SIMULATION AND DESIGN OF IPFC SYSTEM FOR VOLTAGE SAG COMPENSATION

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Abstract

Inter line power flow controller is a new concept for the compensation and effective power flow management of multi-line transmission systems. The IPFC employs a number of Voltage Sourced Converters (VSCs) linked at the same DC terminal, each of which can provide series compensation for the selected line of the transmission system. Through common dc link, any inverters within the IPFC is able to transfer real power to any other and thereby facilitate real power transfer among the line. In this work the IPFC system used for compensation of voltage sag in two identical lines like 11kv and 10kv systems. The prototype IPFC system was developed and verified with hardware results. When the voltage sag is compensated, reactive power is controlled and transmission line efficiency is improved.

Key words - FACTS, SSSC, IPFC, Series Compensation, Power converters.

I. INTRODUCTION

As power systems are encountering increasing power demand, however, it becomes difficult to build new transmission lines for power management. The concept of FACTS controller was timely and appropriate. Due to the advance in power semiconductor industry, high power rating and high-speed gate turn-off power electronic devices are introduced practically in power system applications [1,2]. These developments provide a new generation of FACTS controllers called VSC based FACTS controllers with promising features in flexible power flow control, transient stability and power system oscillation damping enhancement. The family of compensators and power flow controllers based on VSC are the Static Synchronous (shunt) Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) and the Unified Power Flow Controller (UPFC) [3]. The UPFC is used as a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control both the real and reactive power flow. While the Interline Power Flow Controller (IPFC) concept provides a solution for the problem of compensating a number of transmission lines at a given substation. Any inverters within the IPFC are able to transfer real power to any other

and thereby facilitate real power transfer among the lines, together with independently controllable reactive series compensation of each individual line[4,5]. The main objective of the IPFC is to optimize both real and reactive power flow among multi-lines, transfer power from overloaded to under loaded lines. However, it can also be utilized to compensate against reactive voltage drops and the corresponding reactive line power, and to increase the effectiveness of the compensating system against dynamic disturbances [6, 7].

II. VOLTAGE SAG IN POWER SYSTEM

A voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. Most voltage sags do not go below 50 percent of the nominal voltage, and they normally last from 3 to 10 cycles or 50 to 170 milliseconds. Voltage sags are probably the most significant power quality (PQ) problem facing industrial customers today, and they can be a significant problem for large commercial customers as well. Whether or not a voltage sag causes a problem will depend on the magnitude and duration of the sag and on the sensitivity of your equipment. Many types of electronic equipment are sensitive to voltage sags, including variable speed drive controls, motor starter contactors, robotics, programmable logic controllers, controller power supplies, and control relays. Much of this equipment is used in applications that are critical to an overall process, which can lead to very expensive downtime when voltage sags occur.

III. INCOROORATION OF IPFC SYSTEM

In practical applications the IPFC would have to manage the power flow control of a complex, multi-line transmission system in which the length, voltage, and

capacity of the individual lines could widely differ. One of the attractive features of the IPFC is that it is inherently flexible to accommodate complex systems and several operating requirements.

The IPFC is particularly advantageous when controlled series compensation or other series power flow control is already contemplated. Indeed, the IPFC simply combines the otherwise independent series compensators, without any significant hardware addition, and provides some of those greatly enhanced functional capability. This capability can be moved from one line to another, as system conditions may dictate. Moreover, the single inverter of the IPFC can be operated as independent series reactive compensator. The operating areas of the individual inverter of the IPFC can differ significantly, depending on the voltage and power ratings of the individual lines and on the amount of compensation desired. The IPFC is an ideal solution to balance both real and reactive power flow in a multi-line transmission system.

In its general form the IPFC employs a number of dc/ac inverters each providing series compensation for a different line. An elementary configuration of IPFC consists of two dc/ac inverters connected in series with the transmission line and linked together at their DC terminals, as illustrated in Fig. 1. With this scheme any inverter can be controlled to supply real power to the common DC-link from its own transmission line. Naturally, one of the inverters, compensating overloaded lines or lines with a heavy burden of reactive power flow, can be equipped with full two-dimensional, reactive and real power control capability. Evidently, it is fundamental to maintenance in this arrangement the overall power balance at the common DC-link by appropriate control action.

The arrangement shown in Fig. 1 can be functionally represented as in Fig. 2, where two synchronous voltage sources, with phasors $\overline{V}_{dq1}$ and $\overline{V}_{dq2}$, in series with the transmission lines 1 and 2, represent the two dc/ac series inverters (indicated in the following as SeV_1 and SeV_2, respectively). Transmission line 1, represented by reactance X_{l1}, has a sending-end bus with voltage phasor $\overline{V}_{s1}$ and a receiving-end bus with voltage phasor. $\overline{V}_{r1}$. The sending-end voltage phasor of line 2, represented by reactance X_{l2}, is $\overline{V}_{s2}$ and the receiving voltage phasor is $VVar_{r2}$.

For clarity, all the sending-end and receiving-end voltages are assumed to be constant with fixed amplitudes, $V_{s1} = V_{r1} = V_{s2} = V_{r2}$, and with fixed angles resulting in identical transmission angles, $\partial_1 = \partial_2$ for the two transmission systems.
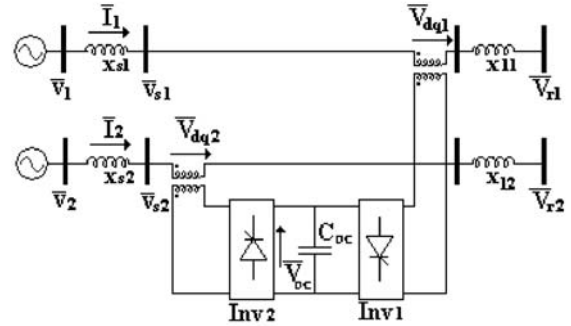

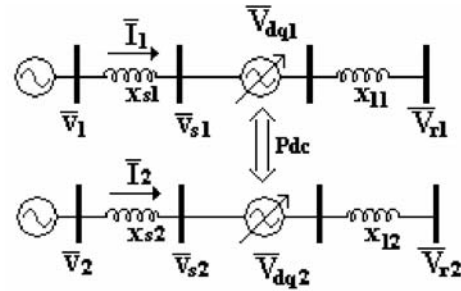Fig. 1 Two inverters IPFC configuration

Fig. 2 Two inverters IPFC functional scheme

In order to establish the transmission relationships between the two systems, system1 is arbitrarily selected to be the "prime" system for which free controllability of both real and reactive line power flow is stipulated. A phasor diagram of system 1, defining the relationship between $\overline{V}_{s1}$, $\overline{V}_{r1}$, $\overline{V}_{x11}$ and the inserted voltage phasor $\overline{V}_{dq1}$ with controllable magnitude $(0 \leq V_{dq1} \leq V_{dq1max})$ and angle $(0 \leq \beta_1 \leq 360°)$, is shown in Fig. 3.

The inserted voltage phasor $\overline{V}_{s1}$ is added to the fixed sending-end voltage phasor $VVar_{s1}$ to produce the effective sending-end voltage $VVar_{s1eff} = \overline{V}_{s1} + \overline{V}_{dq1}$. The difference $\overline{V}_{s1eff} - \overline{V}_{r1}$,

provides the compensated voltage phasor, $\overline{V}_{x/1}$, across X_{l1}. As angle β_1 is varied over its full 360° range, the end of phasor $\overline{V}_{dq1}$ moves along a circle with its centre located at the end of phasor $\overline{V}_{s1}$.

The rotation of phasor $\overline{V}_{dq1}$ with angle β_1 modulates both magnitude and the angle of phasor $\overline{V}_{x/1}$ and, therefore, both the transmitted real power, P_{1p}, and the reactive power, Q_{1p}, vary with $betan_1$ in a sinusoidal manner [4 -5] . This process, of course, requires the voltage source representing SeV1 $\left(\overline{V}_{dq1}\right)$ to supply and absorbs both reactive and real power, Q_{SeV1} and P_{SeV1}, which are also sinusoidal functions of angle β_1.

It is worth to underline, in the case of UPFC, the real power exchanged through the series voltage insertion is supplied via the shunt-connected inverter from the sending-end bus. Otherwise, in the case of IPFC this real power must be obtained from the other transmission line via the series connected compensating inverter of that line.

In order to establish the possible compensation range for the line 2, under the constraints imposed by the unrestricted compensation of line 1, it is helpful to decompose the overall compensating power provided for line 1 into reactive power Q_{SeV1} and real power P_{SeV1}. To this end, the injected voltage phasor $\overline{V}_{dq1}$ is decomposed into two components, one, V_{dq1q}, in quadrature and the other V_{dq1p}, in phase with the line current phasor $\overline{I}_1$. In particular, the in-phase component emulates a positive or negative resistance in series with the line impedance, while the quadrature component an inductive or capacitive reactance in series with the line impedance.
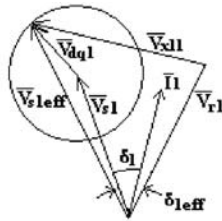

Fig. 3 Phasor diagram of System 1

The scalar product of V_{dq1q} and V_{dq1p} with $\overline{I}_1$ define Q_{SeV1} and P 1, respectively. The component Q_{SeV1}, generated internally by SeV_1, evidently provides series reactive compensation for line 1. The component P_{SeV1} provides real power compensation for line1, but

this power must be supplied by SeV_2 from line 2. It follows therefore that in order to satisfy the active power demand of SeV_1, SeV_2 must be operated so as the relationship $P_{SeV2} = P_{SeV1}$.

Each of the SeV has been realised by a 24-pulse inverter configuration to reduce the presence of harmonic components in the inverter output voltage with quasi square wave operation.

In this paper, the two SeVs provide real and reactive series compensation for line 1 and line 2. The injected series voltages can be so chosen appropriately to force any desired current vector, respecting the thermal and stability limits, to flow on the line, hence establishing a corresponding power flow. Naturally, one SeV can inject a series voltage at any angle with respect to the line current, so to exchange also real power with the transmission line, only when the other SeV is also operating. In this case the exchanged real power at the terminals of the SeV with the line can flow to the terminals of the other SeV through the common DC-link. On the basis of power flow requests the SeV control adjusts the gating of the associated inverter to inject the related voltage vector in series with the transmission line.

IV. SIMULATION MODEL OF IPFC SYSTEM

Consider 11KV transmission line model as shown in the Fig.4. In this model without IPFC system, the real and reactive power are simulated. The numeric values are displayed. By using mat lab simulink line current and output voltage are shown in the Fig 5. The real and reactive powers are shown in the Fig.6 and Fig.7 respectively.
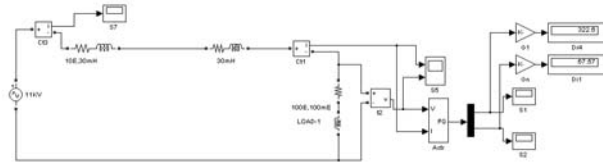

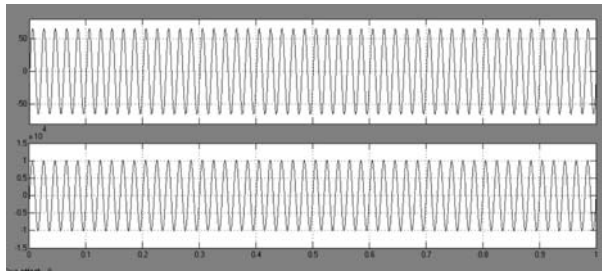Fig.4. Single transmission line-1 model in 11KV

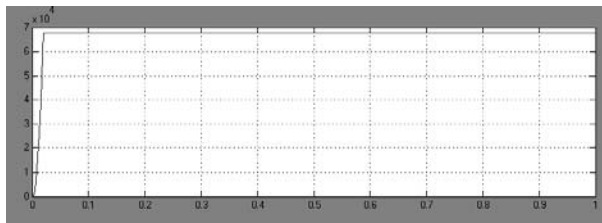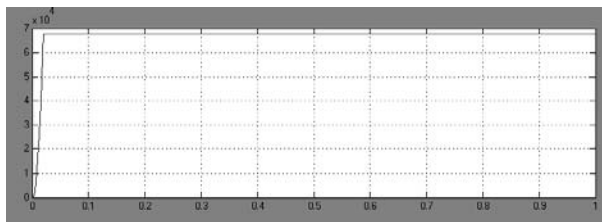Fig.5. Current and voltage output

Fig.6. Real power

Fig.7. Reactive power

Transmission line model 10KV is shown in the Fig.8. The 11Kv and 10KV line voltage model are simulated without IPFC system. The real and reactive powers are shown in Fig.9 and Fig.10 respectively. The voltage sag was created and the additional load 2 was introduced after the time period of 0.5 sec. The power variation at 0.5 sec is as shown in Fig.9 and Fig.10. The uncompensated output voltages at load-1 and load-2 are shown in Fig.11.
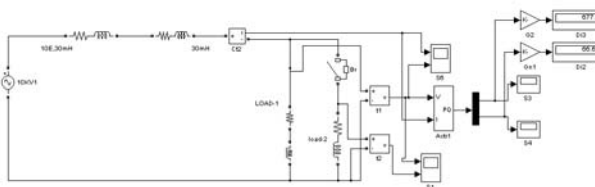

Fig.8. Single transmission line-1 model in 10KV with sag condition
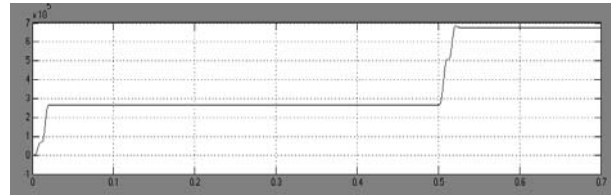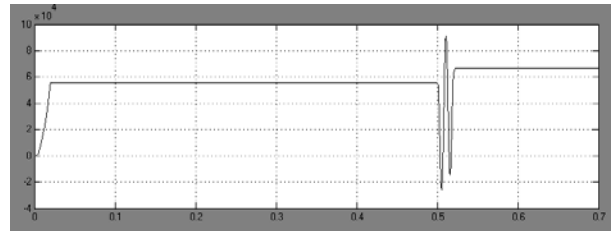

Fig.9. Real power output Across Load
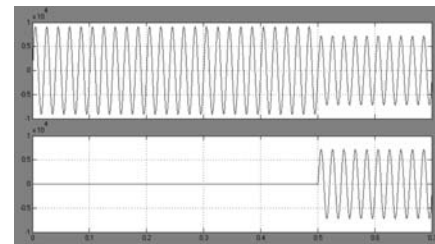

Fig.10. Reactive power in the Load

Fig.11. Voltage Across Load-1 and load-2

In this compensated transmission line IPFC with 11KV and 10 KV are shown in the Fig. 12. The controller system was interlinked between two lines of 11KV and 10KV vice versa. Here MOSFET can be used for both converting and inverting operation of IPFC system. The voltage will be injected to the lines through a series transformer. Now the additional load is connected at 0.5sec onwards. But the voltage sag will be compensated The IPFC power circuit model is as shown in the Fig.13.

In the occurrence of a disturbance in the utility grid, the compensator injects the missing voltage supplying the protected load with voltages free from the disturbances. The energy injected by the equipment is extracted from the utility system through a diode bridge rectifier, which avoids using energy storage system, as battery banks, reducing implementation and maintenance cost.

The driver circuit gives the triggering pulse to MOSFET and the pulse propagation period is controlled by interface circuit
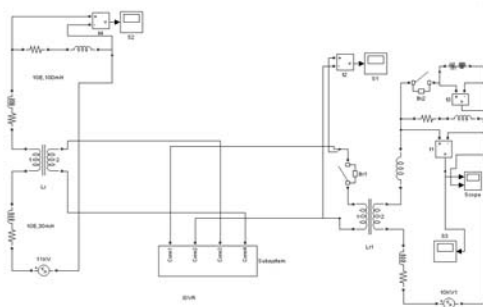
Fig.12. Incorporation of IPFC with 11kv and 10kv systems

In this case the DC link storage system is connected to VSI. The DC link capacitors to maintain the stability of the system. The IR2110 is a high voltage and high speed power MOSFET driver circuit system. The results of voltage across load1, load2 and voltage across IPFC are as shown in the Figs.14 and Fig.15 respectively.
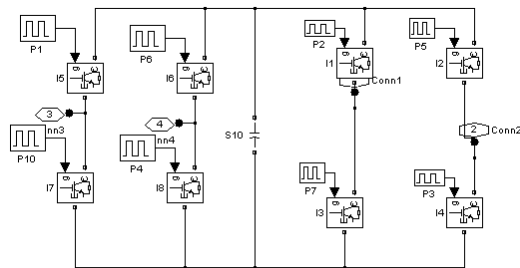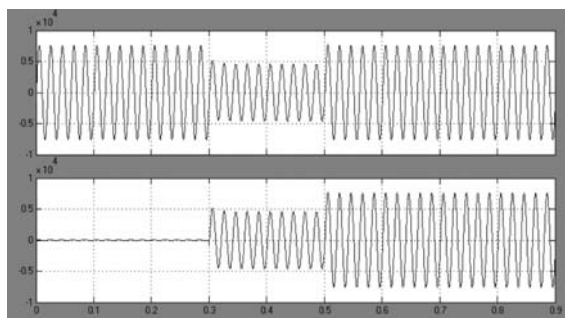

Fig.13. The IPFC power circuit model

Fig.14. Voltages output across load1 and load2

V. HARDWARE RESULTS

This IPFC provides a charging of the DC bus capacitor up to the optimal voltage, stabilizing this when the voltage in the grid is normal and preventing DC capacitor overcharging during longer over voltages. The used voltage dips mitigation strategy corresponds to "pre-sag compensation"
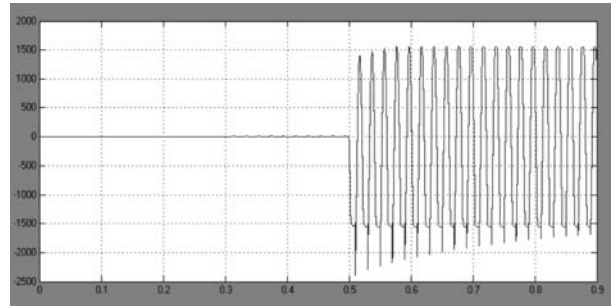

Fig.15. Voltage output across IPFC

method as classified in IPFC system. In this method the appliance voltage can be ideally restored. When the DC bus voltage is optimal and the grid voltage is normal, almost no voltage is present across the IPFC terminals. As such, the losses are minimal during the long period of the normal operation. The waveforms for input and output voltage of rectifier are as shown in the Fig.16 and Fig.17. The sinusoidal voltage is given to the fully controlled rectifier circuit. The capacitor is to maintain the stability of the DC output voltage.
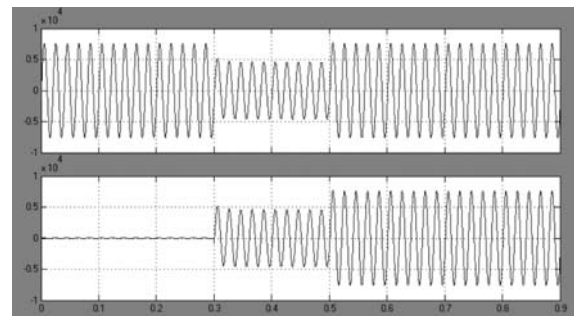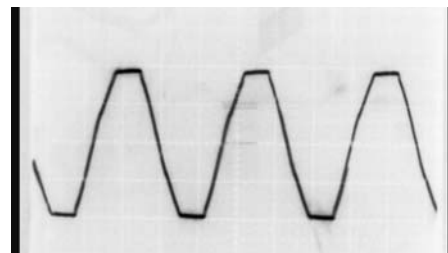

Fig.16. AC input voltage

Fig.17. Rectifier output voltage

In the occurrence of a disturbance in the utility grid, the compensator injects the missing voltage supplying the protected load with voltages free from the disturbances. The energy injected by the equipment is extracted from the utility system through a diode bridge rectifier, which avoids using energy storage system, as battery banks, reducing implementation and

maintenance cost. The driving pulses of inverter are as shown in the Fig.18.
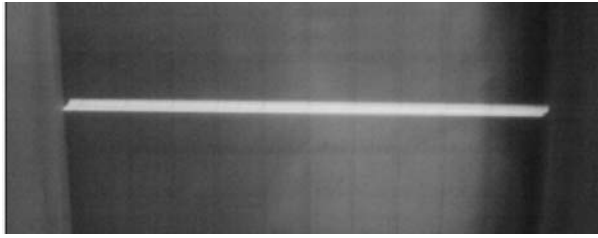

Fig.18. Driving pulses for inverter

This driver circuit gives the triggering pulse to MOSFET and the pulse propagation period is controlled by interface circuit. The configuration of IPFC using micro controller is as shown in the
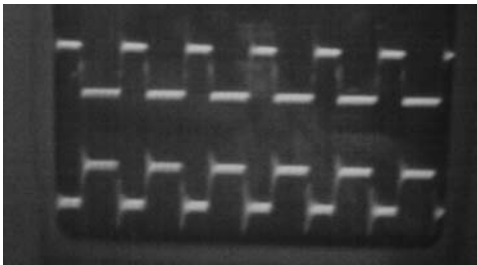

Fig 19. MOSFET output signals

Fig. 20 The IPFC system for Prototype Model

The IPFC maintains the voltage applied to the load during sags and swells by injecting a voltage of compensating amplitude and phase angle into the line. In the IPFC system to satisfies the stringent power quality demands of industrial and commercial customers.

VI   CONCLUSION

The basic IPFC structure is based on zero net power at the common dc terminals with the assumption that in the overall system there is available capacity in the strong and under loaded lines to provide appropriate real power compensation for the weak and overloaded lines. The uncompensated and compensated systems are analyzed. The model of IPFC was verified with simulation results. Hence the hardware results coincide with the simulation results. By using in this model of IPFC system the voltage sag is superiorly compensated for identical transmission lines. In practical if this condition is not satisfied, the basic IPFC structure can be complemented with an additional shunt inverter to provide the differential power from a suitable shunt bus which can also provide shunt reactive compensation. The IPFC configuration offers a flexible utilization of needed compensation assets, without any significant cost addition, is hoped to attract much interest in utilities to solve some difficulties in the recent power system problems. The experiments results are similar to the simulation results.

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