DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab

Course code: EEC507

Location of the Lab: Ground flower, Academic complex (Room no:019 for Exp. 1 to 4 and Room No:26 for Exp. No 5 to 8)

Sl. No.	List of Experiments	Page No.
1.	Study of various system fault using a DC analyzer	2-9
2.	Study of symmetric & asymmetric fault in Transmission line	10-15
3.	Study of Power transfer through a transmission system	16-20
4.	Study of Power transfer through a transmission system	21-26
5.	Experimental study of a Buck-Boost dc-dc converter for R load	27-32
6.	Study the performance of closed-loop Speed Control of Three-Phase Induction motor using Quasi Z-source Inverter	33-38
7.	Study and compare the performance of a Direct Torque Control (DTC) of Induction Motor with Eddy Current Dynamometer with the conventional control technique.	39-43
8.	**Study the Performance of a Three-phase Cascaded H-bridge (CHB) Multilevel Inverter Experimental Setup.**	44-49
9.	**Experimental study of Open- and closed loop Speed Control of a four-phase switched reluctance (SR) Motor drive.**	50-55

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab

Course code: EEC507

Experiment No.: 01

<u>STUDY OF VARIOUS SYSTEM FAULTS USING A DC ANALYZER</u>

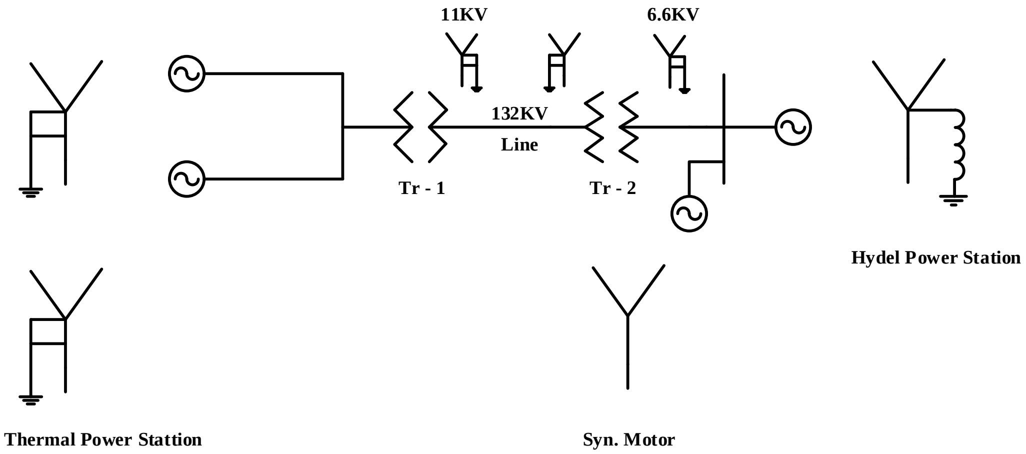
TITLE: Study of various system faults using a DC analyzer.

OBJECTIVE: To simulate the following system in a DC network analyzer and calculate the fault current in different parts of the system for i) 3-phase fault ii) S.L.G fault iii) L.L fault iv) D.L.G fault.

<u>Apparatus List:</u>

SI No.	ITEM	QTY	RANGE / RATING	MAKER'S NAME	MAKER'S NO
1.	Network Analyzer Board	2	0 - 25 - 50 V	-	-
2.	DC Multi-meter (true RMS)	1	i) Used as DC voltmeter 0 - 75 V	-	-

System Diagram:



Turbo alternator: 50MVA, 11KV each
Positive sequence reactance = 5%
Negative sequence reactance = 2.5%
Zero sequence reactance = 2%
Water wheel generator 20MVA, 6.6KV
Positive sequence reactance = 4%
Negative sequence reactance =1%
Neutral reactance = 0.073 ohm
Synchronous Motor: 10MVA, 6.6KV
Positive sequence reactance = 5%
Positive sequence reactance = 2%
Zero sequence reactance = 1%

Step-up Transformer: 11/132KV, 100MVA
Step-down Transformer: 132/11KV, 100MVA
Leakage Reactance = 10%
(for both transformers)
132KV line length = 66Km
Positive sequence reactance = 0.132ohm/KV
Negative sequence reactance = 0.132ohm/KV
Zero sequence reactance = 1%

Procedure:

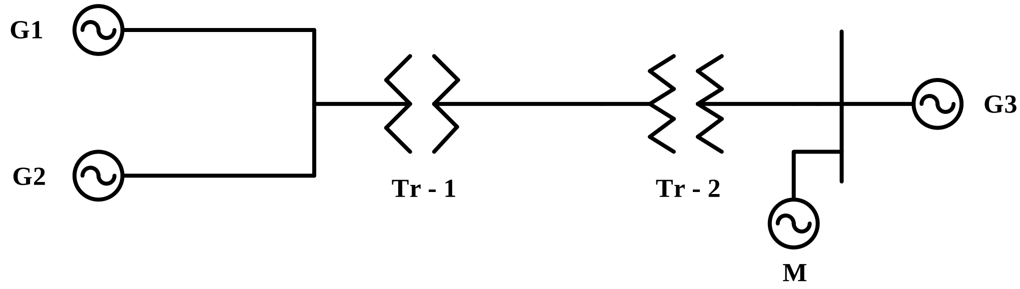
1. Convert all the data to per unit quantities choosing 100MVA base.
2. Draw sequence box connections for above faults, and check it with the help of teacher-in-charge.
3. Simulate the network with proper interconnection on the analyzer, taking a scale factor of

1 p.u volt = 10 volts

1 p.u Ohm = 1 KΩ Determine the scale factor for current.

4. Note the current value in p.u. in all parts of the system.

Single line diagram and their equivalent $Z_{p.u}$



The formulas used in the below calculations are:

$$Z_{p.u} = Z_{actual} * \left(\frac{S_{base}}{V_{base}^2}\right) = Z_{actual} * \frac{MVA}{KV^2}$$

$$Z_{p.u.new} = Z_{p.u.old} * \left(\frac{S_{base\ \ new}}{S_{base\ \ old}}\right) = Z_{p.u.old} * \left(\frac{(MVA)_{new}}{(MVA)_{old}}\right)$$

Base MVA = 100

Turbo Alternators (G1, G2): Base voltage = 11KV

+VE SEQUENCE: $Z_{p.u}$ = 0.05 x (100/50) = 0.1

-VE SEQUENCE: $Z_{p.u}$ = 0.025 x (100/50) = 0.05

ZERO SEQUENCE: $Z_{p.u}$ = 0.02 x (100/50) = 0.04

Transmission Line: Base voltage = 132KV

+VE SEQUENCE: $Z_{p.u}$ = (0.132 x 66) x ($100/132^2$) = 0.05

-VE SEQUENCE: $Z_{p.u}$ = (0.132 x 66) x ($100/132^2$) = 0.05

ZERO SEQUENCE: $Z_{p.u}$ = (0.264 x 66) x ($100/132^2$) = 0.1

Water wheel Generator (G3): Base voltage = 6.6KV

+VE SEQUENCE: $Z_{p.u}$ = 0.04 x (100/20) = 0.2

-VE SEQUENCE: $Z_{p.u}$ = 0.02 x (100/20) = 0.1

ZERO SEQUENCE: $Z_{p.u}$ = 0.01 x (100/20) = 0.05

Neutral grounding: $Z_{p.u}$ = (3 x 0.073) x ($100/6.6^2$) = 0.5

Synchronous Motor (M): Base Voltage = 6.6KV

+VE SEQUENCE: $Z_{p.u}$ = 0.05*(100/10) = 0.5

-VE SEQUENCE: $Z_{p.u}$ = 0.02*(100/10) = 0.2

ZERO SEQUENCE: $Z_{p.u}$ = 0.01*(100/10) = 0.1

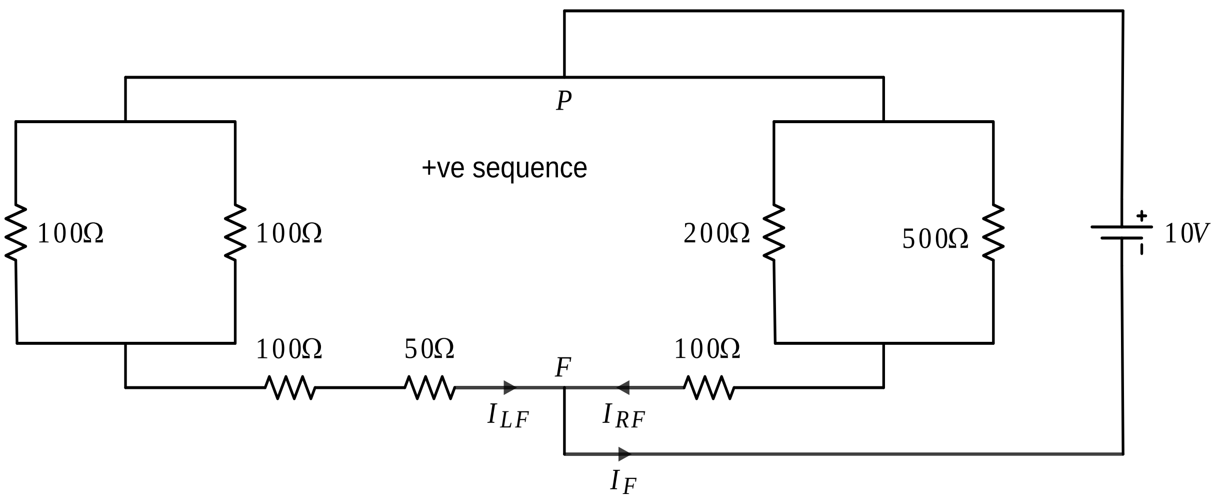
Transformer (T1 & T2):

+VE SEQUENCE, -VE SEQUENCE and ZERO SEQUENCE p.u. reactance: 0.1

1. 3 Phase (3-ø) Fault

$$V_a = V_b = V_c = (I_a + I_b + I_c) Z_f$$

$$I_f = I_a + I_b + I_c = E_a \big/ (Z^1 + Z_f)$$



Observation Table: -

Observation Table 1. 3 Phase (3-ø) Fault

Sl No.	Fault Point	Resistance (Ω)	Voltage (V)	Current (mA)		% Error
				Theoretical	Measured	
1	F_1	50		50.00		
2	F_1	100		41.18		
			Total I_F	**91.18**		

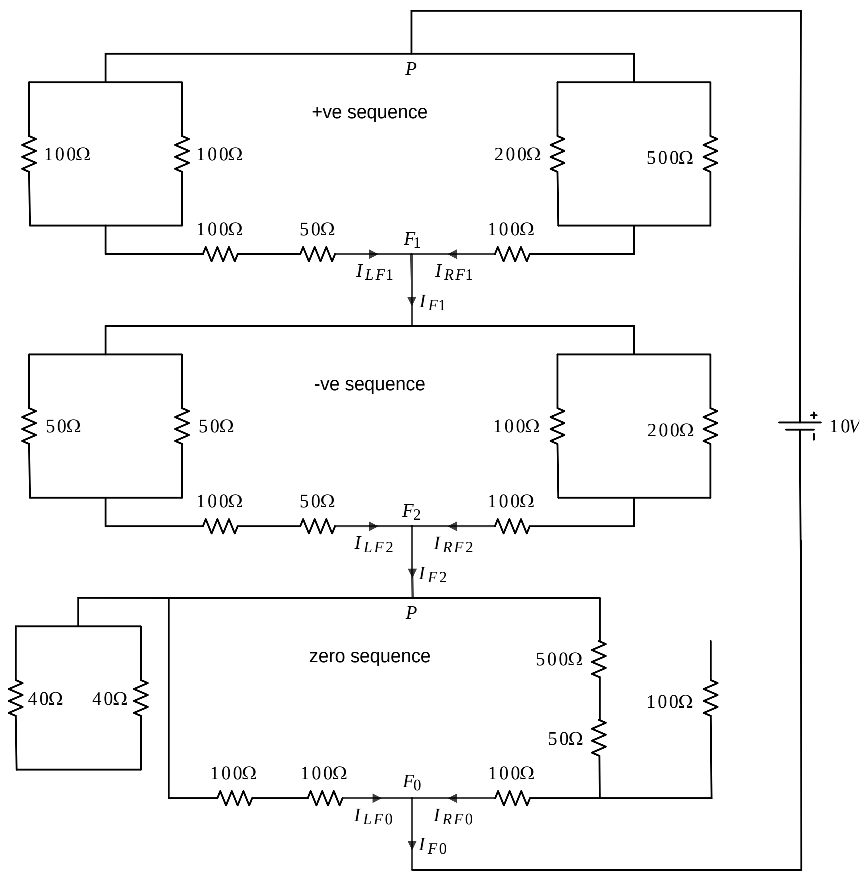
$$I_f = I_L + I_R = 91.18 mA$$

2. Single Line to Ground (SLG) Fault

$$V_a = Z_f I_a, \quad I_b = I_c = 0$$

$$I_a^1 = I_a^2 = I_a^0 = E_a / (Z^1 + Z^2 + Z^0 + 3Z_f)$$

$$I_f = I_a = 3I_a^1$$



Observation Table: -

Observation Table 2. Single Line to Ground (SLG) Fault

Sl No.	Fault Point	Resistance (Ω)	Voltage (V)	Current (mA)		% Error
				Theoretical	Measured	
1	F_1	50		15.76		
2	F_1	100		12.98		
			Total I_{F1}	**28.74**		
3	F_2	50		14.02		
4	F_2	100		14.72		
			Total I_{F2}	**28.74**		
5	F_0	100		21.98		
6	F_0	100		06.76		
			Total I_{F0}	**28.74**		

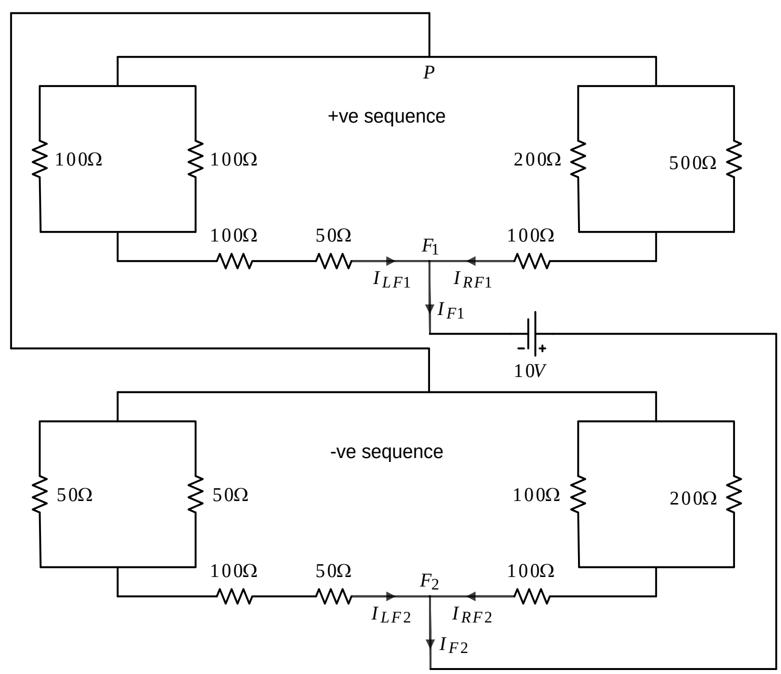
$I_f = 3I_F^1 = 86.22mA$

3. Line to Line (LL) Fault

$V_b - V_c = I_b Z_f$, $I_b + I_c = 0$, $I_a = 0$

$I_a^0 = 0$, $I_a^1 = -I_a^2 = E_a \big/ (Z^1 + Z^2 + Z_f)$

$I_f = I_b = -I_c = (a^2 - a) I_a^1 = -j\sqrt{3} I_a^1$



Observation Table: -

Observation Table 3. Line to Line (LL) Fault

Sl No.	Fault Point	Resistance (Ω)	Voltage (V)	Current (mA)		% Error
				Theoretical	Measured	
1	F_1	50		28.12		
2	F_1	100		23.15		
			Total I_{F1}	**51.27**		
3	F_2	50		-25.01		
4	F_2	100		-26.26		
			Total I_{F2}	**-51.27**		

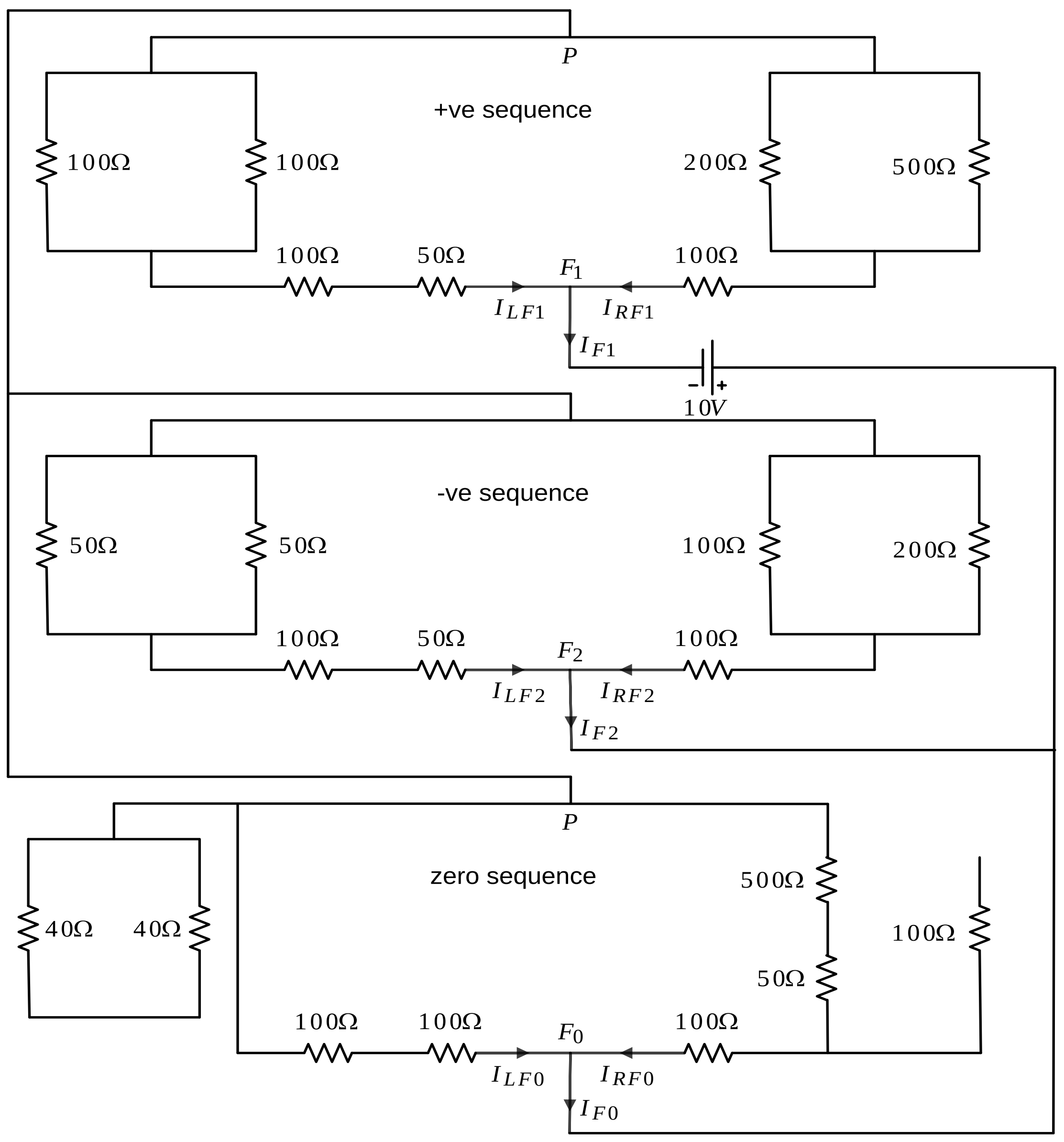
$I_f = \sqrt{3} I_F^1 = 88.80mA$

4. Double Line to Ground (LLG) Fault

$V_b = V_c = (I_b + I_c) Z_f$, $I_a = I_a^1 + I_a^2 + I_a^0 = 0$

$V_a^1 = V_a^2$, $I_a^1 = E_a / \{ Z_1 + \frac{Z^2 (Z^0 + 3Z_f)}{Z^2 + Z^0 + 3Z_f} \}$, $I_a^2 = -\frac{E_a - I_a^1 Z^1}{Z^2}$, $I_a^0 = -\frac{E_a - I_a^1 Z^1}{Z^0 + 3Z_f}$

$I_f = I_b + I_c = 3I_a^0$



Observation Table: -

Observation Table 4. Double Line to Ground (LLG) Fault

Sl No.	Fault Point	Resistance (Ω)	Voltage (V)	Current (mA)		% Error
				Theoretical	Measured	
1	F_1	50		33.34		
2	F_1	100		27.46		
			Total I_{F1}	**60.80**		
3	F_2	50		-19.03		
4	F_2	100		-19.99		
			Total I_{F2}	**-39.02**		
5	F_0	100		-16.65		
6	F_0	100		-5.13		
			Total I_{F0}	**-21.78**		

$I_f = 3I_F^0 = 65.34mA$

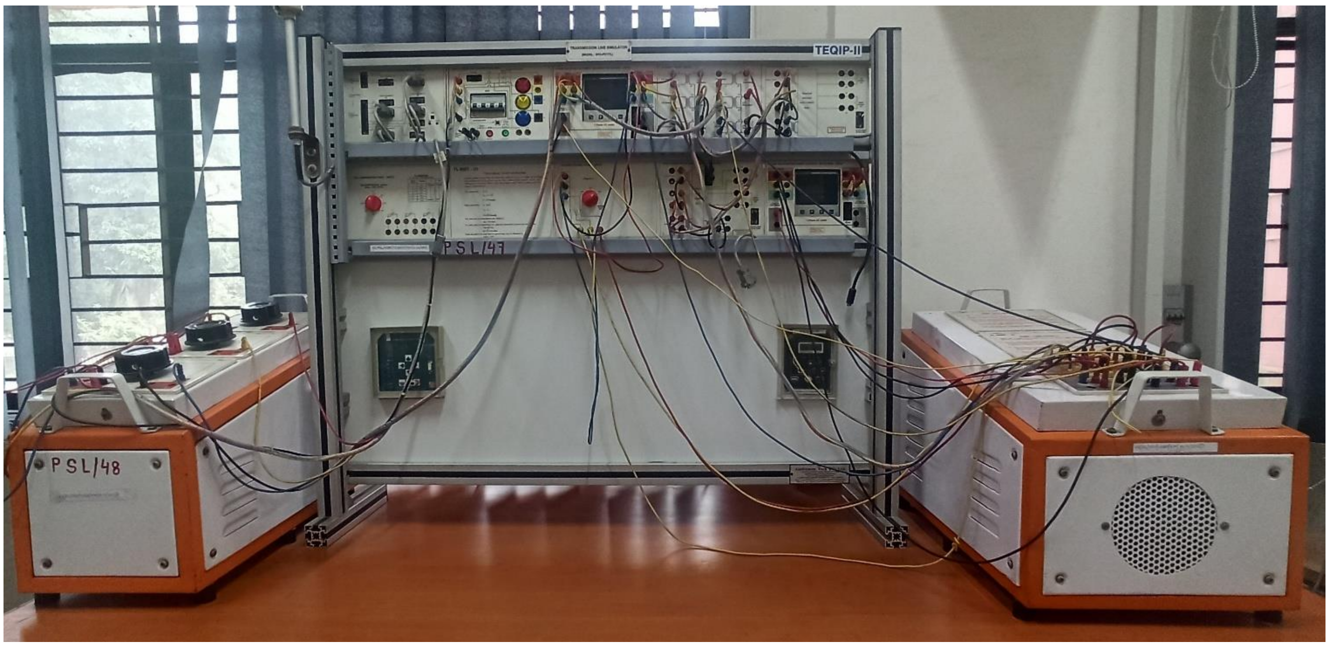
DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab

Course code: EEC507

Experiment No.: 02

SYMMETRIC & ASYMMETRIC FAULTS IN TRANSMISSION LINE



\

Title: Study of the symmetric & asymmetric faults in transmission line.

Objective: To study the symmetrical and asymmetrical faults on the transmission line ‘T ‘model and understand the concept of symmetrical and asymmetrical faults:

1) Line to ground (L-G) fault

2) Line to Line (L-L) fault

3) Double line to ground (L-L-G) fault

4) Three phase fault (L-L-L)

5) Three phase to ground (L-L-L-G) fault

Apparatus used:

1) Three phase supply, 440volt, three phase, 50 Hz

2) Direct online starter

3) Reversing phase panel

4) Three phase AC voltmeter and ammeter

5) Transmission line simulator

6) Current transformer

7) Variac/Dimmer

Theory: Power systems are designed to be symmetrical or balanced i.e. in a three-phase system, the three line to neutral, voltages have same magnitude and differ in phase by 120 degree & line currents have same magnitude & differ in phase by 120 degree.

The most extreme but also common, series fault in the open circuit, this occur for example, when a circuit breaker or isolator is opened or when a line is broken (but does not touch the ground).

Short circuit faults are ordered by occurrence are classified into:

1) Single-line-to-ground (L-G) fault: Unsymmetrical fault between one phase and ground. The phase magnitudes will be no longer identical.

2) Line-to-line (L-L) fault: Unsymmetrical fault between two phases.

3) Double-line-to-ground or line-to-line-to-ground (L-L-G) fault: Unsymmetrical fault between two phases and ground.

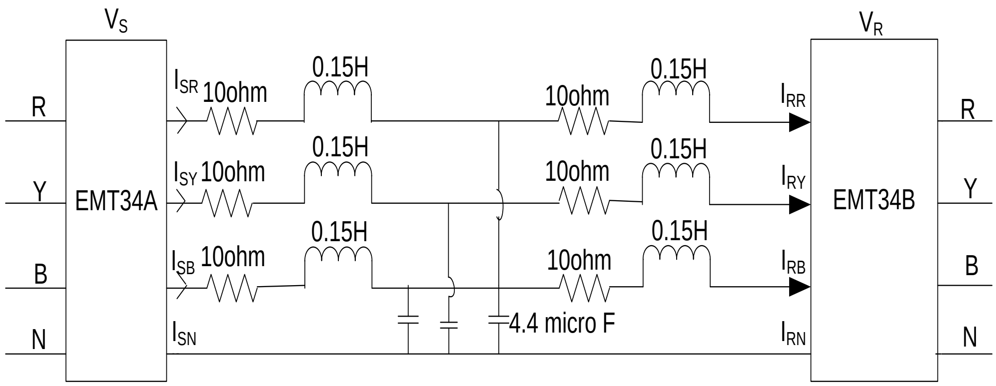
4) Three phase short circuit (L-L-L) fault: It is symmetrical fault that affects the three phases of the power system. This is the most severe short circuit fault.

5) Three phase to ground (L-L-L-G) fault: It is symmetrical fault, all three phases are grounded.

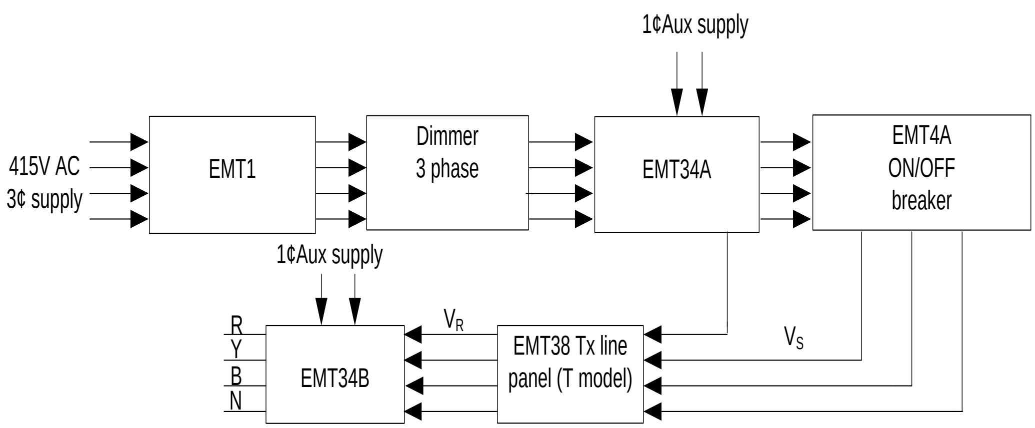
L-G, L-L & L-L-G are the unsymmetrical faults while L-L-L, L-L-L-G are symmetrical faults. In case of symmetrical faults, the system remains balanced even after the faults. For unsymmetrical faults the voltages and currents becomes unbalanced after the fault.

Procedure:

To create L-G, L-L, L-L-G, L-L-L & L-L-L-G faults on medium length transmission line T model.



(a) Circuit diagram for faults on T model



(b)Block diagram for faults on T model

Wiring sequence:

No.	From	To	No.	From	To
1	EMT1(1)	EMT20D/R(1)	2	EMT1(2)	EMT20D/Y(1)
3	EMT1(3)	EMT20D/B(1)	4	EMT1(4)	EMT20D/R(3)
5	EMT20D/R(4)	EMT20D/Y(3)	6	EMT20D/Y(4)	EMT20D/B(3)
7	EMT20D/R(5)	EMT34A(4)	8	EMT20D/R(7)	EMT34A(1)
9	EMT20D/Y(7)	EMT34A(2)	10	EMT20D/B(7)	EMT34A(3)
11	EMT34A(5)	EMT4A(1)	12	EMT34A(6)	EMT4A(2)
13	EMT34A(7)	EMT4A(3)	14	EMT4A(4)	EMT38(1)
15	EMT4A(5)	EMT38(9)	16	EMT4A(6)	EMT38(17)
17	EMT34A(8)	EMT38(2)	**18**	EMT38(3)	EMT38(7)
19	EMT38(11)	EMT38(15)	20	EMT38(19)	EMT38(23)
21	EMT38(4)	EMT38(6)	22	EMT38(8)	EMT38(16)
23	EMT38(14)	EMT38(12)	24	EMT38(10)	EMT38(18)

25	EMT38(20)	EMT38(22)	26	EMT38(5)	EMT38(1)
27	EMT38(13)	EMT38B(2)	28	EMT38(21)	EMT34B(3)
29	EMT38(24)	EMT34B(4)	30		

Wiring schedule for fault:

Sr. No.	Type of fault		From	To
1	L-G	R to G, B&Y open	EMT34B(5)	EMT34B(8)
2	L-L	R to Y, B open	EMT34B(5)	EMT34B(6)
3	L-L-G	R to Y to G, B open	EMT34B(5)	EMT34B(6)
			EMT34B(6)	EMT34B(8)
4	L-L-L	R to Y to B	EMT34B(5)	EMT34B(6)
			EMT34B(6)	EMT34B(7)
5	L-L-L-G	R to Y to B to G	EMT34B(5)	EMT34B(6)
			EMT34B(6)	EMT34B(7)
			EMT34B(7)	EMT34B(8)

1) Make the wiring connection as per wiring schedule for any fault say R to G (L-G). Keep the dimmer at minimum position & switch on EMT4A at FWD position.

2) Here EMT34A will read sending end voltage, current, power factor etc. and EMT34B will read receiving end voltage, current, power factor etc.

3) Here note that we have shorted R phase of transmission line to neutral at EMT34B.

4) Make on three phase supply and now increase dimmer slowly to 230volt AC observing voltage on EMT34A & monitoring current on EMT34B.

5) Now take the readings of sending and receiving end voltage & current as per table given below.

Observation table for faults on T model:

Sr. No.	Type of fault	Sending end(On EMT34A)						Receiving end(On EMT34B)					
		V_{SR}	V_{SY}	V_{SB}	I_{SR}	I_{SY}	I_{SB}	V_{RR}	V_{RY}	V_{RB}	I_{RR}	I_{RY}	I_{RB}
1	L-G												
2	L-L												
3	L-L-G												
4	L-L-L												
5	L-L-L-G												

Conclusion:

Based on above table of observation:

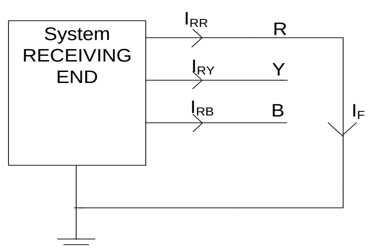
1) Answer following questions:

a) Which one do you thing is most severe fault? Why?

b) Which one of them will be the most severe for the network equipment?

c) How does the location (distance & impedance to source) of the fault increase/decrease the severity of the disturbance? Why?

2) Single line to ground fault (L-G):

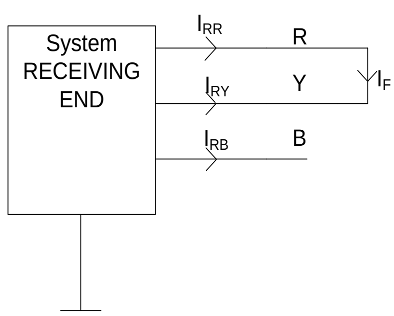


(a) Current in faulted phase R………

(b) Is the system balanced?

(c) What happens with the voltages at phases R, Y & B?

3) Line to line fault (L-L):

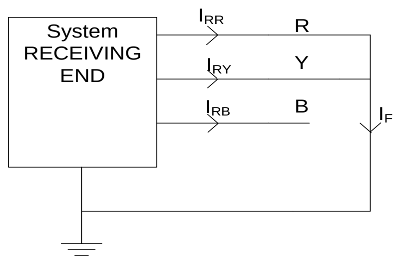


(a) Current in faulted phase R………

(b) Is the system balanced?

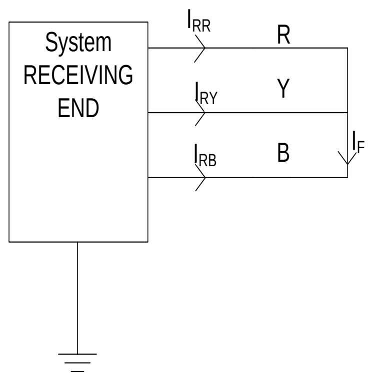
(c) What happens with the voltages at phases R, Y & B?

4) Double line to ground fault (L-L-G):



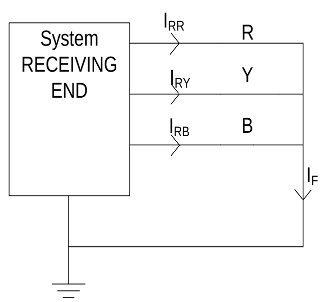
(a) Current in faulted phase R & Y.
(b) Is the system balanced?
(c) What happens with the voltages at phases R, Y & B?

5) Three phase fault (L-L-L):



(a) Current in faulted phase R, Y & B.
(b) Is the system balanced?
(c) What happens with the voltages at phases R, Y & B?

(6) Three phase to ground fault (L-L-L-G):



(a) Current in faulted phase R, Y & B.
(b) Is the system balanced?
(c) What happens with the voltages at phases R, Y & B?

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Power and Switchgear Lab

Course code: EEC507

Experiment No.: 03

<u>STUDY OF POWER TRANSFER THROUGH A TRANSMISSION SYSTEM</u>

TITLE: Study of power transfer through a transmission system.

List of Items:

	Apparatus	**Range**	**Maker**
1.	Ammeter	0-2 A	
2.	Voltmeter	0-150/300/600 V	
3.	Digital Phase-angle meter	(0-360°) 0-150/230 V, I (0-10) A	
4.	3-phase, 6-pole, 6 position rotary switch		
5.	Low Power Factor Wattmeter	0-150/300 V, 1A /2 A	

6.	Three pole ON/OFF switch		
7.	Single Phase Variac	0-250 V, 5 A	
8.	Isolation Transformer (3-phase)	110/110 V, 2 A	
9.	Power Supply Transformer (3- phase)	400-415 V/ 110-120 V (10 A), Star/ Delta	
10.	Single pole two way switch	230 V, 5 A	
11.	Indicating Lamps	0-230 V (AC)	
12.	0-2 A Fuses		
13.	Induction Motor type Phase Sequence Indicator		
14.	Single Pole two way Switch	230 V, 5 A	
15.	An Inductor (Linear air gap type) (It represents a short transmission system)	250/300/500 mh, 2 A	
16.	Sheet metal cubicle housing different equipments mentioned above		

OBJECTIVES:

To plot the power angle diagram of a transmission system under steady state condition and to study the effect of resistance of the line on the power transfer characteristics.

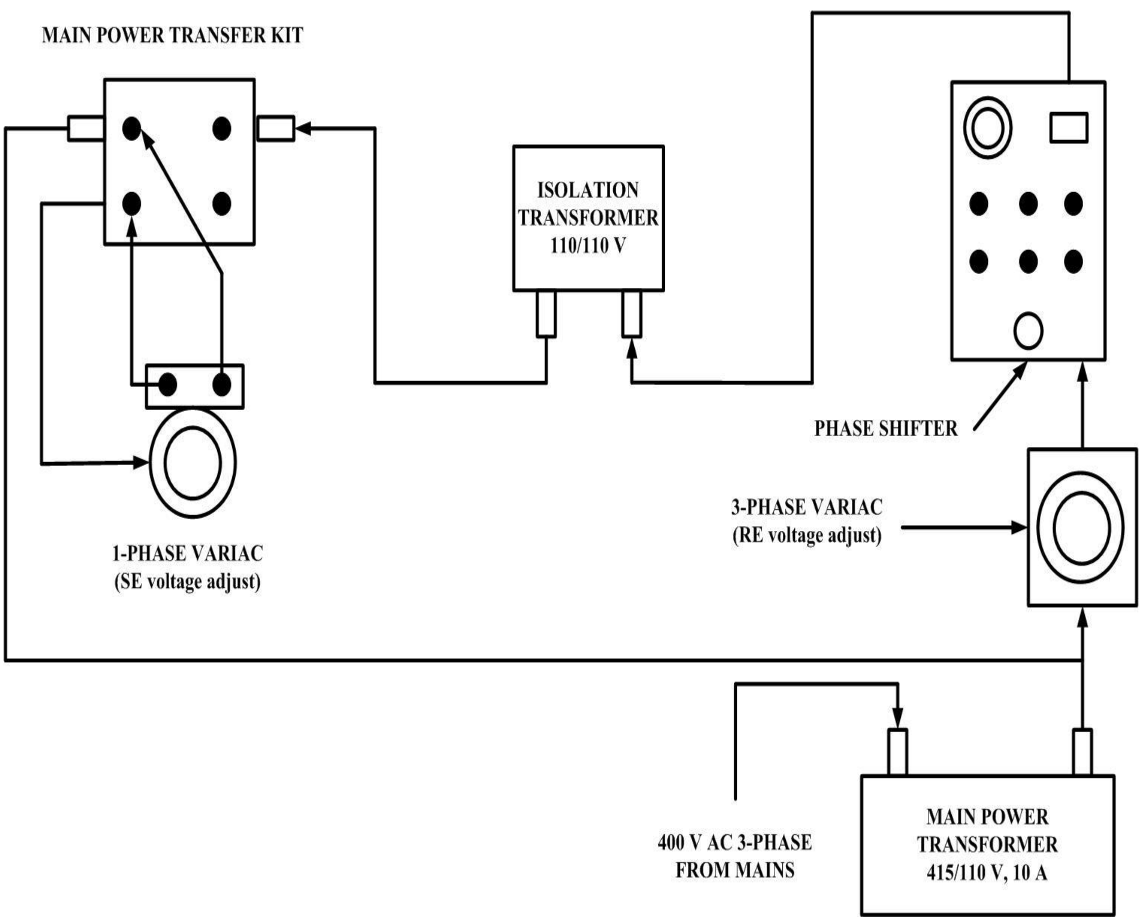


Fig.1 Connection diagram for power transfer experimental set-up

PROCEDURE:

The front view of the power transfer cubicles, and the detail circuit diagram and connection diagrams are shown in figure 1 and 2 respectively.

1) Connect the 3-phase power cable with neutral at the desired terminals provided in the power supply Transformer [i.e. 400-415/ 110-120 V (10A)] cubicle.

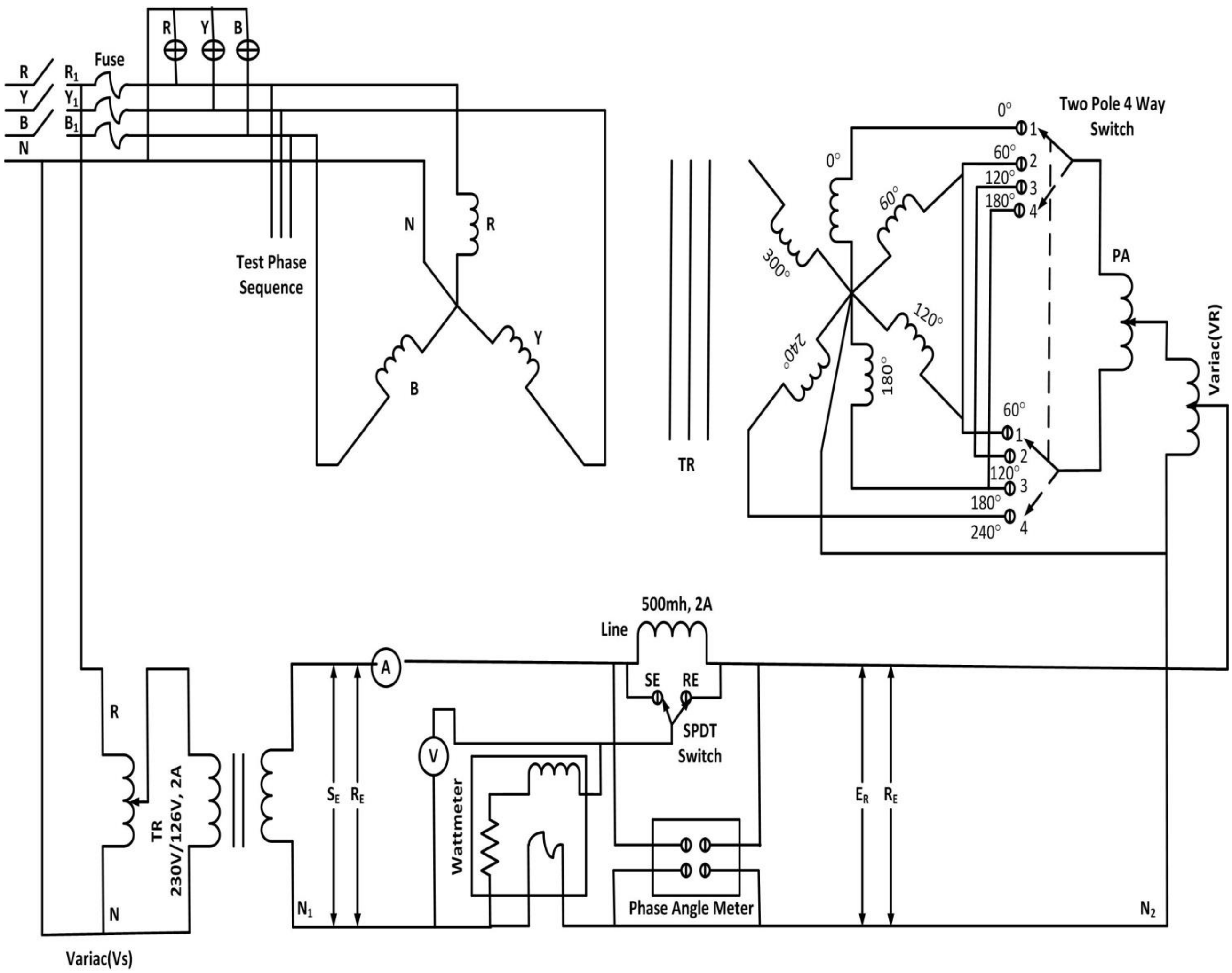


Fig.2 Power Transfer through Transmission System

2) Now connect the 110 or 120 V secondary to the 3-phase Variac and the main Power Transfer Kit Cubicle's left hand/ Sending End (SE) side through the cable entry grommet [110 V (line-to-line) single phase only].
3) Then connect the output of the Variac to the Phase Shifter input while connecting its output to the Isolation transformer [i.e. 110V/110V, 2A transformer].
4) Connect the output of the Isolation Transformer (single phase, the same phases as connected to the sending end only.) to the main Power Transfer Kit cubicle's right hand/Receiving End (RE) side through the cable entry grommet [110V (line-to-line) single phase on the RE side.]

5) Lastly connect the single phase Variac plug to the power plug socket present on the left hand side of the Main Power transfer cubicle while connecting the Variac outputs to the SE of the Main Power transfer cubicle.
6) Connect the Voltmeter, Ammeter, Wattmeter and the Phase-angle meters as shown in the diagram with the terminals on Main Power transfer cubicle.
7) Switch on the 3-phase, ON/OFF switch (on the Power Supply Transformer) to the 'ON' position and observe that the three indicator lamps glow.
8) Set SE voltage (E_S) and RE voltage (E_R) at a constant value of about 100V by the corresponding Variac. The AC voltages will show the actual value of E_S and E_R by throwing the single pole two way switch in either left-ward or right-ward directions.
9) Set the phase angle to zero degree by adjusting the Variac used for adjusting the phase angle. The 6-pole 6-way course phase shift adjust switch should be in POS-1.
10) Under that condition ammeter reading, wattmeter reading and phase angle meter reading should be zero.

RUN 1

Take ammeter and wattmeter readings at ends for E_S leading with respect to E_R from 0° to 180° in steps of 20° interval. This can be done by adjusting the phase shifter.

OBSERVATION TABLE

Sl. No.	Angle(°)	E_S(V)	E_R(V)	I_S(A)	W_S(W)	W_R(W)	Q_S(VAR)	Q_R(VAR)
							To be calculated	To be calculated

THEORY

To measure the active power transfer we are keeping the sending and receiving end voltage constant while varying the phase angle to change the power output.

Known Parameters

1. Angle 'δ' in degrees
2. E_S – Sending end voltage
3. E_R – Receiving end voltage
4. I – Current magnitude in small transmission network in amps
5. W_S – Sending end power in watts
6. W_R – Receiving end power in watts

Unknown Parameters

1. Q_S – Sending end VAr
2. Q_R – Receiving end VAr
3. W_L – Line loss in Watts
4. Angle γ – of current I
5. $Z_S\angle\theta_S = r_s + jx_s$ – the value of the reactor

CALCULATION

Line loss = $W_S - W_R = I^2 r_s$ (1)

From equation (1),

$$r_s = \frac{W \;\; - W_R}{I^2}$$

$(\text{Volt Amp})^2 = (\text{Active Power})^2 + (\text{ Reactive Power})^2$ (2)

$(E_S I)^2 = W_S^2 + Q_S^2$ (3)

Hence $|Q_S|$ is known for every observation.

Also,

$(E_R I)^2 = W_R^2 + Q_R^2$ (4)

Hence $|Q_R|$ is known for every observation.

Now,

$$I\angle\gamma = \frac{W_S - jQ_S}{E_S^{\;*}}$$

$$I\angle\gamma = \frac{W_S - jQ_S}{E_S}$$ (Taking E_S as a reference Phasor) (5)

From equation (5) $I\angle\gamma$ can be determined for every set of observation.

Again,

$$\frac{E_S\angle 0 - E_R\angle -\delta}{I\angle\gamma} = Z_S\angle\theta_S$$ (6)

From equation (6) $Z_S\angle\theta_S$ will be known for every set of observation.

Again,

$Z_S\angle\theta_S = r_s + jx_s$ (7)

From equation (7) $Z_S\angle\theta_S$ and r_s are known so x_s will be known for every set of observation.

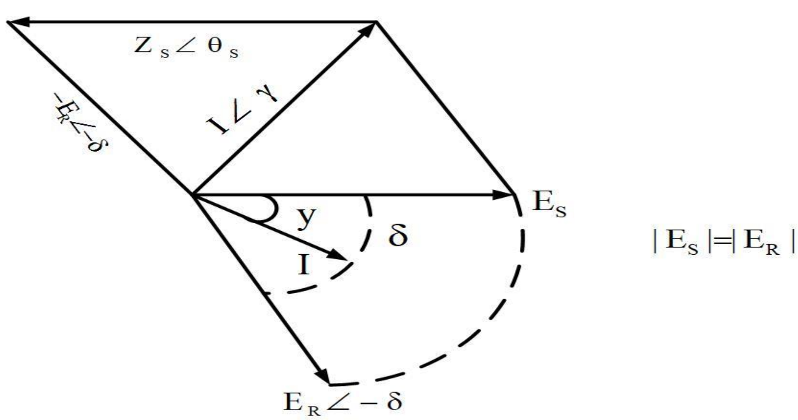


Fig. 3 Phasor diagram for RUN 1

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab

Course code: EEC507

Experiment No.: 04

<u>Study of power transfer through a transmission system</u>

TITLE: **Study of power transfer through a transmission system.**

List of Items:

	Apparatus	Range	Maker
1.	Ammeter	0-2 A	
2.	Voltmeter	0-150/300/600 V	
3.	Digital Phase-angle meter	(0-360°) 0-150/230 V, I (0-10) A	

4.	3-phase, 6-pole, 6 position rotary switch		
5.	Low Power Factor Wattmeter	0-150/300 V, 1A /2 A	
6.	Three pole ON/OFF switch		
7.	Single Phase Variac	0-250 V, 5 A	
8.	Isolation Transformer (3-phase)	110/110 V, 2 A	
9.	Power Supply Transformer (3- phase)	400-415 V/ 110-120 V (10 A), Star/ Delta	
10.	Single pole two way switch	230 V, 5 A	
11.	Indicating Lamps	0-230 V (AC)	
12.	0-2 A Fuses		
13.	Induction Motor type Phase Sequence Indicator		
14.	Single Pole two way Switch	230 V, 5 A	
15.	An Inductor (Linear air gap type) (It represents a short transmission system)	250/300/500 mh, 2 A	
16.	Sheet metal cubicle housing different equipments mentioned above		

Objective:

To plot the power angle diagram of a transmission system under steady state condition and to study the effect of resistance of the line on the power transfer characteristics.

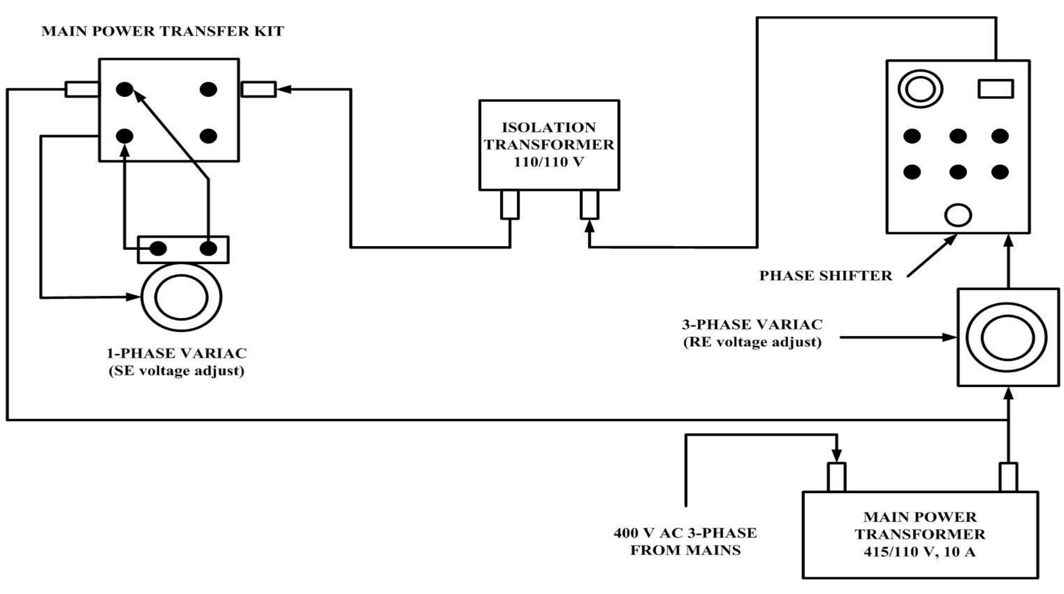


Fig.1 Connection diagram for power transfer experimental set-up

Procedure:

The front view of the power transfer cubicles, and the detail circuit diagram and connection diagrams are shown in figure 1 and 2 respectively.

1) Connect the 3-phase power cable with neutral at the desired terminals provided in the power supply Transformer [i.e. 400-415/ 110-120 V (10A)] cubicle.
2) Now connect the 110 or 120 V secondary to the 3-phase Variac and the main Power Transfer Kit Cubicle’s left hand/ Sending End (SE) side through the cable entry grommet
3) [110 V (line-to-line) single phase only].
4) Then connect the output of the Variac to the Phase Shifter input while connecting its output to the Isolation transformer [i.e. 110V/110V, 2A transformer].
5) Connect the output of the Isolation Transformer (single phase, the same phases as connected to the sending end only.) to the main Power Transfer Kit cubicle’s right hand/Receiving End (RE) side through the cable entry grommet [110V (line-to-line) single phase on the RE side.]
6) Lastly connect the single phase Variac plug to the power plug socket present on the left hand side of the Main Power transfer cubicle while connecting the Variac outputs to the SE of the Main Power transfer cubicle.
7) Connect the Voltmeter, Ammeter, Wattmeter and the Phase-angle meters as shown in the diagram with the terminals on Main Power transfer cubicle.
8) Switch on the 3-phase, ON/OFF switch (on the Power Supply Transformer) to the ‘ON’ position and observe that the three indicator lamps glow.
9) Set SE voltage (E_S) and RE voltage (E_R) at a constant value of about 100V by the corresponding Variac. The AC voltages will show the actual value of E_S and E_R by throwing the single pole two way switch in either left-ward or right-ward directions.
10) Set the phase angle to zero degree by adjusting the Variac used for adjusting the phase angle. The 6-pole 6-way course phase shift adjust switch should be in POS-1.
11) Under that condition ammeter reading, wattmeter reading and phase angle meter reading should be zero.

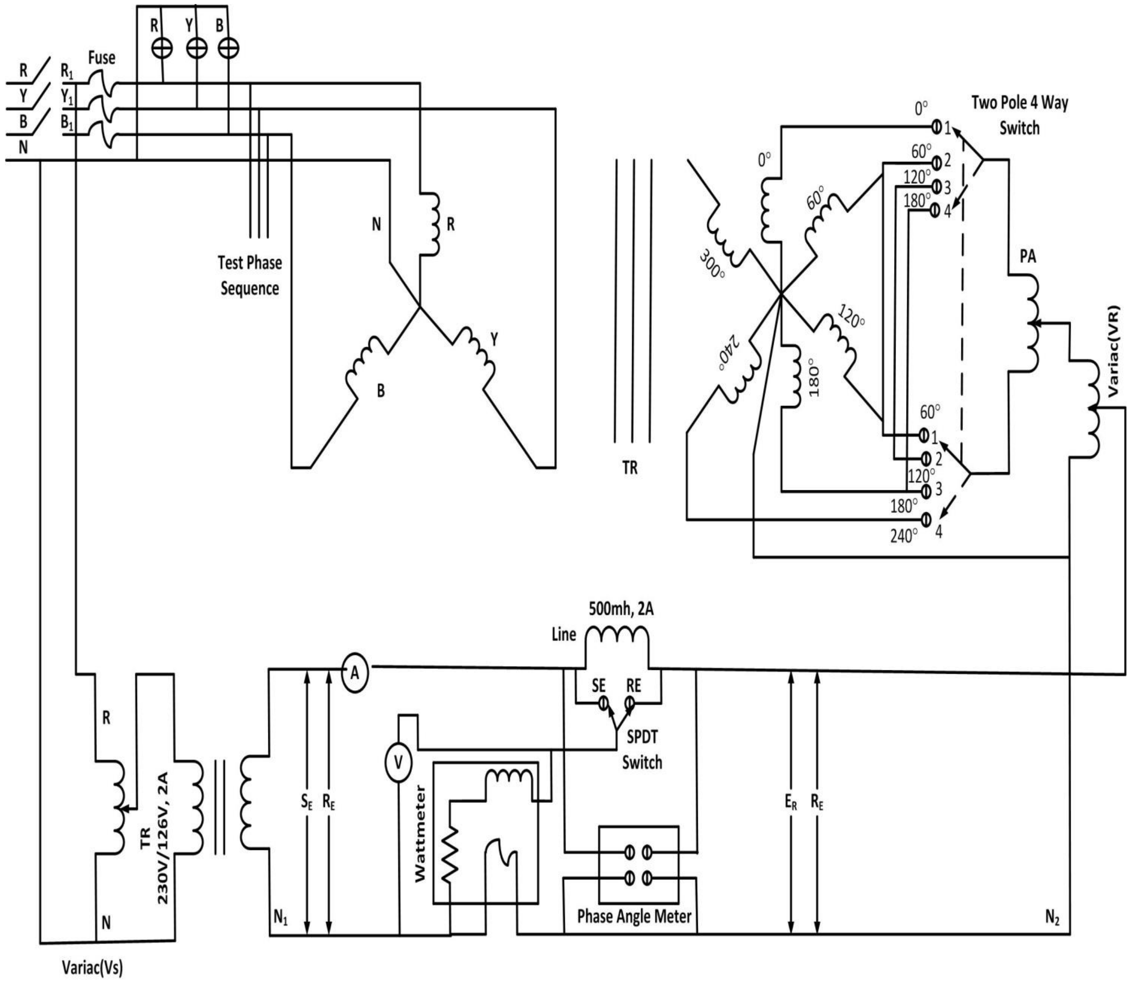


Fig.2 Power Transfer through Transmission System

RUN 2

The value of E_S from 30V to 100V in steps of 10V keeping E_R=50V and phase angle at 20° fixed and take ammeter and wattmeter readings.

OBSERVATION TABLE

Sl. No.	Angle(°)	E_S(V)	E_R(V)	I_S(A)	W_S(W)	W_R(W)	Q_S(VAR)	Q_R(VAR)
							To be calculated	To be calculated

THEORY

To measure the reactive power transfer we are keeping receiving end voltage and phase angle constant while varying the sending end voltage to change the power output.

Known Parameters

7. Angle ‘δ’ in degrees
8. E_S – Sending end voltage
9. E_R – Receiving end voltage
10. I – Current magnitude in small transmission network in amps
11. W_S – Sending end power in watts
12. W_R – Receiving end power in watts

Unknown Parameters

6. Q_S – Sending end VAR
7. Q_R – Receiving end VAR
8. W_L – Line loss in Watts
9. Angle γ – of current I
10. $Z_S\angle\theta_S = r_s + jx_s$ – the value of the reactor

CALCULATION

Line loss = $W_S - W_R = I^2 r_s$ (1)

From equation (1),

$$r_s = \frac{W \ - W_R}{I^2}$$

$(\text{Volt Amp})^2 = (\text{Active Power})^2 + (\text{ Reactive Power})^2$ (2)

$(E_S I)^2 = W_S^2 + Q_S^2$ (3)

Hence $|Q_S|$ is known for every observation.

Also,

$(E_R I)^2 = W_R^2 + Q_R^2$ (4)

Hence $|Q_R|$ is known for every observation.

Now,

$$I\angle\gamma = \frac{W_S - jQ_S}{E_S^*}$$

$$I\angle\gamma = \frac{W_S - jQ_S}{E_S} \quad \text{(Taking } E_S \text{ as a reference Phasor)} \qquad (5)$$

From equation (5) $I\angle\gamma$ can be determined for every set of observation.

Again,

$$\frac{E_S\angle 0 - E_R\angle -\delta}{I\angle\gamma} = Z_S\angle\theta_S \quad (6)$$

From equation (6) $Z_S\angle\theta_S$ will be known for every set of observation.

Again,

$$Z_S\angle\theta_S = r_s + jx_s \quad (7)$$

From equation (7) $Z_S\angle\theta_S$ and r_s are known so x_s will be known for every set of observation.

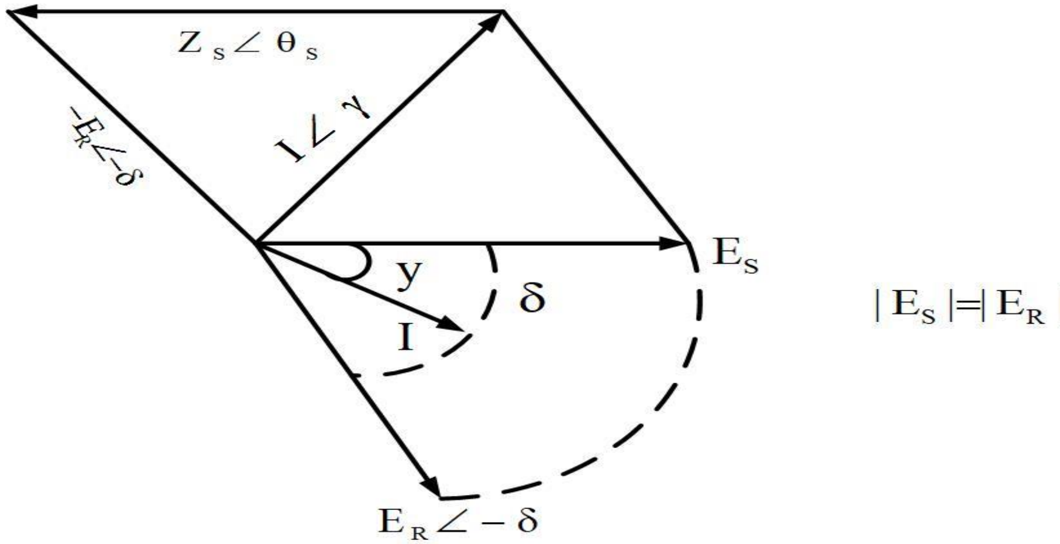


Fig. 3 Phasor diagram for RUN 1

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab

Course code: EEC507

Experiment No.: 05

A. <u>Title: Experimental study of a Buck-Boost dc-dc converter for R load</u>

Objectives:

a) To develop the experimental Buck-Boost DC-DC converter and generate its gate pulses under PWM mode of operation.

b) To observe the output waveform of voltage and current for different reference voltage or duty ratio.

B. Apparatus Required:

1. 1000W (Device) Converter circuit module - 1no.
2. R-LOAD
3. Patch chords.
4. Power chords.
5. Multimeters, current clamps, DSO, etc

C. THEORY:

DC-DC converters are also known as Choppers. Here we will have a look at the **Buck-Boost converter,** which can operate as a DC-DC Step-Down converter or a DC-DC Step-Up converter depending upon the duty cycle, D.

A typical Buck-Boost converter is shown Fig. 1(a). The input voltage source is connected to a switch, S_1 (solid-state device like MOSFET/IGBT). The second switch used is an uncontrolled diode (D). The diode is connected, in reverse to the direction of power flow from the source, to a capacitor and the load and the two are connected in parallel as shown in the figure.

The controlled switch is turned ON and OFF by using Pulse Width Modulation (PWM) controller. PWM can be time-based or frequency-based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch, which in turn will give the desired output voltage. Time-based Modulation is mostly used for DC-DC converters. It is simple to construct and use. However, the frequency remains constant in this type of PWM modulation.

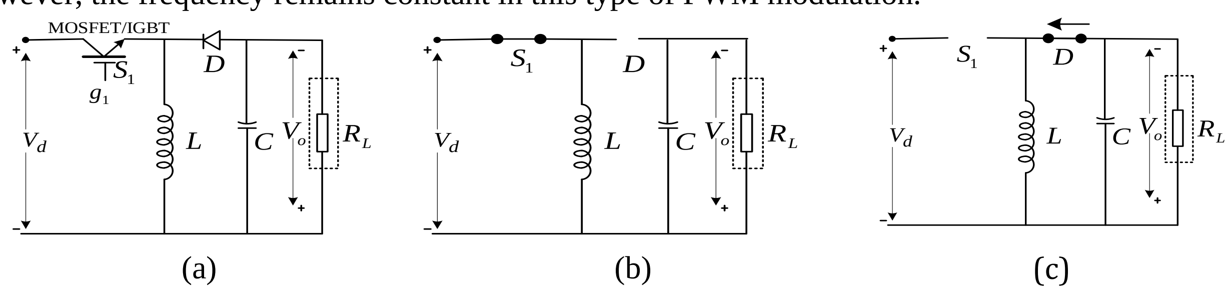


Fig. 1 Schematic diagram of (a) buck-boost converter, (b) under Mode-1 & (c) under Mode-2

The **Buck-Boost converter** has two modes of operation. The first mode is when the switch is ON and conducting.

D. Operation

Mode I : Switch is ON, Diode is OFF

When the switch S_1 is ON as it represents a short circuit ideally offering zero resistance to the flow of current, the current will flow through the switch, through the inductor and back to the DC input source. The inductor stores charge during the time the switch is ON and when the solid-state switch is OFF the polarity of the Inductor reverses so that current flows through the load and through the diode and back to the inductor. So, the direction of current through the inductor remains the same.

Mode II : Switch S_1 is OFF, Diode D is ON

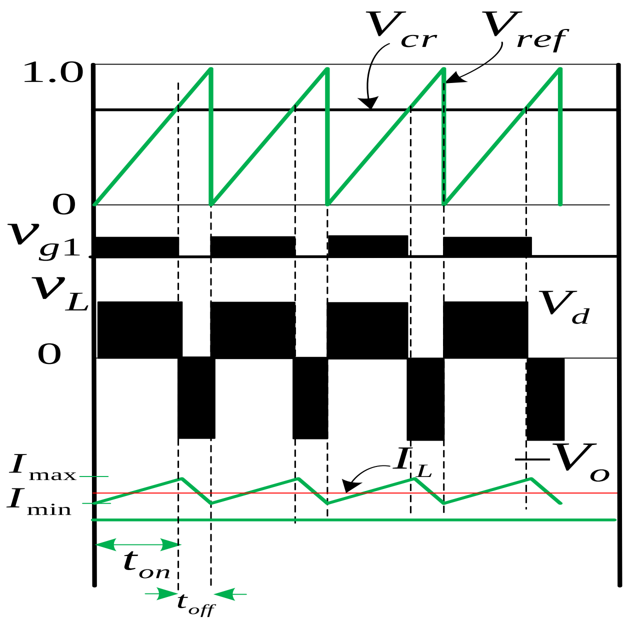
In this mode as the switch S_1 is OFF, the diode D becomes conductive. Thus, the polarity of the inductor voltage is reversed and the energy stored in the inductor is released, which is ultimately dissipated in the load resistance. This helps to maintain the flow of current in the same direction through the load and also step-up the output voltage as the inductor is now also acting as a source in addition to the input source.

The operation of **the Buck-Boost** DC-DC converter under the PWM technique is shown in Fig. 2, where, the constant reference signal or modulating signal (V_{ref}) which is compared with a high-frequency triangular carrier wave (V_{cr}) of constant amplitude V_{cr} to generate controlled DC output voltage. For a buck converter as shown in Fig. 1(a), when the switch S is ON, the inductor L shorted and the inductor current (I_L) increases from a minimum inductor current (I_{min}) to I_{max}. Due to this, the voltage V_L across the inductor becomes positive. During OFF period, the switch S1 remained OFF and the inductive energy is freewheeled to the load through the diode D. The operations of all the three converters can be further explained with the inductor voltage and current waveform as shown in Fig. 2 under PWM mode.

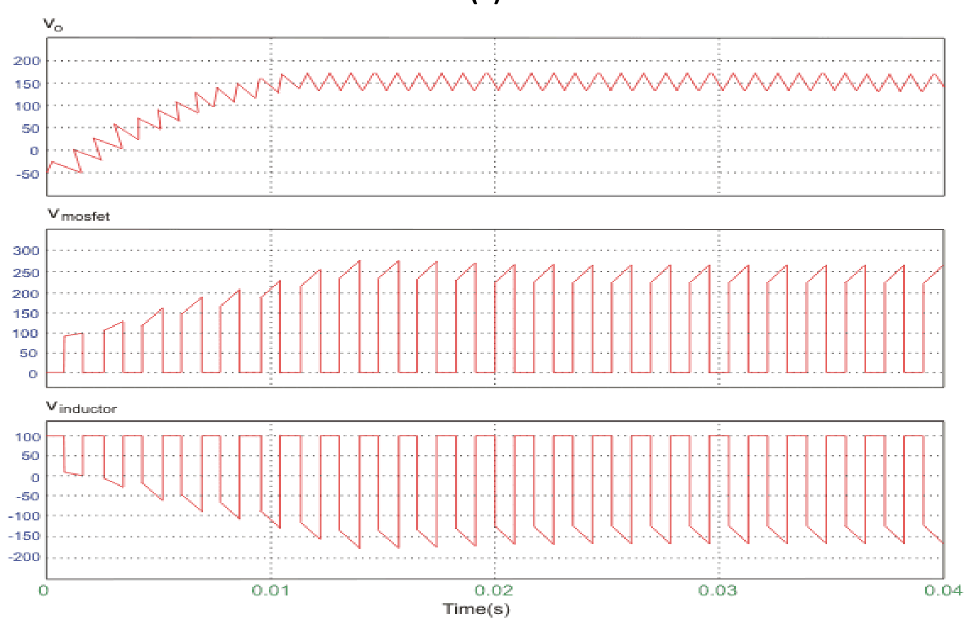
Operation under PWM mode:

To generate the high frequency switching pulses, a PWM can be applied for the above converters having single IGBT switch. For Implementing this PWM scheme, a high frequency sawtooth carrier signal with frequency (f_{cr}) of a constant magnitude (V_{cr}), generally of unity magnitude is continuously compared with a constant reference signal (V_{ref}) to generate the gate pulse for the converter switch as shown in Fig. 2. At any instant of time, the PWM output will be high (Pulse =1) if the reference signal $V_{ref} \geq V_{cr}$ and gate pulse will be low (pulse= 0) for $V_{ref} < V_{cr}$ as illustrated in Fig. 2. Under this PWM technique, the output voltage along with the other voltages of the converter are shown in of the Buck converter V_o is varying between (V_d-V_o) and -V_o during ON and OFF period of the switch respectively as observed in Fig. 2. Similarly, for the Boost as well as Buck-Boost converters, the nature of the output voltage can also be observed from the Fig. 2(b)-(c). The value of the inductor current (I_L) is fluctuating between the I_{min} and I_{max} for all the three converters. The duty ratio (D) as well the output voltage for the above converters can be determined as:

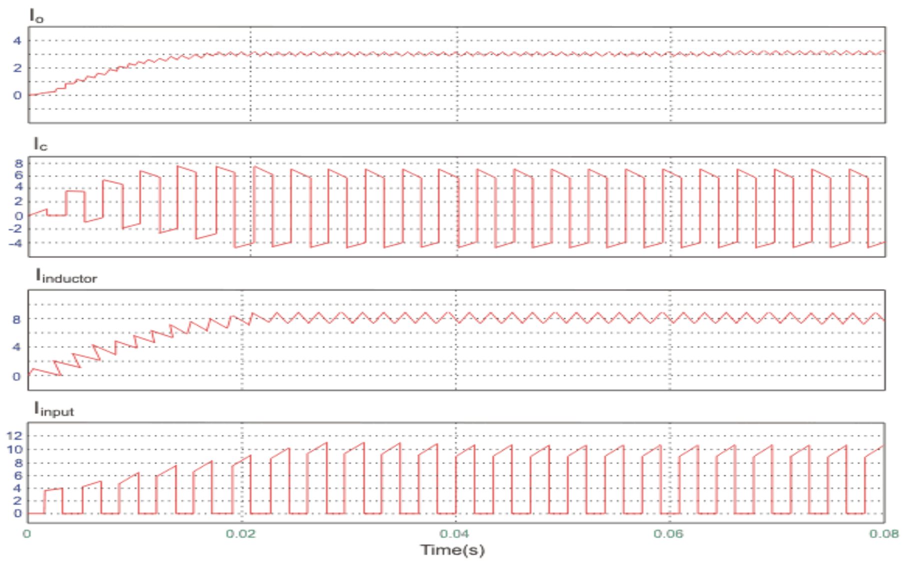
$$
\left.
\begin{aligned}
D &= \frac{t_{on}}{T} \\
V_o &= DV_d \text{ for Buck convereter} \\
V_o &= \frac{1}{1-D}V_d \text{ for Boost convereter} \\
V_o &= \frac{D}{1-D}V_d \text{ for Buck-Boost convereter}
\end{aligned}
\right\} \qquad (1)
$$



(a)



(b)

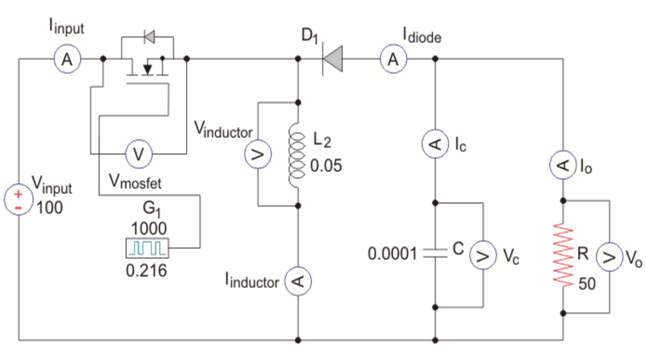


(c)

Fig. 2 Waveforms of the buck-boost converter (a) PWM pulse generation, (b) Voltage waveforms, (c) current waveforms

E. Procedure:

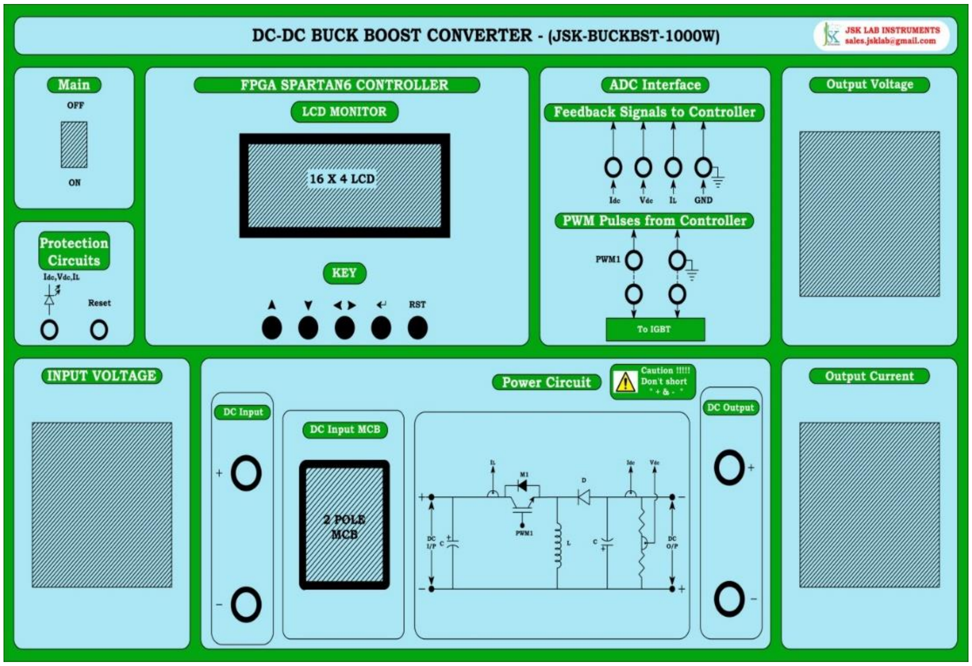
1. Turn on IR switch in DC-DC BUCK BOOST CONVERTER power module as shown in Fig. 3(b).
2. Press reset button in power module as shown in Fig. 3(b) to make sure that the protection LED is gets OFF.
3. Turn ON the 2POLE MCB
4. By varying the 1-ph Auto transformer nob to set DC I/P voltage at 50v
5. By Selecting UP/DOWN key Present in FPGA section, Select Open-loop program
6. Set different reference duty by pressing up/down switch in FPGA board and observe the results in the front panel meter.
7. Verify the results under load changes.
8. Observe PWM pulses and output current waveforms by DSO from test point terminals present in the power module with respect to ground



(a)

(b)

(c)



(d)

Fig. 3 (a) Experimental circuit schematic with voltage/current measurements, (b) Main switch, (c) protection circuit reset and (d) entire experimental set up of Buck-Boost Converter

F. Observations Under OPEN LOOP:

A. Buck Converter (D<50%), V_d=

SNO	SET DUTY CYCLE IN %	Ton, toff & T	I_{max} & I_{min}	ACTUAL LOAD VOLTAGE	THEORITICAL VOLTAGE $V_o = \frac{D}{1-D}V_d$
1.					
2.					
3.					
4.					
5.					

***In open loop when load is applied Torque will increase and speed will be reduced**

B. Boost Converter (D>50%), V_d=

SNO	SET DUTY CYCLE IN %	Ton, toff & T	I_{max} & I_{min}	ACTUAL LOAD VOLTAGE	THEORITICAL VOLTAGE $V_o = \frac{D}{1-D} V_d$
1.					
2.					
3.					
4.					
5.					

I. Answer the following questions:

1. Derive the expressions of output voltage of the above converter in terms of duty ratio of the converter.
2. What is the role of switching frequency in the performance of a DC-DC converter?

Note: While performing the analysis of the Buck-Boost converter we have to keep in mind that

1. The inductor current is continuous and this is made possible by selecting an appropriate value of L.
2. The inductor current in steady-state rises from a value with a positive slope to a maximum value during the ON state and then drops back down to the initial value with a negative slope. Therefore, the net change of the inductor current over any one complete cycle is zero.

Course name: Advanced power System Lab

Course code: EEC507

Experiment No.: 06

A. Title: Study the performance of closed-loop Speed Control of Three-Phase Induction motor using Quasi Z-source Inverter

B. Objectives:

1) To perform the hardware experiment of Quasi Z-source inverter

2) To study the performance of the 3-phase Induction Motor under constant v/f control technique.

C. Apparatus required:

1. FPGA based PWM/Pulse controller.
2. Z-Source Power Module.
3. Three phase Induction with Speed Feed-back as a load.

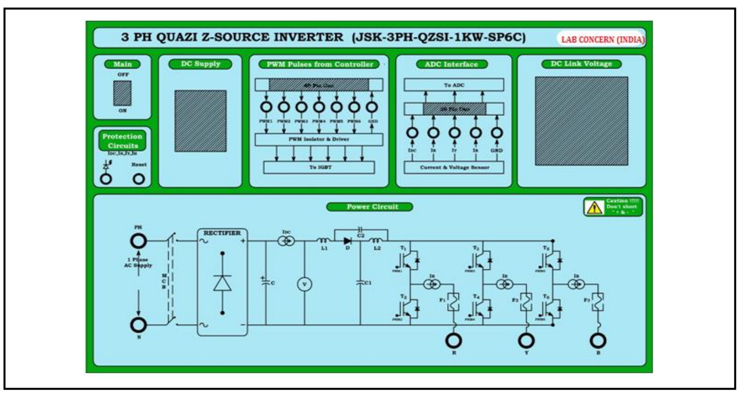


Fig. 1. Front view of the module

In experimental module have the following sub-components

1. Module ON/OFF IR switch
2. Protection circuit and reset switch
3. 40 pin FRC connecter for PWM inputs
4. 20 pin FRC connecter for current and voltage feedback
5. Power circuit
6. DC link voltmeter
7. In back side of the module single phase power card connecters are available, this is for module power supply.
8. 2 pole MCB

D. Introduction

In recent trends PV cells have become more significant to generate electricity and it becomes an alternative for conventional fossil fuels which are reducing rapidly. In order to interface PV cells to grid, a voltage source inverter with combination of boost converter is used. The conventional VSI suffers from the limitation that triggering two switches in the same leg leads to source short. Hence ZSI and QZSI are single stage power converters which are used to interface PV cells to grid by utilising several shoot through zero states [3,4]. A zero state is produced when two switches on the same leg are fired simultaneously. Sustaining the six permissible active states of VSI, the zero states are partially or completely replaced by the shoot through states depends on the voltage boost requirement. Quasi z-source inverter gives all the advantages of z- source inverter and it also provides continuous source current, wide input voltage range, lower component ratings and less EMI problems compared to traditional ZSI. The basic quasi zsource inverter topology is shown in Fig 1. A quasi z-source inverter (QZSI) consists of capacitors and inductors for boosting the input voltage with the help of inverter switches.

The QZSI operates in two modes.

a) Non shoot through mode (active mode) and
b) Shoot through mode (non- active mode).

a) Active Mode: In non-shoot through mode (i.e. in active mode), the switching pattern of QZSI is similar to that of voltage source inverter. The inverter viewed from the dc side is equal to a current source and the dc voltage is appearing as dc linkvoltage to the inverter. In this mode quasi z source inverter behaves as conventional voltage source inverter. The QZSI in active mode is shown in the Fig 1(b).

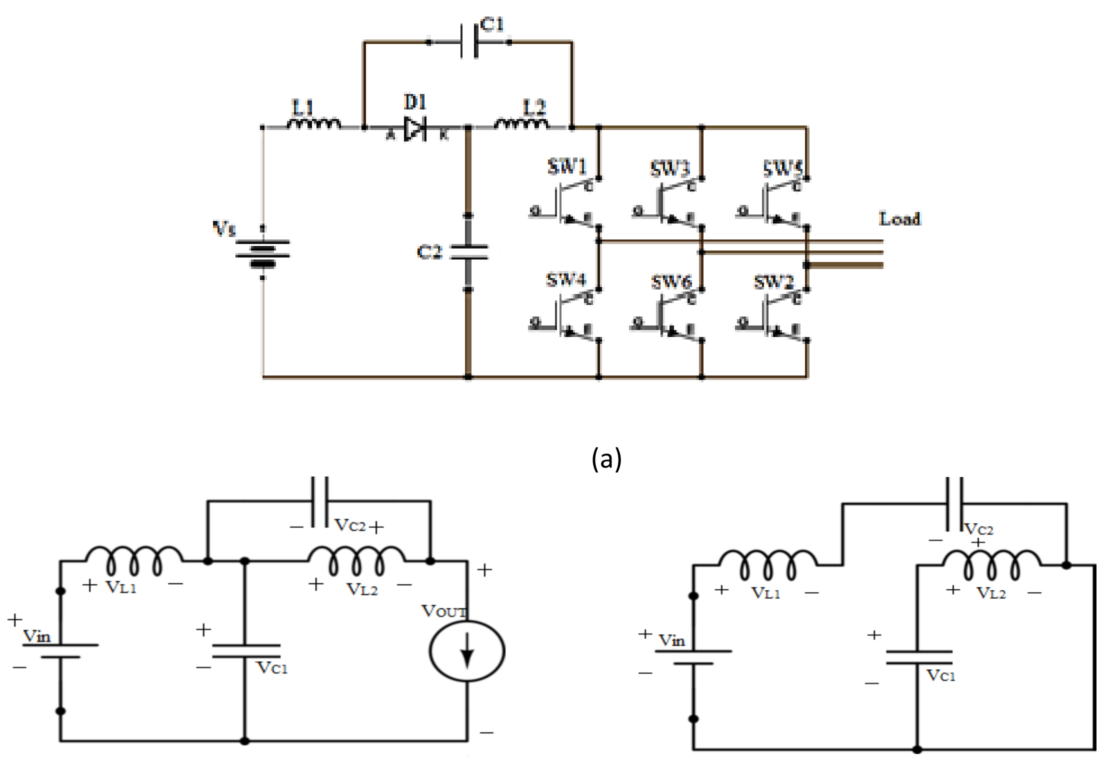


Fig. 1 Schematic diagram of (a) Three phase quasi Z-source Inverter (QZSI), operation under (b) non-shoot through and (b) shoot-though mode

b) Shoot through mode (non-active mode):-

Traditional Z source inverter restrains each other and the inserted shoot-through duty ratio must be less than the zero vectors in a switch cycle. These defects not only limit boost capability but also reduce the flexibility of control strategy. The shoot-through is a forbidden switching state for the traditional VSI. The Z-source inverter intentionally utilizes the shoot- through zero states to boost dc voltage and produce an output voltage greater than the original dc voltage. During shoot through mode both the upper and lower switches on the same leg are gated ON for a very short duration. Because of impedance network the source does not get short circuited and this shoot through mode is used to boost the voltage. The dc voltage during the shoot through state is boosted by a boost factor, whose value depends on the shoot through duty ratio for a given modulation index. The QZSI in shoot through mode is shown in Fig 1(b).

E. Analysis:

From the Fig. 1(b) it is observed that, during the interval of non-shoot through mode (T_1), the voltage across the inductors are

$$V_{L1} = V_{IN} - V_{C1},\ V_{L2} = -V_{C2} \quad (1)$$

Similarly, during the interval of the shoot through mode (T_0)

$$V_{L1} = V_{C2} + V_{IN},\ V_{L2} = V_{C1} \quad (2)$$

$$V_{OUT} = 0,\ V_{DIODE} = V_{C1} + V_{C2} \quad (3)$$

At steady state, the average voltage of the inductors in one switching cycle is zero

$$V_{OUT} = V_{C1} - V_{L2} = V_{C1} + V_{C2},\ \text{and}\ V_{DIODE} = 0 \quad (4)$$

Using equation (1) - (3)

$$\left.\begin{aligned} V_{L1} &= \frac{T_0\left(V_{C2}+V_{IN}\right)+T_1\left(V_{IN}-V_{C1}\right)}{T} \\ V_{L2} &= \frac{T_0\left(V_{C1}\right)+T_1\left(-V_{C2}\right)}{T} \end{aligned}\right\} \quad (5)$$

From the above equations, the capacitor voltages are,

$$\left.\begin{aligned} V_{C1} &= \frac{T_1}{T_1-T_0}V_{IN} \\ V_{C2} &= \frac{T_0}{T_1-T_0}V_{IN} \end{aligned}\right\} \quad (6)$$

From the above equations,

$$V_o = V_{C1}+V_{C2} = \frac{T}{T_1-T_0}V_{IN} = \frac{1}{1-2T_0/T}V_{IN} = BV_{IN} \quad (7)$$

Where B is the boost factor

The average current of the inductors L_1 and L_2 is given by

$$I_{L1} = I_{L2} = I_{IN} = \frac{P}{V_{IN}} \qquad (8)$$

The current of the capacitors and diode are given by

$$I_{C1} = I_{C2} = I_{OUT} - I_{L1}, \quad \text{and} \quad I_D = 2I_{L1} - I_{OUT} \qquad (9)$$

F. PULSE WIDTH MODULATION TECHNIQUES

In normal voltage source inverter, the dc voltage appears across load when any of the six active states are applied and zero voltage appears across the load during two zero states. Zero states are nothing but, both the upper and lower switches on the same leg are triggered simultaneously, so the short circuit would occur and destroy the circuit. In both ZSIand QZSI these zero states are converted into shoot through states in which the switches on the same leg are turned on simultaneously but the impedance network present between the source and the inverter will protect the circuit from damage. Because of this shoot through state the voltage gets boosted up to produce a desired output voltage. There are many PWM control techniques to produce these eight states. In this paper simple boost control technique with sine carrier and triangular carrier are used and compared.

Simple boost PWM control with triangular carrier:

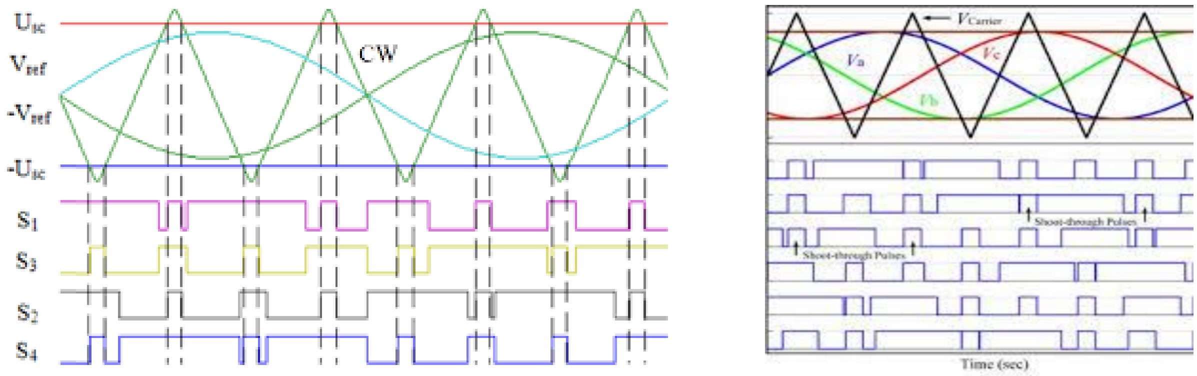
For a single-phase inverter, the generation of gate pulses including shoot-through states are also given in Fig. 2(a). This technique uses a sine wave as reference for each leg and triangular wave as carrier. For a conventional VSI, if the sinusoidal reference signal is greater than triangular carrier signal, the gate pulse of the switches of the individual leg becomes high. However, in order to generate shoot-through state, two constant voltage envelopes (U_{dc} & $-U_{dc}$) have been compared with the triangular carrier wave to obtain shoot-through pulses. When the magnitude of the triangular carrier wave becomes greater than or equal to the positive constant magnitude envelope (i.e., if $V_{cr} \geq U_{dc}$), the shoot-through pulse for the respective switches of the leg generated and they control the shoot through duty ratio (D_0). The reference sine wave along with triangular carrier wave and two constant voltage envelops are shown in the Fig 2(a) for single-phase inverter. However, for a three-phase inverter, three sinusoidal references for each leg are compared with the triangular carrier to generate the pulses under non-shoot through mode. For generating pulses for shoot-through mode, the triangular carrier is compared to the constant magnitude envelops like single phase. The pulse generation for the three-phase QZSI is shown in Fig. 2(b). The expression of shoot through duty cycle (D_0), boost factor (B) and voltage gain (G) with triangular carrier are given as

$$D_o = 1 - M$$

$$B = \frac{1}{2M - 1}$$

$$G = \frac{B}{2M - 1}$$

Where M is the modulation index



(a) (b)

Fig 2: Illustration of simple boost triangular PWM for (a) single-phase (b) three-phase inverter

G. CONNECTION PROCEDURE

- Single phase input from EB supply connected to the **1 phase autotransformer**.
- Auto Transformer output connected to (PH, N) to the Power Module Circuit.
- Built-in Single phase bridge rectifier converts AC to DC in the Power module.
- Generally 3 phase z source inverter working with DC source supply.
- 3-PH Z-source Inverter Power Module having current and voltage sensors present in output for signal feedback.
- 40PIN FRC cable bus connected to **interface card** between FPGA pwm controller and the Power Module.
- One end of the 20PIN FRC cable bus connected to Power Module ADC interface ,other end of the 20PIN FRC cable bus connected to the FPGA controller
- Motor load connected to Power Module Three phase output(R,Y,B).
- Motor Feedback signal 9PIN D- connector feed to Interface card.
- FPGA pwm controller generates the pulse pattern with respect to the Z-Source Power Circuit for open loop/closed loop application.
- Slowly apply the voltage from 1-PH Auto transformer to the Power Module voltage range should not Exceed (0-190V AC).

H. EXPERIMENTAL PROCEDURE

1. Verify the connections as per the connection procedure and wiring diagram.
2. Switch ON the FPGA SPARTAN 6 kit
3. Switch the Power Module Using Main ON/OFF switch present in back panel.
4. Check whether shut down LED glows or not. If LED glows, press the RESET switch, the LED gets OFF.

I. EXPERIMENTAL OBSERVATION (SPEED CONTROL IN CLOSED LOOP):

SNO	REF SPEED(rpm)	ACTUAL SPEED (rpm)	S1(spring balance reading in kg)	S2(spring balance reading in kg)	Torque((S1-S2)*R*9.81) R-radius of the drum=0.09m
1.					
2.					

3.					
4.					

*In Closed loop when load is applied Torque will increase and speed will be maintaining the same speed due to PI control.

J. Answer the following questions

Q1) Derive the expression of shoot through duty cycle ($D_{0)}$, boost factor (B) and voltage gain (G).

Q2) Draw the torque versus speed of the above motor and analyze it.

Precaution: If the input voltage exceeding 190AC ,respectively DC link voltage also increasing gradually. The desired range of the Boosting voltage around 70V.

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab
Course code: EEC507
Experiment No.: 06

A. Title: Study and compare the performance of a Direct Torque Control (DTC) of Induction Motor with Eddy Current Dynamometer with the conventional control technique.

B. Apparatus required:

The experimental setup consists of the following major components

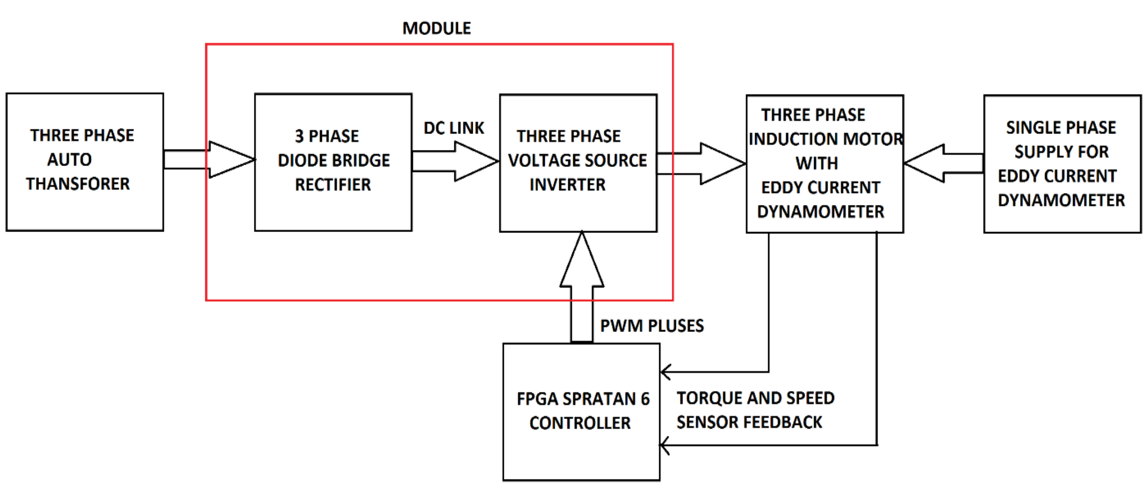
1. Three phase Voltage Source Inverter (VSI) module
2. Three phase induction motor with eddy current dynamometer.
3. SPARTAN 6 FPGA controller kit.
4. Speed sensor encoder kit.
5. Torque sensor and torque controller for eddy current dynamometer.

C. Introduction

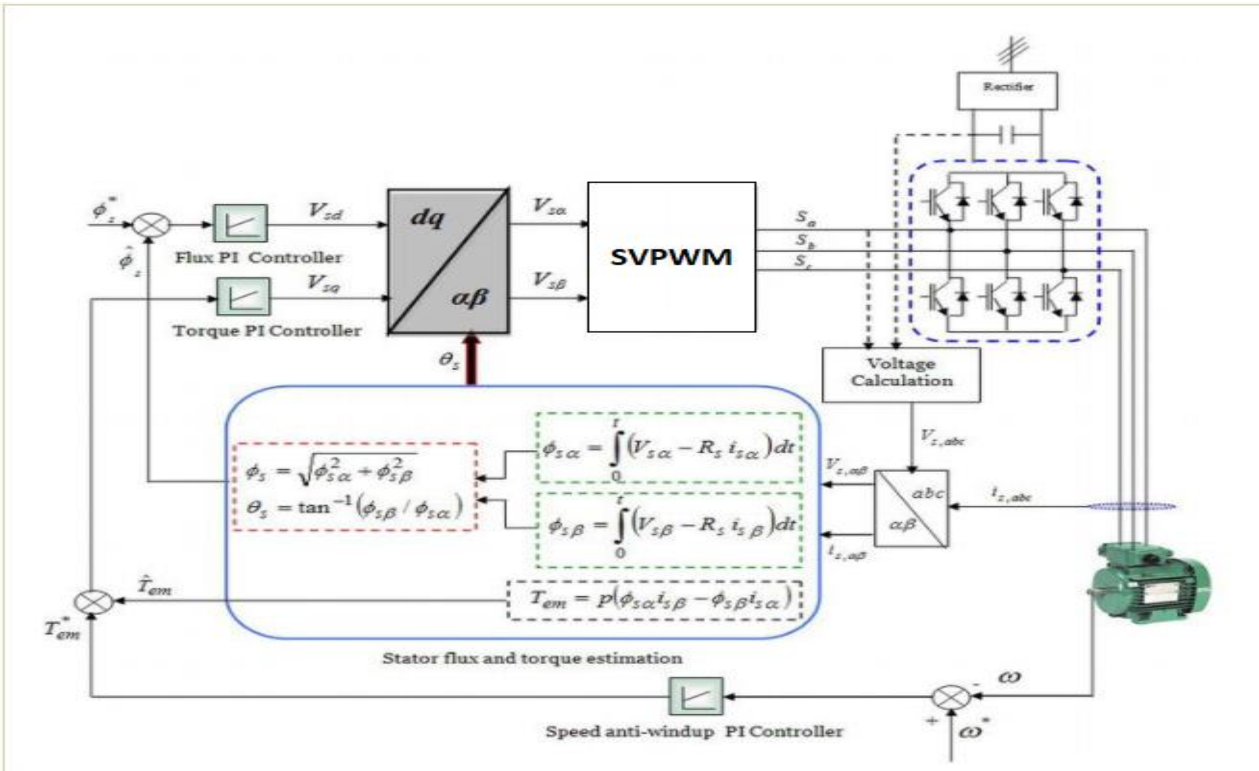
Advanced control of electrical machines requires an independent control of magnetic flux and torque. For that reason it was not surprising that the DC machine played an important role in the early days of high-performance electrical drive systems, since the magnetic flux and torque are easily controlled by the stator and rotor current, respectively. The introduction of field oriented control meant a huge turn in the field of electrical drives, since with this type of control the robust induction machine can be controlled with a high performance. Later in the 1980s, a new control method for induction machines was introduced: The direct torque control (DTC) method. It was proposed by Takahashi and Depenbrock. It bases on the direct selecting of the switching states to control the voltage source inverter (VSI) through a switching look-up table. Due to the limits of the conventional DTC strategy, especially the high torque and flux ripples problem, various control structures are presented to improve the performances of control. The constant switching frequency DTC using the space vector modulation (DTC-SVM) is a well discussed solution; in order to improve the DTC-SVM performances, hysteresis comparators of electromagnetic torque and stator flux have been replaced by PI controllers. The main drawbacks of DTC-SVM using PI controllers are the sensitivity of the performances to the system-parameter variations and the inadequate rejection of external disturbances and load changes. To cope with this disadvantage, it is suggested to replace the conventional regulators used for the speed control, flux, and electromagnetic torque by intelligent controllers by fuzzy logic to make the controls more robust against the disturbances of the parameters of the machine. The aim of this experiment is to study and compare the performances for the direct torque control (DTC) of induction motor (IM) with conventional control technique. The first method is a conventional direct torque control (C-DTC) where the torque and the flux are regulated by the hysteresis controllers. The second one is direct torque control by space vector modulation strategy (SVM-DTC) where the torque and flux are regulated by PI controllers. The third one is fuzzy SVM-DTC with adaptive fuzzy-PI speed controller where the torque and flux are regulated by fuzzy logic controllers can also implemented. The main feature of the proposed (SVM-DTC) strategy is the reduction of torque and flux ripples. The block diagram of the whole system is shown in Fig. 1(a). The details of SVPWM-DTC is depicted in Fig. 1(b). The descriptions of the said DTC controller is given in the following section.

a) Principles of DTC:

Direct torque control principle was introduced in the late 1980s. It achieves a decoupled control of the stator flux and the electromagnetic torque in the stationary frame (α, β), and it allows induction machines to have an accurate and fast electromagnetic torque response. It uses a switching table for the selection of an appropriate voltage vector. The selection of the switching states is related directly to the variation of the stator flux and the torque of the machine. Hence, the selection is made by restricting the flux and torque magnitudes within two hysteresis bands. Those controllers ensure a separated regulation of both of these quantities. The inputs of hysteresis controllers are the flux and the torque errors as well as their outputs determine the appropriate voltage vector for each commutation period.



(a)



(b)

Fig. 1 **DTC Control Logic for the IM Drives**

b) THREE PHASE VOLTAGE SOURCE INVERTER.

An inverter is a power electronic device, used to change the power from one form to other like DC to AC at the necessary frequency & voltage o/p. A three-phase inverter is used to change the DC voltage to three-phase AC supply is shown in Fig. 2. Generally, these are used in high power and variable frequency drive applications like HVDC power transmission. In a 3 phase, the power can be transmitted across the network with the help of three different currents which are out of phase with each other, whereas in single-phase inverter, the power can transmit through a single phase. For instance, if you have a three-phase connection in your home, then the inverter can be connected to one of the phase.

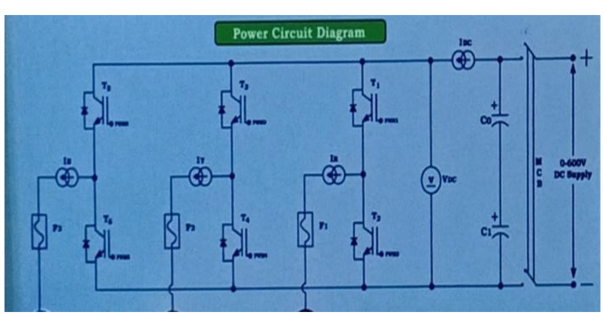


Fig. 2 Circuit diagram of a three-phase VSI

c) Rating of VSI

Inverter rating – 10KVA, Nominal current – 7.3A, Nominal voltage – 230V per phase

Maximum DC link voltage – 750V

d) TORQUE CONTROLLER FOR EDDY CURRENT DYNAMOMETER.

- In this controller need the 230V AC supply.
- It is provide the DC supply to the eddy current dynamometer.
- Maximum it will provide the 5A current to the eddy.
- But induction motor current rating is 2.4 A.
- **So operating the eddy maximum 1.1A only.**
- Eddy current dynamometer provides 0.5 n-m torque and 1500 rpm
- Excitation voltage is 80V.

D. CONNECTON PROCEDURE

- Three phase Autotransformer output is connected to the inverter three phase input.
- Inverter output is connected to the induction motor input terminals.
- Inverter needs auxiliary 230v power supply, so connect power card to the back side of the module from power socket plug point.
- Torque controller needs auxiliary 230v power supply, so connect power card to the back side of the module from power socket plug point.
- Torque controller output (dc) is connected to the eddy current dynamometer.
- In between the induction motor and eddy current dynamometer, having the torque sensor.
- Carefully handle the torque sensor because sensor cost is high.
- In inverter module sensor output connecting point is there near PWM signals test point.
- Connect the torque sensor to that point using the preferred cable (mic connector).
- FPGA controller needs auxiliary 230v power supply, so connect power card to the back side of the module from power socket plug point.
- Then connect the FPGA controller 40 pin connector points to THREE PHASE VOLTAGE SOURCE (PWM Signals to IGBT) module 40 pin connector using the FRC cable.
- Connect the FPGA controller 20 pin ADC connecter to module feedback signal to controller 20 pin connector using the FRC cable.

- Induction motor having a QEP sensor, sensor output is connected to the encoder kit using serial port cable.
- Encoder kit having the 40 pin connector. It will be connected between the 40 pin FRC cables.

E. Protection &Precaution

Protection

- Fuse is provided to protect the trainer from over current fault.
- If voltage is more than 750volt the protection will be enable and also Current is more than 10A that time also protection will be enable.
- Snubber circuit is provided to protect the IGBT from d v / d t.

Precaution

- Before doing connections make all switches in OFF position
- Three phase AC input to the device module should be given through a Variac.

While doing the experiment and fault occurs then immediately protection led's are enable. In this situation, first we reduce the autotransformer voltage to zero and then disable the protection switches do the experiment.

F. OBSERVATION TABLE:

Sl no	Ref speed	Actual speed	Load torque (In term of eddy current(A))	Estimated torque
1				
2				
3				
4				
5				
6				

DEPARTMENT OF ELECTRICAL ENGINEERING

Course name: Advanced power System Lab
Course code: EEC507

Experiment No.: 08

A. Title: Study the Performance of a Three-phase Cascaded H-bridge (CHB) Multilevel Inverter Experimental Setup.

B. Objectives:

1) Connect the circuit components, isolated voltage sources, gate pulses to the experimental circuit of a three-phase cascaded 5-level Inverter.
2) Observe the nature of gate pulses, the individual voltage output from the for the simulation results of PWM pulse patterns, voltage and current waveforms and analyze the harmonics present in the waveforms of the above inverter.

C. Apparatus Required:

1) Experimental setup of three-phase 5-level inverter
2) DSO, voltage and current clamps for measuring and analysis of waveforms
3) Three-phase variac to provide appropriate AC voltage
4) Isolation Transformer (within the setup)
5) Multimeter

D. Three-phase Cascaded Multilevel Inverter

The three-phase structure of a Cascaded 5-level inverter is shown in Fig. 1(b). It has three identical single-phase inverter legs for three-phase load applications. The switching table for a particular inverter phase (x=A, B, C) is given in Table 1. Each H-bridge inverter cell generates three distinct voltage levels of magnitude of +E, 0 & -E, as shown in the switching table. When the switches T_{11} and T_{14} of bridge-1 are ON, a voltage of +E appears across the H-bridge. Similarly, when the other two switches, T_{12} and T_{13} are ON, a voltage equal to -E appears across the output. However, when the two switches either top two switches (T_{11} & T_{13}) or bottom two switches (T_{12} & T_{14}) are ON, it will generate zero voltage. In the same way, the other H-bridge (Bridge-2) can also generate three voltage levels like +E, 0 & -E across the output of H-bridge-2. For cascaded connection of the two H-bridges with equal DC-link voltages (for symmetrical configuration), the two H-bridges can be cascaded to obtain a total five-level voltage across the whole inverter [given in Fig. 1(a)]. For three-phase inverters, three sinusoidal signals of appropriate magnitude are required to compare the switching function, as given in Fig. 2(b). The switching function for each phase is further decoded to obtain the gate pulses of the entire inverter to obtain the line voltages.

These phase voltages are +2E, +E, 0, -E & -2E are shown in Table 1. For a three-phase inverter, similar 5-level voltages are obtained at phase voltage with respect to the neutral. In the line voltages (phase to phase), total

9-level voltage levels of magnitude equal to 4E, +3E, 2E, +E, 0, -E, -2E, -3E & -4E are obtained, which can be generated based on the switching table given in Table 1.

Table 1 Switching Table of a Five-level CHB Inverter with equal Voltage Sources

Output Voltage v_{xn} (x=A,B & C phases)	*Switching Status for A-Phase*				Voltage of bridge-1 ($v_{AA'}$)	Voltage of bridge-2 $v_{A'n}$
	T_{11}	T_{31}	T_{12}	T_{32}		
2*E*	1	0	1	0	*E*	*E*
E	1	0	1	1	*E*	*0*
	1	0	0	0	*E*	*0*
	1	1	1	0	*0*	*E*
	0	0	1	0	*0*	*E*
0	0	0	0	0	*0*	*0*
	0	0	1	1	*0*	*0*
	1	1	0	0	*0*	*0*
	1	1	1	1	*0*	*0*
	1	0	0	1	*E*	-*E*
	0	1	1	0	-*E*	*E*
-*E*	0	1	1	1	-*E*	*0*
	0	1	0	0	-*E*	*0*
	1	1	0	1	*0*	-*E*
	0	0	0	1	*0*	-*E*
-2*E*	0	1	0	1	-*E*	-*E*

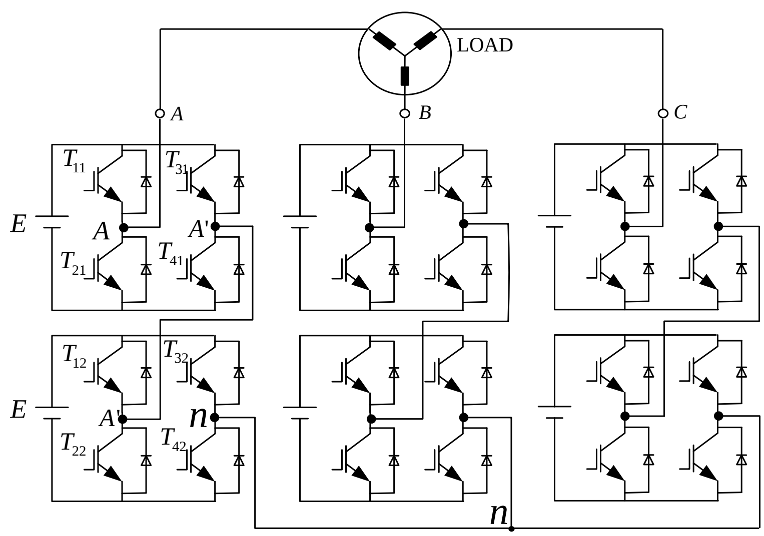


Fig. 1. Three-Phase cascaded 5-level inverters using IGBT

The connection diagram of the experimental 3-phase 5-level inverter with equal DC-link voltages (=E) is shown in Fig. 2. It is observed that one of the terminals of the lower H-bridges is shorted to form the inverter neutral.

The waveforms of the respective phase voltages V_{An}, V_{Bn} and V_{Cn} are also plotted which are identical to the pulse patterns. The corresponding line voltage V_{AB} of the three-phase VSI is also plotted in Fig. 3(b). It is observed that, though the phase voltages are not alternating, however, the line voltages are alternating.

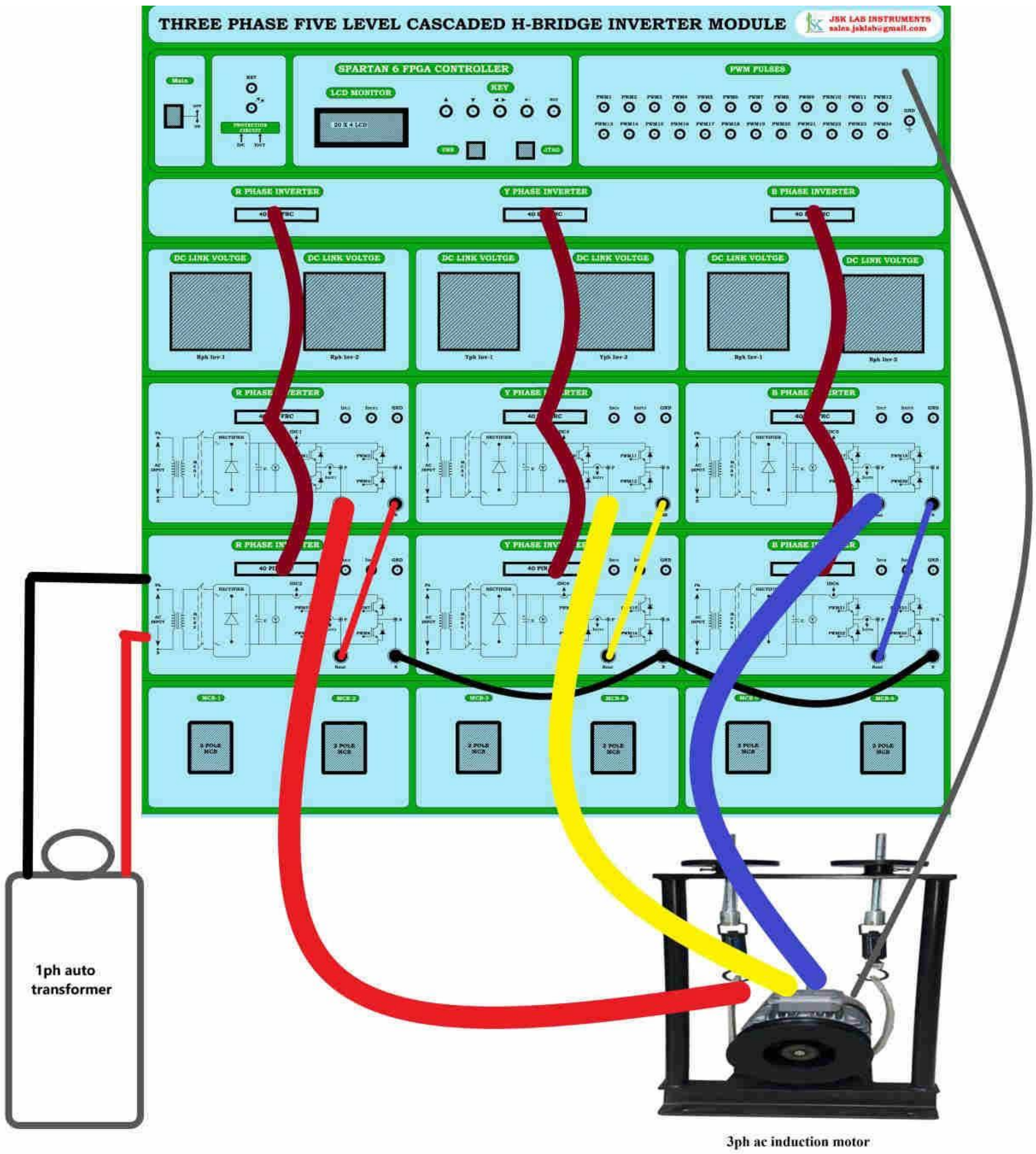


Fig. 2. Connection diagram of the three-phase 5-level cascaded H-Bridge Inverter with equal DC-link voltages

E. Level Shifted PWM Technique for a Cascaded Multilevel Inverter

In this method for a 5-level inverter, four triangular carrier signals with vertical disposition or level shifted along the positive and negative axis is done in such a way that they can be compared with the reference signal to generate the required switching states. The carrier signals which are compared with the reference signal to obtain the switching function. The switching function is further decoded to obtain the gate pulses for the five-level inverter are shown in Fig. 3(a).

The operation of the three-phase 5-level cascaded inverter under level-shifted PWM (LS-PWM) is explained. For implementing three-phase LS-PWM, three reference signals $V_{ref\text{-}A}$, $V_{ref\text{-}B}$ and $V_{ref\text{-}C}$ of 120-degree phase differences are continuously compared with four high-frequency triangular-carrier signals (V_{cr}) as shown in Fig. 3(a). The reference signal for the three-phase references are given by:

$$\left.\begin{aligned} V_{ref,A} &= V_m \sin \omega t \\ V_{ref,B} &= V_m \sin(\omega t - 120^0) \\ V_{ref,C} &= V_m \sin(\omega t - 240^0) \end{aligned}\right\} \tag{2}$$

The carrier signals for a specimen seven-level with the same frequency f_c, phase and the same amplitude V_c are disposed of such that the bands they occupy are contiguous, as shown in Fig. 3. Moreover, the nature of the switching function for a specimen seven-level inverter is also shown in the figure. In multilevel inverters, the amplitude modulation index M_i and frequency modulation index M_f of any phase is defined as

$$\left.\begin{aligned} M_i &= \frac{V_m}{(M-1)V_c} \\ M_f &= \frac{f_c}{f_m} \end{aligned}\right\} \tag{3}$$

The value of M_f should be chosen in such a manner that it should be multiple of three for low switching frequency to reduce inter-harmonics.

If the reference signal for phase x (x=A, B, C phase) is higher than the carrier at a particular instant and the corresponding converter cell has positive output voltage (Sx= +1), then the active device corresponding to that carrier is switched ON. If the reference is less than a carrier signal, then the active device corresponding to that carrier is switched OFF and produce a lower state (Sx= -1). The nature of the switching function for phase-A of the above case is shown in Fig. 3. This switching function can be further decoded as per the switching Table 1 to obtain the actual gate pulses. This LSPWM algorithm is implemented in XILINX_ Spartan-6 XC6SLX9-TQG144 (SP6_LX9) Board using the VHDL language. The entire PWM pulses (24 nos.) are send to the 5V digital I/Os of the FPGA connector listed in Table. 2. Fig. 3(b) Waveforms of phase voltages. It is observed from Fig. 3 that the switching function, as well as the phase voltage, are identical.

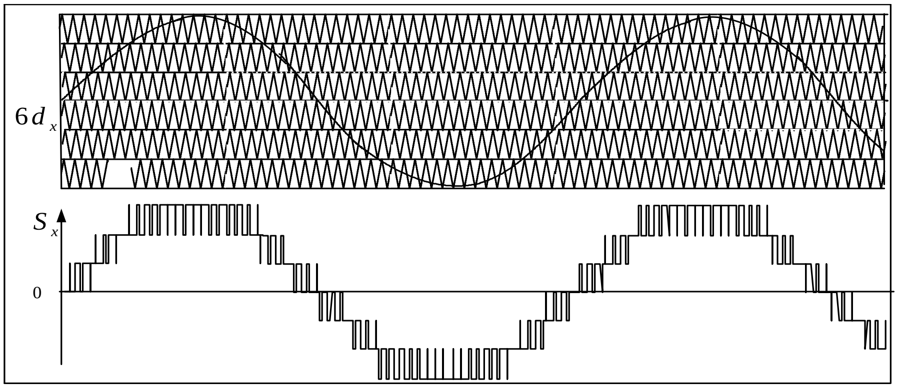


Fig. 3(a) A carrier-based level-shifted PWM (LS-PWM) for a specimen seven-level inverter showing carrier bands and switching function

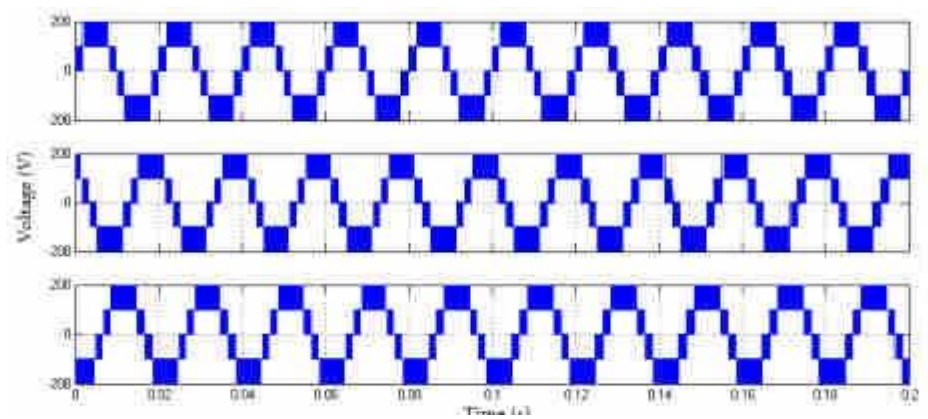


Fig. 3(b) Corresponding pattern of the output phase voltage of the five-level inverter

F. Connection Procedures:

1. Connect Single Phase Power Supply from the Auto Transformer to the Setup as step-up transformer shown in the Figure and parallel short all Phase and all neutral
2. Connect all phase and neutral points in left side of pannel
3. Connect R, Y, B phase of the Inverter to the 3-phase induction motor, respectively.
4. Short the second leg of all the lower H-bridges for the three-phase MLI as shown in Fig. 2.
5. Short 1ST inverter N and 2nd inverter P,
6. Connect the Speed Sensor Feedback Signal from the Motor to the Unit (In the PWM Section) use center latched 40 pin connector for feedback
7. Connect the power supply to 3ph 5 level power module
8. Connect the 40 pin FRC cable from the FPGA to the Inverter. (R PHASE INVERTER TO R PHASE INVERTER) AND Y TO Y, B TO B, respectively.
9. Switch on UNIT verify LCD display to 3ph 5level inverter
10. Turn on all MCB's FROM MCB 1 to MCB6.
11. Give Single phase supply to primary of P, N present in the left side of the panel Apply 100 V Max in all H-

bridge inverter dc voltages as indicated in the meter

12. Vary the reference speed threw push (UP/DOWN) switches in the FPGA board by varying the modulation index or set speed of the MLI.
13. By changing the dip switch (1) position vary the loop
14. Observe the performance in an open and closed-loop
15. Load the motor and observe the current signals in the test points

The 5V input signals are given through the P10 connector. Here level translator is converting these 5V inputs into 3.3V level and it's given to FPGA. The output PWM pulses from the FPGA is obtained from the digital I/O ports with pin numbers are given in Table 2.

Table 2 PWM Ports for the Xilinx FPGA Board (XILINX_ Spartan-6 XC6SLX9-TQG144)

PWM signals and corresponding Xilinx digital I/O ports					
5IO1→ P40	5IO2→ P39	5IO3→ P35	5IO4→ P34	5IO5→ P33	5IO6→P32
5IO7→ P30	5IO8→ P29	5IO9→P50	5IO10→ P48	5IO11→P47	5IO12→ P46
5IO13→P45	5IO14→P44	5IO15→P43	5IO16→ P41	5IO17→P141	5IO18→ P140

G. Observations (under closed-loop operation)

Five-level Inverter with DC-Link voltages: (DC-link voltages, E= , switching frequency, fcr= 3kHz, Load=3-phase IM)

SL. No	Set speed & actual of the 3-ph IM	Inverter fundamental frequency	Output phase voltage (V_{An})	Output phase current (I_{As})	Power Factor	Total 3-phase Power (Watt)

H. Answer the following questions:

1. **Write the best switching combinations from the redundant switching states for minimum switching transitions for lower switching losses of the 5-level inverter.**
2. **Calculate the number of turn-ON and turn-OFF times of each switch for phase-A**

Course name: Power System Lab, Course code: EEC507

EXPERIMENT-9

A. Title: Experimental study of Open- and closed loop Speed Control of a four-phase switched reluctance (SR) Motor drive.

B. Objectives:

a) Perform an experiment for an open-loop and closed-loop control of the four-phase SR Motor.

b) Observe the output waveform of voltage and current for different reference speed.

C. Apparatus Required:

1. LCI-4PHSRM-1HP (Device) module - 1no.
2. SR Motor With spring balance Load setup
3. FPGA Spartan6 controller—1no
4. Patch chords.
5. PC Power chord---1no

D. THEORY:

a) INTRODUCTION

A Switched Reluctance or Variable Reluctance Motor does not contain any permanent magnets. The stator is similar to a brushless dc motor. However, the rotor consists only of iron laminates. The iron rotor is attracted to the energized stator pole. The polarity of the stator pole does not matter. Torque is produced as a result of the attraction between the electromagnet and the iron rotor.

The rotor forms a magnetic circuit with the energized stator pole. The reluctance of a magnetic circuit is the magnetic equivalents to the resistance of an electric circuit. The reluctance of the magnetic circuit decreases as the rotor aligns with the stator pole. When the rotor is in-line with the stator the gap between the rotor and stator is very small. At this point the reluctance is at a minimum. This is where the name "Switched Reluctance" comes from.

Features of SR Motor Drives

- The rotor does not have any windings, commutators, brushes or cages.
- The torque-inertia ratio is high.
- It provides high reliability, wide-speed range at constant power; low manufacturing cost,

  fast dynamic response, ruggedness and fault-tolerance.
- No shoot-through and crossovers in the converter.

- The maximum permissible rotor temperature is higher since there is no permanent magnet.
- Open-circuit voltage and short-circuit current at faults are zero or very small.
- Doubly salient structure causes vibration and acoustic noise.
- High torque-ripple.

A power module to drive Switched Reluctance (SR) or Variable Reluctance Motor is shown in Fig. 1(a). The structure of 8/6 pole variable reluctance SR motor is shown in Fig. 1(b).

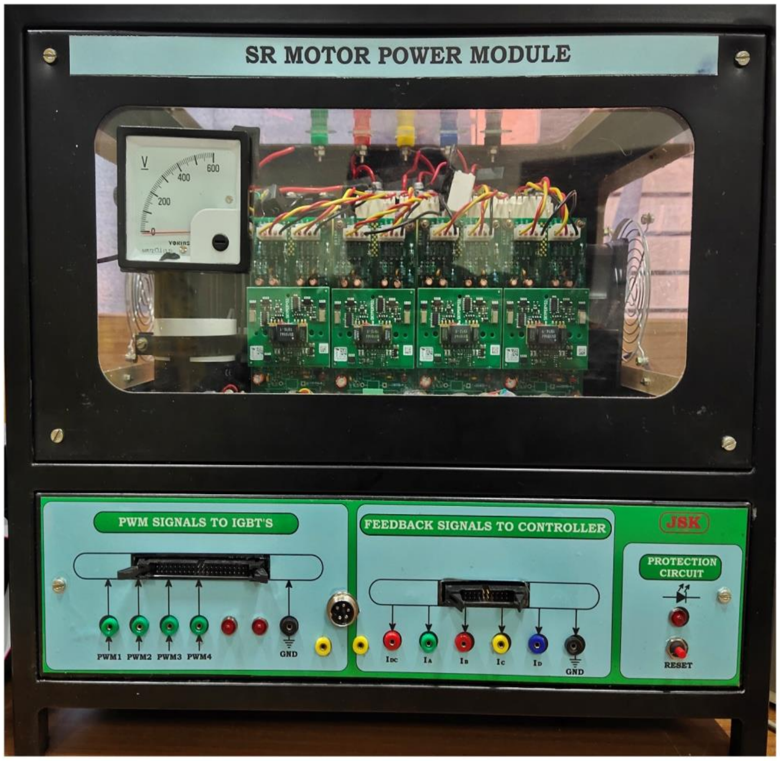


Figure – 1(a) 4PH SRM Power Module

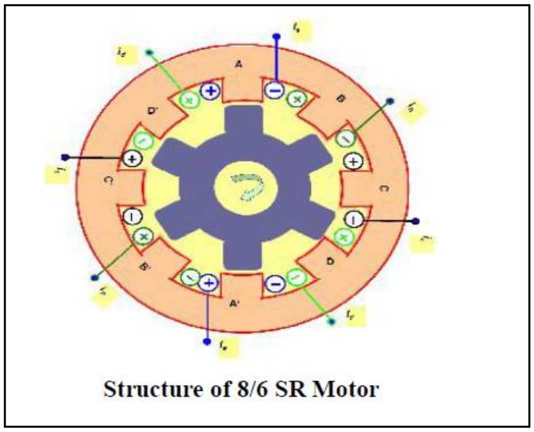


Fig. 1 (b) Cross Sectional View of an SR Motor

b) OPERATING PRINCIPLE:

The SRM has wound field coils as in a DC motor for the stator windings. The rotor however has no magnets or coils attached. It is a solid salient-pole rotor (having projecting magnetic poles) made of soft magnetic material (often laminated-steel). When power is applied to the stator windings, the rotor's magnetic reluctance creates a force that attempts to align the rotor pole with the nearest stator pole. In order to maintain rotation, an electronic control system switches on the windings of successive stator poles in sequence so that the magnetic field of the stator "leads" the rotor pole, pulling it forward. Rather than using a troublesome high-maintenance mechanical commutator to switch the winding current as in traditional motors, the switched-reluctance motor uses an electronic position sensor to determine the angle of the rotor shaft and solid state electronics to switch the stator windings, which also offers the opportunity for dynamic control of pulse timing and shaping. This differs from the apparently similar induction motor which also has windings that are energized in a rotating phased sequence, in that the magnetization of the rotor is static (a salient pole that is made 'North' remains so as the motor rotates) while an induction motor has slip, and rotates at slightly less than synchronous speed. This absence of slip makes it possible to know the rotor position exactly, and the motor can be stepped arbitrarily slowly.

E. SWITCHING TECHNIQUES OF SR MOTOR

a) SIMPLE SWITCHING:

If the poles A0 and A1 are energized then the rotor will align itself with these poles. Once this has occurred it is possible for the stator poles to be de-energized before the stator poles of B0 and B1 are energized. The rotor is now positioned at the stator poles b. This sequence continues through c before arriving back at the start. This sequence can also be reversed to achieve motion in the opposite direction. This sequence can be found to be unstable while in operation, under high load, or high acceleration or deceleration, a step can be missed, and the rotor jumps to wrong angle, perhaps going back one instead of forward three.

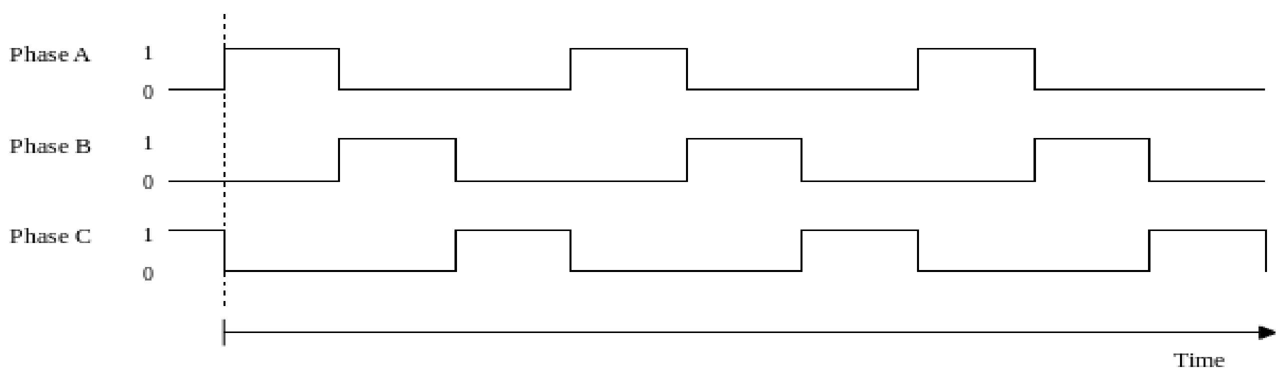


Fig. 2(a) Pulse pattern of the SR Motor (simple switching)

b) IMPROVED SWITCHING SEQUENCE:

A much more stable system can be found by using the following "quadrature" sequence. First, stator poles A0 and A1 are energized. Then stator poles of B0 and B1 are energized which pulls the rotor so that it is aligned in between the stator poles of A and B. Following this the stator poles of A are de- energized and the rotor continues on to be aligned with the stator poles of B,this sequence continues through BC, C and CA before a full rotation has occurred. This sequence can also be reversed to achieve motion in the opposite direction. As at any time two coils are energized, and there are more steps between positions with identical magnetization, so the onset of missed steps occurs at higher speeds or loads.

In addition to more stable operation, this approach provides a well-timed sequence as the timings of the phase being both on and off are equal, rather than being at a 1:2 ratio as in the simpler sequence

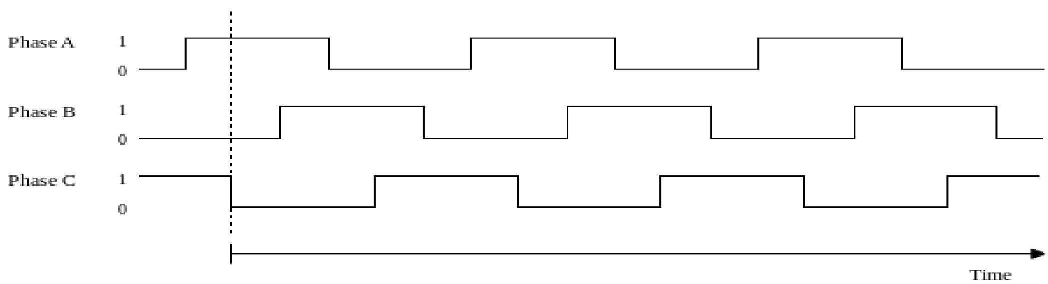


Fig. 2(b) Pulse pattern of the SR Motor (simple switching)

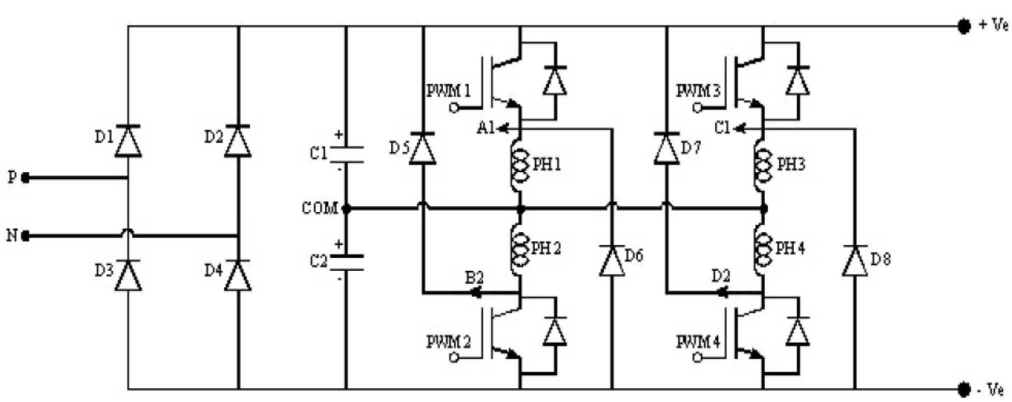


Fig. 3. Power circuit of the 4-phase SR Motor

The most common approach to the powering of a switched reluctance motor is to use an asymmetric bridge converter. There are 4 phases in an asymmetric bridge converter corresponding to the phases of the switched reluctance motor. If both of the power switches on either side of the phase are turned on, then that corresponding phase shall be actuated. Once the current has risen above the set value, the switch shall turn off. The energy now stored within the motor winding shall now maintain the current in the same direction until that energy is depleted. This basic circuitry may be altered so that fewer components are required although the circuit shall perform the same action. This efficient circuit is known as the (n+1) switch and diode configuration. A capacitor, in either configuration, is used to suppress electrical and acoustic noise by limiting fluctuations in the supply voltage.

SR MOTOR SPECIFICATION:

- POWER--------1hp
- No of phase----4phases
- VOLTAGE-----300v
- CURRENT-----2A peak
- SPEED----------2000rpm @FULL LOAD
- Position sensor--optical sensor used
- Type --------8/6

F. Experimental Procedure:

CONNECTION PROCEDURE

1. Connect the 40 pin FRC cable from the FPGA SPARTAN 6 kit to SRM Power module
2. Connect the feedback cable from the motor to Feedback connector in front panel of SRM Power Module.
3. Connect the RYBGB cable from the motor to RYBGB terminals in “b” Top panel of SRM Power Module.
4. Connect the output terminals of 1ph autotransformer and 1phase input terminals in Left Side panel of SRM Power Module using patch chords.
5. Connect the USB cable from the system to FPGA SPARTAN 6 kit.
6. Set the Speed in FPGA for “Ref. speed in RPM”.
7. Then vary the input supply, motor can rotate and settling to Ref. Speed “then the “Actual speed” will be same as “Ref. Speed”.

G. Observations Under

a) OPEN-LOOP CONTROL:

SPEED CONTROL IN OPEN LOOP:

SNO	SET DUTY CYCLE	ACTUAL SPEED (rpm)	S1(spring balance reading in kg)	S2(spring balance reading in kg)	Torque((s1-s2)*R*9.81) R-radius of the drum=0.09m
1.					

2.					
3.					
4.					

*In open loop when load is applied Torque will increase and speed will be reduced

B) CLOSED-LOOP CONTROL:

SPEED CONTROL IN CLOSED LOOP:

SNO	REF SPEED(rpm)	ACTUAL SPEED (rpm)	S1(spring balance reading in kg)	S2(spring balance reading in kg)	Torque((s1-s2)*R*9.81) R-radius of the drum=0.09m
1.					
2.					
3.					
4.					

*In Closed loop when load is applied Torque will increase and speed will be maintaining the same speed due to PI control.

NOTE: To view the output in CRO, it must be isolated

Give the answer to the following equations:

Q1) Draw and analyze the waveforms of reluctance versus rotation angle for a variable reluctance SR motor.

Q2) Derive the expression of torque developed by the variable reluctance SR motor.