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DISTRIBUTED POWER FLOW CONTROLLER: A REVIEW

Mayank Tyagi #1, Deepika Singh *2

#1M.Tech student: Department of EEE, Ajay Kumar Garg Engineering College, Ghaziabad, U.P, India
**2M.Tech student: Department of EEE, Ajay Kumar Garg Engineering College, Ghaziabad, U.P, India*

***Abstract*— in this paper, a method of improving power quality of power system using the distributed power flow control is proposed. A distributed power flow controller is resultant to overcome the limitations of the unified power flow controller. An UPFC can be transformed to DPFC by eliminating the common dc-link between the series and shunt converters and by commissioning distributed FACTS (D-FACTS) concept in which multiple small-size single-phase converters are used instead of one large-size three-phase series converter. This case study of contains the construction, principle, control techniques, advantages and drawbrakes and other key information of DPFC.**

***Index Terms*— UPFC, DPFC, FACTS, third harmonics frequency.**

I. INTRODUCTION

In recent years, greater demands have been employed on the transmission network, and these demands will continue to increase because of the increasing number of utilities. Increasing demand on transmission leads to reduced power quality. The FACTS technology improve grid reliability by controlling and regulating the electrical variables in the power system and hence increase the power transfer capability and can be utilized for power flow control [1].

Currently, the unified power flow controller is the most powerful FACTS device which can simultaneously control multiple parameters of power system such as line impedance, transmission angle and bus voltage. UPFC is widely used because of its ability to pass the real power flow bidirectional, maintaining regulated dc voltage and its wide range of operating conditions.

The UPFC is an amalgamation of static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) coupled via a common dc link to allow bidirectional flow of active power between shunt output terminal of STATCOM and series output terminal of SSSC. Fig 1.1 showing simple representation of UPFC [2].

Due to the common dc link which is a dc storage capacitor, if a failure happens in one converter will influence the whole system. Therefore to achieve a dependable power system, redundant backups are used which make the system costly. Due to high cost and redundancy to failure UPFC are not widely used practically.

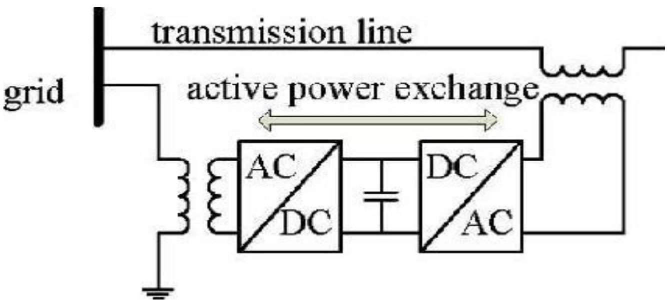

Fig 1.1 unified power flow controller

To overcome limitations of UPFC power engineers developed one such controller which is inexpensive as well as highly reliable named distributed power flow converter (DPFC). DPFC is originated from UPFC and has similar capabilities like to pass the real power flow bidirectional and multiple parameter control of parameter. The DPFC can be achieved by first eliminating dc link from the UPFC and then by replacing three phase converter with distributed series converters [3]. The flow chart for obtaining DPFC is given in fig 1.2. In DPFC transmission line is used to exchange the real power between converters at the 3rd harmonics frequencies. This concept not only make the system trustworthy because of redundancy but also moderates the rating and insulation of the component and hence the overall cost of the system.

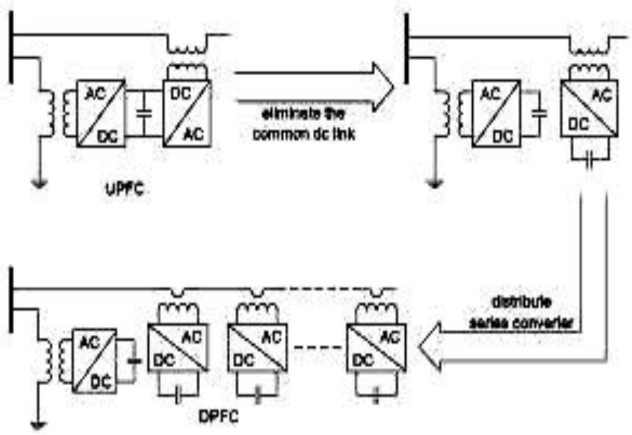

Fig 1.2 flow chart of DPFC

II. Distributed Power Flow Controller

By common dc link elimination and distribution of series converter introduction in UPFC, the DPFC is achieved.

A. Construction of DPFC

Similar as the UPFC, the DPFC consists of shunt and series connected converters. The shunt converter is similar as 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 DPFC is independent and has its own dc capacitor to provide the required dc voltage. DPFC also needs a high pass filter which is shunt connected to the other side of the transmission line and a Y-Δ transformer on each side of line [4]. A basic construction of DPFC is given in fig 2.1.

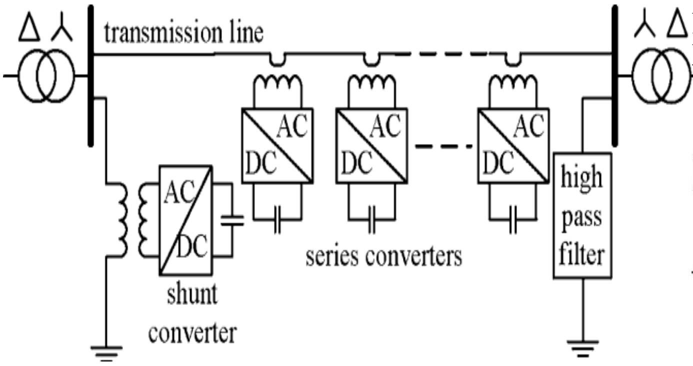

Fig 2.1 simple construction of DPFC

B. Principle of operation

The reactive power flow and compensation is similar to the UPFC [5]. For the active power flow two approaches are used:

- Active power exchange with eliminated dc link
- Using third harmonic components

Active power exchange with eliminated dc link

Within the DPFC, the transmission line presents a common connection between the AC terminals of the shunt and the series converters. Therefore, it is possible to interchange active power through the line. 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. Since the integrals of all the cross product of terms with different frequencies are zero, the active power can be expressed by:

$$P = \sum_{i=1}^{\infty} V_i I_i Cos \ \theta_i \qquad \text{.... (2.1)}$$

Where V_i and I_i are the voltage and current at the ith harmonic frequency respectively and θ_i is the corresponding angle between the voltage and current. Equation (2.1) shows that the active powers at different frequencies are independent from each other and the voltage or current at one frequency has no influence on the active power at other frequencies. This independence makes it possible for a converter without power source to generate active power at one frequency and to absorb this power at other frequency.

In this method, 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 DPFC 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. Figure 2.2 shows how the active power is exchanged between the shunt and the series converters in the DPFC.

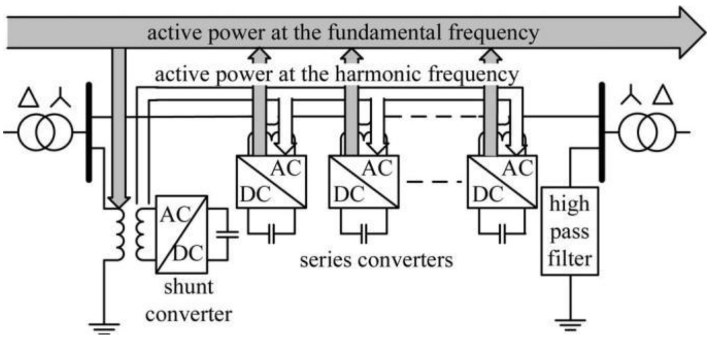

Fig 2.2 active power exchange between converters

The high-pass filter (HPF) within the DPFC blocks the fundamental frequency components and permits harmonic component to pass. Thus the series and shunt converter, HPF and ground forms a closed path for flow of harmonic current. Due to the unique characteristics of third-harmonic frequency components, the third harmonic is selected to exchange the active power in the DPFC.

Using third harmonics component

In a three-phase system, the third harmonic in each phase is identical i.e. zero sequence components. Because the zero-sequence harmonic can be naturally blocked by Y-Δ trans-formers and these are widely used in power systems, there is no extra filter required to stop harmonic leakage [6].

Since the voltage isolation is high and the harmonic frequency is close to the cutoff frequency, the filter will be costly. By using the zero-sequence harmonic, the costly filter can be replaced by a cable that connects the neutral point of the Y-_ transformer on the right side with the ground. Because the Δ-winding appears open-circuit to the 3rd harmonic current, all harmonic current will flow through the Y-winding and concentrate to the grounding cable as shown in Fig 2.3. Therefore, the large high-pass filter is excluded.

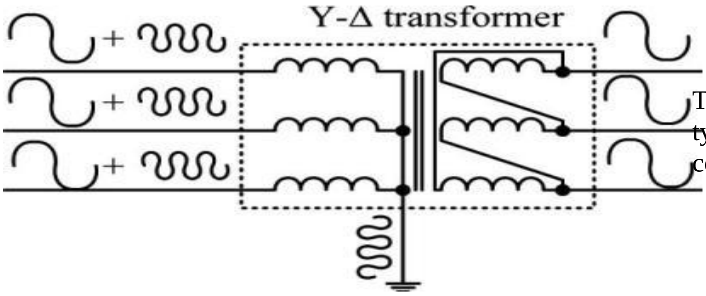

Fig 2.3 Utilize grounded Y-Δ transformer

The grounding of the Y-Δ transformers can be used to direction the harmonic current in a meshed network. If the network requires the harmonic current to flow through a particular branch, the neutral point of the Y-Δ transformer in that branch, at the side opposite to the shunt converter, will be grounded and vice versa. Fig 2.4 shows a simple example of routing the harmonic current by using the grounding of the Y-Δ transformer. Because the floating neutral point is located on the transformer of the line without the series converter, it is an open-circuit for 3rd harmonic components and therefore no 3rd harmonic current will flow through this line.

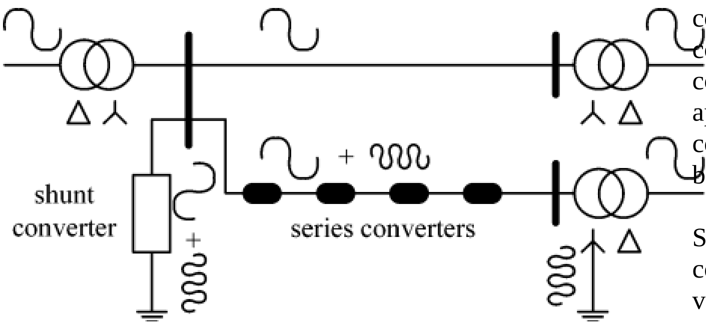

Fig 2.4 Route the harmonic current by using the grounding of the Y-Δ transformer

The harmonic at the frequencies like 3rd, 6th, 9th... are all zero-sequence and all can be used to exchange active power in the DPFC. However, the 3rd harmonic is selected, because it is the lowest frequency among all zero-sequence harmonics. The relationship between the exchanged active power at the ith harmonic frequency Pi and the voltages generated by the converters is expressed by the well known the power flow equation and given as:

$$P_i = \frac{|V|_{sh,i}|V_{se,i}|}{X_i}\sin(\theta_{sh} - \theta_{se}) \qquad \text{…. (2.2)}$$

Where Xi is the line impedance at ith frequency, |Vsh,i| and |Vse,i| are the voltage magnitudes of the ith harmonic of the shunt and series converters, and θsh,i-θse,i is the angle difference between the two voltages. To exchange the same amount of active power, the line with high impedance requires higher voltages. Because the transmission line impedance is mostly inductive and proportional to frequency, high transmission frequencies will cause high impedance and result in high voltage within converters. Consequently, the zero-sequence harmonic with the lowest frequency - the 3rd harmonic - has been selected.

III. DPFC CONTROL

To control multiple converters, a DPFC consists of three types of controllers: central control, shunt control and series control, as shown in fig 3.1 [7]

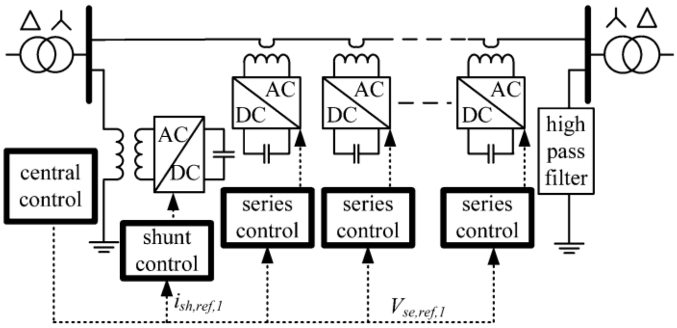

Fig 3.1 DPFC control block diagram

Central control: According to the system utility, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals generated by the central control concern the fundamental frequency components. Its control function depends on the specifics of the DPFC application at the power system level, such as power flow control, low frequency power oscillation damping and balancing of asymmetrical 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. Series control block diagram is given in fig 3.2

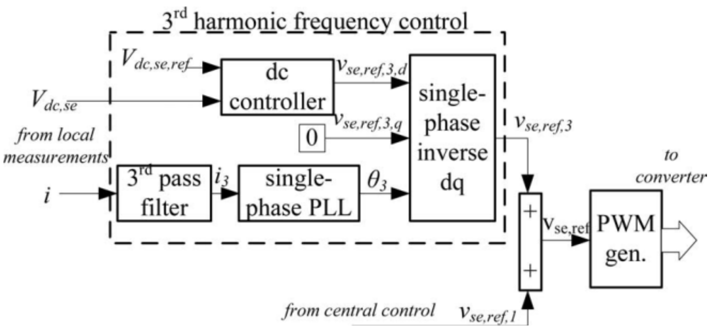

Fig 3.2 series control block diagram

Shunt control: The shunt control is used to inject a constant 3rd harmonic current into the line to supply active power for the series converters [8]. 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. Block diagram of shunt control is given in fig 3.3

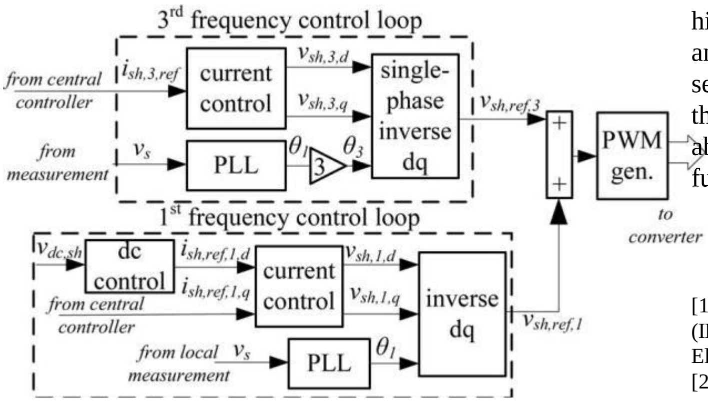

Fig 3.3 shunt control block diagram

IV. ADVANTAGES OF DPFC

The DPFC can be considered a UPFC that employs the D-FACTS concept and the concept of exchanging power through the 3rd harmonic [9]. In this way, the DPFC inherits all their advantages:

· *High controllability:* the DPFC can simultaneously control all the parameters of the transmission network: line impedance, transmission angle and bus voltage.

· *High reliability:* the redundancy of the series converter gives high reliability without increasing cost. In addition, the shunt and series converters are independent and failure of one will not influence the other converters.

· *Low cost:* there is no phase-to-phase voltage isolation required between the series converters of different phases. The power rating of each converter is also low. Because of the large number of the series converters, they can be manufactured in series production. If the power system is already equipped with the STATCOM, the system can be updated to the DPFC with only low additional costs.

However, there is a drawback to using the DPFC:

· *Extra currents***:** Because the exchange of power between the converters takes place through the same transmission line as the main power, extra currents at the 3rd harmonic frequency are introduced. These currents reduce the capacity of the transmission line and result in extra losses within the line and the two Y-Δ transformers.

V. CONCLUSION

This paper has presented a new concept called DPFC. The DPFC emerges from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, the transmission angle, and the bus-voltage magnitude. The common dc link between the shunt and series converters, which is used for exchanging active power in the UPFC, is eliminated. This power is now transmitted through the transmission line at the third-harmonic frequency. The series converter of the DPFC employs the D-FACTS concept, which uses multiple small single-phase converters instead of one large-size converter. The reliability of the DPFC is greatly increased because of the redundancy of the series converters. The total cost of the DPFC is also much lower than the UPFC, because no high-voltage isolation is required at the series-converter part and the rating of the components of is low. The shunt and series converters in the DPFC 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.

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Authors Biography:

Mayank Tyagi is pursuing M.Tech from Ajay Kumar Garg Engineering College, Ghaziabad (affiliated to Dr. A.P.J. Abdul Kalam Technical University, Lucknow) in electrical power and energy system branch. His area of interests are focused on renewable energy and FACTS devices. He completed his B.Tech from Hindustan college of science and technology, Mathura (affiliated to Dr. A.P.J. Abdul Kalam Technical University, Lucknow) in electrical and electronics engineering with first class degree in year 2013. He did his major work on project in electrical drives control in the respective branch for consecutive four years during his B.Tech.

Deepika Singh is pursuing M.Tech from Ajay Kumar Garg Engineering College, Ghaziabad (affiliated to Dr. A.P.J. Abdul Kalam Technical University, Lucknow) in electrical power and energy system branch. Her area of interest is energy system and design. She completed her B.Tech from ABES institute of technology (affiliated to Dr. A.P.J. Abdul Kalam Technical University, Lucknow) in electrical and electronics engineering with first class degree in year 2013. She did her major work on project in electrical power system controlling and dynamic power system in the respective branch for consecutive four years during his B.Tech.