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# Simulation of Power Quality Improvement in transmission Systems Using IPFC

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**ABSTRACT:** Now-a-days power quality becomes a major issue due to the introduction of sophisticated power electronic components. In order to improve the power system stability, the facts controllers are implemented. Interline Power Flow Controller(IPFC) is a power flow controller with two or more independently controllable static synchronous series compensators (SSSC) which are solid state voltage source converters injecting an almost sinusoidal voltage at variable magnitude and are linked via a common DC capacitor. IPFC can transfer power from over-to under-loaded lines to reduce the line resistive voltage drop and improve the reliability of the power system. The active power exchange between the shunt and series converters is done through the common dc link in the IPFC. The large number of series converters provides redundancy, thereby increasing the system reliability. As the D-FACTS converters are single-phase and floating with respect to the ground, there is no high-voltage isolation required between the phases. The cost of the IPFC system is lower than the UPFC. The IPFC has the same control capability as the UPFC, which comprises the adjustment of the line impedance, the transmission angle, and the bus voltage. Due to the high control capability, IPFC can also be used to improve the power quality and system stability, such as low-frequency power oscillation damping, voltage sag restoration and balancing asymmetry.

## I. INTRODUCTION

Power quality is important in the distribution system. To provide power supply with good quality is not easy because it depends on the type of load used. Phenomenon that causes an interruption in the electrical system such as overvoltage, voltage sags, voltage surges and harmonic.

Harmonic distortion problem has existed in the power system for a long time. It causes a wave of the line current and voltage in the power system to be distorted. In the past, discussions about the existence of harmonics have been discussed. However, at that time, the impact and influence of harmonic distortion is slightly lower than at present, where it only covers in the delta grounded w-ye connection of the transformer and also in some design of power transformer.

At present, the creation of modern equipment, especially electronic equipment and also the increased use of non-linear loads in industry has produced harmonic distortion, harmonic distortion in electrical systems became more serious because the use of electronic equipment are among the largest contributors to the formation of harmonic distortion.

Harmonic effects that occur in the electrical system depend on the harmonic source, the location of the power system and network features that allow the propagation of harmonic. The main cause leading to the generation of harmonics is the use of non-linearloads such as: -

1. Office equipment such as computers and electronic equipment.
2. Discharge lamps.
3. Saturation and magnetic currents in the transformer.
4. Frequency converter, arc furnaces, welding and voltage regulator.
5. Power semiconductor switching devices such as rectifiers and inverters that candistort the sine wave.
6. Motor control devices.
7. Conversion and HVDC transmission.

The waveform of voltage and current in the electrical system is disturbed by harmonics usually no longer pure sine waveform. The waveform of the line voltage is usually satisfactory, but for line current harmonic distortion occurs. Each of the distorted sine wave is contained harmonic. Only the fundamental components that will be consist of pure sine wave. The harmonic effects are: -

1. Failure of the capacitor bank.
2. Power line carrier system disorders can cause long-haul operations of switching devices,

3. Load control and metering to be less accurate.
4. Heat loss in synchronous and induction machines.
5. Current and voltage range of epoch in the past.
6. Error in the induction watt-hour meter.
7. Interference signal and the relay do not work, especially in the solid state and microprocessor systems.
8. Interference in large motor controller and excitation system of power station will cause the output of the motor is not uniform.

The existence of harmonics, as informed will cause distorted current and voltage waves.

Total harmonic distortion is the total current and voltage harmonic distortion. It is defined as the ratio of root mean square of all current or voltage harmonics to the fundamental of current or voltage. All even harmonic components are neglected because the effect is minimal in the three-phase system.

## II. REACTIVE POWER

Reactive power is the power that supplies the stored energy in reactive elements. Power, as we know, consists of two components, active and reactive power. The total sum of active and reactive power is called as apparent power. In AC circuits, energy is stored temporarily in inductive and capacitive elements, which results in the periodic reversal of the direction of flow of energy between the source and the load. The average power after the completion of one whole cycle of the AC waveform is the real power, and this is the usable energy of the system and is used to do work, whereas the portion of power flow which is temporarily stored in the form of magnetic or electric fields and flows back and forth in the transmission line due to inductive and capacitive network elements is known as reactive power. This is the unused power which the system has to incur in order to transmit power. Inductors (reactors) are said to store or absorb reactive power, because they store energy in the form of a magnetic field. Therefore, when a voltage is initially applied across a coil, a magnetic field builds up, and the current reaches the full value after a certain period of time. This in turn causes the current to lag the voltage in phase. Capacitors are said to generate reactive power, because they store energy in the form of an electric field. Therefore when current passes through the capacitor, a charge is built up to produce the full voltage difference over a certain period of time.

In an inductive circuit, we know the instantaneous power to be

$$p = V_{\max} I_{\max} \cos \omega t \cos(\omega t - \theta)$$

$$p = \frac{V_{\max} I_{\max}}{2} \cos \theta (1 + \cos 2\omega t) + \frac{V_{\max} I_{\max}}{2} \sin \theta \sin 2\omega t$$

The instantaneous reactive power is given by

$$\frac{V_{\max} I_{\max}}{2} \sin \theta \sin 2\omega t$$

Where:

$p$  = instantaneous power

$V_{\max}$  = Peak value of the voltage waveform

$I_{\max}$  = Peak value of the current waveform

$\omega$  = Angular frequency

=  $2\pi f$  where  $f$  is the frequency of the waveform.

$t$  = Time period

$\theta$  = Angle by which the current lags the voltage in phase

From here, we can conclude that the instantaneous reactive power pulsates at twice the system frequency and its average value is zero and the maximum instantaneous reactive power is given by

$$Q = |V| |I| \sin \theta$$

The zero average does not necessarily mean that no energy is flowing, but the actual amount that is flowing for half a cycle in one direction, is coming back in the next half cycle.

### Compensation Techniques

The principles of both shunt and series reactive power compensation techniques are described below:

#### Shunt compensation

The phasor diagram of these is also shown above. The active current  $I_p$  is in phase with the load voltage  $V_2$ . Here, the load is inductive and hence it requires reactive power for its proper operation and this has to be supplied by the source, thus increasing the current from the generator and through the power lines. Instead of the lines carrying this, if the reactive power can be supplied near the load, the line current can be minimized, reducing the power losses and improving the voltage regulation at the load terminals. This can be done in three ways: 1) A voltage source. 2) A current source. 3) A capacitor.

In this case, a current source device is used to compensate  $I_q$ , which is the reactive component of the load current. In turn the voltage regulation of the system is improved and the reactive current component from the source is reduced or almost eliminated. This is in case of lagging compensation. For leading compensation, we require an inductor. Therefore current source or a voltage source can be used for both leading and lagging shunt compensation, the main advantages being the reactive power generated is independent of the voltage at the point of connection. .

#### Series compensation

Series compensation can be implemented like shunt compensation, i.e. with a current or a voltage source as shown in figure 3.4. We can see the results which are obtained by series compensation through a voltage source and it is adjusted to have unity power factor at  $V_2$ . However series compensation techniques are different from shunt compensation techniques, as capacitors are used mostly for series compensation techniques. In this case, the voltage  $V_{comp}$  has been added between the line and the load to change the angle  $V_2'$ . Now, this is the voltage at the load side.

### FACTS devices

Flexible AC transmission system or FACTS devices used are

- 1) VAR generators.
  - a) Fixed or mechanically switched capacitors.
  - b) Synchronous condensers.
  - c) Thyristorized VAR compensators.
    - (i) Thyristor switched capacitors (TSCs).
    - (ii) Thyristor controlled reactor (TCRs).
    - (iii) Combined TSC and TCR.
    - (iv) Thyristor controlled series capacitor (TCSC).
- 2) Self Commutated VAR compensators.
  - a) Static synchronous compensators (STATCOMs).
  - b) Static synchronous series compensators (SSSCs).
  - c) Unified power flow controllers (UPFCs).
  - d) Dynamic voltage restorers (DVRs).

#### Need for Reactive power compensation.

The main reason for reactive power compensation in a system is: 1) the voltage regulation; 2) increased system stability; 3) better utilization of machines connected to the system; 4) reducing losses associated with the system; and 5) to prevent voltage collapse as well as voltage sag.

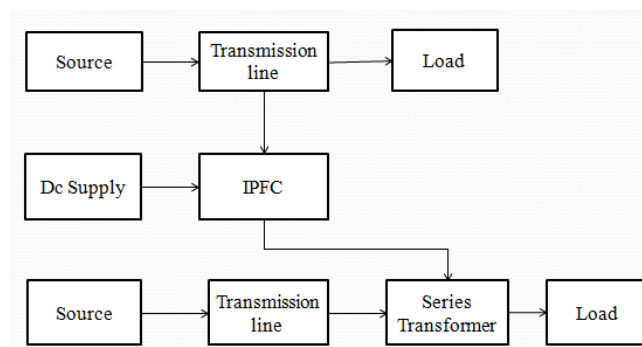
The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading



to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

### III. INTERLINE POWER FLOW CONTROLLER (IPFC)

Interline Power Flow Controller (IPFC) is one of series - series controlled Flexible Alternating Current Transmission System (FACTS) devices, which has the capability of controlling the power flow in multi transmission lines. In this paper, Power Injection Model (PIM) is proposed by using voltage source converters (VSCs).

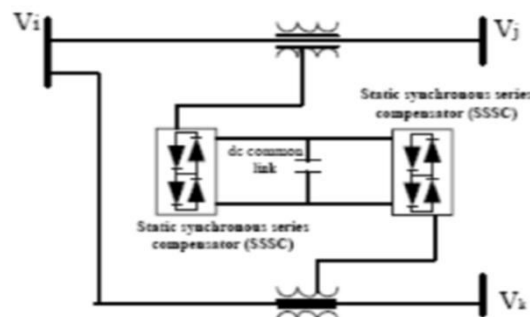


Block diagram of IPFC controller

The proposed model is incorporated in Newton-Raphson (NR) power flow solution method and analyzed with a MATLAB program. A study on variation of power flow, bus voltages in all transmission lines and buses for different values of IPFC parameter.

The Interline Power Flow Controller (IPFC) is comprised of a STATCOM and a SSSC, coupled via a common DC link to allow bi-directional flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM.

Each converter can independently generate (or) absorb reactive power at its own AC terminal. The two converters are operated from a DC link provided by a DC storage capacitor.



Performance of IPFC

The same as the DPFC, the IPFC is able to control all system parameters like line impedance, transmission angle and bus voltage. The IPFC provides the common dc link between the shunt and series converters. The active power exchange between the shunt and the series converter is through the transmission line at the third-harmonic frequency. The series converter of the IPFC employs the distributed FACTS (D-FACTS) concept.

The injected voltage essentially acts as a synchronous ac- voltage source, which is used to vary the transmission angle and line impedance, thereby independently controlling the active and reactive power flow through the line. The series voltage results in active and reactive power injection or absorption between the series converter and the transmission line.

This reactive power is generated internally by the series converter and the active power is supplied by the shunt converter that is back-to-back connected. The shunt converter controls the voltage of the dc capacitor by absorbing or generating active power from the bus; therefore, it acts as a synchronous source in parallel with the system. Similar to the STATCOM, the shunt converter can also provide reactive compensation for the bus.

This paper introduces a new concept, called interline power-flow controller (IPFC) that is derived from the DPFC. The same as the DPFC, the IPFC is able to control all system parameters. The Interline Power Flow Controller (IPFC) concept proposed in this paper addresses the problem of compensating a number of transmission lines at a given substation.

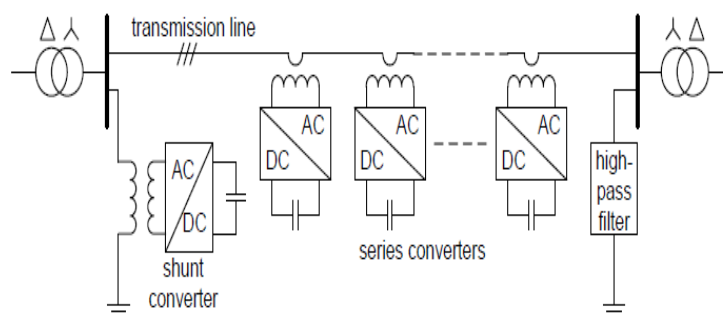
Conventionally, series capacitive compensation (fixed, thyristor-controlled or SSSC based) is employed to increase the transmittable real power over a given line and also to balance the loading of a normally encountered multi-line transmission system. This capability makes it possible to equalize both real and reactive power flow between the lines; transfer power demand from overloaded to under loaded lines; compensate against resistive line voltage drops and the corresponding reactive power demand; increase the effectiveness of the overall compensating system for dynamic disturbances. In other words, the IPFC can potentially provide a highly effective scheme for power transmission management at a multi-line substation.

Comparing with the DPFC, the IPFC have two major advantages: 1) low cost because of the low-voltage isolation and the low component rating of the series converter and 2) high reliability because of the redundancy of the series converters.

### IPFC TOPOLOGY

By introducing the two approaches outlined in the previous section (The common DC link and distribution of the series converter) into the DPFC, the IPFC is achieved. Similar as the DPFC, the IPFC consists of shunt and series connected converters.

The shunt converter is similar as a STATCOM, while the series converter employs the DSSC concept, which is to use multiple single -phase converters instead of one three-phase converter. Each converter within the IPFC is independent and has its own DC capacitor to provide the required DC voltage. The configuration of the IPFC is shown in Figure 3.3



IPFC configuration

As shown, besides the key components shunt and series converters, a IPFC also requires a high pass filter that is shunt connected to the other side of the transmission line and a Y – Δ Transformer on each side of the line. The reason for these extra components will be explained later. The unique control capability of the DPFC is given by the back-to-back connection between the shunt and series converters, which allows the active power to freely exchange. To ensure the IPFC has the same control capability as the DPFC, a method that allows active power exchange between converters with an eliminated DC link is required.

### IPFC OPERATING PRINCIPLE

Within the IPFC, the transmission line presents a common connection between the AC ports of the shunt and the series converters. Therefore, it is possible to exchange active power through the AC ports. The method is based on power theory of non-sinusoidal components. According to the Fourier analysis, non-sinusoidal voltage and current can be expressed as the sum of sinusoidal functions in different frequencies with different amplitudes.

The active power resulting from this non-sinusoidal voltage and current is defined as the mean value of the product of voltage and current.

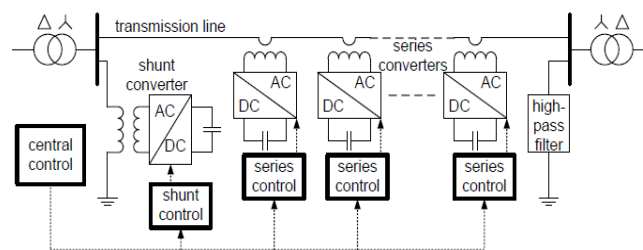
By applying this method to the IPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a harmonic frequency. This harmonic active power flows through a transmission line equipped with series converters. According to the amount of required active power at the fundamental frequency, the IPFC series converters generate a voltage at the harmonic frequency, thereby absorbing the active power from harmonic components. Neglecting losses, the active power generated at the fundamental frequency is equal to the power absorbed at the harmonic frequency.

The IPFC addresses the problem of compensating a number of transmission lines at a given substation. Standing alone series capacitive compensators normally are used to increase the transmittable active power over a given line however they are unable to control the reactive power flow in, and thus the proper load balancing of the line. Therefore in an IPFC, series VSCs are tied together at their DC link Capacitors.

The high-pass filter within the IPFC blocks the fundamental frequency components and allows the harmonic components to pass, thereby providing a return path for the harmonic components. The shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current.

### IPFC CONTROL

To control multiple converters, IPFC consists of three types of controllers: central control, shunt control and series control, as shown in Fig.



IPFC control block diagram

The shunt and series control are localized controllers and are responsible for maintaining their own converters parameters. The central control takes care of the IPFC functions at the power system level. The function of each controller is listed:

- **Central control:**

The central control generates the reference signals for both the shunt and series converters of the IPFC. Its control function depends on the specifics of the IPFC application at the power system level, such as power flow control, low frequency power oscillation damping and balancing of asymmetrical components. According to the system requirements, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt components. All the reference signals generated by the central control concern the fundamental frequency components.

• **Series control:**

Each series converter has its own series control. The controller is used to maintain the capacitor DC voltage of its own converter, by using 3rd harmonic frequency components, in addition to generating series voltage at the fundamental frequency as required by the central control.

• **Shunt control:**

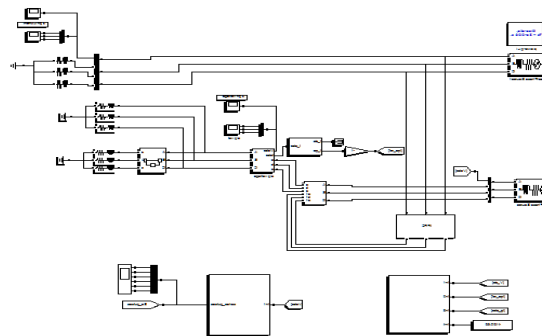
The objective of the shunt control is to inject a constant 3rd harmonic current into the line to supply active power for the series converters. At the same time, it maintains the capacitor DC voltage of the shunt converter at a constant value by absorbing active power from the grid at the fundamental frequency and injecting the required reactive current at the fundamental frequency into the grid

**IV. SIMULATION RESULT**

The IPFC will be installed at the time voltage is injected to transmission system. The voltage sag will be reduced using IPFC controller. So maintained system performance and also reliability can be improved using IPFC.

Here using transformer to injecting voltage, when disturbance is occurred in transmission system. Fig-4.3 shows that the IPFC. IPFC System is now introduced at the two Transmission side with IPFC system to compensate the voltage sag occurred due to the Disturbance. When the IPFC is in operation the voltage interruption is compensated almost completely and the rms voltage at the sensitive transmission side is maintained at normal condition.

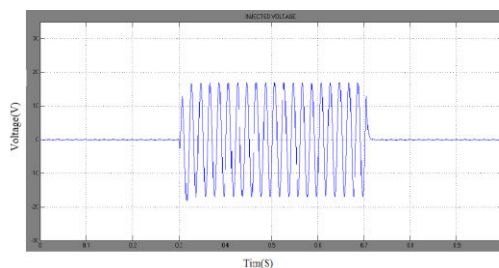
The output drawn between voltage and time taken in X-axis and Y-axis respectively. From the graph we can see the variations of voltage magnitude with respect to time during the sag condition.



Simulink model of IPFC system

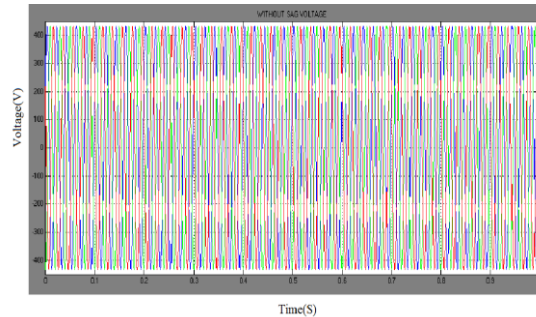
**Injected Voltage**

When sag is occurred at the time transformer is used to injecting voltage as 15V. So IPFC will be cleared all disturbance and it improving reliability operation.



Injected voltage during sag condition

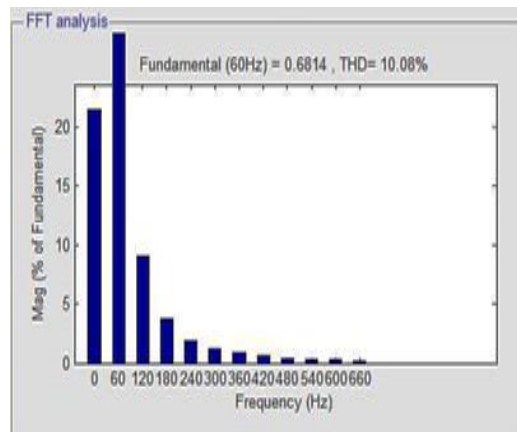




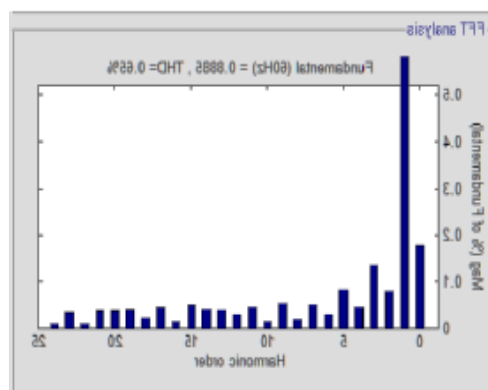
Elimination of sag voltage

### THD ANALYSIS

The load voltage harmonic analysis without presence of IPFC is illustrated in Fig. It can be seen, after DPFC implementation in system, the even harmonics is eliminated, the odd harmonics are reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized from 45.67 to 0.65 percentage (Fig-4.11), i.e., the standard THD is less than 5 percent in IEEE standards.



Total harmonic distortion of load voltage without IPFC.



Total harmonic distortion of load voltage with IPFC.



**SYSTEM PARAMETERS**

System Parameters	Values
AC source voltage	415 V, 50 Hz
Line Impedance	Ls= 2.5 mH, Rs=0.01 $\Omega$
DC bus capacitance of IPFC	1000 $\mu$ F
DC bus voltage of IPFC	140 V
DC bus voltage	Kpd=0.1, Kid=0.6
Load voltage	Kpq =0.2, Kiq =0.5
PWM switching frequency	15 kHz

**V. CONCLUSION AND FUTURE WORKING**

The series converter of the IPFC employs the D-FACTS concept, which uses multiple small single-phase converters instead of one large-size converter. It is proved that the shunt and series converters in the IPFC can exchange active power at the third-harmonic frequency, and the series converters are able to inject controllable active and reactive power at the fundamental frequency. The IPFC is also used to improving power quality problems such as sag and swell.

The reliability of the IPFC is greatly increased because of the redundancy of the series converters. The total cost of the IPFC is also much lower than the DPFC, because no high-voltage isolation is required at the series converter part and the rating of the components of is low. Various operational conditions such as the effect of the transmission angle variation over both primary and secondary systems as well as upon the response of the converters were also addressed. The IPFC, in its simplest form (i.e. with only two series converters), can be very useful in relieving congested systems. Issues like the IPFC instantaneous response and its dynamic behavior, along with their respective simulations, are currently underway.

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