G. Pulla Reddy Engineering College (Autonomous): Kurnool
Electrical & Electronics Engineering Department
B.Tech EEE –VII Semester (S-17)
Drives & Static Control Lab (DSC (P))

LIST OF EXPERIMENTS

Course Outcomes: At the end of the course students will be able to

CO1: Apply stator side control methods for the speed control of induction motor and verify the results through simulation and experimentation

CO2: Apply slip power control schemes for the speed control of induction motor through experimentation using power converters.

CO3: Apply speed control method for the speed control of DC separately excited motor and verify the results through simulation and experimentation

CO4: Evaluate the performance characteristics of inverter fed induction motor drive

Note: At least 8 of the following experiments shall be conducted

1. Speed control of induction motor using rotor resistance control
2. Speed control of induction using emf injection method (static Kramer's drive)
3. Speed control of induction motor using three phase AC voltage controller
4. dSPACE based scalar control of induction motor using DC link converter
5. Speed control of DC motor using 4-quadrant Chopper
6. Simulation of v/f control of induction motor drive using DC link converter
7. Simulation of three phase rectifier fed separately excited DC motor drive
8. Simulation of step down chopper fed separately excited DC motor drive
9. Simulation of induction motor and DC motor from direct power supply with using any power electronic converter.
10. Simulation of cycloconverter fed induction motor drive.
11. Speed control of separately excited DC motor drive using three phase rectifier
12. Speed control of separately excited DC motor drive using Dc link converter
13. Speed control of separately excited DC motor using Step up chopper
14. Harmonic analysis of output voltage and current of inverter fed induction motor drive
15. Simulation of PWM controlled multilevel inverter fed induction motor drive

Revision No.: 1

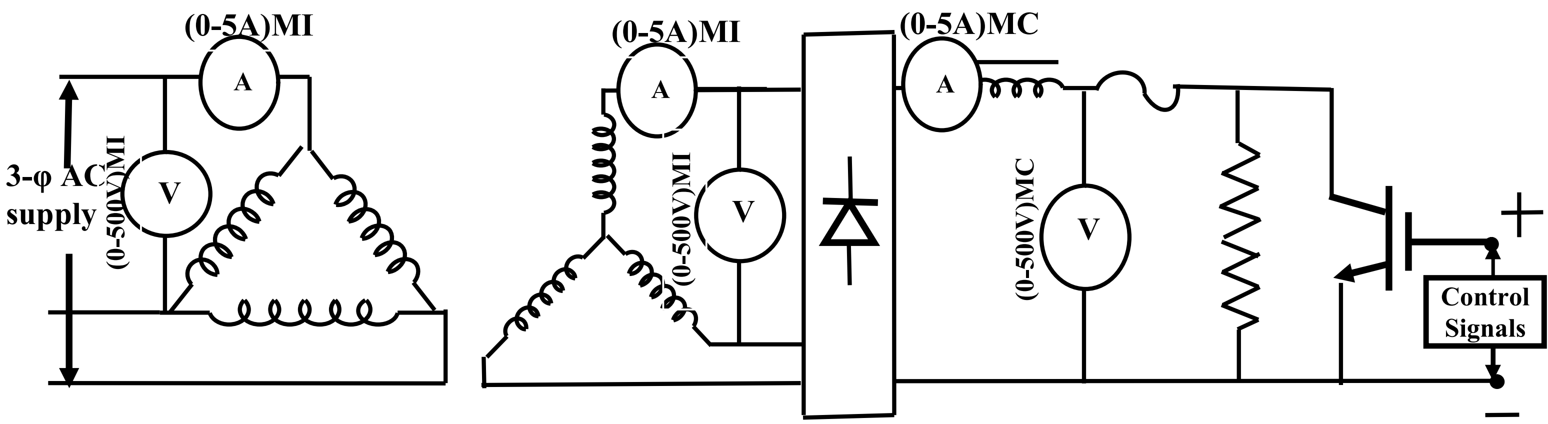
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: **Speed Control of Induction Motor Using Rotor Resistance Control** | **GPREC/EEE/EXPT-DSC (P)-1** | **Date: 01-07-2020**

Objective: To control the speed of the three-phase slip-ring induction motor using rotor resistance control.

Circuit Diagram:



Apparatus:

Name	Type	Numbers Required
3-phase slip-ring induction motor		1
3-phase autotransformer		1
Chopper control unit		1
Patch cards		required
Tachometer	digital	1
Voltmeters	MI	2
Voltmeters	MC	1
Ammeter	MI	2
Ammeter	MC	1
Connecting wires		required

Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Speed Control of Induction Motor Using Rotor Resistance Control	**GPREC/EEE/EXPT-DSC (P)-1** **Date: 01-07-2020**

Theory:

The speed torque relation in induction motor is given by

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2} \qquad (1)$$

Under steady state conditions when operated near to synchronous speed slip is small

$$R'_r / s >> R_s$$

$X_s + X'_r$ can be neglected as slip frequency is small

Substituting these conditions in equation (1) we get

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2}{(R'_r / s)} = \frac{3}{\omega_{ms}} \frac{V^2 s}{(R'_r)}$$

$$\frac{T_e \omega_{ms}}{3V^2} R'_r = s \qquad (2)$$

Form the equation (2) it can be observed that for constant torque the slip is directly proportional to rotor resistance. Hence by varying the rotor resistance speed of the induction motor can be controlled.

Compared to squirrel cage induction motor, the slip ring induction motor has number of disadvantages, such as high cost, weight, volume and inertia and frequent maintenance due to the presence of brushes and slip rings. However, the control of a slip ring induction motor from rotor allows cheaper drives suitable for few applications. Rotor side control methods vary the slip power for the speed control. The portion of air gap power which is not converted in to mechanical power is called slip power. Slip power control methods regulate the amount of slip power. Hence for a given air gap power, the power converted in to mechanical power is altered. Consequently the speed for a given torque is changed.

As discussed power delivered to the rotor across the air gap (P_{ag}) is equal to the sum of mechanical power (P_m) delivered to the load and the rotor copper loss (P_{cu}).

$$P_{ag} = P_m + P_{cu}$$

The air gap flux of the machine is established by the stator supply and it remains practically constant. Now the mechanical power can be varied by

- Rotor resistance control method

- EMF (voltage) injection method

In this experiment rotor resistance speed control method is discussed. In this experiment instead of mechanically varying the rotor resistance, it is statically varied by using principle of chopper. This gives step less and smooth variation in resistance and consequently of motor speed. As shown in the circuit diagram the slip frequency ac rotor voltages are converted in to dc by a three phase diode bridge and applied across the external resistance. The ac output voltage of rotor is specified by a diode bridge and parallel combination of a fixed resistance R and a semi conductor switch realized by a IGBT. Effective value of resistance across terminals is varied by varying duty ratio (δ) of IGBT which in turn varies rotor circuit resistance.

Inductance L_d is added to reduce ripple and discontinuity in the dc link current I_d , rotor rms current is $I_r=\sqrt{2/3}\ I_d$. Resistance between terminals will be zero when transistor is on and it will be R when it is off. Therefore average value of resistance between the terminals is given by (1- δ)R. Power consumed by R_{AB} is $P_{AB}= I_d^2R(1-\delta)$. Power consumed per phase is $P_{AB}/3= 0.5I_r^2R(1-\delta)$. From the above equation the rotor circuit resistance per phase is increased by 0.5R(1- δ). Thus total rotor circuit resistance per phase will now be $R_{rTotal}= R_r+ 0.5R(1-\delta)$. R_{rTotal} can be varied from R_r to $R_r+ 0.5R$ as δ is changed from 1 to 0.

Procedure:

1. Switch ON the mains supply to the control circuit. Observe the driver output signal by varying duty cycle potentiometer and frequency potentiometer. Make sure that the driver output is correct before connecting to the gate and emitter of IGBT.
2. Connect 3-phase variable supply through 3-phase autotransformer to the stator terminals of the slip-ring induction motor.
3. Connect the rotor terminals in the slip-ring motor to the rotor terminals provided in the power circuit.
4. Connect the rotor resistance between DC output points. Connect the positive point of driver output to gate terminal of the IGBT and negative point to the emitter terminal.
5. Keeping ON/OFF switch of the control board in OFF position, switch ON the supply to the control circuit. Keep the duty cycle at minimum position.
6. Now switch ON the 3-phase supply to the motor. Now motor rotates at a speed determined by the external rotor resistance.
7. Note down the dc output voltage and speed.

Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

8. Switch ON the control board. Vary the duty cycle potentiometer and note down the corresponding stator voltage, stator current, rotor current, speed and dc voltage.

Observations:

S.No	Stator Voltage(V)	Stator current(A)	Rotor voltage(V)	Rotor current(A)	Speed (rpm)	DC voltage(V)	DC current(A)	Duty cycle

Result: Speed control of slip ring induction motor using rotor resistance is done.

Remarks in Any:

VIVA QUESTIONS:

1. **What are different speed control methods for an induction motor and which type is used in this experiment.**

Ans.

Stator side control methods
- Stator voltage control
- Stator frequency control
- Stator v/f control

Rotor side control Methods
- **Slip Power recovery schemes**
  - Rotor resistance control
  - EMF injection method

Rotor resistance control method is used in this experiment.

2. **Explain the operation of static rotor resistance control method.**

Ans.

Rotor AC output voltage of rotor is rectified by diode bridge and fed to parallel combination of resistor and IGBT switch. By varying duty cycle (δ) of the switch , effective resistance can be varied. Thus speed can be varied.

3. **What is effective value of resistance across chopper that can be varied by varying duty cycle?**

Ans. It will be zero when switch is ON, R when it is OFF. So effective resistance is $(1-\delta)R$.

4. **What is total rotor resistance per phase after using rotor resistance method?**

Ans. $R_{rTotal} = R_r + 0.5R(1-\delta)$.

5. **What are advantages and disadvantages of rotor resistance control?**

Advantages: High starting torque and hence fast transient response.
Wide range of speed can be controlled.
Low converter cost (converter power rating is low because of its connection to rotor side).

Disadvantages: Much amount of power is wasted in External resistance.

What is the relation between source current (I_r) and output current (I_d)^2.

a) $Ir=\sqrt{2/3}\ I_d$

6. **Write expression for power consumed by resistor across chopper?**

a) $P = I_d^2 R(1-\delta)$

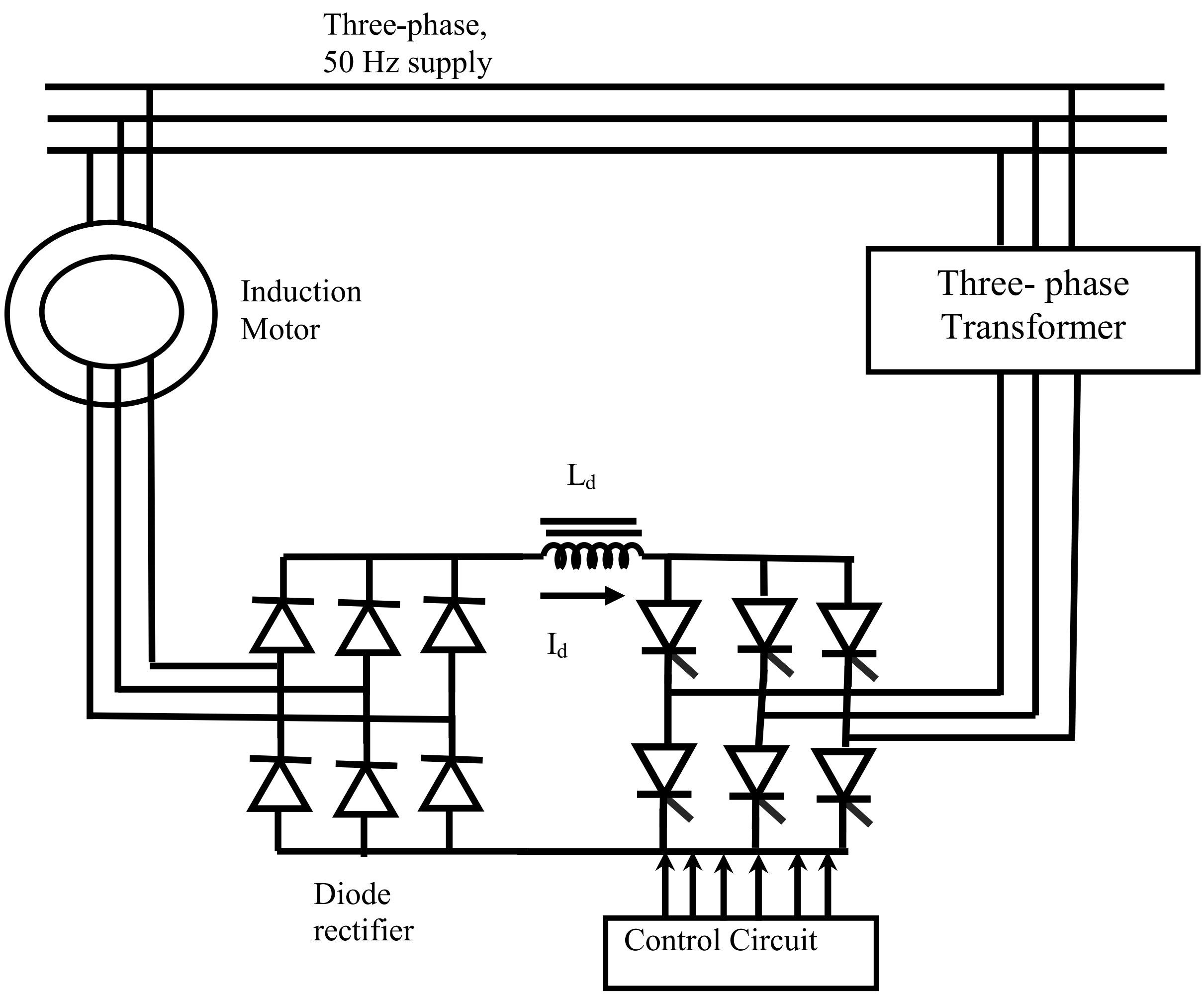
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Speed Control of Induction Motor Using EMF Injection Method (Static Kramer Drive)	GPREC/EEE/EXPT-DSC (P)-2 Date: 01-07-2020

Objective: To control the speed of the three-phase slip ring induction motor using EMF injection method.

Circuit Diagram:



Apparatus:

Name	**Type**	**Numbers Required**
3-phase slip-ring induction motor		1
PEC16HV10B module		1
3-phase autotransformer		1
3-phase isolation transformer		1
Rheostat (150 ohm/5A)		1
Inductor (150 mH)		1
Tachometer	Digital	1
Multimeter	Digital	1
Connecting wires		required
Patch cards		required

Theory:

Compared to squirrel cage induction motor, the slip ring induction motor has number of disadvantages, such as high cost, weight, volume and inertia and frequent maintenance due to the presence of brushes and slip rings. However, the control of a slip ring induction motor from rotor allow cheaper drives suitable for few applications. Rotor side control methods vary the slip power for the speed control. The portion of air gap power which is not converted in to mechanical power is called slip power. Slip power control methods regulate the amount of slip power. Hence for a given air gap power, the power converted in to mechanical power is altered. Consequently the speed for a given torque is changed.

As discussed power delivered to the rotor across the air gap (P_{ag}) is equal to sum of the mechanical power (P_m) delivered to the load and the rotor copper loss (P_{cu}).

$$P_{ag} = P_m + P_{cu} \tag{1}$$

The air gap flux of the machine is established by the stator supply and it remains practically constant. The speed of induction motor can be controlled by varying the amount of mechanical power delivered. This can be achieved by increasing the rotor copper losses. This method of speed control is called rotor resistance control. The main drawback of the rotor resistance control system is large slip power is dissipated in the external resistance connected to the rotor and this reduces the efficiency of the motor at low speeds.

Without connecting any external resistance to rotor, when compared to total air gap power rotor copper losses will be very small. In such situations if rotor copper losses are neglected then equation (1) can be written as

$$P_{ag} = P_m \qquad (2)$$

At this condition mechanical power is equal to air gap power. Now to vary the speed, mechanical power need to be varied. This can be achieved by injecting voltage into the rotor circuit. Such method is called emf injection method. This emf injection or voltage injection can be achieved by Static Kramer system and scherbius system. When a voltage is injected to the rotor circuit the equation (2) can changed as.

$$P_m = P_{ag} - P_r \qquad (3)$$

Where P_r is the power absorbed or dissipated by the voltage source connected to the rotor circuit. The magnitude and sign of P_r can be controlled by controlling magnitude and phase of voltage source connected to the rotor. When P_r is zero motor runs at natural speed. A positive P_r (voltage source connected to rotor act as sink) will reduce P_m and therefore motor will run at reduced speed. Thus by varying P_r from 0 to P_{ag} will allow speed control from synchronous speed to zero speed. When P_r is negative (Voltage source connected to rotor act as source of power) P_m will be larger than P_{ag} and the motor will run at a speed higher than synchronous speed.

In the static Kramer system power P_r can be controlled by controlling the inverter firing angle. The relation between slip and firing angle in Static Kramer system may be derived as

$$s = |-\cos\alpha|$$

Procedure:

1. Connect the 3-phase input supply to the AC input terminals of the module through an isolation transformer or autotransformer.
2. Connect the motor stator terminals to the R, Y, B terminals of the module.
3. Connect the slip-ring induction motor rotor terminals to the u, v, w terminals of the module.
4. Connect the secondary R, Y, B terminals to the transformer secondary terminals.
5. Connect the primary R, Y, B terminals to the transformer primary terminals.
6. Connect the PULSE OUTPUT from the pulse transformer to the PULSE INPUT of the power circuit through the cable.
7. Switch ON the 3-phase ac power supply to the power module.

8. Switch ON the MCB provided on the left side of the module.
9. Check for the waveforms at each test points. Now the motor starts to rotate.
10. Switch ON the MCB provided on the right side of the module.
11. Vary the firing angle of the inverter using the 90^o to 180^o varying pot provided on the front panel of the module.
12. Note down the motor speed values for every firing angle and plot it down on a graph.

Observations:

S.No	Firing angle (degrees)	Speed (rpm)

Result: Speed control of slip ring induction motor using emf injection is done.

Remarks in Any:

VIVA QUESTIONS

1. **What are different speed control methods for an induction motor and which type is used in this experiment.**

Ans.

Stator side control methods

Stator voltage control
Stator frequency control
Stator v/f control

Rotor side control Methods

Slip Power recovery schemes

Rotor resistance control
EMF injection method

EMF injection method is used in this experiment.

2. **Name the methods used for speed control of induction motor using emf injection method?**

Static scherbius drive scheme for above and below synchronous speed
Static Kramer drive scheme for below synchronous speed.

3. **What are advantages and disadvantages of rotor resistance control?**

Advantages: Wide range of speed can be controlled.
Low converter cost (converter power rating is low because of its connection to rotor side).

Disadvantages: Poor power factor.

4. **Write the relation between speed or slip and firing angle in slip power recovery scheme**

Ans. $S=|-\cos\alpha|$ α is varied from 90^0 to 180^0

5. **As compared to squirrel cage induction motor, a wound rotor induction motor is preferred when the major consideration is**

Ans: High starting torque, Low windage losses and slow speed operation.

6. **What is the maximum value of firing angle for safe commutation of thyristors?**

$\approx 165^0$

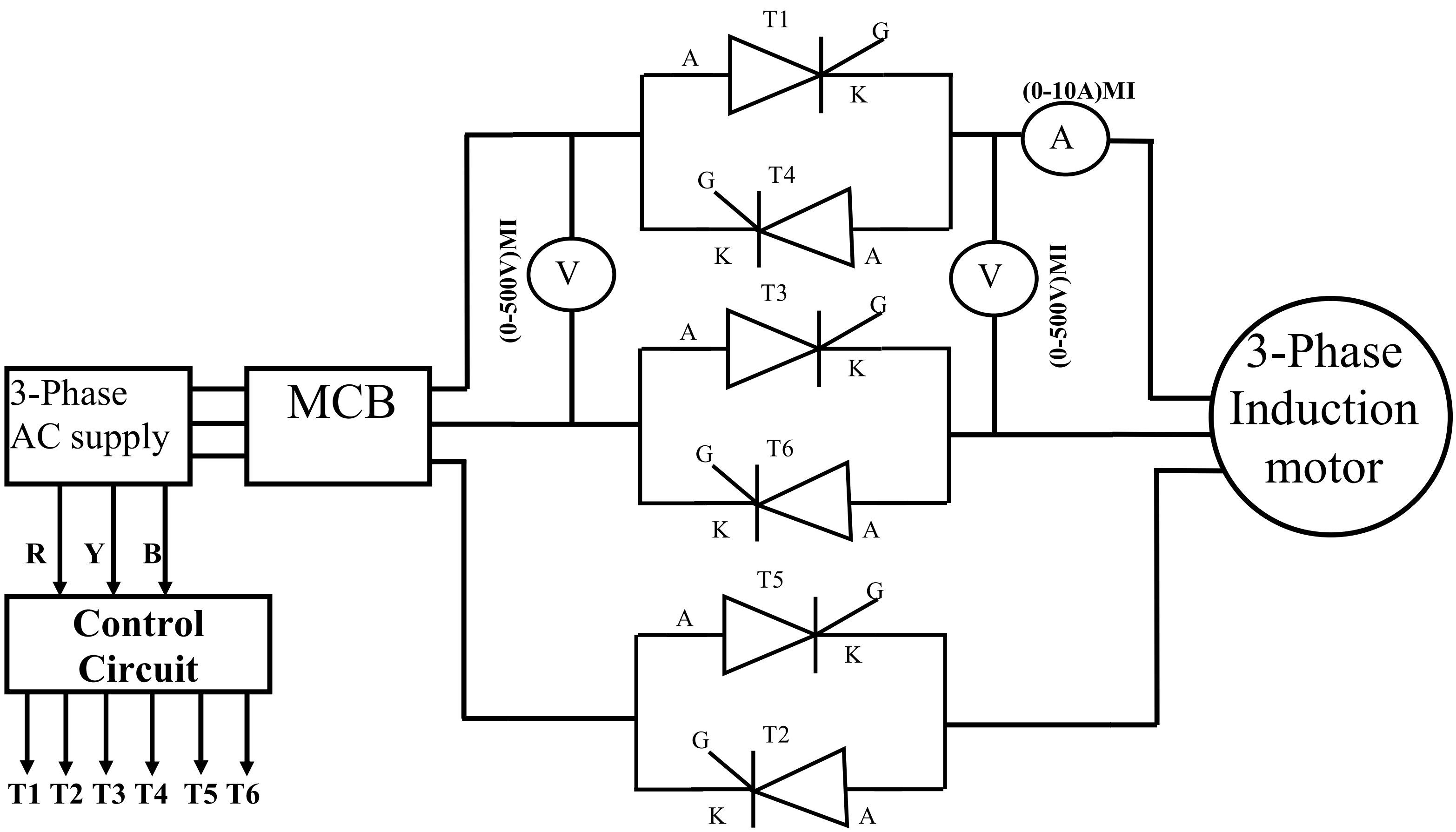
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Speed Control of Induction Motor Using Three-Phase AC Voltage Controllers	GPREC/EEE/EXPT-DSCP-3 Date: 01-07-2020

Objective: To control the speed of a 3-phase induction motor using 3-phase AC voltage controller.

Circuit Diagram:



Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Speed Control of Induction Motor Using Three-Phase AC Voltage Controllers	**GPREC/EEE/EXPT-DSCP-3 Date: 01-07-2020**

Apparatus:

Name	**Type**	**Numbers Required**
3-phase AC voltage controller power circuit		
3-phase AC voltage controller firing circuit		
3-phase autotransformer		
3-phase induction motor		
Multimeter	Digital	1
Voltmeter (0-500) V	MI	2
Ammeter (0-5) A	MI	1
Connecting wires		required

Name Plate Details:

Theory:

The speed-torque relation for an induction motor is given by

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2} \qquad (1)$$

Under steady state conditions when operated near to synchronous speed slip is small

$$R'_r / s >> R_s$$

$X_s + X'_r$ can be neglected as slip frequency is small

Substituting these conditions in equation (1) we get

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2}{(R'_r / s)} = \frac{3}{\omega_{ms}} \frac{V^2 s}{(R'_r)}$$

$$\frac{\omega_{ms} T_e R'_r}{3s} = V^2 \qquad (2)$$

For the equation (2) it can be observed that for constant torque the slip is inversely proportional to stator voltage. Hence by varying the stator voltage speed of the induction motor can be controlled. This stator voltage can be varied by using three phase AC voltage controller.

The three phase AC voltage controller fed induction motor can be connected either in three phase four wire connection or three phase three wire connection. In this experiment three phase three wire connection is considered. The rms value of output voltage can be varied by controlling the firing angle of the thyristors connected in anti parallel in each phase.

From the equation (2) it is also observed that the torque is proportional to the square of its stator voltage. For the same slip and frequency a small change in the stator voltage results in a relatively large change in torque. A 10% reduction in voltage causes 19% reduction in developed torque. With the change in voltage, slip at the maximum torque remains unchanged but the maximum torque at a given slip changes. So this method of speed control is not used for wide range of speed control and constant torque loads. This method of speed control is used for low power applications like fans, blowers and centrifugal pumps requiring low starting torque.

Procedure:

1. Check all the SCRs before making the connections.
2. Connect 3-phase, 440 V ac supply to the R Y B (3-phase terminals) provided in the front panel of firing circuit for phase synchronization. Connect 3-phase neutral point to the green terminal provided in the back panel.
3. Switch ON the 3-phase supply to the firing unit and observe the R Y B test signals with respect to the ground. If the proper neutral point is connected to the back panel we can observe clear R Y B signals with 15 V amplitude.
4. Connect firing pulses from the firing circuit to the respective SCR’s gate and cathode.
5. Connect the 3-phase AC input to the power circuit preferably through 3-phase isolation transformer/ 3-phase autotransformer.
6. Initially set the input AC voltage to 60 V, switch ON the firing circuit. Vary the firing angle potentiometer and observe the voltage waveforms across the load.
7. If the bridge output is coming properly, switch OFF the MCB, connect the induction motor between load points and increase the input voltage to rated voltage.
8. Switch ON the MCB, switch ON the trigger outputs and note down the output voltage, output current and speed for different firing angles.

Title: Speed Control of Induction Motor Using Three-Phase AC Voltage Controllers	GPREC/EEE/EXPT-DSCP-3 Date: 01-07-2020

Observations:

Firing angle (degrees)	Output voltage(V)	Output current(A)	Speed (rpm)

Result: Speed control induction motor using AC voltage controller is done.

Remarks in Any:

VIVA QUESTIONS:

Title: Speed Control of Induction Motor Using Three-Phase AC Voltage Controllers	**GPREC/EEE/EXPT-DSCP-3 Date: 01-07-2020**

1. **What are different speed control methods for an induction motor and which type is used in this experiment.**

Ans. **Stator side control methods**
   - Stator voltage control
   - Stator frequency control
   - Stator v/f control

Rotor side control Methods

Slip Power recovery schemes
   - Rotor resistance control
   - EMF injection method

Stator voltage control method is used in this experiment.

2. **Write the relation between speed and torque in an induction motor.**

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2}$$

Simplifying the above equation

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2}{(R'_r / s)} = \frac{3}{\omega_{ms}} \frac{V^2 s}{(R'_r)}$$

$$\frac{\omega_{ms} TeR'_r}{3s} = V^2$$

3. **Draw the speed torque characteristics of induction motor with variation of stator voltage.**

4. **What are the disadvantages of three phase AC voltage controller for induction motor.**
   - Limited range of speed control
   - Harmonics will be generated.

5. **Application of AC voltage controllers**

Lighting / Illumination control in ac power circuits, Induction heating, Industrial heating & Domestic heating and Speed control of induction motors (single phase and poly phase ac induction motor control).

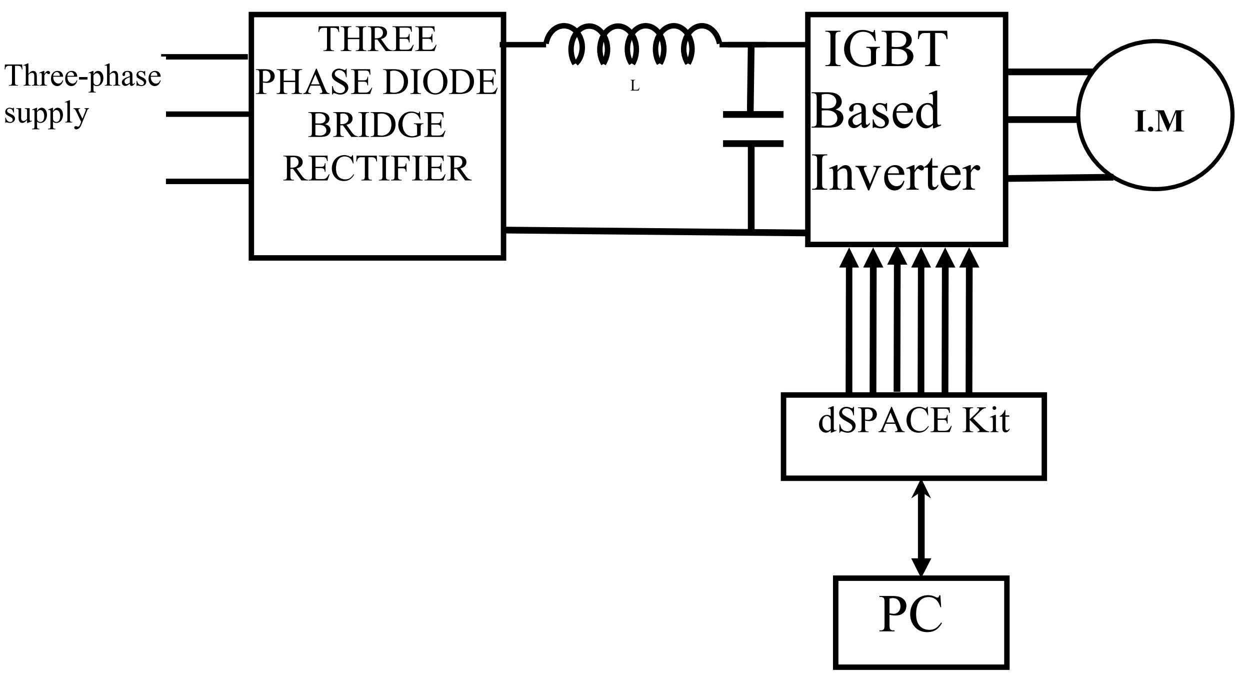
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: dSPACE based Scalar Control Induction Motor using DC Link Converter	**GPREC/EEE/EXPT-DSC(P)-4 Date: 01-07-2020**

Objective: To implement the sinusoidal pulse width modulation algorithm using dSPACE kit for the V/f (scalar) control of DC-link converter fed induction motor drive.

Circuit diagram:



Apparatus:

Name	**Type**	**Numbers Required**
DC-Link converter		1
Induction Motor		1
Patch cards		required
Multimeter		1
Connecting wires		required
dSPACE control board		1
current and voltage sensors		1
DSO		1

Prepared by: **Dr. M. Harsha Vardhan Reddy**, Associate Professor
Approved by: **Dr.T.Bramhananda Reddy**, HEAD, EEE Dept

Title: dSPACE based Scalar Control Induction Motor using DC Link Converter	**GPREC/EEE/EXPT-DSC(P)-4 Date: 01-07-2020**

Theory:

The speed- torque relation in induction motor is given by equation (1)

$$Te = \frac{3}{2\pi f}\frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2} \tag{1}$$

From equation (1) it is observed that speed of squirrel cage induction motor can be controlled by controlling.

(a) Stator voltage (V)
(b) Stator frequency (f)
(c) Stator voltage and frequency control.

In this experiment focus is given on V/f control of induction motor drive. To convert fixed AC power to variable AC power, different converter configurations can be used.

(a)AC voltage controller
(b) Cycloconverter
(c) DC-link converter

AC voltage controller converts fixed AC voltage (power) to variable AC voltage (power) but frequency is maintained constant. So for V/f control AC voltage contoller cannot be used. Cycloconverter converts fixed AC voltage to variable AC voltage and variable frequency. With cycloconverter smooth variation in voltage is possible but smooth variation in frequency is not possible. Hence wide range of speed control with constant air gap flux is not possible. Moreover, as phase control principle is employed in both the converters (AC voltage controller and cycloconverter), for low output voltages the converters draws poor input power factor.

DC-link converter can overcome both these drawbacks. DC-link converter is employed with uncontrolled rectifier at its front end and a PWM inverter at its back end. Uncontrolled rectifier converts fixed AC voltage and frequency to fixed DC voltage. This constant DC voltage is converted to variable AC voltage with variable frequency using PWM inverter. As uncontrolled rectifier is employed, better input power factor is maintained. With PWM inverter smooth variation in voltage and frequency is possible.

The control signals for PWM inverter are generated using dSPACE 1104 control board. The pulse pattern or control signals are designed in MATLAB Simulink. MATLAB software is interfaced with dSPACE control board using PCI slots on mother board of CPU. The MATLAB code is converted in to suitable high level language code of the processor embedded in dSPACE control board. In the MATLAB code itself, we need to assign the appropriate port numbers to the control signals.

Prepared by: **Dr. M. Harsha Vardhan Reddy**, Associate Professor
Approved by: **Dr.T.Bramhananda Reddy**, HEAD, EEE Dept

The sinusoidal pulse width modulated control signals are generated through MATLAB. In this modulation method several pulses for half cycle are present and pulse width of each pulse varies in a sinusoidal fashion. These control signals are generated by comparing three reference signals with common high frequency carrier signals. The intersection point of reference signals with carrier signals defines the switching instants. The output voltage of inverter is controlled varying the amplitude of reference signal and output frequency is controlled by changing the frequency of reference signals. Number of pulses per half cycle can be varied by changing the switching frequency or carrier signal frequency. As number of pulses per half cycle is increased lower order harmonics in the output voltage are reduced.

Procedure:

1. Connect the dspace kit to the personal computer.
2. Connect the 3-φ supply to the power module through 3-φ isolation transformer
3. Connect the 3-φ Induction motor to the UVW terminals of the power module.
4. Open the dspace control desk and open the MATLAB.
5. Write coding or design a Simulink model to generate control signals (Sinusoidal PWM). For simulation file give the approximate configuration parameters (start time =0 sec, stop time=inf, select the real time workshop system target file as rfil and build the program.
6. After the computation of build process, check the pulses in oscilloscope and connect the pulse outputs to the appropriate terminals in the power circuit.
7. Switch on the 3-φ main supply and MCB of power module.
8. Slowly increase the input voltage by using auto transformer to get a DC voltage of about 510V. Now it can be observed that the induction motor starts to rotate.
9. Observe the performance of induction motor drive at various modulation indicies.
10. Observe the line current and line voltage plots in DSO using current and voltage sensors.

Result: Sinusoidal Pulse Width Modulation algorithm is implemented using MATLAB based dSPACE control board for the speed control of induction motor.

REMARKS IF ANY:

Title: dSPACE based Scalar Control Induction Motor using DC Link Converter	**GPREC/EEE/EXPT-DSC(P)-4 Date: 01-07-2020**

VIVA QUESTIONS:

1. **What are different speed control methods for an induction motor and which type is used in this experiment.**

Ans.

Stator side control methods
- Stator voltage control
- Stator frequency control
- Stator v/f control

Rotor side control Methods
- **Slip Power recovery schemes**
  - Rotor resistance control
  - EMF injection method

Stator V/f control method is used in this experiment.

2. **Write the relation between speed and torque in an induction motor.**

$$T_e = \frac{3}{\omega_{ms}} \frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2}$$

3. **Draw the speed torque characteristics of induction motor with variation of V/f control.**

4. **What are different converters that are used for the V/f control?**

Cycloconverter and DC-link converter

Smooth variation in frequency is not possible with cycloconverter (Only step variation in frequency). Hence DC-link converter is used in this experiment for V/f control of induction motor.

5. **Write different operating methods in an inverter.**

180^0 Mode of operation
120^0 Mode of operation
PWM mode of operation

In this experiment PWM control of inverter is used for v/f control of induction motor.

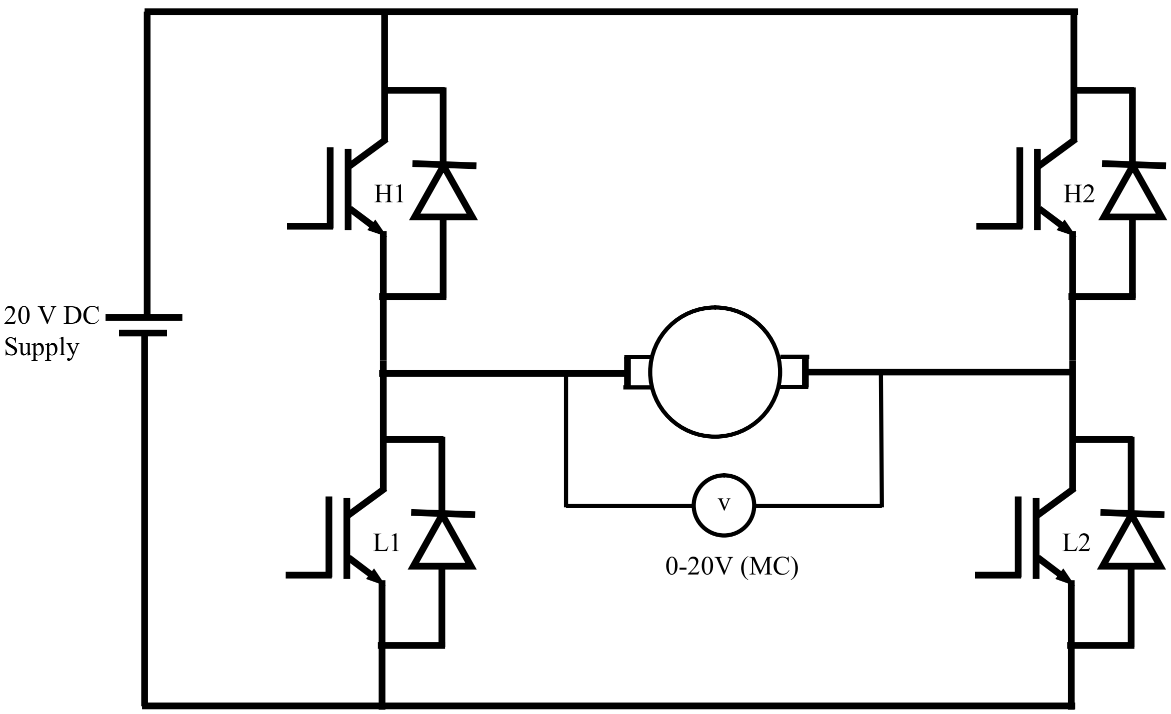
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr.T.Bramhananda Reddy
HEAD, EEE Dept

Title: Speed Control of DC Motor Using 4-Quadrant Chopper	**GPREC/EEE/EXPT-DSC(P)-5 Date: 01-07-2020**

Objective: To control the speed of the DC motor drive using four quadrant chopper.

Circuit Diagram:



Apparatus:

Name	**Type**	**Numbers Required**
Four-Quadrant IGBT module		1
DC Motor		1
Patch cards		required
Tachometer		1
Multimeter		1
Connecting wires		requi

Theory:

Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

The torque speed relation in a DC motor can be written as

$$\omega_m = \frac{V_a}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2} \tag{1}$$

From equation (1) three methods of speed controls are possible by varying

(1) The applied armature voltage (V_a)
(2) The resistance in the armature circuit (R_a)
(3) The flux(ϕ)

In this experiment armature voltage control method is discussed for permanent magnet DC (PMDC) motor. As the considered motor is PMDC motor field flux remains constant ($K_a\phi = K$). Hence equation (1) can be modified as

$$\omega_m = \frac{V_a}{K} - \frac{T_e R_a}{(K)^2} \tag{2}$$

From the equation (2) it is observed that speed of PMDC motor is controlled by varying the armature voltage (V_a). As the available voltage source is DC, choppr can be used for the variation of armature voltage. The chopper used in this experiment is four quadrant chopper. The appropriate control signals are programmed in a micro controller. By varying the duty cycle of the control signals output voltage of the chopper is controlled. The relation between input and output voltage of a chopper is given by (3)

$$V_a = \delta V_{dc}$$

$$where\ \delta = \frac{T_{on}}{T} = duty\ cycle$$

Without changing any mechanical connections the drive operates in both forward and reverse directions with different speeds.

Procedure:

1. Using connecting wires connections are made as per the circuit diagram.
2. Using patch cards connect control signals to gate and emitter terminals of corresponding IGBT's.
3. Switch ON 20 volts DC supply to the power module.
4. Duty cycle is varied step by step from 0% to 100% in forward direction.
5. The corresponding speed of DC motor is measured using tachometer and the voltage is measured using multimeter and tabulated.
6. Repeat Step 3 and 4 in reverse direction.

Title: Speed Control of DC Motor Using 4-Quadrant Chopper	GPREC/EEE/EXPT-DSC(P)-5 Date: 01-07-2020

Observations:

Forward Direction:

S.No	Duty cycle (%)	Output voltage (V)	Speed (rpm)
1	10		
2	20		
3	30		
4	40		
5	50		
6	60		
7	70		
8	80		
9	90		
10	100		

Reverse Direction:

S.No	Duty cycle (%)	Output voltage (V)	Speed (rpm)
1	10		
2	20		
3	30		
4	40		
5	50		
6	60		
7	70		
8	80		
9	90		
10	100		

Result: Speed control of PMDC motor in both forward and reverse direction is done using 4-quadrant chopper.

Remarks if any:

VIVA-QUESTIONS:

Title: Speed Control of DC Motor Using 4-Quadrant Chopper	GPREC/EEE/EXPT-DSC(P)-5 Date: 01-07-2020

1. **Define four quadrant operation of a DC motor.**
   A motor operate in two modes namely motoring and braking. In motoring, it converts electrical energy into mechanical energy, which supports its motion. In braking it works as a generator converting mathematical energy into electrical energy and thus, opposes the motion. DC Motor may be operated in motoring and braking modes for both forward and reverse directions.

2. **What are advantages of Electrical Drive**
   Ans: Electric drives have following advantages. 1. It is simple, clean, compact, and reliable. 2. It provides easy and smooth control, flexibility in layout, easy starting and facility for remote control. 3. It is cheaper in terms of installation and maintenance.

3. **When quick speed reversal is a consideration, the motor preferred** is DC Motor why ?
   Ans: Because of decoupled control between armature flux and filed flux DC motor gives fast dynamic response. Hence quick speed reversal.

4. **The selection of electric motor for any application depends on which factors.**
   Ans: Electrical characteristics, Mechanical characteristics, size and rating of motors and Cost.
5. **What is an electric drive and what are its basic parts.**
   Ans: The system which employed for motion control is called electric drive. Hence basic elements of electric drive are electric motor, power electronic converter and control circuit.

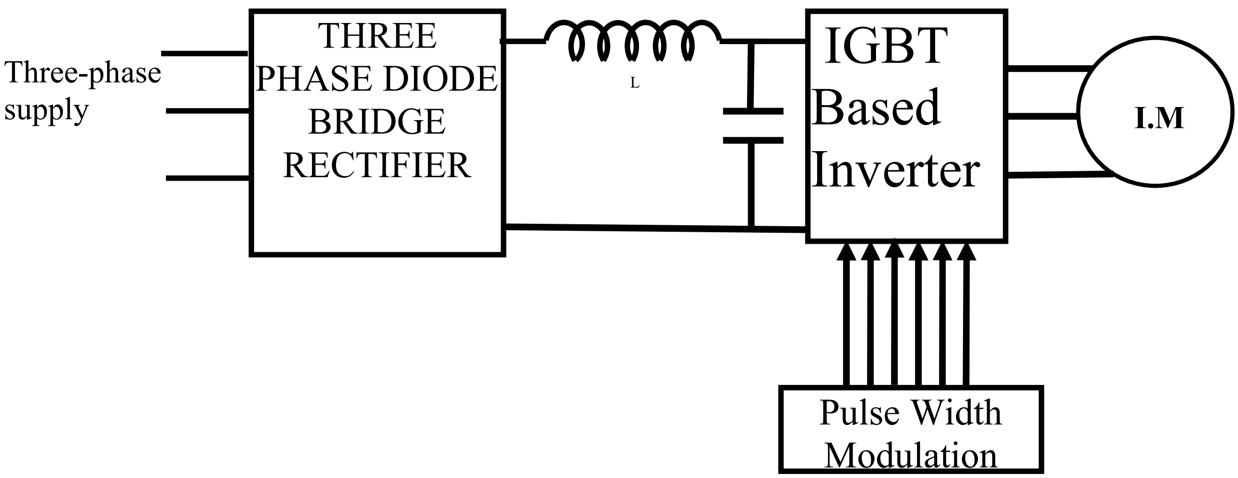
Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Simulation of V/f Controlled DC link Converter fed Induction Motor Drive	**GPREC/EEE/EXPT-DSC (P)-6** **Date: 01-07-2020**

Objective: To simulate V/f controlled DC link converter fed induction motor drive, where the load side converter is controlled using pulse width modulation.

Circuit diagram:



Apparatus:

Name	**Type**	**Numbers Required**
MATLAB Software	2009A	1

Theory:

The speed torque relation in induction motor is given by equation (1)

$$T_e = \frac{3}{2\pi f}\frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2} \tag{1}$$

From equation (1) it is observed that speed of squirrel cage induction motor can be controlled by controlling.

(a) Stator voltage (V)
(b) Stator frequency (f)
(c) Stator voltage and frequency control.

In this experiment focus is given on V/f control of induction motor drive. To convert fixed AC power to variable AC power, different converter configurations can be used.

(a)AC voltage controller
(b) Cycloconverter
(c) DC-link converter

AC voltage controller converts fixed AC voltage (power) to variable AC voltage (power) but frequency is maintained constant. So for V/f control AC voltage contoller cannot be used. Cycloconverter converts fixed AC voltage to variable AC voltage and variable frequency. With cycloconverter smooth variation in voltage is possible but smooth variation in frequency is not possible. Hence wide range of speed control with constant air gap flux is not possible. Moreover, as phase control principle is employed in both the converters (AC voltage controller and cycloconverter), for low output voltages the converters draws poor input power factor.

DC-link converter can overcome both these drawbacks. DC-link converter is employed with uncontrolled rectifier at its front end and a PWM inverter at its back end. Uncontrolled rectifier converts fixed AC voltage and frequency to fixed DC voltage. This constant DC voltage is converted to variable AC voltage with variable frequency using PWM inverter. As uncontrolled rectifier is employed better input power factor is maintained. With PWM inverter smooth variation in voltage and frequency is possible.

The DC link converter and control signals are designed in MATLAB simulink platform. Control signals are generated using sinusoidal pulse width modulation where three sinusoidal reference signals are compared with a common high frequency carrier signal. The intersection point of reference signals with carrier signals defines the switching instants. The output voltage of inverter is controlled by varying the amplitude of reference signal and output frequency is controlled by changing the frequency of reference signals. Number of pulses per half cycle can be varied by changing the switching frequency or carrier signal frequency. As number of pulses per half cycle are increased lower order harmonics in the output voltage are reduced.

Title: Simulation of V/f Controlled DC link Converter fed Induction Motor Drive	GPREC/EEE/EXPT-DSC (P)-6 Date: 01-07-2020

Procedure:

1. Open the Model file from the MATLAB main window.
2. From the simulink library browser drag and place the required components on to the model window.
3. The required blocks needed for the experiment are available in the simpower systems and sumulink tool boxes.
4. Connect all the components to form the required circuit.
5. Set the model parameters and configuration parameters.
6. Save and execute the model file.
7. Observe the results.

Result: V/f controlled DC link converter fed induction motor drive is simulated and different performance parameters of inverter and motor are plotted.

REMARKS IF ANY:

Title: Simulation of V/f Controlled DC link Converter fed Induction Motor Drive	GPREC/EEE/EXPT-DSC (P)-6 Date: 01-07-2020

VIVA QUESTIONS:

1. **What are different speed control methods for an induction motor and which type is used in this experiment.**

Ans.

Stator side control methods

Stator voltage control

Stator frequency control

Stator v/f control

Rotor side control Methods

Slip Power recovery schemes

Rotor resistance control

EMF injection method

Stator V/f control method is used in this experiment.

2. **Write the relation between speed and torque in an induction motor.**

$$Te = \frac{3}{\omega_{ms}} \frac{V^2 R'_r / s}{(R_s + R'_r / s)^2 + (X_s + X'_r)^2}$$

3. **Draw the speed torque characteristics of induction motor with variation of V/f control.**

4. **What are different converters that are used for the v/f control?**

Cycloconverter and DC-link converter

Smooth variation in frequency is not possible with cycloconverter (Only step variation in frequency). Hence DC-link converter is used in this experiment for v/f control of induction motor.

5. **Write different operating methods in an inverter.**

180^0 Mode of operation

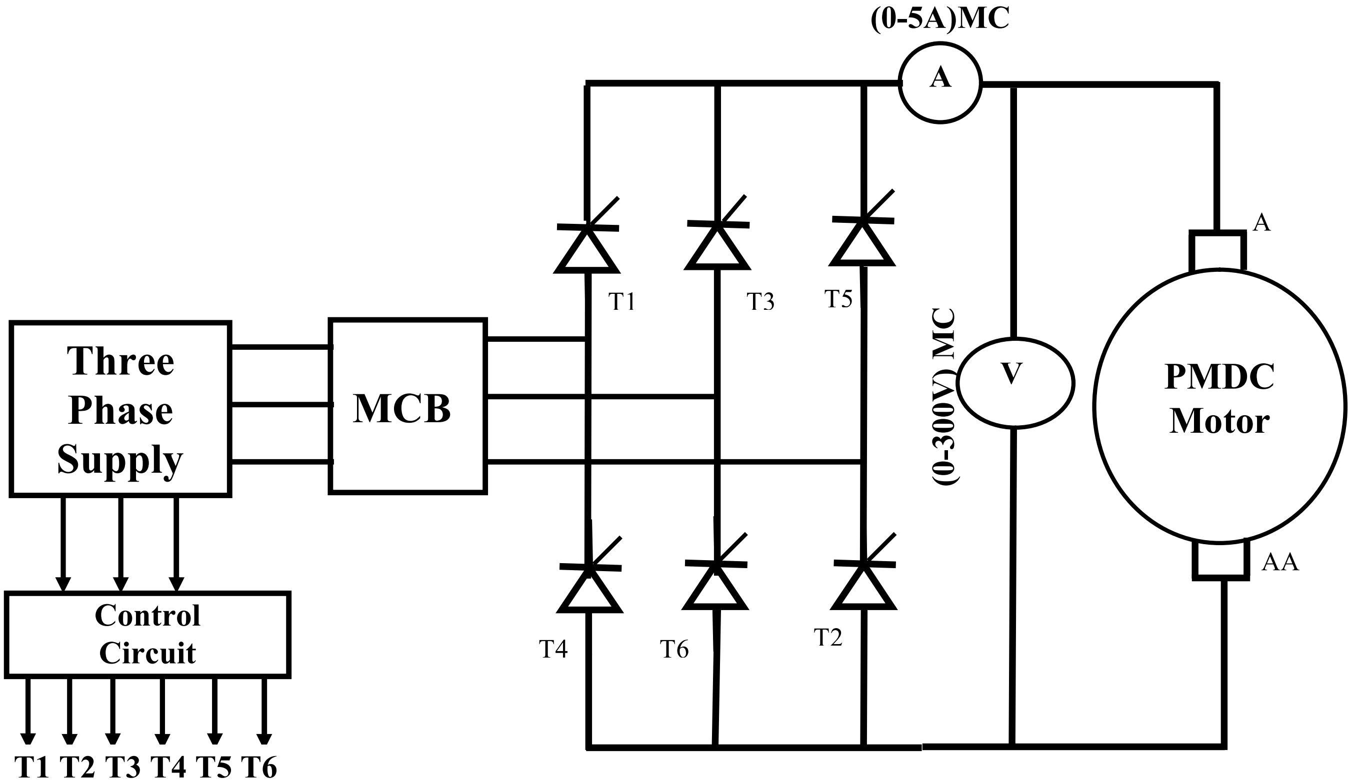
120^0 Mode of operation

PWM mode of operation

In this experiment PWM control of inverter is used for v/f control of induction motor.

Title: Speed Control of Permanent Magnet DC Motor Using Three Phase Rectifier	**GPREC/EEE/EXPT-DSC(P)-11 Date: 01-07-2020**

Objective: To control the speed of the permanent magnet DC motor drive using 3-phase fully controlled bridge rectifier.



Apparatus:

Name	**Type**	**Numbers Required**
PMDC Motor		1
3-phase isolation transformer		1
IGBT based PWM module		1
Firing circuit		1
Patch cards		required
Tachometer		1
Multimeter		1
Connecting wires		required

Title: Speed Control of Permanent Magnet DC Motor Using Three Phase Rectifier	**GPREC/EEE/EXPT-DSC(P)-11 Date: 01-07-2020**

Theory:

The torque speed relation in a DC motor can be written as

$$\omega_m = \frac{V_a}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2} \quad (1)$$

From equation (1) three methods of speed controls are possible by varying

- The applied armature voltage (V_a)
- The resistance in the armature circuit (R_a)
- The flux(ϕ)

In this experiment armature voltage control method is employed for the speed control of permanent magnet DC (PMDC) motor. As the considered motor is PMDC motor field flux remains constant ($K_a\phi = K$). Hence equation (1) can be modified as

$$\omega_m = \frac{V_a}{K} - \frac{T_e R_a}{(K)^2} \quad (2)$$

For the equation (2) it is observed that speed of PMDC motor can be controlled by varying the armature voltage (V_a). This armature voltage can be varied by using a single phase or three phase controlled rectifier by connecting it between load (PMDC motor) and supply. The controlled rectifier converts fixed AC voltage to variable DC voltage. By varying the firing angle of the converter, variable DC voltage is obtained. Because of advantages like high DC output voltage, high ripple frequency three phase rectifiers are preferred over single phase rectifiers. Semi converter and full converter are the mostly preferred and commonly used converters for all practical applications. In this experiment full converter fed PMDC motor is considered. Assuming continuous conduction mode of operation the relation between output voltage (armature voltage) and firing angle is by (3).

$$Va = \frac{3V_{ml}}{\pi}\cos\alpha \quad (3)$$

V_{ml} = Peak value of the input line voltage.

α= Firing angle.

From equation (3) it is observed that by varying the firing angle between 0^0 to 180^0 armature voltage is controlled. Hence the speed of PMDC motor is also controlled.

The three phase full converter is a two quadrant converter. Using this we can operate the PMDC motor in first (forward motoring) and fourth (reverse braking) quadrant operation. If sufficient and large inductance is connected in series with the load or any sufficient mechanical energy is provided the PMDC motor operates in first quadrant from 0^0 to 90^0 and fourth quadrant from 90^0 to 180^0.

With discontinuous mode of operation in 0^0 to 90^0 the PMDC motor operates in motoring mode of operation.

Procedure:

1. Check all the SCRs for performance before making the connections.
2. Connect 3-phase, 400 V ac supply to the R Y B (3-phase terminals) provided in the front panel of firing circuit for phase synchronization. Connect 3-phase neutral point to the green terminal provided in the back panel.
3. Switch ON the 3-phase supply to the firing unit and observe the R Y B test signals with respect to the ground. If the proper neutral point is connected to the back panel we can observe clear R Y B signals with 15 V amplitude.
4. Connect firing pulses from the firing circuit to the respective SCR's gate and cathode.
5. Connect the 3-phase AC input to the power circuit preferably through 3-phase isolation transformer (connect the primary in delta and secondary in star)
6. Initially set the input AC voltage to 60 V, switch ON the firing circuit. Vary the firing angle potentiometer and observe the voltage waveforms across the load.
7. If the bridge output is coming properly, switch OFF the MCB, connect the separately excited DC motor between load points and increase the input voltage to rated voltage.
8. Switch ON the MCB, switch ON the trigger outputs and note down the output voltage, output current and speed for different firing angles.

Observations:

S.No	Firing angle (α)	Output voltage(V)	Output current(A)	Speed (rpm)

Result: Speed control of PMDC motor using three phase rectifier is done.

Remarks in Any:

Prepared by:
Dr. M. Harsha Vardhan Reddy
Associate Professor

Approved by:
Dr. T. Bramhananda Reddy
Head, EEE Department

Title: Speed Control of Permanent Magnet DC Motor Using Three Phase Rectifier	GPREC/EEE/EXPT-DSC(P)-11 Date: 01-07-2020

VIVA-QUESTIONS:

1. **What are different speed control methods for an DC motor which type is used in this experiment.**

Ans. The armature voltage control (V_a)
Filed voltage control or flux (ϕ)

For permanent magnet DC motor (PMDC motor) field flux is constant and hence field voltage cannot be controlled. Hence armature voltage control is used.

Armature voltage control method is used in this experiment.

2. **Give the relation between speed and torque in a three phase full controlled rectifier fed PMDC drive?**

$$\omega_m = \frac{V_a}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2} \quad \text{and} \quad Va = \frac{3V_{ml}}{\pi}\cos\alpha$$

3. **Draw the speed torque characteristics of DC motor with armature voltage control.**

4. **What are the advantages of three phase rectifier fed DC drives over single phase rectifier fed DC drives?**

High power rating of the drive system, size and cost of the filters are reduced, input power factor is improved and efficiency of the drive is improved.

5. **What are different types of braking methods for DC Motor?**

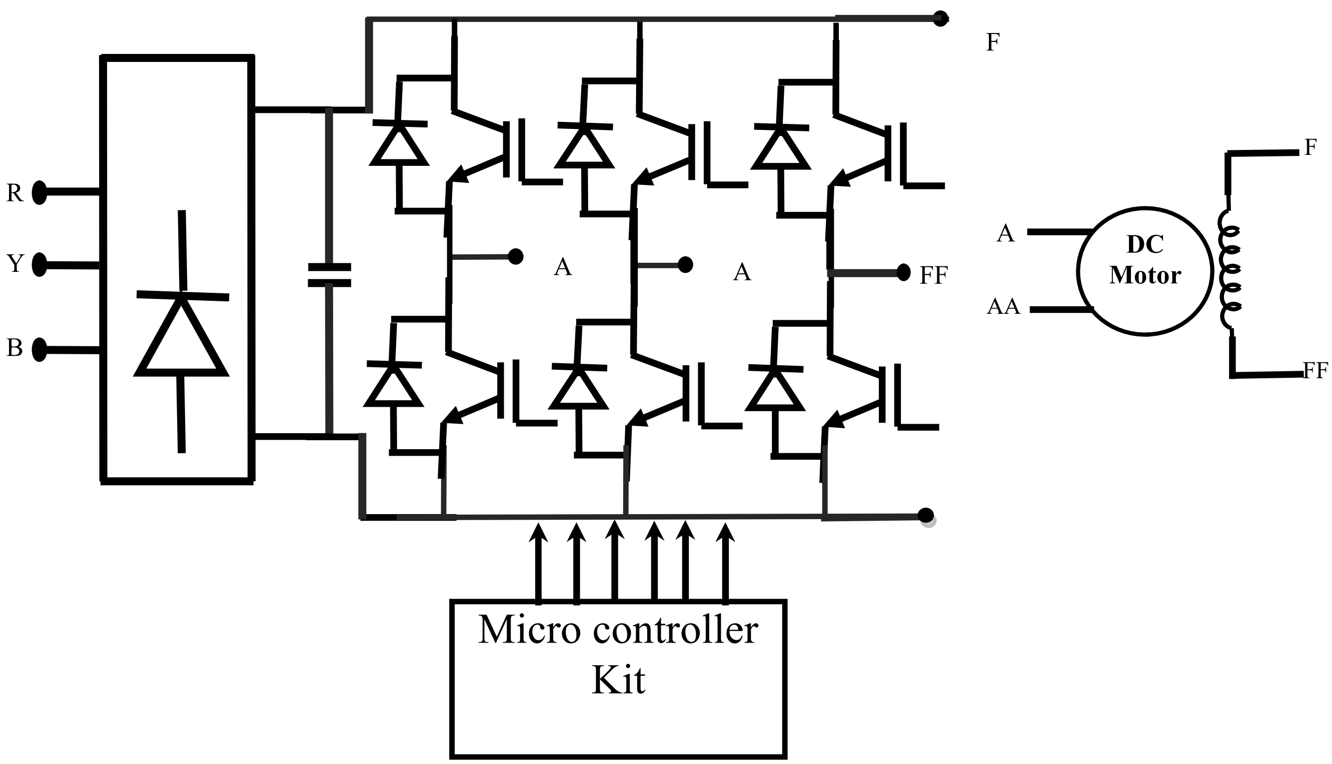
Ans: Regenerative braking, Dynamic braking and Plugging.

Prepared by: Approved by: Revision No.: 1
Dr. M. Harsha Vardhan Reddy **Dr. T. Bramhananda Reddy**
Associate Professor Head, EEE Department

Title: Speed Control of Separately Excited DC Motor Drive Using DC Link Converter	**GPREC/EEE/EXPT-DSC(P)-12 Date: 01-07-2020**

Objective: Micro controller based speed control of DC link converter fed separately excited DC motor

Circuit Diagram:



Apparatus:

Name	**Type**	**Numbers Required**
DC Motor		1
3-phase isolation transformer		1
IGBT based PWM module		1
Firing circuit		1
Patch cards		required
Tachometer		1
Multimeter		1
Connecting wires		required

Title: Speed Control of Separately Excited DC Motor Drive Using DC Link Converter	GPREC/EEE/EXPT-DSC(P)-12 Date: 01-07-2020

Theory:

The torque speed relation in a DC motor can be written as

$$\omega_m = \frac{V_a}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2} \quad (1)$$

From equation (1) three methods of speed controls are possible by varying

- The applied armature voltage (V_a)
- The resistance in the armature circuit (R_a)
- The flux(ϕ)

In this experiment armature voltage control method is discussed for separately excited motor. As the considered motor is separately excited motor field flux can be varied by varying the field voltage. But to show the effectiveness of the drive in this experiment field flux is maintained constant. So the term $K_a\phi$ in equation (1) remains constant. Hence equation (1) can be modified as

$$\omega_m = \frac{V_a}{K} - \frac{T_e R_a}{(K)^2} \quad (2)$$

Form the equation (2) it is observed that speed of separately excited DC motor may be controlled by varying the armature voltage (V_a). As the source of supply is AC, the armature voltage can be varied by using a rectifier or a DC-link converter. With the use of rectifier at low speed (low output voltage) operation, the drive operates at low input power factor. So the distortion factor and displacement factor increases and make the drive less efficient. The input power factor can be improved by using DC-link converter. In this converter at the front end an uncontrolled rectifier is employed, which converts fixed AC voltage to fixed DC voltage. This fixed DC voltage is converted to variable DC voltage by using a chopper. Because of using uncontrolled rectifier at the front end the phase angle between source voltage and source current is small. Hence source power factor can be improved.

The circuit diagram of DC-link converter with uncontrolled rectifier at the front end and chopper at the backend is shown. In the circuit diagram three IGBT legs are shown. Among the three legs, two legs are used as four quadrant chopper for the control of armature voltage. The remaining leg serves as chopper and it is used to control the field voltage. In this experiment only armature control is employed and the field voltage is kept constant. The four quadrant chopper operates the drive in all four quadrants by controlling the armature voltage. Using chopper the armature voltage may be controlled by giving the suitable control signals to four IGBT's. The appropriate control signals are programmed in a micro controller. By varying the duty cycle of the control signals output voltage of the chopper is controlled. The relation between input and output voltage in a chopper is given by (3)

$$V_a = \delta V_{dc}$$

$$where\ \delta = \frac{T_{on}}{T} = duty\ cycle$$

Without changing any mechanical connections the drive operates in both forward and reverse directions with different speeds.

Procedure:

1. Connect the 3-phase supply to the AC input terminals of the module through an isolation transformer.
2. Connect A and AA, F and FF terminals of separately excited DC motor to the output terminals A and AA, F and FF of power module.
3. Switch ON the MCB provided on the left side of the power module.
4. Now switch ON the micro controller based trainee kit.
5. Two push buttons are available on the micro controller board to vary the speed of the DC motor.
6. The corresponding armature voltage, field voltage and speed of the DC motor are measured and tabulated.
7. It is observed that without inter changing any terminals by just using push buttons the motor speed can be controlled both in forward and reverse directions.
8. Tabulate corresponding armature voltage, field voltage and speed of DC motor both in forward and reverse speed operations.

Observations:

S.No	Forward direction			Reverse direction		
	Armature voltage(V)	Field voltage(V)	Speed (rpm)	Armature voltage(V)	Field voltage(V)	Speed (rpm)

Result: Speed control of a separately excited DC motor is done using microcontroller based trainee kit.

Remarks in Any:

VIVA-QUESTIONS:

1. **What are different speed control methods for a separately excited DC motor which type is used in this experiment?**

Ans. The armature voltage control (V_a)
Filed voltage control or flux (ϕ)
Armature voltage control method is used in this experiment

2. **If supply is AC and for speed control of DC motor which type of converters can be used.**

   Ans. Controlled rectifier
   DC- link converter (combination of uncontrolled rectifier and chopper)
   DC-Link converter is used in this experiment for speed control of separately excited DC motor.

3. **What are the different control strategies used in chopper for the control of output voltage**

   Ans: Time ratio control and current limit control
   In this experiment time ratio control method (T_{ON} variation) is used for the control of output voltage

4. **Define duty cycle**

   Ans: The ratio of ON time (T_{ON}) to total time (T) is called Duty cycle.

5. **How can we change the direction of rotation of separately excited dc motor?**

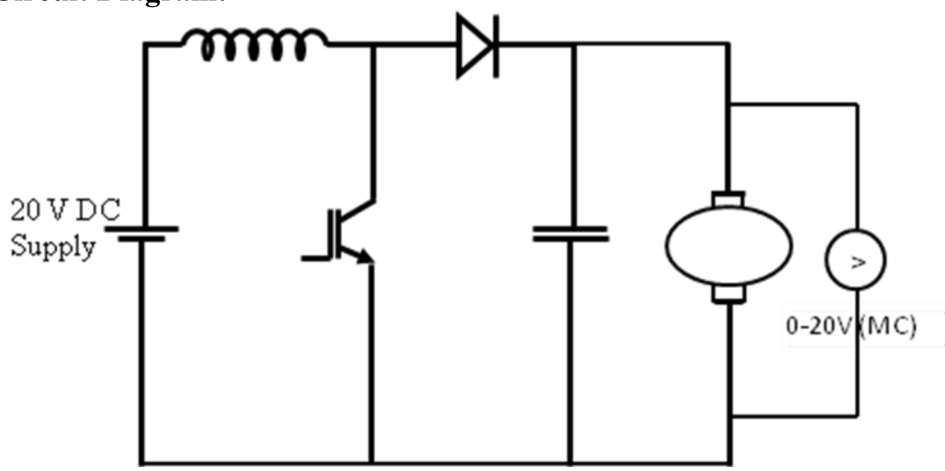
   Ans: The direction can be reversed by inter changing armature terminals or field terminals

This can be achieved by reversing the armature voltage or field voltage. In this experiment armature voltage is reversed to change the direction of rotation using push battens on the microcontroller kit.

Title: Speed Control of Separately Excited DC Motor Using Step Up Chopper	**GPREC/EEE/EXPT-DSC (P)-13 Date: 01-07-202**

Objective: To control the speed of DC Motor using step up Chopper.

Circuit Diagram:



Apparatus:

Name	Type	Numbers Required
DC chopper module		1
DC motor		1
Patch cards		required
Multimeter		1
Connecting wires		required
Power Scope		1

Theory:

The torque- speed relation in a DC motor can be written as

$$\omega_m = \frac{V_a}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2} \qquad (1)$$

From equation (1) three methods of speed controls are possible by varying

- The applied armature voltage (V_a)
- The resistance in the armature circuit (R_a)
- The flux(ϕ)

In this experiment armature voltage control method is employed for the speed control of permanent magnet DC (PMDC) motor. As the considered motor is PMDC field flux remains constant ($K_a\phi = K$). Hence equation (1) can be modified as

Title: Speed Control of Separately Excited DC Motor Using Step Up Chopper	GPREC/EEE/EXPT-DSC (P)-13 Date: 01-07-202

$$\omega_m = \frac{V_a}{K} - \frac{T_e R_a}{(K)^2} \tag{2}$$

From the equation (2) it is observed that speed of PMDC motor can be controlled by varying the armature voltage (V_a). As the available voltage source is DC, step down chopper can be used for the variation DC voltage applied to armature circuit. The appropriate control signal is programmed in a micro controller. By varying the duty cycle of the control signals output voltage of the step up chopper is controlled. The relation between input and output voltage in a step up chopper is given by (3).

$$V_a = \frac{V_{dc}}{1-\delta}$$

$$where\ \delta = \frac{\mathrm{T_{on}}}{T} = duty\ \text{cycle}$$

Hence by changing the duty cycle speed of the DC motor can be controlled.

Procedure:

1. Using connecting wires connections are made as per the circuit diagram.
2. Using patch cards connect control signals to gate and emitter terminals of corresponding IGBT's.
3. Switch ON 20 Volts DC supply to the power module.
4. Duty cycle is varied step by step from 0% to 100%.
5. The corresponding speed of DC motor is measured using tachometer and the voltage is measured using multi meter and tabulated.

Observations:

S.No	Duty cycle (%)	Output voltage (V)	Speed (rpm)
1	10		
2	20		
3	30		
4	40		

Result: Speed control of PMDC motor using step up chopper is done

Remarks in Any:

VIVA QUESTIONS:

1. **Which braking is not possible in series motor?**
   Ans: In case of regenerative braking back emf is greater than the supply voltage. In series motor back emf cannot exceed the supply voltage. So regenerative braking is not possible.

2. **In industries which electrical braking is preferred?**
   Ans: Usually braking means converting kinetic energy to electrical energy and then to heat energy but in case of regenerative braking the kinetic energy converts to electrical energy and then feed back to supply but it is not possible to feed back to supply with the help of power electronic devices so that electrical energy will charge the capacitors there by saving electrical energy. Hence it is an advantage to industries.

3. **What type electric drive is used in cranes?**
   Ans: In multi-motor drive system there are several drives, each of which serves to actuate one of the working parts of the driven mechanism.

Prepared by: Approved by: Revision No.: 1
Dr. M. Harsha Vardhan Reddy **Dr. T. Bramhananda Reddy**
Associate Professor Head, EEE Department