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Original Article

Enhancing Power System Stability and Quality With Interline Power Flow Controllers (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 beused to improve the power quality and system stability, such as low-frequency power oscillationdamping, voltage sag restoration and balancing asymmetry.*

Keywords: *Dynamic Stability, Voltage Stability, Power Quality, Reactive Power Compensation, Harmonic Mitigation, Power Flow Control, Load Balancing, Voltage, Regulation System Reliability, Energy Efficiency, Power Distribution, System Protection.*

INTRODUCTION

Electricity with a bad quality is dangerous and uneconomical at both utility and consumer end. There is a big need to focus on the quality of power being supplied to the loads. Read more as we covercauses of poor power quality, different measuring parameters, power quality standards and various techniques to improve the power quality.Power quality is the ability of a power grid to supply power to the consumers efficiently and it also expresses the ability of equipment to consume the power being supplied to it. In technical terms, power quality is the measure, study and enhancement of sinusoidal waveform at the rated voltage and frequency.

Power quality can have a big impact on the performance and cost of a power system. So, it is essential to make sure that the power being consumed by the system is of right quality and the systemis compatible to function with the power delivered to it. Nowadays consumers have become well aware of power quality, that's why many governments have revised their policies to force electric utilities for making sure the power quality according to the designed standards. Also the modern equipment is more sensitive to any changes in power quality.

PROPOSED METHOD

INTRODUCTION

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).

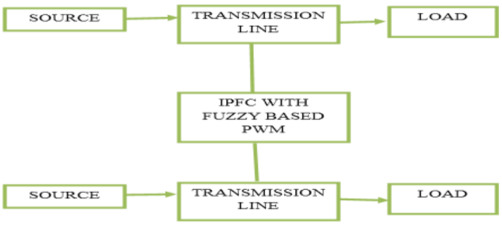

Figure1: Block diagram of IPFC controller

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.

INTERLINE POWER FLOW CONTROLLER (IPFC)

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.

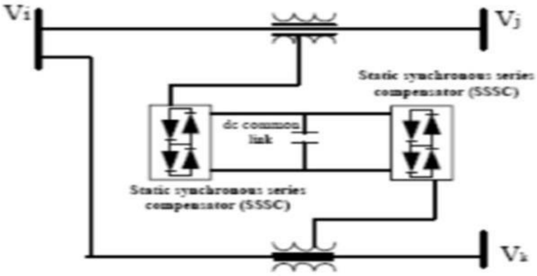

Figure 2: Performance of IPFC

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.

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, theIPFC 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

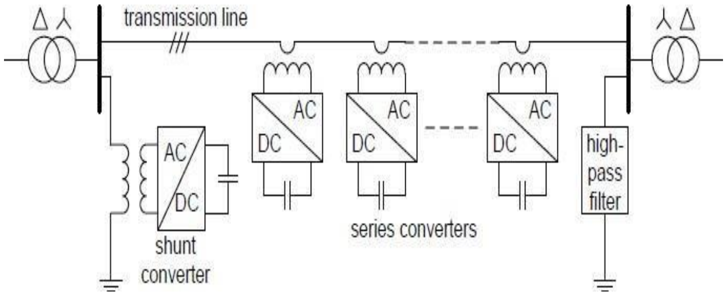

Figure3: IPFC configuration

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 Υ – 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, there by 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.

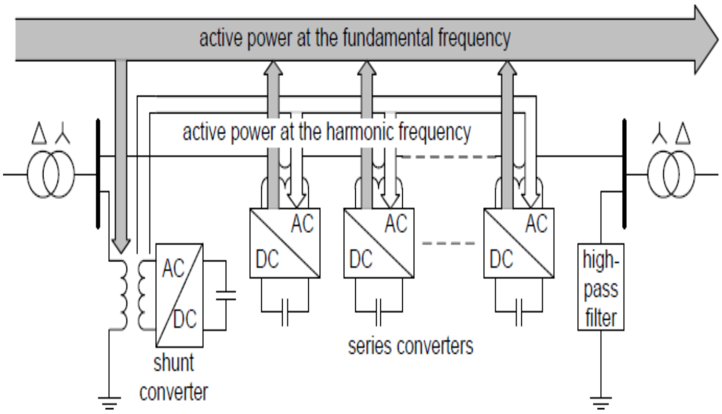

Figure 4: Active Power Exchange between IPFC Converters

Fig indicates how the active power is exchanged between the shunt and the seriesconverters in the IPFC system. 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.

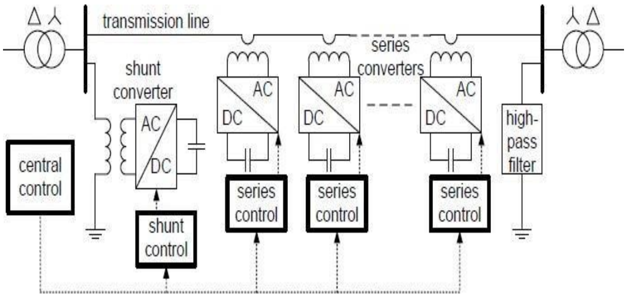

Figure 5: IPFC control block diagram

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:

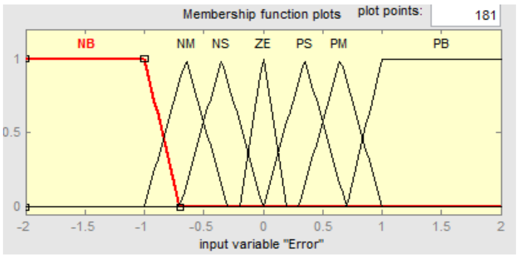

Figure 6: Membership function of input variable error

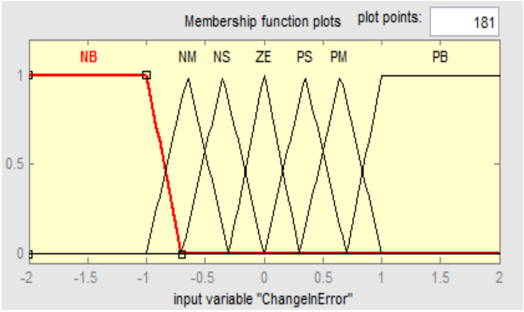

Figure 7: Membership function of input variable change in error

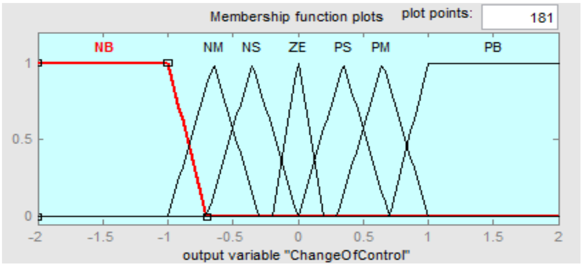

Figure 8: Membership function of output variable change of control

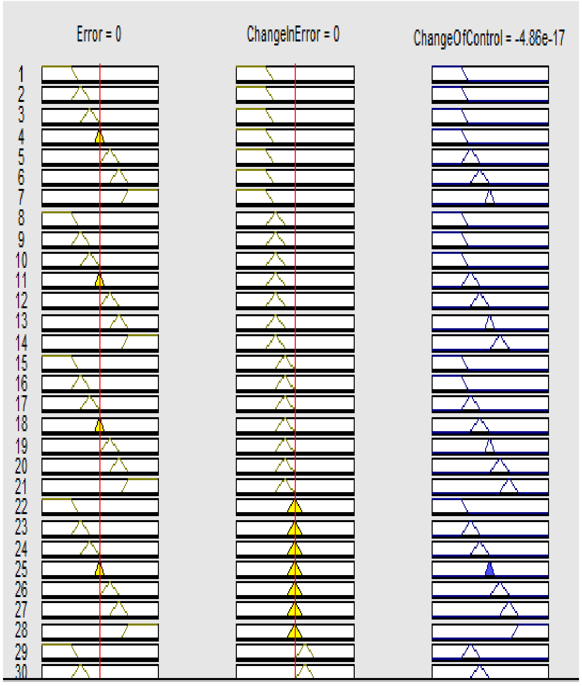

Figure 9: Rule based FLC

HARDWARE DETAILS

POWER SUPPLY

A power supply (sometimes known as a power supply unit or PSU) is a device or system that supplies electrical or other types of energy to an output load or group of loads. The term is most commonly applied to electrical energy supplies, less often to mechanical ones, and rarely to others.

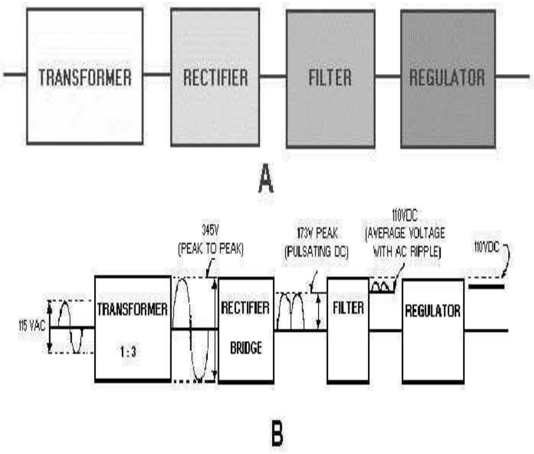

Figure 10: Power supply unit

The transformer steps up or steps down the input line voltage and isolates the power supply from the power line.The RECTIFIER section converts the alternating current input signal to a pulsating direct current. However, as you proceed in this chapter you will learn that pulsating dc is not desirable. For this reason a FILTER section is used to convert pulsating dc to a purer, more desirable form of dc voltage. The final section, the REGULATOR, does just what the name implies. It maintains the output ofthe power supply at a constant level in spite of large changes in load current or input line voltages.

DRIVER CIRCUIT

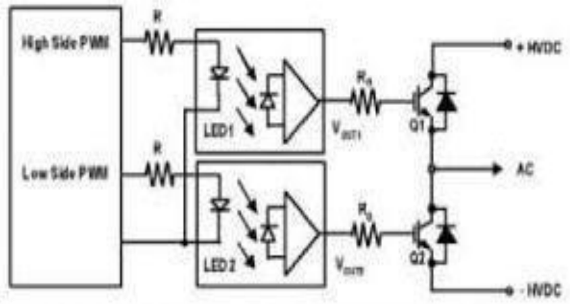

Figure 11: Driver circuit

N-CHANNEL MOSFET (IRF 540)

Features:

- 13A, 500V
- rDS(ON) = 0.400W
- Single Pulse Avalanche Energy Rated
- SOA is Power Dissipation Limited
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance

13A, 500V, 0.400 Ohm, N-Channel Power MOSFET

This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation.**All of these power MOSFETs are designed for applications such as switching regulators, switching convertors, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.**

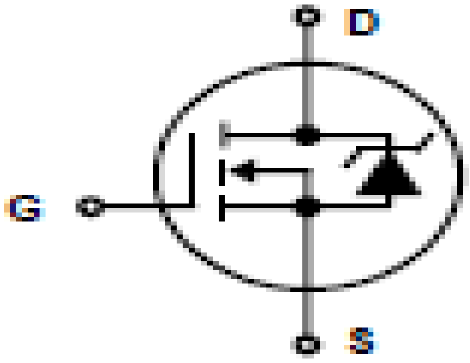

Figure 12: N-Channel MOSFET

PIC 16F877A

PIC is a family of modified Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1650 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "Peripheral Interface Controller".PICs are popular with both industrial developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability.

FEATURES

HIGH PERFORMANCE RISC CPU

PIC has only 35 single word instructions. All are single cycle instructions except for program branches, which uses two-cycle. The Operating speed of PIC in DC is 20 MHz and clock input in DC is 200 ns instruction cycle. The PIC has 8K x 14 words of flash Program Memory, 368 x 8 bytes of Data Memory (RAM).

PERIPHERAL FEATURES

- Timer0: 8-bit timer/counter with 8-bit prescaler.

- Timer1: 16-bit timer/counter with prescaler.
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler.
- It has a Capture, Compare, PWM (CCP) module. Capture is of 16-bit and it has a maximum resolution of 12.5 ns. Compare is of 16-bit and it has a maximum resolution of 200ns.Pulse Width Modulation has a maximum resolution of 10-bit.8-bit,
- 8 channel analog-to-digital converter with 10 bit each.
- It has a Synchronous Serial Port (SSP) with SPI (Master/Slave) and I2C, USART with 9 bit detection. It also has a Brown-out detection circuitry for Brown-out Reset (BOR).

CMOS TECHNOLOGY

PIC has a Low power, high speed CMOS FLASH technology with a fully static design. It provides a wide operating voltage range of 2.0V to 5.5V.It has Low power consumption and used in commercial and industrial temperature ranges.

PIN DIAGRAM

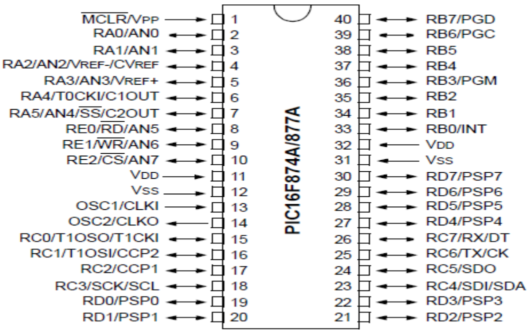

Figure 13: Pin diagram of microcontroller

RESULT'S AND DISCUSSION

BEFORE INSTALLING IPFC (DURING SAG OCCURRENCE)

This simulation shows the before installing of IPFC with circuit breaker as open condition with supply voltage as 415V as shown in figure 5.$P_{e1} + P_{e2} = V_{1p}I_1 + V_{2p}I_2 = 0$Therefore, VSC2 must be operated along the complementary voltage compensation line, such as point B, to satisfy the real power demand ofVSC1.The protective actions can be divided into two levelsin each converter station. In case a failure occurs and affects all components, the protection system willbypass all of the components.

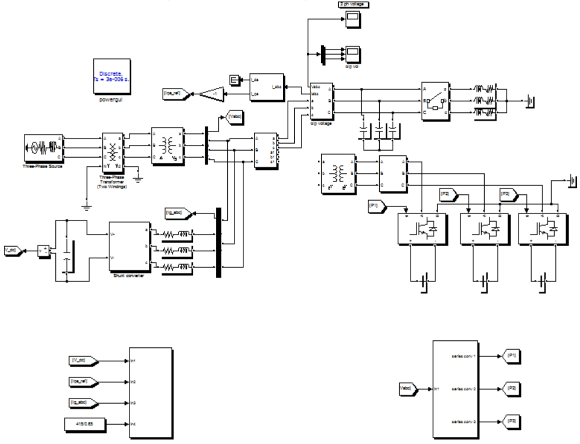

Figure 14: Simulink model without IPFC system

When disturbance is occurred in transmission system depends on the voltage variation sag and swell is occurred in the system. But now circuit breaker as opened at the time voltage as reduced during time period t=0.3s to t=0.7s.The sag occurrence is showing in fig-6.2

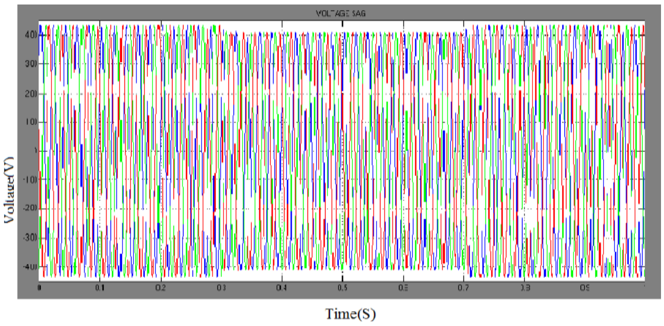

Figure 15: Supply voltage during sag condition

AFTER INSTALLING IPFC

The IPFC will be installed at the time voltage is injected to transmission system. The voltage sagwill 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-4.3shows 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.

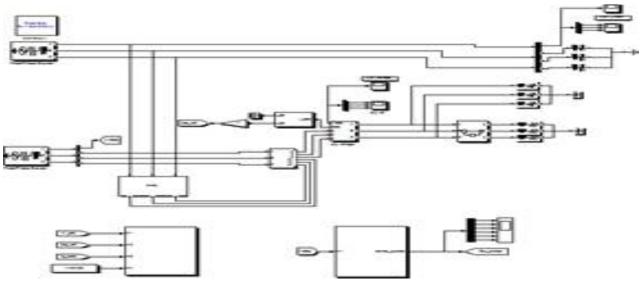

Figure 16: Simulink model of IPFC system

The sag will be cleared using IPFC control as shown in Fig.4.5

Injected Voltage

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

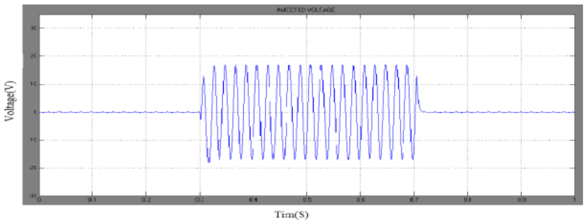

Figure 17: Injected voltage during sag condition

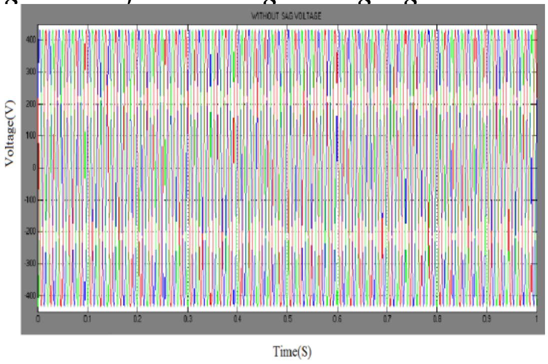

Figure 18: Elimination of sag voltage

IPFC Controller Block

IPFC having block as shown in Fig-4.6. Here using controller block as DQ frame theory.Then PWM generator is used to generating pulses.

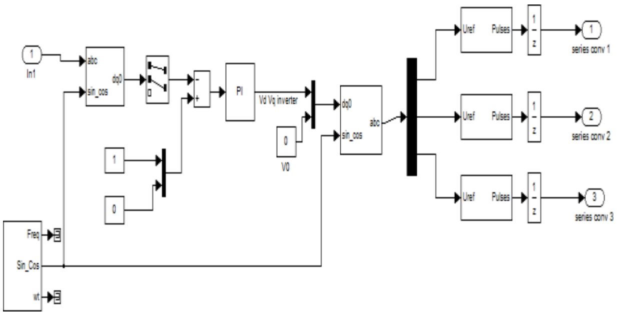

Figure 19: Simulation of IPFC controller block

BEFORE INSTALLING IPF (DURING SWELL OCCURRENCE)

The simulation shows that the swell will be occurred without IPFC condition. And eliminating swell during IPFC controller. The swell is occurred during time period of 0.3s to 0.7s. Using IPFC controller swell will be eliminated. At the time of swell voltage will be increased.This simulation shows the before installing of IPFC with circuit breaker as close condition with supply voltage as 415v as shown in Fig-4.7. It is similar to Sag occurrence but in swell voltage as increased. The Figure 12 shows the occurrences of swell.

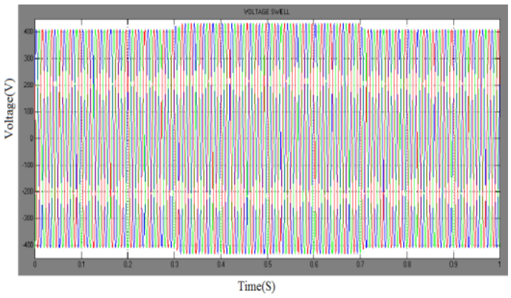

Figure 20: Supply voltage during swell

AFTER INSTALLING IPFC

A step change of the fundamental reference voltage of the series converter is made, which consists of both active and reactive variations, as shown in Fig. As shown, the dc voltage of the series converter is stabilized before and after the step change. To verify if the series converter can inject or absorb active and reactive power from the grid at the fundamental frequency, the power is calculated from the measured voltage and current in Fig.The measured data in one phase are processed in the computer by using MATLAB. To analyze the voltage and current at the fundamental frequency, the measured data that contains harmonicdistortion are filtered by a low-pass digital filter with the 50-Hz cutoff frequency. Because of this filter, the calculated voltage and current at the fundamental frequency have a 1.5 cycle delay to the actual values, thereby causing a delay of the measured active and reactive power.Fig. 4.7 illustrated the active and reactive power injected by the series converter. After eliminating swell the voltage at IPFC controller will fulfill that voltage.

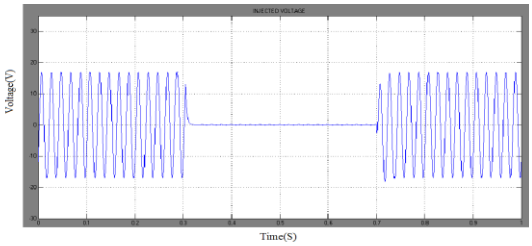

Figure 21: Injected voltage for swell

The swell will be cleared using IPFC controller to injecting voltage. so using IPFC control sag and swell will be eliminated and also reliability can be maintained.A comparison is made between the measured power and the calculated power. We can see that the series converters are able to absorb and inject both active and reactive power to the grid at the fundamental frequency.

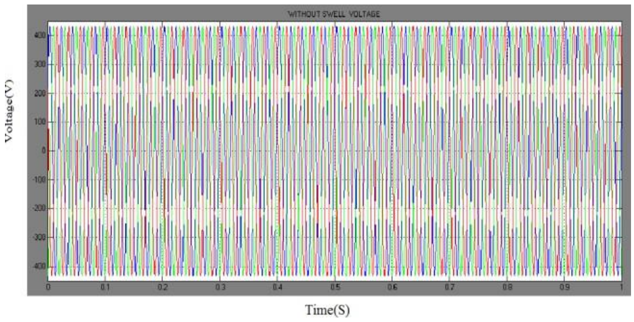

Figure 22: Elimination of swell voltage

CONCLUSION AND FUTURE WORKING

The study of an IPFC system with two parallel lines has demonstrated the flexible control of active/reactive power to assist in the transmission system. The behavior of the system under various transient and load changes at the receiving-end of the transmission system are presented and analyzed. 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 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. The IPFC is implemented with Fuzzy based PWM using MATLAB simulation.

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