# DC MOTOR SIMULATION AND ITS SPEED CONTROL USING PID,FUZZY AND FUZZY PID CONTROLLER IN LABVIEW AND SIMULINK

## AIM

To use LabVIEW and Simulink to simulate the response of a dc motor based on a mathematical model derived from the physical model of the actual system. And then its speed control using PID, Fuzzy and Fuzzy PID Controller.

## APPARATUS REQUIRED

PC with LabVIEW 8.5 Software and MATLAB 2013a.

## DESCRIPTION

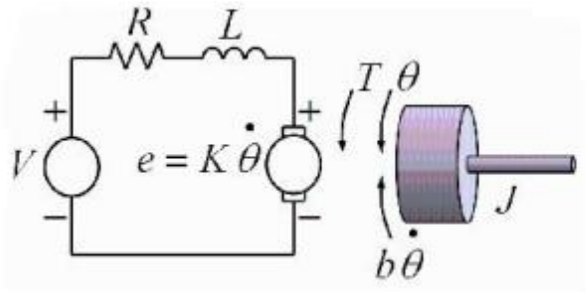


Fig 1. Mathematical model of a dc motor

| Electrical Subsystem | Mechanical Subsystem |
|---|---|
| $Vapp = L\frac{di}{dt} + Ri + Eb$<br>$Eb = Kb * \frac{d\theta}{dt}$<br>$\frac{di}{dt} = \frac{(Vapp - Ri - Kb*\frac{d\theta}{dt})}{L}$ | $J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} = T$<br>$T = Kt * i$<br>$\frac{d^2\theta}{dt^2} = \frac{(Kt * i - B * \frac{d\theta}{dt})}{J}$ |

| | | | |
|---|---|---|---|
| J | = | Motor Inertia = 8.5E-6 (kg-m2) | |
| B | = | Viscous damping coefficient | = 3.7E-6 |
| R | = | Internal resistance | = 1.85(Ω) |
| L | = | Internal inductance | =1.95(mH) |
| Kt | = | Torque constant | =4.24E-2 (N-m/A) |
| Kemf | = | Back emf constant | =4.24E-2 (V/rad/sec) |
| Vapp | = | Applied voltage (volt) | |
| ϴ | = | Angular position of motor shaft (rad) | |
| i(t) | = | Current through the motor at time t sec | |

**PROCEDURE IN LABVIEW**

Step 1:

Open the LabVIEW 8.5. Open a new project (empty project). The project window will appear then right click on "my computer"→"New"→"VI". A blank front panel will appear and behind that an empty block diagram.

Step 2:

Select the block diagram window (press control and E keys simultaneously). To view both block diagram and front panel windows simultaneously, press control +T.

Step 3:

Add a simulation loop within which the equations will be implemented. For this open LabVIEW function palette. Next click "control design and simulation" then click "simulation" and finally click the simulation loop.

Step 4:

Before implementing the equations save the VI file. Create 4 constant doubles 'Vapp', 'Kemf', 'R' and 'L' and one control "Theta dot".

Make sure each of these is set to double precision.

Step 5:

Implement the electrical subsystem

$$\frac{di}{dt} = \frac{(Vapp - Ri - Kb * \frac{d\theta}{dt})}{L}$$

This can be done by adding suitable blocks from function palette (like multiplication (3), addition (2) etc). Properly wire the blocks according to the equation given above.

Step 6:

Next we will want to encapsulate all that we have created thus far in order to reduce the complexity of the block diagram. To do this, select all of the blocks that we have placed inside the simulation loop by clicking and dragging a box around them. Then select “Edit”→”Create simulation subsystem”. The blocks have now been incorporated into a separate VI. Save the VI.

Step 7:

Open a new VI. Create a simulation loop ass above and implement the equation for the mechanical portion of the system. To do this, first add three constant doubles, three multiplication blocks and one addition block. The three constants will be ‘Kt’, ‘B’ and “J”. Wire them according to the equation given.

$$\frac{d^2\theta}{dt^2} = \frac{(Kt * i - B * \frac{d\theta}{dt})}{J}$$

Select the mechanical system blocks and create mechanical subsystem. Save the subsystem VI.

Step 8:

Open a new VI. Right click in the block diagram. Open a simulation loop. Click open “select a VI”. Select the electrical subsystem and mechanical subsystem VI s. Interconnect the subsystems appropriately.

Add measuring blocks to graphi(t) and omega. Before running the VI, adjust the simulation parameters. Switch back to the block diagram, then right click on the simulation loop border and select “configure simulation parameters”.

Change the final time to 0.1 seconds, ODE solver to “Runga-kutta1 (Euler)” and step size to 0.00001 seconds. Then click ok. Before running the completed VI, switch back to the front panel then right click on the graphs and select ”chart history length”. Enter 50000 for this value.

Change the ranges of X and Y axis. To do this double click the final value and change it to 0.10 for x-axis. Also change the y axis on the i(t) plot to range from 0-5 and the y-axis on the range omega plot to 0-150. Uncheck “Auto scale Y axis”. Finally click the run button to view the simulation results.

Step 9:

Replace the input voltage by a PID control block and check the system response by giving various values of the controller gains.

**<u>Procedure in Simulink</u>**

1. Model the DC Motor as according to the above equations.

2. Give load torque in the form of a STEP input.

3. Add a PID block and condition the error signal generated from the reference value, by entering different Kp, Ki and Kd values and hence check the response.

4. Open the fuzzy editor by typing fuzzy in the command prompt window.

5. Set up the membership functions for the input variables and the output variables.

6. Design a rule base for the input and the output variables and then export the editor file to the workspace.

7. Generate two input signals for the fuzzy controller, one is the error signal another change in error signal.

8. Pass the input signals through a multiplexor hence vectorizing them and hence give them as input to the fuzzy controller where the name of the editor file should be mentioned.

9. Observe the response of the fuzzy logic based speed control of DC Motor.

10. In a similar way design the fuzzy logic membership functions and rule base for Kp, Ki and Kd for implementing fuzzy-pid speed control of DC motor.

11. The output generated from the fuzzy controllers should be conditioned in such a way to generate a PID control signal.

12. Observe the response of fuzzy logic based PID controller based speed control of DC Motor.

**Prerequisites**

Study the following:

1) The mathematical modeling of the DC motor.

2) The speed-time and current-time curves.
3) Types of connections used for DC motors
4) Speed torque characteristics of DC motor.

## **Experiment on NI myDAQ**

**Aim:** To study and understand the Compact Field Point hardware and software configuration

**Principle:**

NI Compact Field Point is a Programmable Automation Controller(PAC) which offers flexibility and ease of use of a PC and the reliability of a PLC. With Compact Field Point , powerful control and measurement systems can be developed using LABVIEW Real Time application. Thus it can be deployed on the intelligent controllers for reliable distributed I/O or standalone process control applications. In CFP, all the intelligence, advanced control and analytical capabilities of LABVIEW can be embedded in a small modular package which is suitable for industrial environment.

The Compact Field Point I/O modules can filter, calibrate and scale raw sensor signals to engineering units as well as perform self diagnostics to look for problems such as open thermocouple. Through built in net and servers, CFP interface automatically publishes measurement over Ethernet.

**I/O module features**

Analog and Digital I/O modules for Compact Field Point are having the following features

- Direct Connectivity to sensors and actuators.
- 8 and 16 channel modules; individually configurable channels.
- Hot swappable and auto configurable.
- Programmable power up states.
- -40$^{o}$C to 70$^{o}$C operating range.

**Connections Between PC and CFP**

1. Connect the CFP to your PC using an Ethernet cross over cable.

2. Install and configure the CFP.

(i) Use the Measurement and Automation Explorer (MAX) to configure the CFP.

(ii) Go to remote systems. Right click on remote system and click create new.

(iii) Click on Field Point Ethernet and set the IP address.

(iv) All the CFP modules appear at that time.

Hardware Procedure

1. Connect the power supply cable to the NI Compact Field Point.
2. Connect the Ethernet cable between PC and CFP.

3. Select the respective I/O Module remove it from the backplane.

4. Make the respective wiring for input/output, power supply and common connector.

5. Place the I/O module to the backplane and lock it with the screw properly.

6. Give the analog/digital input to the respective wire or measure the output from the respective wire depending upon the applications.

Software Procedure

1. Open LABVIEW and select the Real Time Project.

2. Select the project type as "Continous Communication Architecture" and check "Application includes deterministic components". Enter the project name and the folder where it will be saved.

3. Choose the target configuration as one loop (default).

4. For selecting signal target, click browse→select "Existing device or target". From targets and devices explorer select "Real Time Field

Point”. Select Compact and press OK in the premium project explorer and click Finish.

5. Project Explorer will list the available analog and digital I/Os in the CFP.

6. Select the respective CFP and channel.

7. Juts drag and drop in the target window. Field Point I/O point will appear. Select the Value Pin and connect it to the system as either input/output

8. Perform the required operation and check the functionality on the respective analog/digital I/O.

## Experiment on NI myDAQ

**Aim:** To acquire Analog/Digital signal by interfacing NI myDAQ with LABVIEW

**Components Required:**

1. PC with LABVIEW installed
2. NI myDAQ
3. Regulated Power Supply
4. Connecting wires

**Theory:**

NI myDAQ is a portable low cost data acquisition (DAQ) device that uses NI LABVIEW software to measure and analyse real time signals. NI myDAQ is ideal for exploring and measuring real time sensor data. Combined with NI LABVIEW on the PC, acquired signals can be analysed, processed and controlled.

NI myDAQ provides analog input (AI), analog output (AO), digital input and output( DIO), audio, power supplies and digital multimeter(DMM) functions and a compact USB Device. The functions of each port of NI myDAQ is as follows

(i) Analog Input(AI): These are two analog input channels on NI myDAQ. These channels can be configured as general purpose high impedance differential voltage input or audio input.

(ii) Analog Output(AO): These are two analog output channels on NI myDAQ. These channels can be configured as either general purpose voltage output or audio output.

(iii) Digital Input/output(DIO): There are 8 DIO lines on NI myDAQ. Each line is a programmable function interface(PFI), meaning that it can be configured as a general purpose software timed digital input or output or it can act as a special function or output for a digital counter.

**Procedure**

1. Connect NI myDAQ with PC using USB port and switch on RPS.

2. Connect positive terminal of the 0-30 V power supply to NI myDAQ(AI0+).

3. Connect negative terminal of the 0-30 V power supply to NI myDAQ(AI0-).

4. Open blank VI in LABVIEW.

5. Right click on the block diagram and obtain the DAQ assistant by clicking on Express→Input→DAQ assistant.

6. Click on the acquire signal→ Analog Input→Voltage→ ai→finish

7. Now DAQ assistant window will appear select acquisition model as 1 sample (on demand) then click OK.

8. Connect a numeric indicator with data terminal of DAQ assistant block.

9. Now run the VI and observe the result.

10. Now apply the same procedure to apply input voltage supply through myDAQ to the DC Motor model in LABVIEW and observe the result.

11. Same procedure can be followed to acquire the digital input signal as well.

# LAB MANUAL

## STATCOM AND FACTS CONTROLLER

## HYBRID MICROGRID SETUP

The setup consists of a hybrid micro-grid with sources as solar energy and wind energy. Solar panels and a wind turbine are installed on the roof top whose terminals are available at the solar-wind wiring panel. The rating of the solar panels and wind turbine is given below.

Solar Panel: 1 kW, 450 V, 25 panels

Wind Turbine: 1 kW, 24 V (line to line), PMSG.

Apart from the wind turbine at the rooftop, a wind turbine generator is provided in the wind simulator lab, where the turbine is run using the artificial wind generated by the wind simulator for testing purposes. An uncontrolled rectifier converts the AC output of the wind turbine generator into DC and the voltage is stepped up by a DC boost converter. The output of both the wind turbines and the solar panels is then fed to the hybrid power controller which is a buck-boost converter with MPPT algorithm and dsPIC based PWM generator. By varying the modulation index of the PWM signal generated by dsPIC based PWM generator, maximum power point can be obtained. The output of the hybrid power controller is then connected to the battery bank with the rating of 300 V, 42 Ah.

The DC link voltage of the battery bank is converted into three phase 110V, 50Hz AC voltage using an intelligent power module (IPM) which is basically a voltage source inverter. The output of this IPM is then fed to an equivalent pi transmission line model with FACTS devices (STATCOM and SSSC) on the receiving end of which different AC loads can be connected. The 300 V DC output of the battery bank is also fed to a 300 V DC bus where different DC loads can be connected.

As a future expansion, researches are being going on in order to connect this micro-grid setup to utility grid.

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# Flexible AC Transmission Systems (FACTS)

The increase in the loading of the transmission lines sometimes can lead to voltage collapse due to the shortage of reactive power delivered at the load centers. This is due to the increased consumption of the reactive power in the transmission network and the characteristics of the load (such as induction motors supplying constant torque).

Flexible AC Transmission Systems (FACTS) refers to alternating current transmission systems incorporating power electronics-based controllers to enhance the controllability and increase power transfer capability. The FACTS technology opens up new opportunities for controlling both active and reactive powers and enhancing the usable capacity of present transmission systems. The possibility that power through a line can be controlled enables a large potential of increasing the capacity of lines. This opportunity is arises through the ability of FACTS controllers to adjust the power system electrical parameters including series and shunt impedances, current, voltage, phase angle, and damping of oscillations etc.

The FACTS controllers can be classified as

1. Shunt connected controllers
2. Series connected controllers
3. Combined series-series controllers
4. Combined shunt-series controllers

Depending on the power electronic devices used in the control, the FACTS controllers can be classified as

A. Variable impedance type
B. Voltage Source Converter (VSC) based.

The variable impedance type controllers include:

i. Static VAR Compensator (SVC), (shunt connected)
ii. Thyristor Controlled Series Capacitor or compensator (TCSC), (series connected)
iii. Thyristor Controlled Phase Shifting Transformer (TCPST) of Static PST (combined shunt and series)

The VSC based FACTS controllers are:

i. Static synchronous Compensator (STATCOM) (shunt connected)
ii. Static Synchronous Series Compensator (SSSC) (series connected)
iii. Interline Power Flow Controller (IPFC) (combined series-series)
iv. Unified Power Flow Controller (UPFC) (combined shunt-series)

Some of the special purpose FACTS controllers are

a) Thyristor Controller Braking Resistor (TCBR)

b) Thyristor Controlled Voltage Limiter (TCVL)
c) Thyristor Controlled Voltage Regulator (TCVR)
d) Interphase Power Controller (IPC)
e) NGH-SSR damping

The FACTS controllers based on VSC have several advantages over the variable impedance type. For example, a STATCOM is much more compact than a SVC for similar rating and is technically superior. It can supply required reactive current even at low values of the bus voltage and can be designed to have in built short term overload capability. Also, a STATCOM can supply active power if it has an energy source or large energy storage at its DC terminals.

The only drawback with VSC based controllers is the requirement of using self-commutating power semiconductor devices such as Gate Turnoff (GTO) Thyristor, Insulated Gate Bipolar Transistors (IGBT), and Integrated Gate Commutated Thyristors (IGCT). Thyristors do not have this capability and cannot be used although they are available in higher voltage ratings and tend to be cheaper with reduced losses. However, the technical advantages with VSC based controllers coupled will emerging power semiconductor devices using silicon carbide technology are expected to lead to the wide spread use of VSC based controllers in future.

**Benefits with the Application of FACTS Controllers**

Primarily, the FACTS controllers provide voltage support at critical buses in the system (with shunt connected controllers) and regulate power flow in critical lines (with series connected controllers). Both voltage and power flow are controlled by the combined series and shunt controller (UPFC).

The power electronic control is quite fast and this enables regulation both under steady state and dynamic conditions (when the system is subjected to disturbances). The benefits due to FACTS controllers are listed below.

1. They contribute to optimal system operation by reducing power losses and improving voltage profile.

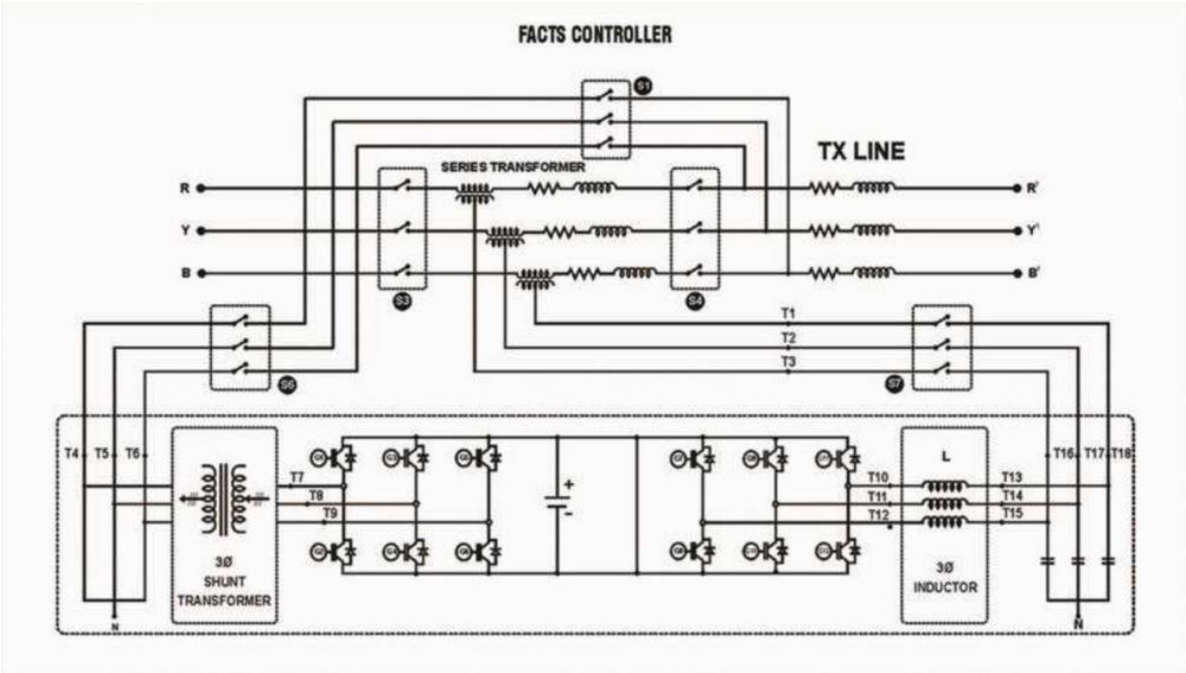
2. The power flow in critical lines can be enhanced as the operating margins can be reduced due to fast controllability. In general, the power carrying capacity of lines can be increased to values up to the thermal limits (imposed by current carrying capacity of the conductors).

3. The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.

4. The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations.

5. FACTS controllers such as TCSC can counter the problem of Sub-synchronous Resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal power stations (with turbo-generators).

6. The problem of voltage fluctuations and in particular, dynamic over voltages can be overcome by FACTS controllers.




## Application of FACTS Controllers in Distribution Systems

Although the concept of FACTS was developed originally for transmission network; this has been extended since last 10 years for improvement of Power Quality (PQ) in distribution systems operating at low or medium voltages.

In the early days, the power quality referred primarily to the continuity of power supply at acceptable voltage and frequency. However, the prolific increase in the use of computers, microprocessors and power electronic systems has resulted in power quality issues involving transient disturbances in voltage magnitude, waveform and frequency. The nonlinear loads not only cause PQ problems but are also very sensitive to the voltage deviations.

In the modern context, PQ problem is defined as "Any problem manifested in voltage, current or frequency deviations that result in failure or maloperation of customer equipment".

The PQ problems are categorized as follows

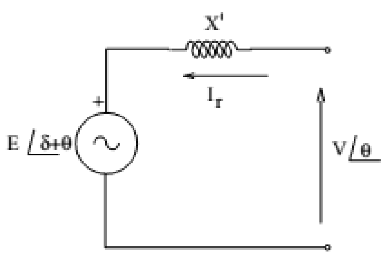
1. Transients
   a. Impulsive
   b. Oscillatory
2. Short-duration and Long-duration variations
   a. Interruptions

b. Sag (dip)
c. Swell
3. Voltage unbalance
4. Waveform distortion
a. DC offset
b. Harmonics
c. Inter-harmonics
d. Notching
e. Noise
5. Voltage Flicker
6. Power frequency variations

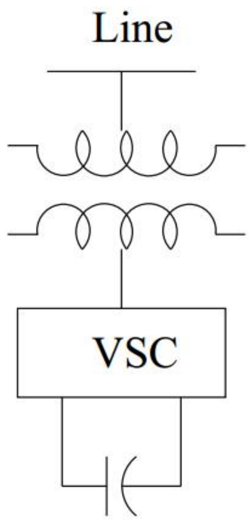
**Static Synchronous Compensator (STATCOM)**

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig. below, which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle (δ) difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When E = V, the reactive current output is zero. When E > V, the SC acts as a capacitor whereas when E < V, the SC acts as an inductor. When δ = 0, the reactive current drawn ($I_r$) is given by

$$I_r = \frac{V - E}{X'}$$




A STATCOM (previously called as static condenser (STATCON)) has a similar equivalent circuit as that of a SC. The AC voltage is directly proportional to the DC voltage ($V_{dc}$) across the capacitor




If an energy source (a battery or a rectifier) is present on the DC side, the voltage $V_{dc}$ can be held constant. The self-commutated switches $T_1$ and $T_2$ (based on say GTOs) are switched on and off once in a cycle.

Unlike in the case of a SC, the capacitors can be charged from the AC side and there is no need of an energy source on the DC side if only reactive current is to be provided in steady state. The losses in the STATCOM can be met from the AC source. The advantages of a STATCOM over a SC are:

a. The response is much faster to changing system conditions.
b. It does not contribute to short circuit current.
c. It has a symmetric lead-lag capability.
d. It has no moving parts and hence the maintenance is easier.
e. It has no problems of loss of synchronism under a major disturbance.

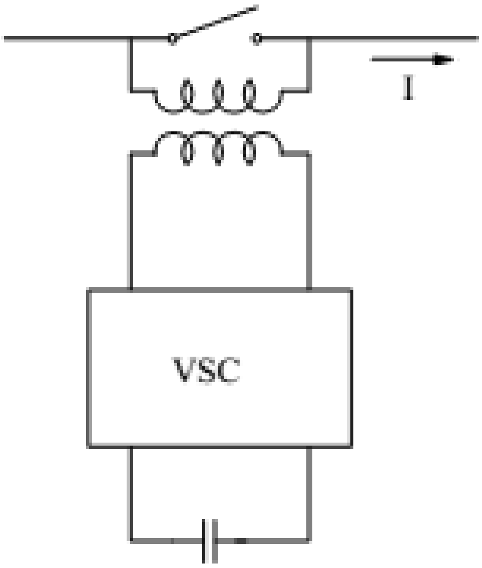
**Static Synchronous Series Compensator**

The Static Synchronous Series Compensator (SSSC) is a series connected FACTS controller based on VSC and can be viewed as an advanced type of controlled series compensation, just as a STATCOM is an advanced SVC. A SSSC has several advantages over a TCSC such as

a. Elimination of bulky passive components – capacitors and reactors
b. Improved technical characteristics
c. Symmetric capability in both inductive and capacitive operating modes
d. Possibility of connecting an energy source on the DC side to exchange real power with the AC network.

However, a SSSC is yet to be installed in practice except as a part of UPFC or Convertible Static Compensator (CSC

The schematic of a SSSC is shown in figure below.




**Unified Power Flow Controller**

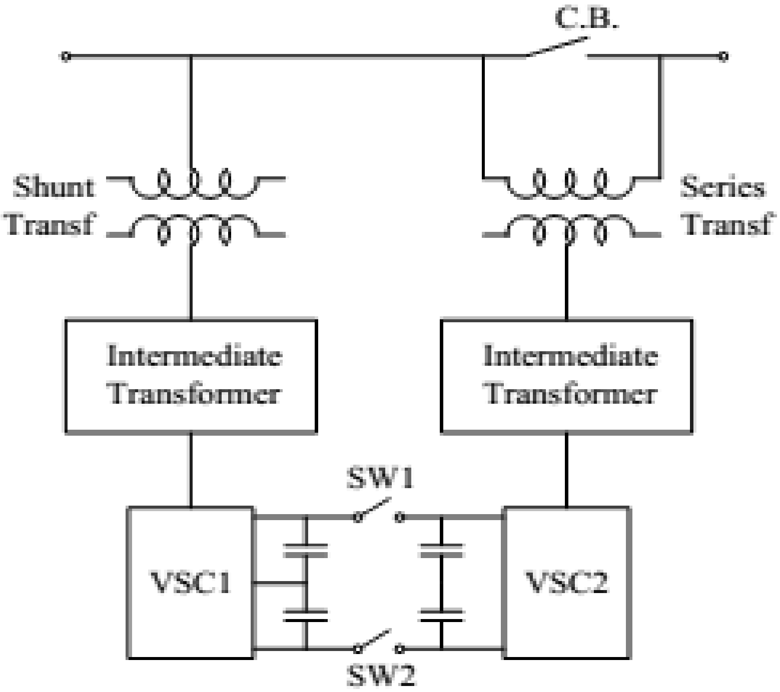
The Unified Power Flow Controller (UPFC) proposed by Gyugyi is the most versatile FACTS controller for the regulation of voltage and power flow in a transmission line. The UPFC is a device which can control simultaneously all three parameters of line power flow. Such "new" FACTS device combines together the features of two "old" FACTS devices:

1. STATCOM
2. SSSC

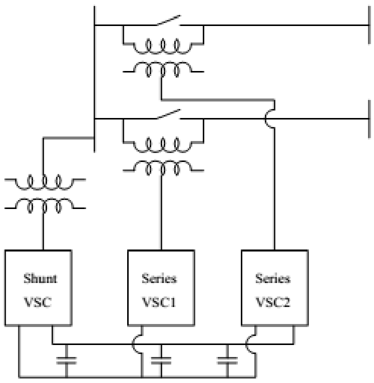
These two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer, connected to each other by a common dc link including a storage capacitor.

It consists of two voltage source converters (VSC) one shunt connected and the other series connected. The DC capacitors of the two converters are connected in parallel. If the switches 1 and 2 are open, the two converters work as STATCOM and SSSC controlling the reactive current and reactive voltage injected in shunt and series respectively in the line. The closing of the switches 1 and 2 enable the two converters to exchange real (active) power flow between the two converters. The active power can be either absorbed or supplied by the series connected converter.

The provision of a controllable power source on the DC side of the series connected converter, results in the control of both real and reactive power flow in the line (say, measured at the receiving end of the line). The shunt connected converter not only provides the necessary power required, but also the reactive current injected at the converter bus. Thus, a UPFC has 3 degrees of freedom unlike other FACTS controllers which have only one degree of freedom (control variable)




UPFC Schematic Diagram



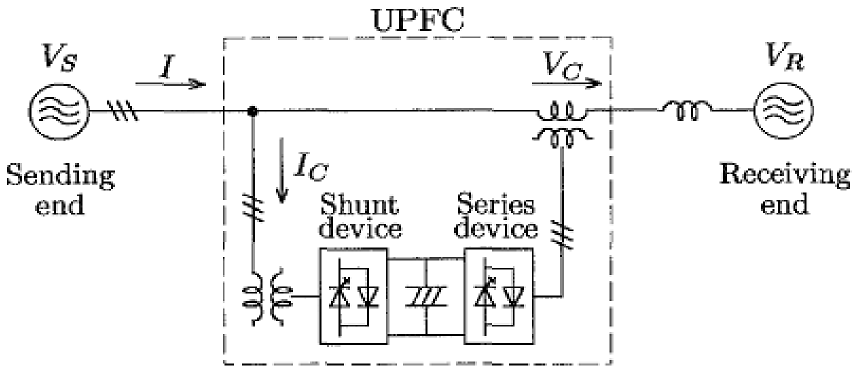

Three Converter GUPFC

The concept of combining two or more converters can be extended to provide flexibility and additional degrees of freedom. A Generalized UPFC (GUPFC) refers to 3 or more converters out of which one is shunt connected while the remaining converters are series connected

**Operation of a UPFC**

A UPFC system can regulate the active and reactive power at same time. It has the ability to adjust the three control parameters (bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently). The converter 2 has the main function of the UPFC; it injects an AC voltage to the line, where magnitude and phase angle are controllable through a serial transformer. Converter 1 give or absorb the real power that the converter 2 demands.

| Device | Load Flow Control | Voltage Control | Transient stability | Dynamic Stability |
|---|---|---|---|---|
| SVC | LESS | HIGH | LOW | MEDIUM |
| STATCOM | LESS | HIGH | MEDIUM | MEDIUM |
| UPFC | HIGH | HIGH | MEDIUM | MEDIUM |




The shunt inverter is operating in such a way to inject a controllable current $I_c$ into the transmission line.

This current consist of two components with respect to the line voltage**:**

1. Real or direct component $i_d$
2. Reactive or quadrature component $i_q$

The direct component is automatically determined by the requirement to balance the real power of the series inverter. The quadrature component, instead, can be independently set to any desired reference level (inductive or capacitive) within the capability of the inverter, to absorb or generate respectively reactive power from the line. So, two control modes are possible:

- VAR control mode : the reference input is an inductive or capacitive VAR request;
- Automatic Voltage Control mode: the goal is to maintain the transmission line voltage at the connection point to a reference value.

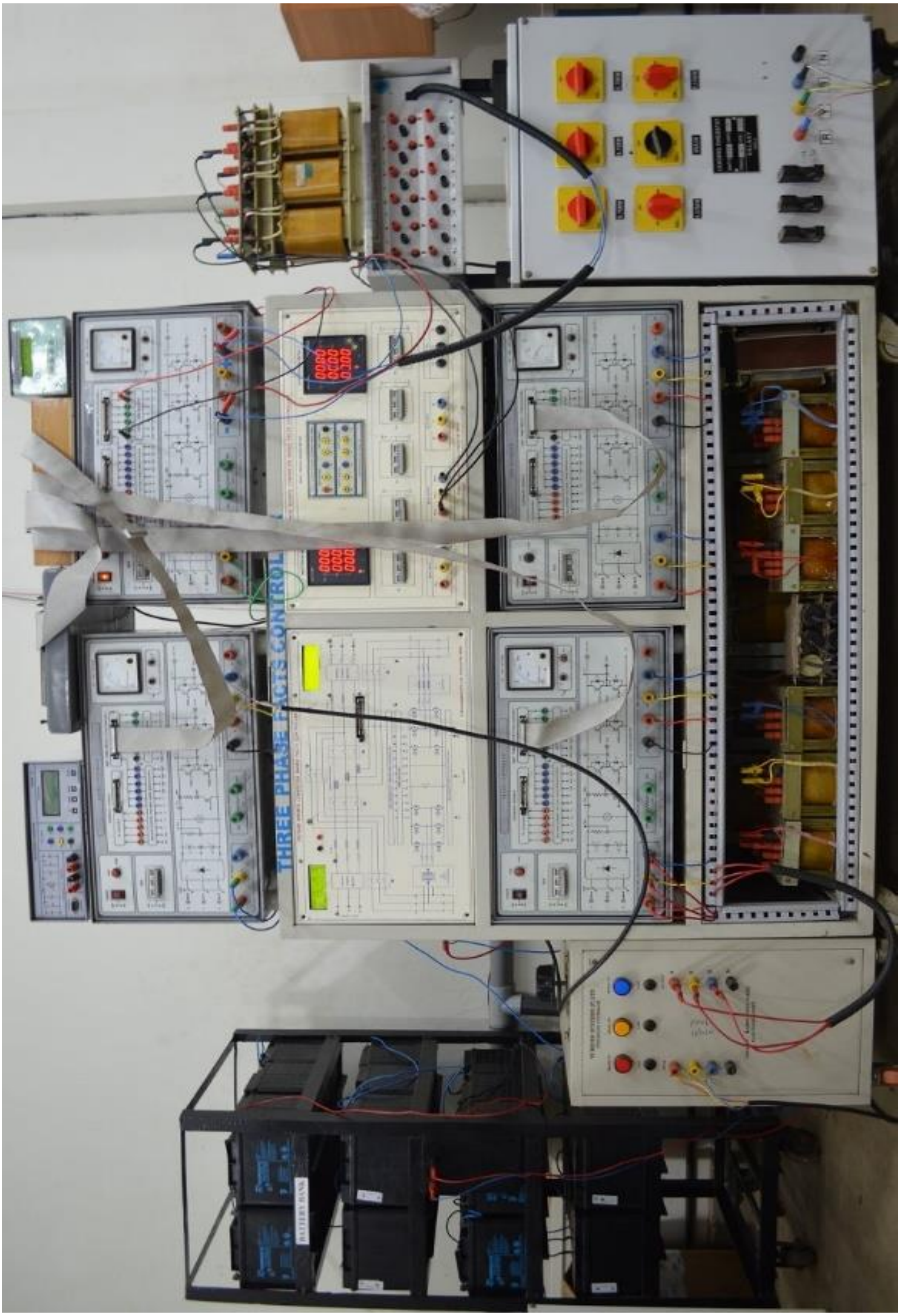
The series inverter injects a voltage, $V_{se}$ which is controllable in amplitude and phase angle in series with the transmission line.

This series voltage can be determined in different ways:

- Direct Voltage Injection Mode: The reference inputs are directly the magnitude and phase angle of the series voltage.

- Phase Angle Shifter Emulation Mode: The reference input is phase displacement between the sending end voltage and the receiving end voltage.
- Line Impedance Emulation Mode: The reference input is an impedance value to insert in series with the line impedance.
- Automatic Power flow Control Mode: The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

## Experimental Setup:



# POWER QUALITY IMPROVEMENT OF A TRANSMISSION LINE USING FACTS

## Aim:

1. To study the Flexible AC Transmission System set up for power factor compensation and voltage regulation of a transmission line module.
2. To provide combined shunt and series compensation in the transmission line using the FACTS controller to improve the receiving end power factor and zero voltage regulation for,
   i. Inductive loading.
   ii. Capacitive loading.

## Procedure:

### For Battery Charging

1. Check the voltage rating of series connected battery bank.
2. Connect the output of the solar-wind wiring panel to the hybrid power controller. Connect the output terminals of the hybrid power controller to the battery bank through an ammeter.
3. Switch on the hybrid power controller, reset the protection circuit on it and check the DC rail voltage. Switch on the MCB on the battery charger.
4. Switch on the dsPIC based PWM generator and increase the duty ratio of PWM signal to obtain maximum power point.

### STATCOM

1. Turn on the power switch of source inverter and STATCOM inverter.
2. Check whether any protection circuit is activated, and reset it.
3. Turn on the FPGA kit and select STATCOM operation.
4. Switch on MCB 1 and adjust the sending end voltage to 110 V (line to neutral) using switches $SW_1$ and $SW_2$ (select-switch upwards) on the interface board and note down the voltage, current, power factor, active power and reactive power at the sending end and receiving end for the applied load.
5. Increase the STATCOM modulation index to 95% using switches $SW_1$ and $SW_2$ (select switch downwards) on the interface board and Switch on MCB 4.
6. Adjust the angle of STATCOM using the switches $SW_5$ and $SW_6$ on the FPGA kit to make the sending and receiving end power factor to unity.
7. Note down the voltage, current, power factor, active power and reactive power at the sending end and receiving end and the STATCOM angle.
8. Switch off MCB 1 and MCB 4, reset the FPGA kit and repeat the procedure for different loading conditions.

SSSC

1. Turn on the power switch of source inverter and SSSC inverter.
2. Check whether any protection circuit is activated, and reset it.
3. Turn on the FPGA kit and select SSSC operation.
4. Switch on MCB 1 and adjust the sending end voltage to 110 V (line to neutral) using switches $SW_1$ and $SW_2$ (select-switch upwards) on the interface board and note down the voltage, current, power factor, active power and reactive power at the receiving end for the applied load.
5. Switch on MCB 2 and MCB 3, switch off MCB 1 and then switch on MCB 5.
6. Adjust the angle of SSSC using the switches $SW_3$ and $SW_4$ on the interface board to make the sending and receiving end voltage equal.
7. Note down the voltage, current, power factor, active power and reactive power at the sending end and the receiving end and the SSSC angle.
8. Switch off all the MCBs and reset the FPGA kit and repeat the procedure for different loading conditions.

UPFC

1. Turn on the power switch of source inverter, STATCOM inverter and SSSC inverter.
2. Check whether any protection circuit is activated, and reset it.
3. Turn on the FPGA kit and select UPFC operation.
4. Switch on MCB 1 and adjust the sending end voltage to 110 V (line to neutral) using switches $SW_1$ and $SW_2$ (select-switch upwards) on the interface board and note down the voltage, current, power factor, active power and reactive power at the sending end and the receiving end for the applied load.
5. Increase the STATCOM modulation index to 95% using switches $SW_1$ and $SW_2$ (select switch downwards) on the interface board and Switch on MCB 4.
6. Adjust the angle of STATCOM using the switches $SW_5$ and $SW_6$ on the FPGA kit to make the sending and receiving end power factor to unity.
7. Switch on MCB 2 and MCB 3, switch off MCB 1 and then switch on MCB 5.
8. Adjust the angle of SSSC using the switches $S_3$ and $S_4$ on the interface board to make the sending and receiving end voltage equal.
9. Note down the voltage, current, power factor, active power and reactive power at the sending end and the receiving end, STATCOM angle and the SSSC angle.
10. Switch off all the MCBs and reset the FPGA kit and repeat the procedure for different loading conditions.

**Result:**

## Observations:

<u>STATCOM</u>

i. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

ii. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

iii. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

IPA

SSSC

i. Inductive Loading = _____%

| Quantity | Without SSSC | With SSSC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Amplitude of SSSC = _____

ii. Inductive Loading = _____%

| Quantity | Without SSSC | With SSSC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Amplitude of SSSC = _____

iii. Inductive Loading = _____%

| Quantity | Without SSSC | With SSSC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Amplitude of SSSC = _____

UPFC

i. Inductive Loading = _____%

| Quantity | Without UPFC | With UPFC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Amplitude of SSSC = _____

ii. Inductive Loading = _____%

| Quantity | Without UPFC | With UPFC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Amplitude of SSSC= _____

iii. Inductive Loading = _____%

| Quantity | Without UPFC | With UPFC |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

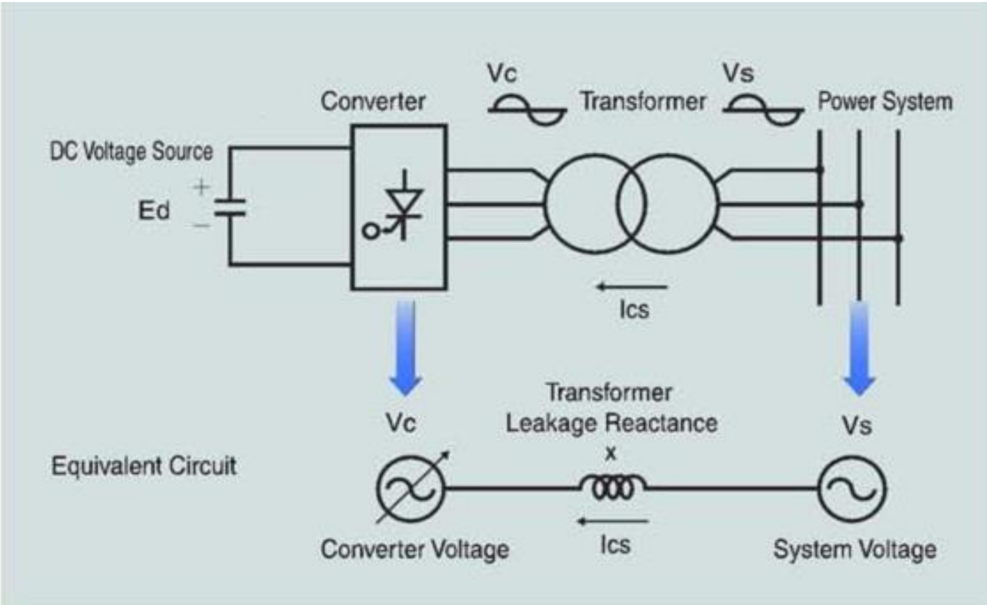
Amplitude of SSSC = _____

IPA

# STATCOM CONTROLLER

## Theory:

A static synchronous compensator (STATCOM), also known as a "static synchronous condenser" (STATCON), is a shunt connected FACTS device which uses force commutated power electronics(GTO, IGBT etc.) to inject reactive current into a power system for the purpose of controlling system voltage or power factor. It is based on a power electronics voltage source converter and can act as either a source or sink of reactive AC power to an electrical network. If connected to a source of power it can also provide active AC power.




STATCOM is basically a voltage source converter (VSC) that converts a dc voltage at its input terminals into three phase ac voltages at fundamental frequency of controlled magnitude and phase angle. VSCs use pulse width modulation (PWM) technology, which makes it capable of providing high quality ac output voltage to the grid or even to a passive load. STATCOM provides shunt compensation in a similar way as static VAR compensator but utilizes a voltage source converter rather shunt capacitors and reactors. The basic principle of operation of a STATCOM is the generation of a controllable AC voltage source behind a transformer leakage reactance by a voltage source converter connected to a DC capacitor. The voltage difference across the reactance produces active and reactive power exchanges between the STATCOM and the power system.

Unlike SVC, STATCOM controls the output current independently of the AC system voltage, while the DC side voltage is automatically maintained to serve as a voltage source. Mostly, STATCOM is designed based on the voltage source inverter. Also, the combination of STATCOM with a different storage device or power source endows the STATCOM the ability to control the real power output.

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. The reactive power at the terminals of the

STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; on the other hand, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of an SVC, mainly due to the fast switching times provided by the IGBTs of the voltage source converter.

In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to disturbances. The point of compensation can be sending end, midpoint or receiving end. Midpoint compensation is the most preferred one for transmission lines which results in improved voltage profile, reduced losses and increased transmission capability.

In distribution system, medium and low voltage STATCOM is employed mainly for

- Reactive power support at the load points.
- Harmonic control for nonlinear loads.

In addition, static synchronous compensators are installed in select points in the power system to perform the following:

- Voltage support and control
- Voltage fluctuation and flicker mitigation
- Unsymmetrical load balancing
- Power factor correction
- Active harmonics cancellation
- Improve transient stability of the power system

**Components of the system**

The lab consists of both solar panel based STSTCOM and wind generator based STATCOM. In solar panel based STSTCOM, solar panels are used for charging the battery bank while in wind generator based STATCOM, battery is charged using the wind turbine output. All other components of both the experimental setups are same, which are listed below.

i. Artificial Transmission Line Model.
    - Type : 3 Phase Pi equivalent Model.
    - Operating voltage : 220 V line to line.
    - Current Rating : 2.5 A.
    - Short Circuit Strength : 5 A.
    - Line Simulation through iron cored inductor. Each Pi section for 30km.

ii. Micro controller based charger for battery.
    - Micro controller based buck boost converter with MPPT algorithm.
    - IGBT switches.

- Input voltage: 0-600 V.

iii. Battery Bank for 3 phase set up.
- Low maintenance tubular batteries/ maintenance free.
- For 1 kW: 12V/42 Ah – a set of 25 Nos.
- Total battery delivery capacity: 300 V/ 42 Ah.

iv. Source Inverter: A voltage source inverter based converter fed from battery bank with only magnitude control

v. STATCOM Inverter: A voltage source inverter with control over both magnitude and angle of injection.

vi. DSP Based Controller: PWM signals to both the source inverter and STATCOM inverter are controlled using a DSP based controller.

vii. R-L /R-C load.

**Basic Principle of Operation**

In the case of two AC sources, which have the same frequency and are connected through a series reactance, the power flows will be:

- Active or Real Power flows from the leading source to the lagging source.
- Reactive Power flows from the higher to the lower voltage magnitude source.

Consequently, the phase angle difference between the sources decides the active power flow, while the voltage magnitude difference between the sources determines the reactive power flow. Based on this principle, a STATCOM can be used to regulate the reactive power flow by changing the output voltage of the voltage-source converter with respect to the system voltage.

**Modes of Operation**

The STATCOM can be operated in two different modes:

A. Voltage Regulation

The static synchronous compensator regulates voltage at its connection point by controlling the amount of reactive power that is absorbed from or injected into the power system through a voltage-source converter.

In steady-state operation, the voltage $V_2$ generated by the VSC through the DC capacitor is in phase with the system voltage $V_1$ ($\delta$=0), so that only reactive power (Q) is flowing (P=0)

- From a DC input voltage source, provided by the charged capacitor $C_S$, the converter produces a set of controllable three-phase output voltages with the frequency of the ac power system. Each output voltage is in phase with, and coupled to the corresponding ac system voltage via a relatively small (0.1-0.15 p.u.) tie reactance (which in practice is provided by the per phase leakage inductance of the coupling transformer).

- By varying the amplitude of the output voltages produced, the reactive power exchange between the converter and the ac system can be controlled in a manner similar to that of the rotating synchronous machine.

- That is, if the amplitude of the output voltage is increased above that of the ac system voltage, then the current flows through the tie reactance from the converter to the ac system, and the converter generates reactive (capacitive) power for the ac system.

- If the amplitude of the output voltage is decreased below that of the ac system, then the reactive current flows from the ac system to the converter, and the converter absorbs reactive (inductive) power. If the amplitude of the output voltage is equal to that of the ac system voltage, the reactive power exchange is zero.

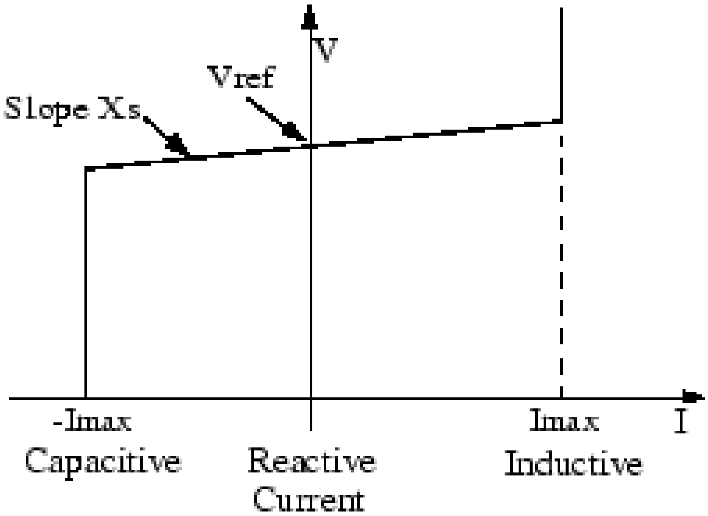
Subsequently, the amount of reactive power flow is given by the equation:

$$\mathbf{Q = [V_1 (V_1 - V_2)] / X}$$

B. VAR Control

In this mode, the STATCOM reactive power output is kept constant independent of other system parameter

**<u>STATCOM V-I characteristic</u>**

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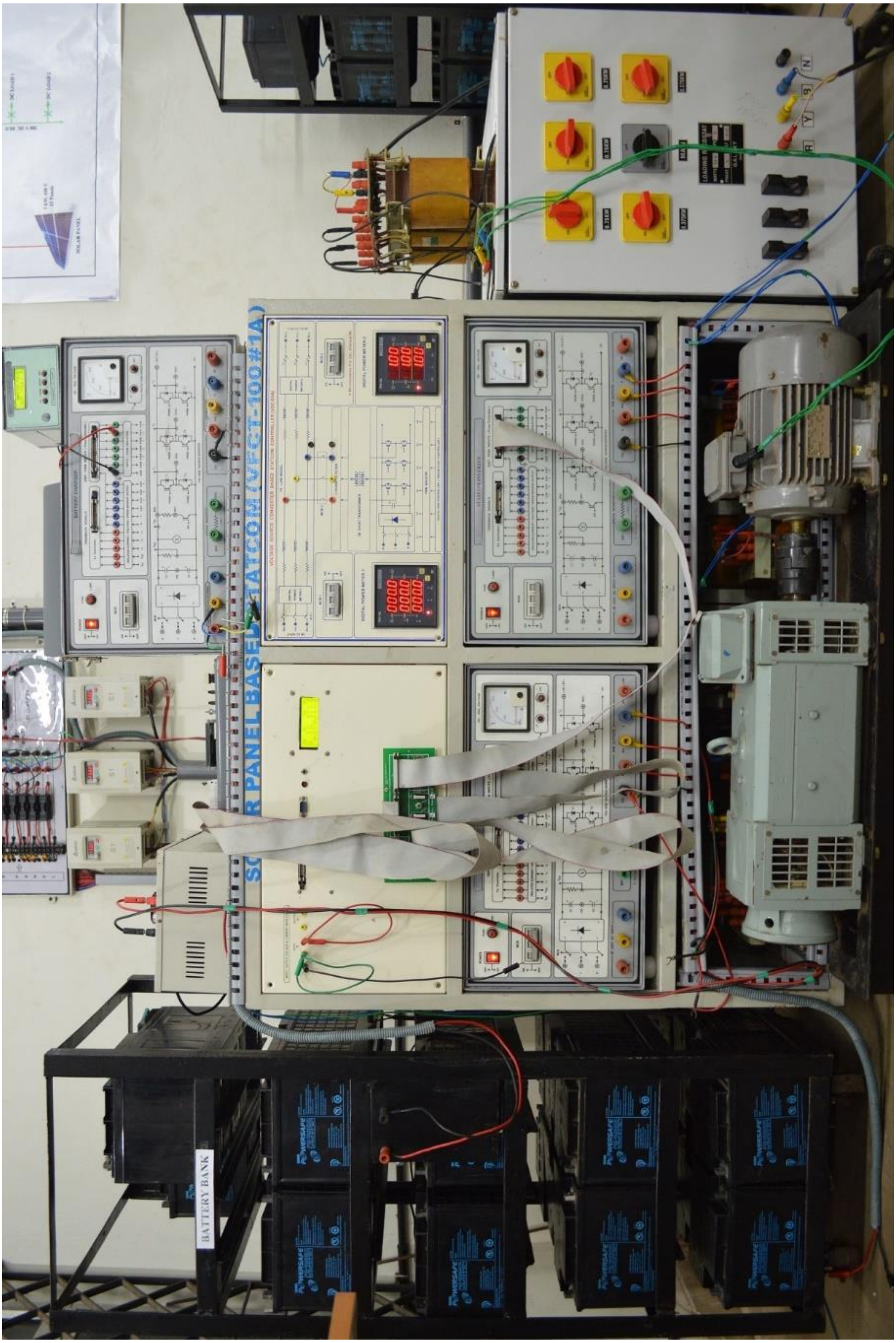
## Experimental Setup - Solar Panel Based STATCOM:



## Experimental Setup – Wind Generator Based STATCOM:

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## Connection Diagram - Solar Panel Based STATCOM:

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## Connection Diagram - Wind Generator Based STATCOM:

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# REACTIVE POWER COMPENSATION OF A TRANSMISSION LINE USING STATCOM

## Aim:

1. To study the Solar Panel based STATCOM set up for power factor compensation of a transmission line module.
2. To adjust the midpoint compensation given by the Solar Panel based STATCOM to improve the sending end power factor of the transmission line for different loading conditions and compare the voltage regulation of the uncompensated and compensated lines.

## Procedure

### For Battery Charging

1. Check the voltage rating of series connected battery bank.
2. From the solar-wind wiring panel, connect the required number of solar panels in series so that the total output voltage is 10 – 20% more than the voltage rating of battery bank. The voltage rating of each solar panel is 90 volts.
3. Now connect the output terminals of solar cell wiring panel to the input terminals of the battery charger. Connect the output terminals of battery charger to the battery bank through an ammeter.
4. Switch on the battery charger, reset the protection circuit on it and check the DC rail voltage. Switch on the MCB on the battery charger.
5. Switch on the DSPIC based PWM generator and increase the duty ratio of PWM signal to obtain maximum power point.

### STATCOM

9. Turn on the power supply to source, battery charger and STATCOM.
10. Check whether any protection circuit is activated, and reset it.
11. Check the DC rail voltage for the battery charger.
12. Turn on the DSP kit and select STATCOM operation using the switch $SW_2$ on it.
13. Switch on MCB 1.
14. Adjust the sending end voltage to 110 V (line to neutral) using switches $SW_1$ and $SW_2$ on the interface board and note down the voltage, current, power factor, active power and reactive power at the receiving end for the applied load.
15. Increase the STATCOM modulation index to 80% using switches $SW_3$ and $SW_4$ on the interface board.
16. Switch on MCB 2 and note down the sending end and receiving end parameters.
17. Adjust the angle of STATCOM using the switches $SW_2$ and $SW_3$ on the DSP kit to improve the sending end and receiving end power factor.

18. Note down the voltage, current, power factor, active power and reactive power at both the ends.
19. Switch off MCB 2 and MCB 1.
20. Reset the DSP kit and repeat the procedure for different loading conditions.

## Results:

## Observations:

A) Power Factor Compensation

i. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

ii. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

iii. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

iv. Inductive Loading = _____%

| Quantity | Without STATCOM | With STATCOM |
|---|---|---|
| Voltage (V) | | |
| Current (A) | | |
| Active Power (kW) | | |
| Reactive Power (kVAR) | | |
| Power Factor | | |

Phase Angle of STATCOM = _____

Reactive power supplied by STATCOM = _______ kVAR.

B) Voltage Regulation

Sending End Voltage = 110V.

| Inductive Loading | Receiving End Voltage | | Voltage Regulation | |
|---|---|---|---|---|
| | Without STATCOM | With STATCOM | Without STATCOM | With STATCOM |
| 100% | | | | |
| 80% | | | | |
| 60% | | | | |
| 40% | | | | |