Conceptual comparative study of New FACTS Technology: Unified Power Flow Controller,Distributed Power Flow Controller,Interline Power Flow Controller and Separated-Interline Power Flow Controller

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***Abstract*—According to the increasing demand of electricity and increasing number of non-linear loads in power grid, it requires a high quality of electrical power to be considered. The Flexible Alternating Current Transmission (FACTS), based on power electronics, it offers an opportunity to enhance controllability, stability, and power transfer capability. The FACTS devices can be used to mitigate the power quality problems. The most versatile FACTS devices are Combined compensators that is The Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC). The first controller is UPFC which is multifunctional FACTS Controller based on the back-to-back voltage-sourced converter connected with the common capacitor dc link. In this arrangement, one converter of the back-to-back arrangement is in series and the other is in shunt with the transmission line. The Distributed Power Flow Controller (DPFC) is derived from the UPFC with eliminated common dc link. The second controller is IPFC in which both converters of the back-to-back arrangement are connected in series with, usually, a different line via a common dc link. The Separated Interline Power Flow Controller (S-IPFC) is derived from the IPFC with eliminating the common dc link between the different lines. This paper first deals with the conceptual comparative study of "UPFC and DPFC" and secondly the comparative study between "IPFC and S-IPFC".**

Keywords— Flexible Alternating Current Transmission, Unified Power Flow Controller, Distributed Power Flow Controller, Interline Power Flow Controller, Separated Interline Power Flow Controller,Distributed-FACTS (D-FACTS),Voltage Source Converter (VSC).

I. INTRODUCTION

As power transfer grows with increasing demand on transmission line, the power system becomes highly complex to operate and system becomes less secure for riding through the major outages [1]. The conventional power systems are majorly mechanically controlled. Also, there are problems associated with in mechanical devices which are as follows:

- Little high-speed control and response
- Control cannot be initiated frequently
- These devices tend to wear out very quickly compared to static devices
- In fact, from the point of view of both dynamic and steady-state operation, the system is really uncontrolled.

Therefore, the power system requires suitable design of new effective and reliable devices to regulated electric power industry for flexible power flow. In the late 1980s, the Electric Power Research Institute (EPRI) introduces a new approach to solve the problem of designing, controlling and operating power systems: the proposed concept is known as Flexible AC Transmission Systems (FACTS) [2]. It is the target for long-term development to provide new opportunities for controlling power and to enhance the capacity of existing as well as new lines. The main objectives of FACTS technology are to increase power transmission capability, voltage control, voltage stability enhancement and power system stability improvement. Its first concept was introduced by N.G. Hingorani in April 19, 1988 [3]. The FACTS controllers are becoming an integral component of modern power transmission systems.

The family of FACTS technology is a collection of controllers which can be applied individually or in coordination with other FACTS devices. The classification of FACTS controllers has followed two distinctly different technical approaches which are as follows:

Thyristor based FACTS controllers - Static VAR Compensators (SVCs), Thyristor Controlled Series Compensators (TCSCs).

Voltage Source Converter based FACTS controllers - Static Synchronous Compensators (STATCOMs), Static Synchronous Series Compensators (SSSCs) and Unified Power Flow Controllers (UPFCs), Interline Power Flow Controller (IPFC).

Currently, the unified power-flow controller (UPFC) is the most powerful FACTS device, which can simultaneously control all the parameters of the power system: the line impedance, the transmission angle, and bus voltage [4]. The

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UPFC is the combined controller (shunt-series controller) formed by a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC), which are coupled with the help of a common dc link, to allow bi-directional flow of active power between the series output terminals of the SSSC [5] and the shunt output terminals of the STATCOM [6].

The components of the UPFC handle the voltages and currents with high rating; therefore, the total cost of the system is high. Due to the common dc-link interconnection, a failure that happens at one converter will influence the whole system. The paper presented by Zhihui Yuan in the IEEE Transaction on Power Electronics in 2010, firstly introduces a new concept, called Distributed Power-Flow Controller (DPFC) that is derived from the UPFC. [7]

As same as the UPFC, the DPFC is able to control all system parameters of the transmission lines. The DPFC eliminates the common dc link between the shunt and series converters [7]. 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 DPFC is based on the distributed FACTS (D-FACTS) concept [8]. The shunt converter of the DPFC is as same as STATCOM.

In the context, to the Unified Power Flow Controller (UPFC), the Interline Power Flow Controller (IPFC) provides a relatively economical solution for multiple transmission lines power flow control, since here only one shunt converter is involved [9]. The IPFC also gains more control capability than the Static Synchronous Series Compensator (SSSC), where both are series compensation but IPFC is with common dc link [10], because to provide the active compensation. From probabilistic point of view in the paper presented by R. Strzelecki; G. Benysek; Z. Fedyczak [11], the performance of the IPFC will be better when more series converter involves into the IPFC system.

However, the converters are connected through the common dc link, they have to be physically close to each other. The common dc link becomes a constraint of location for the IPFC and limits its commercial application in the future. Therefore, method which eliminates the IPFC common dc link and provided the active power exchange between converters are proposed by Zhihui Yuan, Sjoerd W.H. de Haan and Braham Ferreira in 2008 [12].

This paper presents [12] a new concept called Separated Interline Power Flow Controller (S-IPFC) that allow the converters of the IPFC exchange active power without any common dc link. The method eliminates common dc link and only use a capacitor to provide the dc voltage for each converter in the power lines [12]. The active power is exchanged at a harmonic frequency through the ac transmission line [13]. Theoretically, this method allows as many as series converters employed to the IPFC. In the next section of this paper, we will study the conceptual comprative study of the UPFC, DPFC, IPFC and S-IPFC.

II. UPFC AND DPFC TOPOLOGY

A. *Unified Power Flow Controller (UPFC)*

The UPFC is a device for real-time control and dynamic compensation of ac transmission systems. UPFC is able to control synchronic or individually all the parameters (i.e. voltage, phase angle, and impedance) affecting power flow in the power system network. Thus this unique capability is announced by the adjective "unified" [4]. The main reason behind the widespread of UPFC is its ability to power flow bi-directionally, maintaining well regulated DC voltage, and the wide range of operating conditions [12].

1.Basic principle of operation

UPFC consist of two back to back Voltage Source Converters (VSCs) named VSC1 and VSC2, are operated via a DC link provided by a dc storage capacitor. This arrangement operates as an ideal AC to AC converter in which the real power can freely flow in either direction between the ac terminals of the two converters. Each converter can independently generate or absorb reactive power as its own ac output terminal.

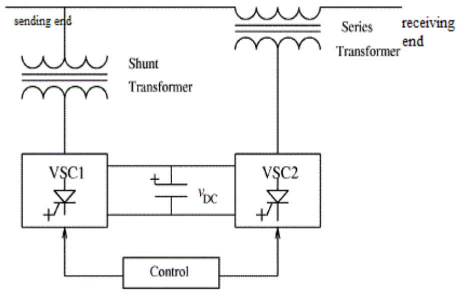

Fig. 1. basic systematic UPFC diagram [12]

One VSC is connected in shunt to the transmission line via a shunt transformer and other one is connected in series through a series transformer. The DC terminal of two VSCs is coupled and it creates a path for active power exchange between the converters.

The second VSC provides the main function of UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an injection transformer. This injected voltage act as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and active power exchange between it and the ac system. The reactive power exchanged at the dc terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc power which appears at the dc link as a real power demand [1] [12].

VSC1 supply or absorb the active power demanded by VSC2 at the common dc link to support active power exchange resulting from the series voltage injection. This dc link power demand of VSC2 is converted back to AC by VSC1 and coupled to the transmission line bus via shunt connected transformer.

In addition, VSC1 can also generate or absorb controllable reactive power if it is required and thereby provide independent shunt reactive compensation for the line. Thus VSC1 can be operated at a unity power factor or to be controlled to have a reactive power exchange with the line independent of the

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reactive power exchanged by VSC1. There can be no reactive power flow through the UPFC dc link [12].

2.Equivalent circuit of UPFC:

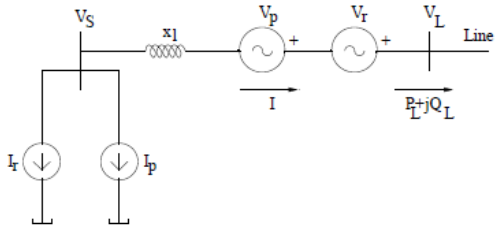

Fig. 2. equivalent circuit of UPFC [12]

The equivalent circuit of the UPFC is shown in Fig. 2 in which the shunt converter draws both active (Ip) and reactive current (Ir). The active current (Ip) is not independent and is related to Vp by the relation in steady state.

$$V*I_p = I*V_p \tag{1}$$

The equivalent circuit of the UPFC can be viewed as a two-port network. The shunt converter is connected at one port while the series converter is connected in series with the line at the other port. The voltage at the latter port is denoted by VL. If the series injected voltages, V_p and V_r are controlled to regulate the power and reactive power in the line; these quantities are conveniently measured at the line side port of the UPFC.

3. Control of UPFC

UPFC have two control i.e. series control and shunt control.

a) Control of the shunt converter

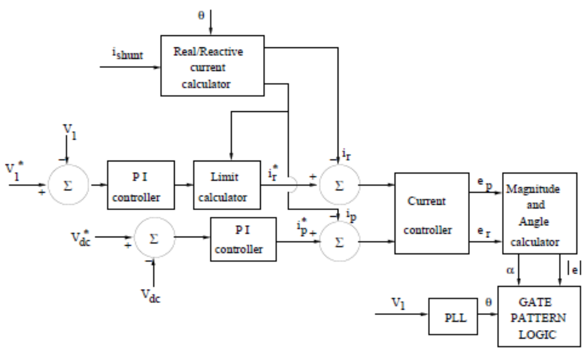

Fig. 3. block diagram of shunt controller [12]

b) Control of the series converter

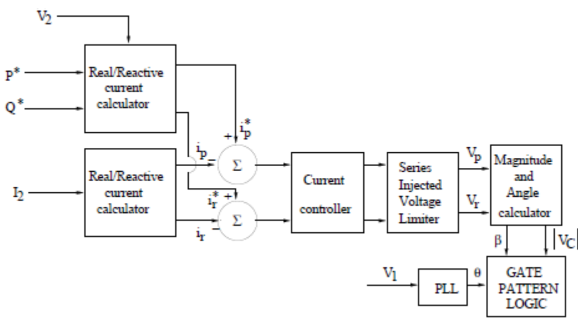

Fig. 4. Block diagram of series controller [12]

B. Distributed Power Flow Controller

The DPFC consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the D-FACTS concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own dc capacitor to provide the required dc voltage [7] [17]. The configuration of the DPFC is shown in Fig. 5.

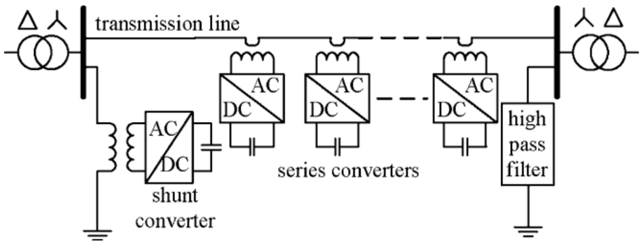

Fig. 5. DPFC configuration [7].

The key components of DPFC are as follows:

- The shunt and series converters,
- High pass filter that is shunt connected at the other side of the transmission line, and
- Two Y–Δ transformers at each side of the line.

1. Basic control operation of DPFC

Within the DPFC, there is a common connection between the ac terminals of the shunt and the series converters, which is the transmission line.

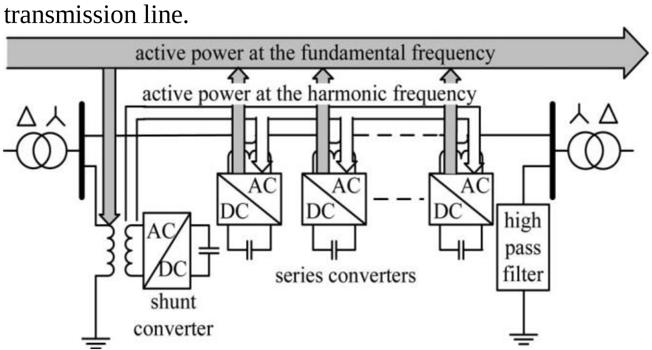

Fig. 6. Active power exchange between DPFC converters [7].

Therefore, it is possible to exchange the active power through the ac terminals of the converters. The method is based on the power theory of non-sinusoidal components. According to the Fourier analysis, a non-sinusoidal voltage and current can be expressed by 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 [7]. Since the integrals of all the cross product of terms with different frequencies are zero, the active power can be expressed by

$$P = \sum_{i=1}^{\infty} V_i \; I_i \; cos\emptyset_i \tag{2}$$

where Vi and Ii are the voltage and current at the i^{th} harmonic frequency, respectively, and $\emptyset_i$ is the corresponding

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angle between the voltage and current. Equation (2) describes that the active power at different frequencies is isolated from each other and the voltage or current in one frequency has no influence on the active power at other frequencies. The independent feature of the active power at different frequencies gives the possibility that a converter without power source can generate active power at one frequency and absorb this power from other frequencies [7].

By applying this method to the DPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the current back into the grid at a harmonic frequency.

This harmonic current will flow through the transmission line. According to the required active power at the fundamental frequency, the DPFC series converters generate a voltage at the harmonic frequency and thereby absorbing the active power from harmonic components. Assuming a lossless converter, the active power generated at fundamental frequency is equal to the power absorbed from the harmonic frequency. Fig. 6 shows the active power exchanges between the shunt and the series converters in the DPFC system.

2. Equivalent circuit of DPFC

To simplify the DPFC, the converters are replaced by controllable voltage sources in series with impedance. Since each converter generates the voltage at two different frequencies, it is represented by two series-connected controllable voltage sources, one at the fundamental frequency and the other at the third-harmonic frequency. Assuming that the converters and the transmission line are lossless, the total active power generated by the two frequency voltage sources will be zero. The multiple series converters are simplified as one large converter with the voltage, which is equal to the sum of the voltages for all series converter, as shown in fig. 7.

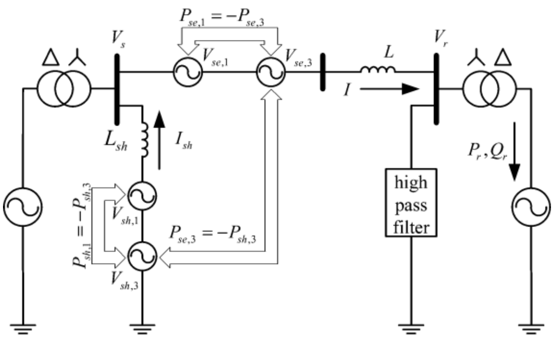

Fig. 7. DPFC simplified representation. [7]

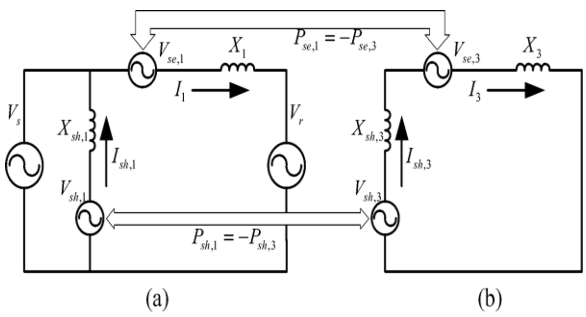

Fig. 8. DPFC equivalent circuit. (a) Fundamental frequency. (b) Third harmonic Frequency [7].

3. Control of DPFC

DPFC consists of three controls that is central control, series control, and shunt control [7].

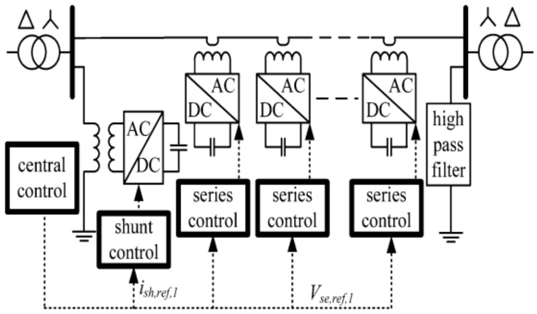

Fig. 9. DPFC control block diagram [7].

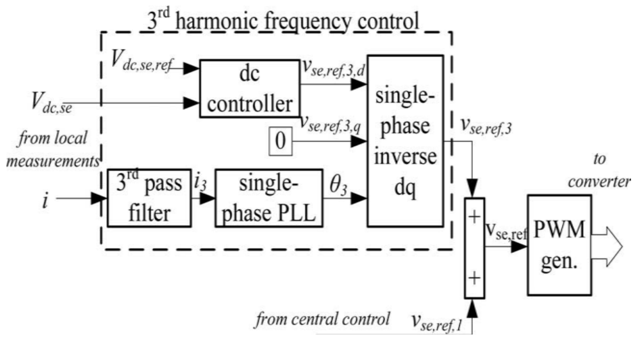

Fig. 10. Block diagram of the series converter control [7].

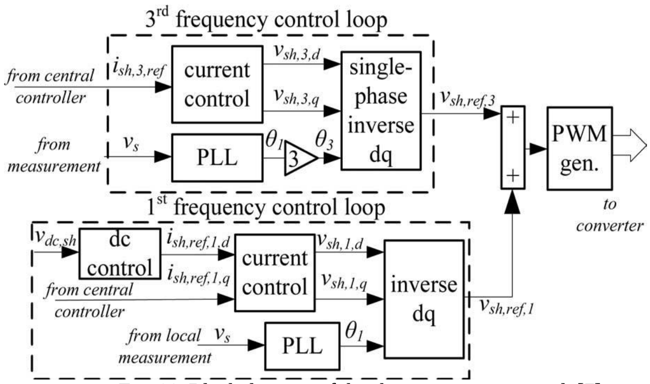

Fig. 11. Block diagram of the shunt converter control. [7]

4. Comparison of UPFC and DPFC

a. High cost

Any sort of failure in one converter will influence the whole system due to the common dc-link in UPFC. To achieve the required reliability for power systems, by-pass circuits and backup transformer, etc. are needed, which also increases the cost of the existing systems [15]. The components of the UPFC handle the voltages and currents with high rating so the total cost of the system is high. Whereas in DPFC converters whether its shunt or series converters, failure of any will cause least effect on the line.

If in case of shunt failure, all the other series converters will act as a series compensation to the line and in case of any of Distributed series converter failure, all the rest converters will compensate it effect individually.

b. High Flexibility

The UPFC is not widely used in utility grids because it fails, if there is ak8ny disturbances or faults in the source side. It is less reliable [15]. Whereas DPFC provides higher flexibility and reliability at lower cost. The DPFC is an improvement of UPFC that employs the D-FACTS concept and in addition, the concept of exchanging power through the 3rd harmonics.

c. High controllability

The DPFC can simultaneously control all the parameters of the transmission network: line impedance, transmission angle and bus voltage as same as UPFC.

d. High reliability during Failure

The redundancy of the series converter gives high reliability without any increase in cost due to the implementation of D-FACTS concept in DPFC. The shunt and series converters are independent and failure of one will not influence the other converter. Thus, high reliable during failure than UPFC [16] [18].

e. Low cost

In DPFC we use low power rating converters instead of using one high power converters as in UPFC which lowers its cost. There is no phase-to-phase voltage isolation required between the series converters of different phases. The large number of the series converters, they can be manufactured in series production.

III. IPFC AND S-IPFC TOPOLOGY

A. Interline Power Flow Controller

The Interline Power Flow controller (IPFC), proposed by Gyugyi with Sen and Schauder in 1999, addresses the problem of compensating a number of transmission [9] lines at a given substation [3]. 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 multiline transmission system. However, series reactive compensators are unable to control the reactive power flow, and thus no proper load balancing of the lines [3].

The above mention problem becomes particularly most prominent in those cases where the ratio of reactive to resistive line impedance (X/R) is relatively low. Series reactive compensation reduces only the effective reactive impedance X and, thus, significantly decreases the effective X/R ratio and thereby increases the reactive power flow and losses in the line.

The IPFC, together with independently distributed controllable reactive series compensation (employed D-FACTS) of each individual line, provides a capability to directly transfer real power between the compensated lines [3] [7]. Due to this IPFC have following capabilities:

- It equalizes both real and reactive power flow between the lines.
- It reduces the burden of overloaded lines by real power transfer.
- It compensates against resistive line voltage drops and the corresponding reactive power demand and
- It increases 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 multiline substation.

1. Basic Operation of IPFC

IPFC comprises a number of Static synchronous compensators each providing series compensation for a different line. It may or may not include a shunt converter, which in case connected between transmission line and ground. The series compensating terminals are linked together at their dc terminal. As shown in fig 10.

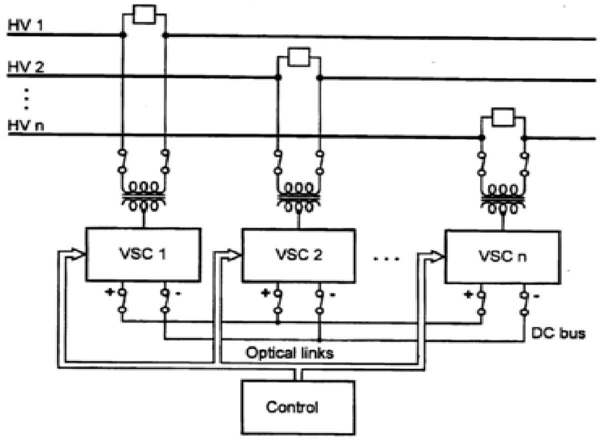

Fig 10. Interline Power Flow Controller comprising n Converters [3].

In IPFC, rather than providing series compensation any converter can be controlled to supply real power to the common dc link from its own transmission line. Therefore, an overall surplus power can be made available from the under load lines which then can be used by other lines for real power compensation. In this way, some of the converters compensate the 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 [3].

2. The Equivalent Circuit of IPFC [3]

Consider an elementary IPFC scheme consisting of two back-to-back dc-to-ac converters, each compensating a transmission line by series voltage injection. This is shown in Fig 11, where two synchronous voltage sources, with phasors V_{1pq} and V_{2pq} in series with transmission Lines 1 and 2, represent the two back-to-back dc-to-ac converters. The common dc link is represented by a bi-directional link for real power exchange between the two voltage sources. Transmission Line 1, represented by reactance X_1, has a sending-end bus with voltage phasor V_{1s} and a receiving-end bus with voltage phasor V_{1r}. The sending-end voltage phasor of Line 2, represented by reactance X_2, is V_{2s} and the receiving-end voltage phasor is V_{2r}.

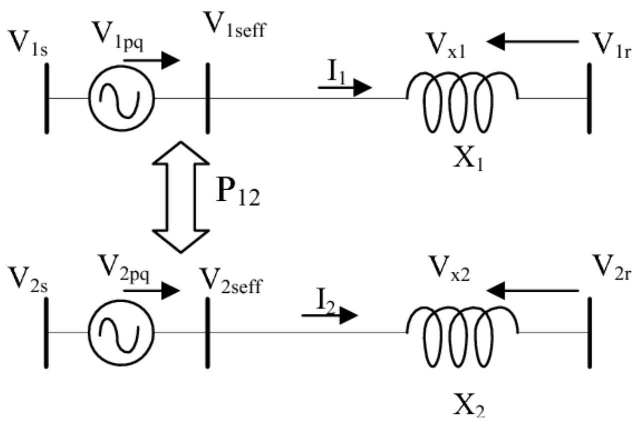

Fig 11. Basic two-converter Interline Power Flow Controller [3].

B. Separated Interline Power Flow Controller (S-IPFC)

S-IPFC is the new approach that allows the converters of the IPFC to exchange active power without dc link. This arrangement eliminates the common dc link and only use a capacitor to provide the dc voltage for each converter [12].

1. Basic principle of S-IPFC

As same as in the DPFC, the method for active power exchanged is based on the non-sinusoidal power theory [7]. According to Fourier analysis, a non-sinusoidal voltage and current can be expressed by the sum of sinusoidal functions in different frequencies with different amplitudes as expressed in equation (2). The definition of active power is the mean value of the product of voltage and current. Since the integrals of all the cross-product of terms with different frequencies are zero, the active power can be expressed by:

$$P = \sum_{n=1}^{\infty} V_{sn} I_{sn} \cos\emptyset_n \quad (3)$$

where, $\cos\emptyset_n$ = power factor and n= harmonic frequency.

Fundamental active power can be exchanged through AC terminal instead of the common dc link between converters.

- Each converter extracts active power from fundamental frequency and injects power back to the ac terminal at a harmonic frequency.
- Other converts absorb the harmonic power and converts it to the fundamental frequency back to the ac terminal.

2. Basic configuration of S-IPFC:

In S-IPFC exchange of active power is through the transmission line. In objective to transmit power without common dc link, the ac sides of the S-IPFC converters have to be connected.

For S-IPFC the series converters should be installed in power lines which have a physical AC connection to allow the harmonic current or the power to flow.

Why 3rd harmonics?

The 3rd harmonic frequency is so chosen to transmit the active power, because the 3rd harmonic can be easily blocked by star-delta transformer which is also used to change the voltage level as in DPFC.

Two conditions to be satisfied by S-IPFC are as follows [12]:

- Network of S-IPFC is closed by star-delta transformers to block the 3rd harmonic.
- The series converters installed in ac lines should have physical connection to allow 3rd harmonic current to pass.

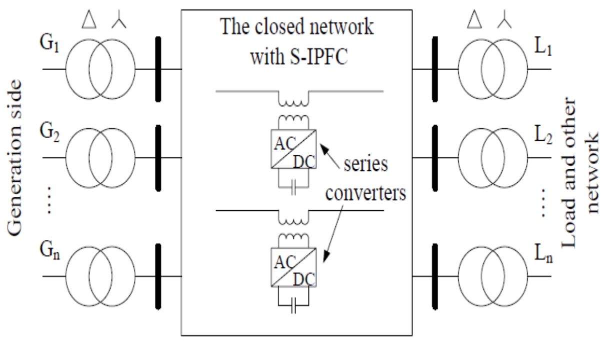

Fig 12. S-IPFC operation network [12].

Constraints of 3rd harmonic:

The 3rd harmonic current flowing through series converters, since the 3rd harmonic current is in-phase, so the typical 3-leg full bridge converter can't allow 3rd harmonic current to pass through.

To allow the 3rd harmonic current flow, the topology of series converter should be specially designed, such as

- 3-leg 4-wires topology
- 4-leg 4-wires topology

The significance of using the 4th wire is that it acts as a return conductor for the 3rd harmonic current that flow in the AC lines.

Most important advantage of S-IPFC is that it employs D-FACTS as in DPFC [7].

The most important common property between DPFC and S-IPFC is that as one shunt converter is to be used in case of DPFC, but in case of shunt converter failure in DPFC, it acts as a series compensation device [16].

In S-IPFC it's not compulsory to have shunt converter:

Case 1. S-IPFC without shunt converter- In this case the sum of the active powers of all the series converters should be zero.

Case 2. S-IPFC with one shunt converter- Shunt converter will provide more capability because it can supply active power to series converter. Now, every series converter can inject fully controlled voltage phasor. Therefore, active and reactive power flow through the transmission line can be independently controlled.

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- In case of one shunt converter,3_{rd} harmonic pass filter is required to provide a close loop for 3^{rd} harmonic current because the neutral point floating in star-delta is open-circuit to 3rd harmonic current, and so there will be no return path for 3rd harmonic current.
- In case of multiple shunt converter, 3rd pass filter is not required because shunt converters themselves construct a closed loop for harmonic current.

3. Equivalent diagram of S-IPFC [12]

In the equivalent S-IPFC, two three-phase converters are series connected to parallel transmission lines. To ensure that the 3rd harmonic current can flow between the converters, the neutral points of star-delta transformers are floating. The floating star-delta transformer is open circuit to 3rd harmonic, and forces the 3rd harmonic current to flow through the lines. To show the function of S-IPFC, each converter will be replaced by two controlled voltage sources. One is at the fundamental frequency, the other is at the 3rd harmonic. Assuming a lossless converter, the active power exchange in single converter between different frequencies is represented by a bidirectional link (P1 = P3). The transmission lines a and b are represented by inductor L_a and L_b respectively. The sending-end of transmission lines voltage phasor is Vs. The receiving-end is V_r. The magnitude and angle of Vs and V_r are fixed during the S-IPFC operation. The schematic diagram of basic S-IPFC is shown in Fig. 13.

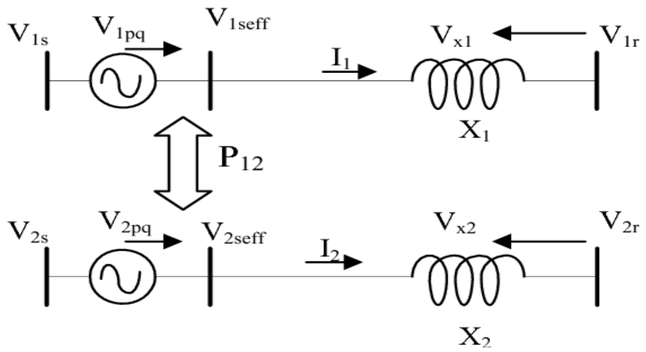

Fig 13. Schematic equivalent diagram of S-IPFC with two converters [12].

4. Control of S-IPFC

The control of S-IPFC is more complex than the conventional IPFC, because it has two components at different frequency to control and it also maintain the voltage of two capacitors [12].

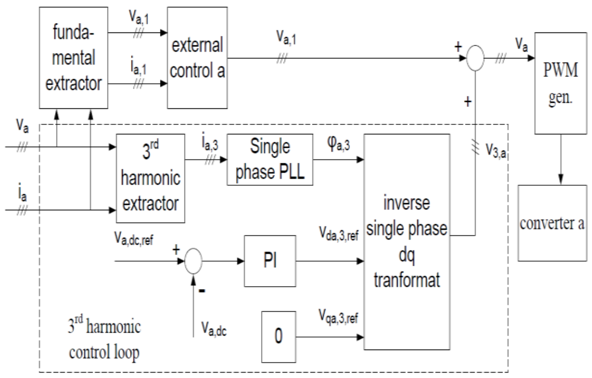

Fig 14. Basic control loop for converter a [12].

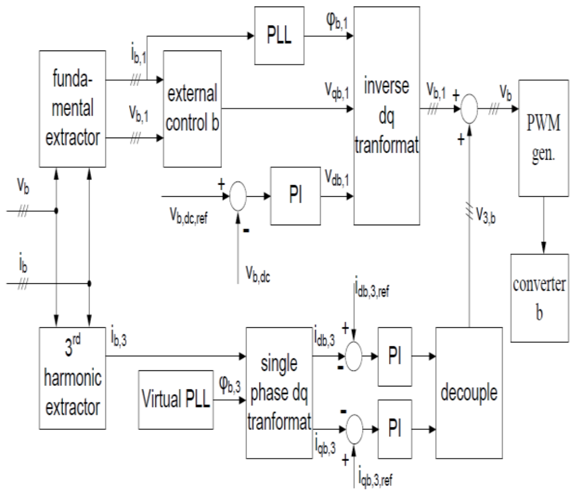

Fig 15. Basic control loop for converter b [12].

5. Comparison between IPFC and S-IPFC

a. Complexity

S-IPFC is less complex than IPFC in terms of construction basis because it eliminates the common dc link but it is more complex than IPFC in terms of controlling because it has to maintain at the components at different frequency.

b. Reliability

S-IPFC is more reliable than IPFC in meshed network because it allows multiple shunt and series converters.

c. Low cost

S-IPFC employs D-FACTS as the series converter, so it provides low cost because low power rating converters are required and no isolation requirement for compensators. D-FACTS provides high because of redundancy.

IV. CONCLUSION

This paper has presented the conceptual comparison between the most prominent FACTS technology that is UPFC, DPFC, IPFC and S-IPFC. We studied the concepts of each device in detail. Hence, we conclude that in transmission line DPFC has more control capabilities than UPFC and in the meshed network or in multi-lines transmission S-IPFC is better than IPFC.DPFC and S-IPFC both have advantages of D-FACTS concept and exchange active power without the common dc link, with the help of 3rd harmonic frequency. Hopefully, these devices are placed in transmission network and provide better power flow control in future.

REFERENCES

[1] Y.-H. Song and A. Johns, Flexible ac Transmission Systems (FACTS) (IEE Power and Energy Series), vol. 30. London, U.K.: Institution of Electrical Engineers, 1999.

[2] “Electric Power Research Institute”-Wikipedia, https://en.wikipedia.org/wiki/Electric_Power_Research_Institute

[3] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York: IEEE Press, 2000.

[4] L.Gyugyi, C.D. Schauder, S. L.Williams, T. R. Rietman,D. R. Torgerson,and A. Edris, “The unified power flow controller: A new approach to power transmission control,” IEEE Trans. Power Del., vol. 10, no. 2, pp. 1085–1097, Apr. 1995.

[5] K. K. Sen, “Sssc-static synchronous series compensator: Theory, modeling, and application,” IEEE Trans. Power Del., vol. 13, no. 1, pp. 241–246, Jan. 1998.

[6] M. D. Deepak, E. B. William, S. S. Robert, K. Bill, W. G. Randal, T. B. Dale, R. I. Michael, and S. G. Ian, “A distributed static series compensator system for realizing active power flow control on existing power lines,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 642–649, Jan.2007.

[7] Zhihui Yuan, Sjoerd W.H de Haan,Jam Braham Ferreira, “ A FACTS Device: Distributed Power-Flow Controller (DPFC)”,IEEE Transaction on Power Electronics, vol. 25. No. 10,October2010.

[8] D. Divan and H. Johal, “Distributed facts—A new concept for realizing grid power flow control,” in Proc. IEEE 36th Power Electron. Spec. Conf. (PESC), 2005, pp. 8–14.

[9] Gyugyi, L.; Sen, K.K.; Schauder, C.D.: The interline power flow controller concept: a new approach to power flow management in transmission systems, Power Delivery, IEEE Transactions on Volume 14, Issue 3, July 1999.

[10] Xiao-Ping Zhang: Advanced modeling of the multi-control functional static synchronous series compensator (SSSC) in Newton power flow, Power Systems, IEEE Transactions on Volume 18, Issue 4, Nov. 2003 Page(s):1410 - 1416.

[11] R. Strzelecki; G. Benysek; Z. Fedyczak: “Interline Power Flow Controller-Probabilisitic Approach”,2002.

[12] Zhihui Yuan,Sjoerd W.H. de Haan,Braham Ferreira, “A New Concept of Exchanging Active Power without Common DC Link for Interline Power Flow Controller (S-IPFC),2008 IEEE.

[13] Yuan, Zhihui; de Haan, Sjoerd W.H.; Ferreira, Braham: UPFC with Eliminated Common DC Link Connection Between Shunt and Series Part, Power Engineering Society General Meeting, 2007. IEEE 24-28 June 2007 Page(s):1 - 4.

[14] Sapna Khanchi, Vijay Kumar Garg, “Unified Power Flow Controller (FACTS Device): A Review”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 3, Issue 4, Jul-Aug 2013, pp.1430-1435.

[15] Nikita Gupta, Vahadood Hasan, “Comparison of Performance of Distributed Power Flow Controller (DPFC) and Unified Power Flow Controller (UPFC)”, International Journal of Advance Engineering and Research Development Volume 2,Issue 4, April -2015.

[16] Zhihui Yuan,Sjoerd W.H. de Haan,Braham Ferreira, “DPFC Control during Shunt Converter Failure”, 978-1-4244-2893-9/09 ©2009 IEEE.

[17] Yuan, Zhihui; de Haan, Sjoerd W.H.; Ferreira, Braham: UPFC with Eliminated Common DC Link Connection Between Shunt and Series Part, Power Engineering Society General Meeting, 2007. IEEE 24-28 June 2007 Page(s):1 - 4.

[18] Z. Yuan, S.W.H. de Haan and J.A. Ferreira, “Control Scheme to Improve DPFC Performance during Series Converter Failures” 978-1-4244-6551-4/10 ©2010 IEEE.