and (b) Salient rotor structures

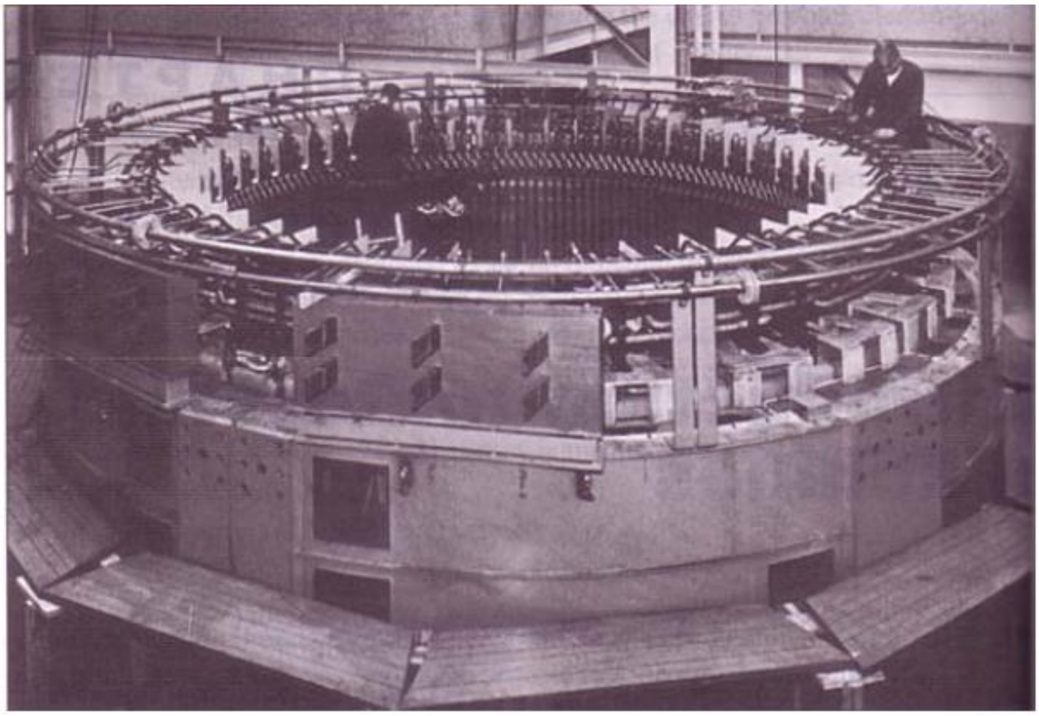


Figure 2.2: Stator of a 190-MVA three phase 12-kV 375 r/min hydroelectric generator. The conductors have hollow passages through which cooling water is circulated (Brown Boveri Corporation)

Figure 2.3: Rotor of a two-pole 3600 r/min turbine generator (Westinghouse Electric Corporation)

Figure 2.4: End view of the stator a 26-kV 908-MVA 3600 r/min turbine generator with water-cooled winding. Hydraulic connections for coolant flow are provided for each winding end turn (General Electric Company)

2.3 Synchronous Machines

There are many models of synchronous machines can be found in many sources such as [6]–[7]. Most of the references make various assumptions, such as steady state and/or balanced sinusoidal voltages/currents, to simplify the analysis. Here, it briefly outline a model that is a (nonlinear) passive dynamic system without any assumptions on the signals, from the perspective of system analysis and controller design. Consider a round rotor machine so that all stator inductances are constant. In this model assumes that there are no damper windings in the rotor, that there is one pair of poles per phase (and one pair of poles on the rotor), and that there are no magnetic saturation effects in the iron core and no eddy currents. As is known, the damper windings help to suppress hunting and also help to bring the machine into synchronism with the grid [7].

The synchronous machines are classified into two types based on type of rotor used in construction. Synchronous machine rotor types:

1. Salient pole rotor: the individual rotor poles protrude from the center of the rotor, characterized by concentrated windings, non-uniform air gap, larger rotor diameters, used in applications requiring low machine speed and a large number of machine poles (example, hydroelectric generation).
2. Cylindrical rotor: the individual rotor poles are produced using a slotted cylindrical rotor, characterized by distributed windings, nearly-uniform air gap, smaller rotor diameters, used in applications requiring high machine speed and a small number of machine poles, typically 2 or 4 poles (example, steam or gas turbine generators).

The cylindrical rotor is typically a solid piece of steel (made from a single forging) for reasons of strength given the high rotational speeds to which the rotor is subjected. The salient pole rotor does not provide the mechanical strength necessary for these high speed applications. Also, the salient pole rotor presents too much wind resistance when rotating at high speeds [5].

2.3.1 Electrical Part

The field and the identical stator windings are distributed in slots around the periphery of the uniform air gap. The stator windings can be regarded as concentrated coils having self-inductance L and mutual inductance $-M$ ($M > 0$ with a typical value $\frac{1}{2}L$, the negative sign is due to the $2\frac{\pi}{3}$ phase angle), as shown in Figure 2.5. Field (or rotor) winding can be regarded as a concentrated coil having self-inductance L_f. Mutual inductance between the field coil and each of the three stator coils varies with the rotor angle [1].

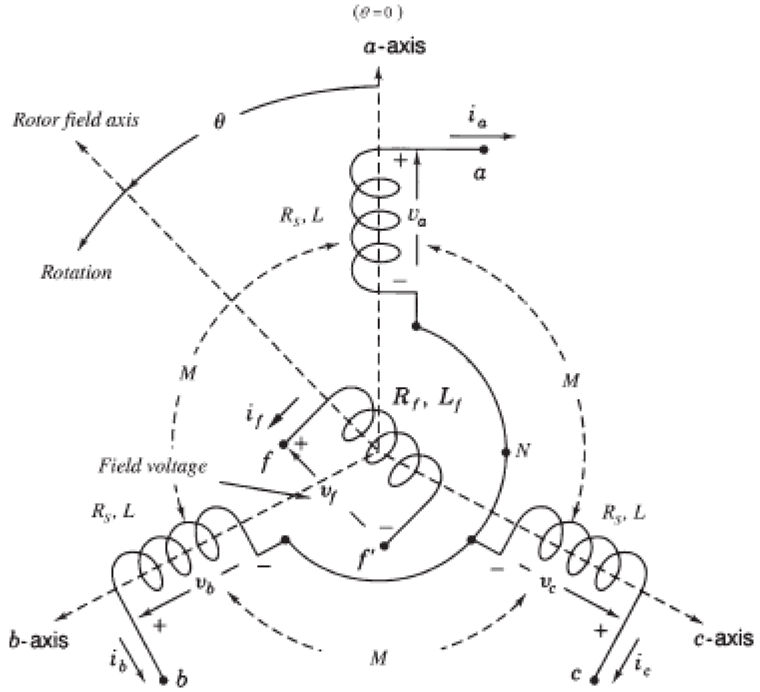


Figure 2.5: Structure of an idealized three-phase round-rotor SG modified

$$M_{af} = M_f \cos(\theta)$$
$$M_{bf} = M_f \cos(\theta - \frac{2\pi}{3})$$
$$M_{cf} = M_f \cos(\theta - \frac{4\pi}{3})$$

where $M_f > 0$. The flux linkages of the windings are

$$\varphi_a = Li_a - Mi_b - Mi_c + Ma_f i_f$$
$$\varphi_b = -Mi_a + Li_b - Mi_c + Mb_f i_f$$
$$\varphi_c = -Mi_a - Mi_b + Li_c + Mc_f i_f$$
$$\varphi_f = Ma_f i_a + Mb_f i_b + Mc_f i_c + L_f i_f$$

where i_a,i_b and i_c are the stator phase currents and i_f is the rotor excitation current. Denote

$$\varphi = \begin{bmatrix} \varphi_a \\ \varphi_b \\ \varphi_c \end{bmatrix} \qquad i = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$A = \begin{bmatrix} cos\theta \\ \cos\left(\theta - \frac{2\pi}{3}\right) \\ \cos(\theta - \frac{4\pi}{3}) \end{bmatrix} \quad B = \begin{bmatrix} sin\theta \\ \sin\left(\theta - \frac{2\pi}{3}\right) \\ \sin(\theta - \frac{4\pi}{3}) \end{bmatrix}$$

Assume for the moment that the neutral line is not connected, then

$$i_a + i_b + i_c = o \qquad (2.1)$$

It follows that the stator flux linkages can be rewritten as [1].

$$\varphi = L_s i + M_f i_f A \qquad (2.2)$$

where $L_s = L + M,$ and the field flux linkage can be rewritten as [1].

$$\varphi_f = L_f i_f + M_f(i, A) \quad (2.3)$$

As it has been noted that the second term $M_f(i, A)$ (called armature reaction) is constant if the three phase currents are sinusoidal (as functions of θ) and balanced. To remind also mention that $\sqrt{3/2}$ (i, A) is called the d-axis component of the current.

Assume that the resistance of the stator windings is R_s; then, the phase terminal voltages $v = [v_a \quad v_b \quad v_c]^T$ can be obtained from (1) as [1].

$$\mathrm{v} = -Rsi - \frac{d\varphi}{dt} = -Rsi - Ls\,\frac{di}{dt} + e \qquad (2.4)$$

where $e = [e_a \quad e_b \quad e_c]^T$ *is* the back electromotive force (EMF) due to the rotor movement given by [1].

$$e = M_f i_f \theta B - M_f \frac{\mathrm{di_f}}{\mathrm{dt}} A \qquad (2.5)$$

The voltage vector e is also called no-load voltage or synchronous internal voltage. From equation (2), the field terminal voltage is [1].

$$v_f = -R_f i_f - \frac{\mathrm{d}\varphi_\mathrm{f}}{\mathrm{dt}} \qquad (2.6)$$

where R_f is the resistance of the rotor winding. However, do not need the expression for v_f because will be use i_f instead of v_f as an adjustable constant input. This completes the modelling of the electrical part of the machine.

2.3.2 Mechanical Part

The mechanical part of a three phase synchronous generator consists mainly of a rotor core. The mechanical part of the generator is used to input mechanical power to the machine and its dynamic behavior affects the machines performance. In this part, the differential equations of the mechanical part of a three phase synchronous [8].

$$J\ddot{\theta} = T_m - T_e - D_p\dot{\theta} \qquad (2.7)$$

where J is the moment of inertia of all the parts rotating with the rotor, T_m is the mechanical torque, T_e is the electromagnetic torque, and D_p is a damping factor. T_e can be found from the energy E stored in the machine magnetic field, i.e [8].

$$E = \frac{1}{2}(i,\varphi) + \frac{1}{2}i_f\varphi_f + \frac{1}{2}\ (i, L_s i + M_f i_f A) + \frac{1}{2}\ i_f(L_f i_f + M_f(i,A))$$

$$E = \frac{1}{2}(i, L_s i) + M_f i_f(i,A) + \frac{1}{2}\ L_f {i^2}_f$$

From simple energy considerations:

$$T_e = \left.\frac{\partial E}{\partial \theta}\right| \varphi, \varphi_f \; constant$$

Because constant flux linkages mean no back EMF, all the power flow is mechanical. It is not difficult to verify using the formula for the derivative of the inverse of matrix function that this is equivalent to [8].

$$Te = -\left.\frac{\partial E}{\partial \theta}\right| i, if \; constant$$

Thus

$$T_e = -M_f i_f (i, \frac{\partial}{\partial \theta} A) = M_f i_f (i, B) \qquad (2.8)$$

To mention that $-\sqrt{3/2}\,(i, B)$ is called the q-axis component of the current. Note that if $i = i_0 \sin \varphi$ or some arbitrary angle φ, then

$$T_e = M_f i_f i_0 (\sin\varphi\,, \mathrm{B}) = \frac{3}{2}\, M_f i_f i_0 \cos(\theta - \varphi)$$

Note also that if if is constant (as is usually the case), then (2.8) with (2.5) yields

$$T_e \dot{\theta} = (i, e)$$

2.3.3 Per Phase Equivalent Electrical Circuit Model

Figure 2.6 shows schematically the cross section of a three phase, two pole cylindrical rotor synchronous machine. Coils (*aa'*, *bb'*, and *cc'*) represent the distributed stator windings producing sinusoidal *mmf* and flux density waves rotating in the air gap. The reference directions for the currents are shown by dots and crosses. The field winding (*ff'*) on the rotor also represents a distributed winding which produces sinusoidal *mmf* and flux density waves centered on its magnetic axis and rotating with the rotor [5]. The electrical circuit equations for the three phase stator winding can be written by the Kirchhoff's voltage law as:

$$v_a = R_a\, i_a + \frac{d\lambda_a}{dt}$$

$$v_b = R_b i_b + \frac{d\lambda_b}{dt}$$

$$v_c = R_c i_c + \frac{d\lambda_c}{dt}$$

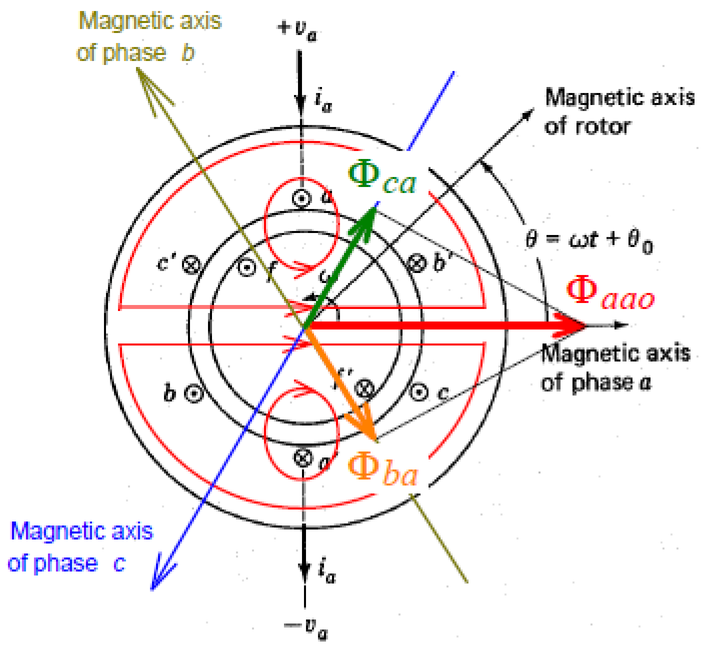


Figure 2.6: Schematic diagram of a three phase cylindrical rotor synchronous machine

Where v_a, v_b and v_c are the voltages across the windings, R_a, R_b, and R_c are the winding resistances , and λ_a, λ_b, and λ_c are the total flux linkages of the windings of phases a, b, and c, respectively. For a symmetric three phase stator winding, it has

$$R_a = R_b = R_c$$

The flux linkages of phase windings a, b, and c can be expressed in terms of the self and mutual inductances as the following [5].

$$\lambda_a = \lambda_{aa} + \lambda_{ab} + \lambda_{ac} + \lambda_{af} = L_{aa}i_a + L_{ab}i_b + L_{ac}i_c + L_{af}i_f \qquad (2.9)$$

$$\lambda_b = \lambda_{ba} + \lambda_{bb} + \lambda_{bc} + \lambda_{bf} = L_{ba}i_a + L_{bb}i_b + L_{bc}i_c + L_{bf}i_f \qquad (2.10)$$

$$\lambda_c = \lambda_{ca} + \lambda_{cb} + \lambda_{cc} + \lambda_{cf} = L_{ca}i_a + L_{cb}i_b + L_{cc}i_c + L_{cf}i_f \qquad (2.11)$$

where

$$L_{aa} = L_{bb} = L_{cc} = L_{aao} + L_{al}$$

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = -\frac{L_{aao}}{2}$$

$$L_{af} = L_{afm}\, cos\theta \qquad (2.12)$$

$$L_{bf} = L_{afm} \cos(\theta - 120°) \qquad (2.13)$$

$$L_{cf} = L_{afm} \cos(\theta - 240°)(2.14)$$

For a balanced three phase machine, $\mathrm{Li}_{aao} = \varphi_{aao}/\mathrm{i}_a$, $L_{al} = \varphi_{al}/\mathrm{i}_a$, φ_{aao} is the flux that links all three phase windings, φ_{al} the flux that links only phase a winding and $\theta = wt + \theta_0$. When the stator windings are excited by balanced three phase currents, it has

$$i_a + i_b + i_c = 0 \quad (2.15)$$

The total flux linkage of phase a winding can be further written as [5].

$$\lambda a = (L_{aao} + l_{al})i_a - L_{aao}\frac{i_b}{2} - L_{aao}\frac{i_c}{2} + L_{afm}i_f cos(\omega t + \theta_o)$$

$$= (L_{aao} + l_{al})i_a - \frac{L_{aao}(i_b + i_c)}{2} + L_{afm}i_f cos(\omega t + \theta_o)$$

$$= (L_{aao} + l_{al})i_a + \frac{L_{aao}}{2} + L_{afm}i_f cos(\omega t + \theta_o)$$

$$= \left(\frac{3L_{aao}}{2} + l_{al}\right) i_a + L_{afm}i_f cos(\omega t + \theta_o)$$

$$= L_s i_a + L_{afm}i_f\; cos(\,\omega t + \theta_o) \qquad (2.16)$$

Similarly, can be write

$$\lambda_b = L_s i_b + L_{afm}i_f\; cos(\omega t + \theta_o - 120°) \qquad (2.17)$$

$$\lambda_c = L_s i_c + L_{afm}i_f cos(\,\omega t + \theta_o - 240°) \qquad (2.18)$$

where $L_s = \frac{3L_{aao}}{2} + L_{al}$ is known as the synchronous inductance.

In this way, the three phase windings are mathematically de-coupled, and hence for a balanced three phase synchronous machine, in this case just need to solve the circuit equation of one phase. Substituting the above expression of flux linkage into the circuit equation of phase a, thus find that

$$V_a = R_a i_a + \frac{L_s di_a}{dt} + \frac{d\lambda_{af}}{dt} \qquad (2.19)$$

In steady state, the above equation can be expressed in terms of voltage and current phasors as

$$V_a = E_a + (R_a + j\omega L_s)I_a = E_a + (R_a + jX_s)I_a \quad (2.20)$$

where $X_s = \omega L_s$ is known as the synchronous rectance , and

$$E_a = j\frac{\omega L_{afm} I_f}{\sqrt{2}} = j\frac{2\pi}{\sqrt{2}} f k_w N_{ph} \varphi_f = j4.44 f k_w N_{ph} \varphi_f \qquad (2.21)$$

Is the induced *emf* phasor, noting that $L_{afm} I_f = \lambda_{afm} = k_w N_{ph} \varphi_f$, I_f is the DC current in the rotor winding and φ_f the rotor magnetic flux in the air gap. It should be noticed that the above circuit equation was derived under the assumption that the phase current flows into the positive terminal, i.e. the reference direction of the phase current was chosen assuming the machine is a motor. In the case of a generator, where the phase current is assumed to flow out of the positive terminal, the circuit equation becomes

$$V_a = E_a - (R_a + jX_s)I_a \qquad (2.22)$$

The following circuit diagrams shows the per phase equivalent circuits of a round rotor synchronous machine in the motor and generator mode respectively.

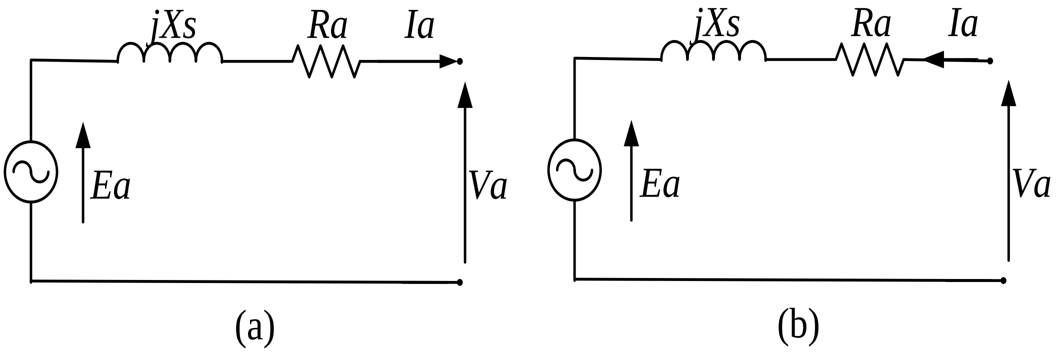


Figure 2.7: Synchronous machine per phase equivalent circuits in (a) generator, and (b) motor reference directions.

2.4 Inverter

Power inverter, or inverter, is an electrical power converter that changes direct current (DC) to alternating current (AC). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. The inverter performs the opposite function of a rectifier. The electrical inverter is a high power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus was "inverted", to convert DC to AC.

2.4.1 Three Phase Inverter

The DC to AC converters more often known as inverters, depending on the kind of the source of feeding and the related topology of the power circuit, are classified as voltage source inverters (VSI) and current source inverters (CSI). The following Figure 2.8 shows the types of inverter.

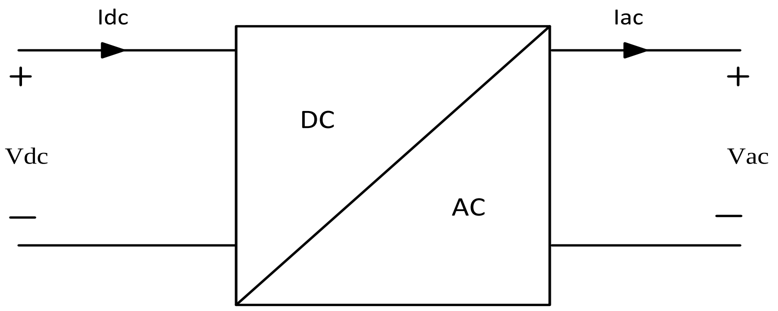


Figure 2.8 :(a) General block diagram

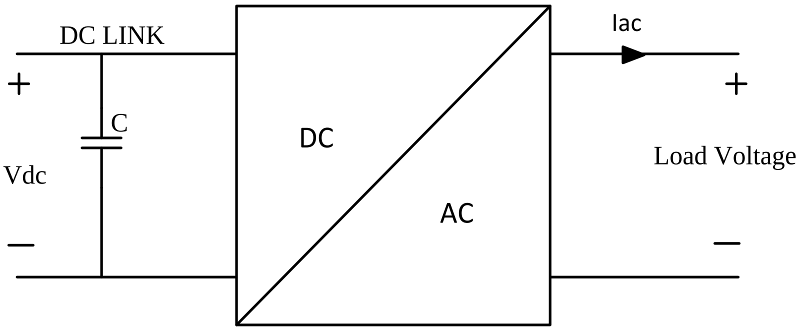


Figure 2.8 :(b) Voltage Source Inverter (VSI)

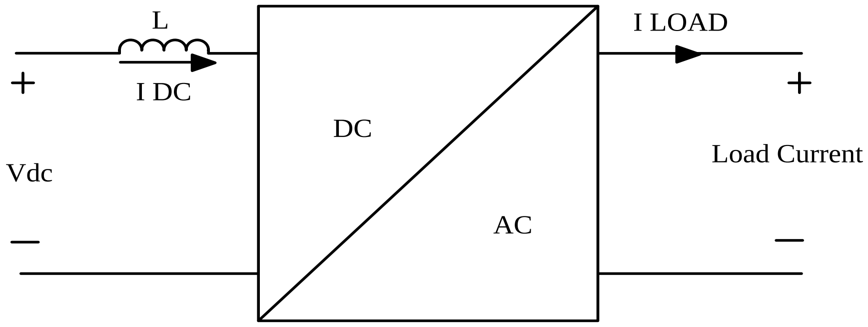


Figure 2.8 :(c) Current Source Inverter (CSI)

Figure 2.8: Types of the inverter

Three phase counterparts of the single phase half and full bridge voltage source inverters are shown in Figures 2.9 and 2.10. Single phase (VSI) cover low range power applications and three phase (VSI) cover medium to high power applications. The main purpose of these topologies is to provide a three phase voltage source, where the amplitude, phase and frequency of the voltages can be controlled. The three phase DC-AC voltage source inverters are extensively being used in motor drives, active filters and unified power flow controllers in power systems and uninterrupted power supplies to generate controllable frequency and AC voltage magnitudes using various pulse width modulation (PWM) strategies. The standard three phase inverter shown in Figure 2.10 has six switches the switching of which depends on the modulation scheme. The input DC is usually obtained from a single phase or three phase utility power supply through a diode bridge rectifier and LC or C filter [2]. There are many applications required DC-AC conversion especially in industrial. In example, motor control and renewable energy where the DC source will be inverted to AC output to suit the motor rating. The speed of the AC motor can be controlled by controlling the output voltage frequency and amplitude.

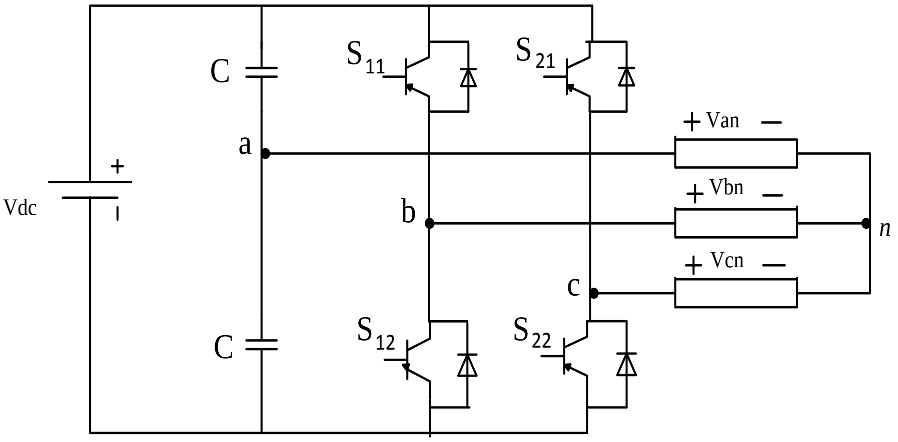


Figure 2.9: Three phase half bridge inverter

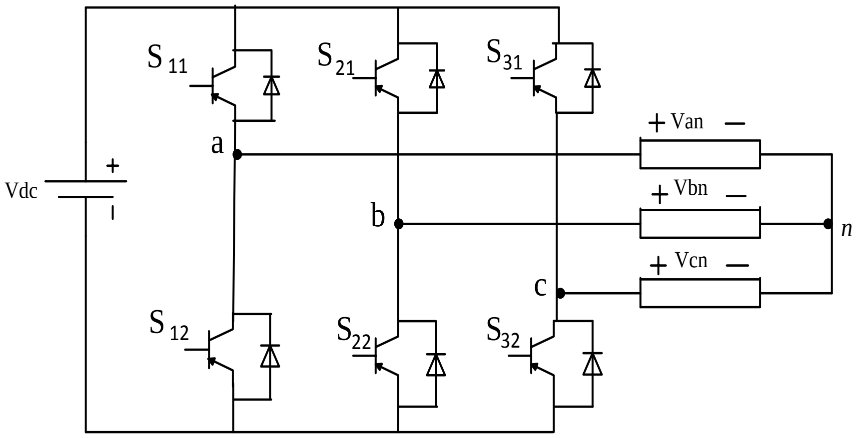


Figure 2.10: Three phase full bridge inverter

The load is fed form a voltage source inverter with current control. The control is performed by regulating the flow of current to load. Current controllers are used to generate gate signals for the inverter. Proper selection of the inverter devices and selection of the control technique will guarantee the efficacy of the drive. Voltage source inverters (VSI) are devices that convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well-defined switched voltage wave form in the terminals [15]. Figure 2.8(b) shows a voltage source inverter. The AC voltage frequency can be variable or constant depending on the application.

Three phase inverters consist of six power switches connected as shown in Figure 2.11 to a DC voltage source [21]. The inverter switches must be carefully selected based on the requirements of operation, ratings and the application. There are several devices available today and these are thyristors, bipolar junction transistors (BJTs), MOS field effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs) and gate turn off thyristors (GTOs). The devices list with their respective power switching capabilities are shown in Table 2.1 MOSFETs and IGBTs are preferred by industry because of the MOS gating permits high power gain and control advantages.

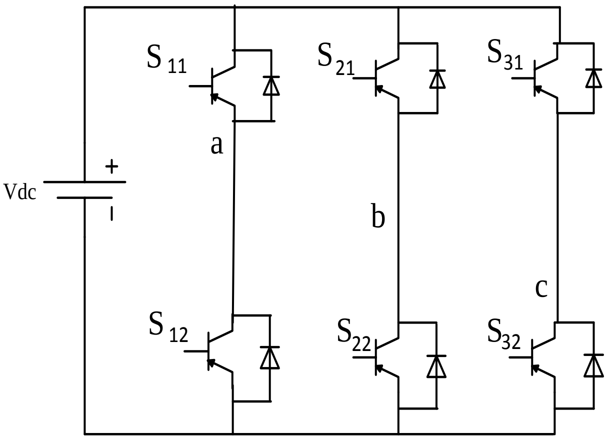


Figure 2.11: Voltage Source Inverter

While MOSFET is considered a universal power device for low power and low voltage applications, IGBT has wide acceptance for motor drives and other application in the low and medium power range. The power devices when used in motor drives applications require an inductive motor current path provided by antiparallel diodes when the switch is turned off [20].

Table 2.1: Devices Power and Switching Capabilities

Device	Power Capability	Switching Speed
BJT	Medium	Medium
GTO	High	Low
IGBT	Medium	Medium
MOSFET	Low	High
THYRISTOR	High	Low

2.4.2 IGBTs

IGBTs provide high input impedance and are used for high voltage applications. The high input impedance allows the device to switch with a small amount of energy and for high voltage applications the device must have large blocking voltage ratings. The device behavior is described by parameters like voltage drop or on resistance, turn on time and turn off time. Figure 2.13 shows the characteristic plot of the device. Inverter with IGBTs is shown in Figure 2.12.

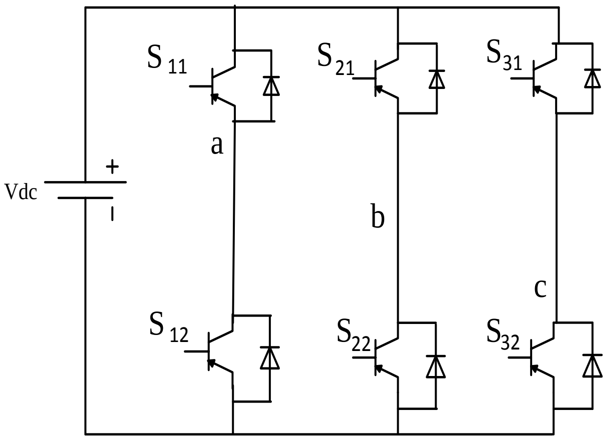


Figure 2.12: Inverter with IGBTs and Antiparallel Diodes

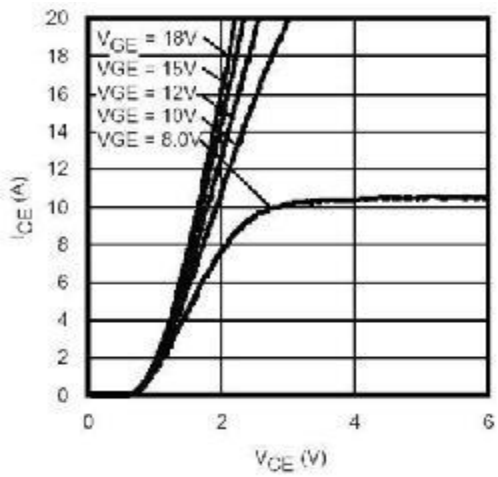


Figure 2.13: Typical IGBT Output Characteristics for IRGIB10B60KD1

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