# Distributed Power Flow Controller for Power System Oscillation Damping

**Aditya S. Raut[1] C. R. Gowder[2]**
[1]PG Scholar [2]Assistant Professor
[1,2]Shri Sai College of Engineering & Technology, Bhadrawati, India

*Abstract*— This technique presents a brand new element inside the Flexible ac-transmission system (FACTS); family, known as distributed power-flow controller (DPFC). The DPFC comes from the unified power-flow controller (UPFC). The DPFC are often thought of as a UPFC with associate eliminated common dc link. The active power exchange between the shunt and series converters that is thru the common dc link within the UPFC is currently through the transmission lines at the third-harmonic frequency. The DPFC employs the distributed FACTS (D-FACTS) construct that is to use multiple small-size single-phase devices rather than the one large-size three-phase series converter within the UPFC. The massive range of series converters provides redundancy, thereby increasing the system dependableness. Because the D-FACTS converters area unit single-phase and floating with regard to the bottom, there's no high-voltage isolation needed between the phases. Consequently, the price of the DPFC system is not up to the UPFC. The DPFC has a similar management capability because the UPFC, that includes the adjustment of transmission line resistance, the transmission angle, and therefore the bus voltage. The principle and analysis of the DPFC area unit conferred during this work and therefore the corresponding experimental results that area unit disbursed in MATLAB simulink. The DPFC controller style in MATLAB Simulink and tested with unbalanced loading condition cable. The simulation results shows that the DPFC improve the system performance throughout unbalance loading conditions.

***Keywords:*** UPFC, FACTS, PFCD, MATLAB Simulink

## I. Introduction

Power flow is controlled by adjusting the parameters of a system, like voltage magnitude, line electrical resistance and transmission angle. The device that makes an attempt to vary system parameters to manage the ability flow will be delineate as an influence Flow dominant Device (PFCD).

Depending on however devices square measure connected in systems, PFCDs will be divided into shunt devices, series devices, and combined devices (both in shunt and series with the system), as shown in Figure 1.

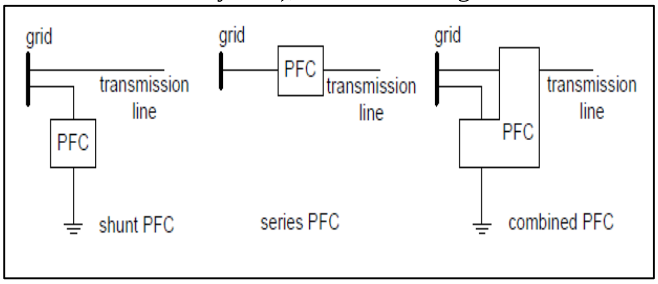


Fig. 1: Simplified diagram of shunt, series and combined devices

A shunt device could be a device that connects between the grid and therefore the ground. Shunt devices generate or absorb reactive power at the purpose of affiliation thereby dominant the voltage magnitude. As a result of the bus voltage magnitude will solely be varied at intervals sure limits, dominant the ability flow during this means is proscribed and shunt devices principally serve different functions. For instance, the voltage support provided by a shunt device at the point of an extended line will boost the ability transmission capability.

Another application of shunt devices is to produce reactive power domestically, thereby reducing unwanted reactive power flow through the road and reducing network losses. Also, consumer-side shunt devices will improve power quality, particularly throughout giant demand fluctuations.

A device that's connected serial with the line is mentioned as a ‘series device’. Series devices influence the electric resistance of transmission lines. The principle is to alter (reduce or increase) the transmission line electric resistance by inserting a reactor or electrical condenser. To complete the inductive fall, a electrical condenser will be inserted within the line to scale back the transmission line resistance. By increasing the inductive electric resistance of the line, series devices are accustomed limit the present flowing through bound lines to stop heating.

A combined device may be a two-port device that's connected to the grid, each as a shunt and during a series, to modify active power exchange between the shunt and series elements. Combined devices square measure appropriate for power flow management as a result of they will at the same time vary multiple system parameters, like the transmission angle, the bus voltage magnitude and therefore the line electric resistance.

Based on the enforced technology, PFCDs are often categorized into mechanical- primarily based devices and power natural philosophy (PE)-based devices. Mechanical PFCDs contains fastened or mechanical interchangeable passive parts, like inductors or capacitors, beside transformers. Typically, mechanical PFCDs have comparatively low value and high dependability. However, as a result of their comparatively low change speed (from many seconds to minutes) and step-wise changes of mechanical PFCDs, they need comparatively poor management capability and don't seem to be appropriate for complicated networks of the long run. Letter PFCDs additionally contain passive parts, however embody extra letter switches to attain smaller steps and quicker changes. there's another term – versatile AC gear mechanism (FACTS) - that overlaps with the letter PFCDs. in keeping with the IEEE, FACTS is outlined as an ‘alternating current gear mechanism incorporating power electronic primarily based and different static controllers to boost controllability and increase power transfer capability’. Normally, the High

Voltage DC transmission (HVDC) and letter devices that are applied at the distribution network, like a Dynamic Voltage. Restorer (DVR), also are thought of as FACTS controllers. Most of the FACTS controllers are often used for power flow control. However, the HVDC and also the DVR ar out of the scope of the PFCD. the connection between the PFCDs, FACTS controllers and mechanical controller is shown in Figure 2.

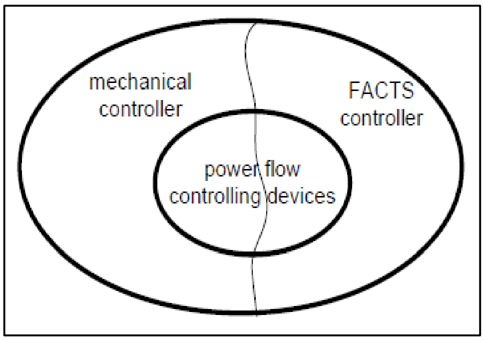


Fig. 2: Relationship between the PFCDs, FACTS controllers and mechanical controller

PE PFCD devices are often any subcategorized into 2 varieties in line with the applied switch technologies: thyristor-based devices and Voltage supply device (VSC) based mostly devices.

Thyristor PFCDs use inverse-parallel thyristors nonparallel or in parallel with passive parts. By dominant the firing angle of the thyristors, the electric resistance of the device are often adjusted. A thyristor are often controlled to show on however to not close up. It'll close up mechanically once this goes negative. Consequently, the thyristor will solely be turned on once inside one cycle. The switch frequency of thyristor PFCDs is thus restricted to the system frequency (50/60Hz), leading to low switch losses. As a result of thyristors will handle larger voltages and currents than different power semiconductors, the facility level of thyristor PFCDs are higher. The thyristor PFCDs are easier than VSC PFCDs, permitting them higher irresponsibleness. However, the waveforms of voltages and currents generated by thyristor PFCDs contain an outsized quantity of harmonics, thereby requiring giant filters.

VSC PFCDs use advanced switch technologies, like Insulated Gate Bipolar Transistors (IGBT), Insulated Gate Commutated Thyristors (IGCT), or Metal compound Semiconductor Field Effect Transistors (MOSFET) to create converters. As a result of these switches have input and turn-off capability, the output voltage of a VSC is freelance from the present. Consequently, it's doable to show the switches on and off among the VSC multiple times among one cycle. Many styles of VSCs are developed, like multi-pulse converters, multi-level converters, square-wave converters, etc.

These VSCs tested a free manageable voltage in each magnitude and section. Thanks to their comparatively high switch frequency, VSC PFCDs build much instant management (less than one cycle) doable. High switch frequencies additionally scale back low frequency harmonics of the outputs and even change PFCDs to compensate disturbances from networks.

Therefore, VSC PFCDs are the foremost appropriate devices for future power systems. On the opposite hand, there are some challenges facing VSC PFCDs. Firstly, as a result of giant amounts of switches are connected nonparallel or in parallel to permit the high voltage and high current through, the VSC PFCDs are pricy. Additionally, thanks to their higher shift frequency and better on-state voltage as compared with thyristors, VSC PFCD losses are higher moreover. However, with developments in power physical science (such as Silicon-carbide, Gallium-Nitride and artificial diamond), VSC PFCDs will become additional possible and efficient within the future.

According to the on top of concerns of various varieties of PFCDs, it is finished that PFCDs (also stated as combined FACTS) have the most effective management capability among all PFCDs. They inherit the benefits of alphabetic character PFCDs and combined PFCDs, that is that the quick adjustment of multiple system parameters. The Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) are presently the foremost powerful PFCDs; they'll regulate all system parameters: line electrical resistance, transmission angle, and bus voltage.

## II. PROPOSED METHODOLOGY

### *A. MATLAB Simulation Model*

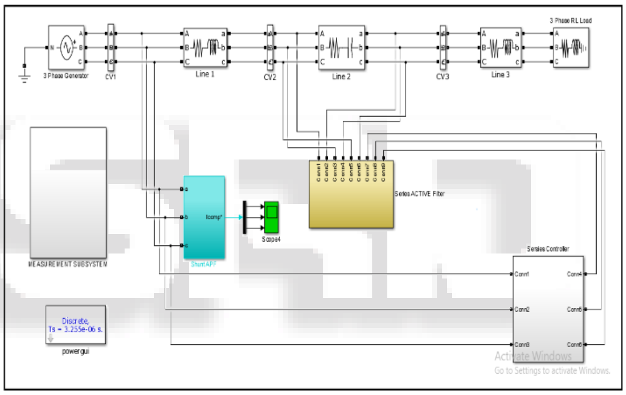

Fig. 3: Block diagram of proposed approach

### *B. Series Controller Subsystem*

The Series controller is used to compensate the source side disturbances such as voltage sags, swells and also harmonic distortions. In this configuration, the filter is connected in series with the line being compensated.

Therefore the configurations are often referred to as a series active filter. The approach is based on the principle of injecting voltage in series with the line through the injection transformer to cancel the source side voltage disturbances and thus it makes the load side voltage sinusoidal.

Fig. 3 shows the MATLAB/ Simulink model of designed system. The main components of the below system are as follows.

- Mains supply
- Nonlinear load
- Active Power Filter
- Voltage source inverter
- Interface reactor
- Reference voltage generator
- Hysteresis voltage controller

| Sr No | Name of block | Specification |
|---|---|---|
| 1 | 3 phase generator | Three phase to phase voltage = 415 V; Phase angle of phase A = 0 Degree; Frequency of supply = 50 Hz |
| 2 | Line 1 | Inductance L = 0.5mH; Resistance R = 0.1 Ω |
| 3 | Line 2 | Capacitance c = 6 µF; Resistance R = 6 Ω |
| 4 | Line 3 | Inductance L = 1 mH; Resistance R = 50 Ω |
| 5 | Three phase load | Nominal phase to phase voltage = 400V; Nominal frequency = 50Hz; Active power = 10 KW; Inductive reactive power = 100 VAr |

Table 1: MATLAB simulink model parameter specification

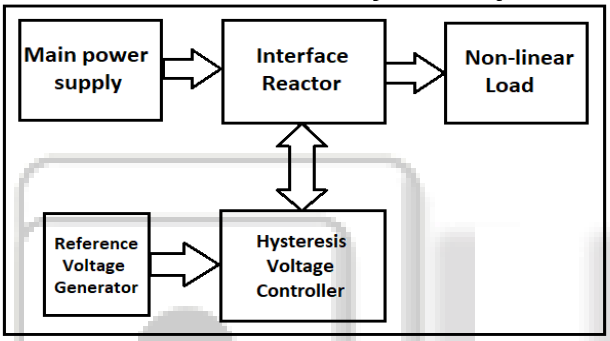


Fig. 4: Block diagram of proposed series active power controller

### C. *Shunt Controller Subsystem*

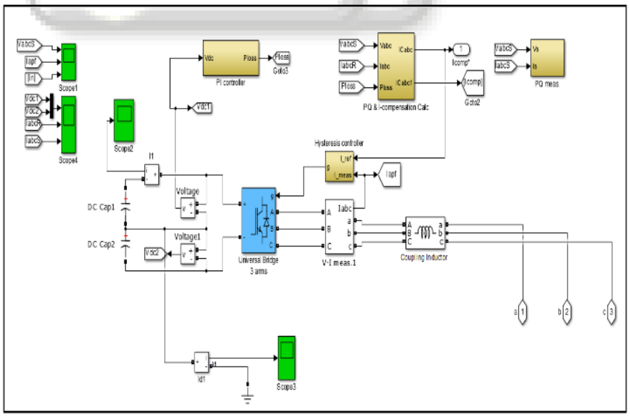

Fig. 5: MATLAB simulation model of shunt controller

Figure 5 shows the matlab simulink model of shunt active power controller. In this universal bridge which is act as inverter which convert the DC link supply into AC output which fed to the transmission line. That controller control the current of transmission line based on firing pulses of inverter. As the voltage of transmission line drops due to high loading then that time controller absorbed the current from transmission line by decreasing pulses rate of inverter. Similarly, for high voltage increases due to highly capacitive load then that time controller insert the current into the transmission line by increasing the pulse rate of inverter.

Figure 6 shows the shunt controller pulse generator subsystem model in which different block consist of like Clarke transformation for conversion of three phase voltage and three phase current into Valpha, Vbeta, Ialpha and Vbeta conversion. The Three phase voltage convert into Alpha and Beta component are calibrate using following formula:

$$V_{alpha} = \sqrt{\frac{2}{3}} * (V_a - 0.5V_b - 0.5V_c)$$

$$V_{beta} = \sqrt{2} * (V_a + 0.5V_b - 0.5V_c)$$

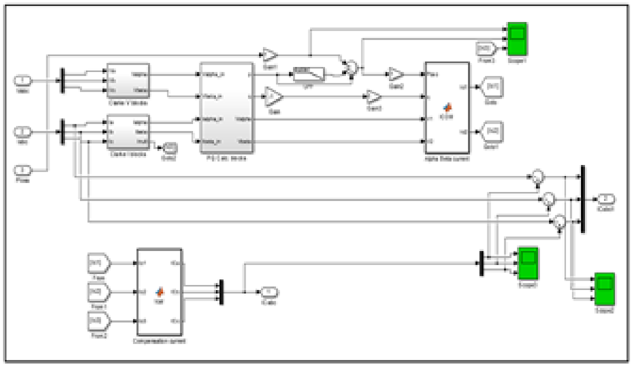

Fig. 5: PQ components calibration subsystem model

The Three phase current convert into Alpha, Beta and Null component are calibrating using following formula:

$$I_{alpha} = \sqrt{\frac{2}{3}} * (I_a - 0.5I_b - 0.5I_c)$$

$$I_{beta} = \sqrt{2} * (I_a - 0.5I_b + 0.5I_c)$$

$$I_{null} = \sqrt{\frac{1}{3}} * (I_a + I_b + I_c)$$

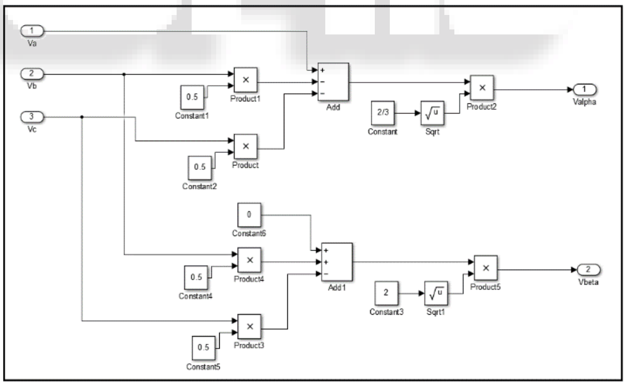

Fig. 6: Clarke transformation for Valpha and V beta Calibration

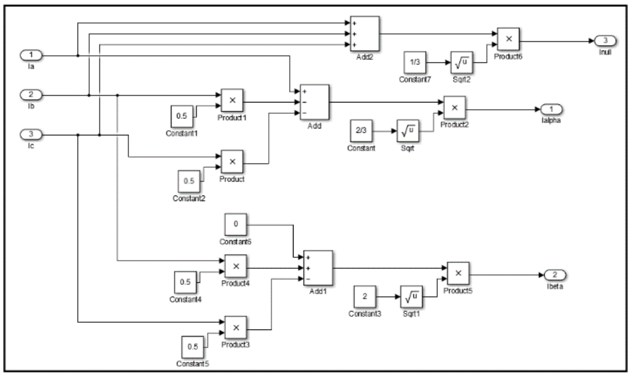

Fig. 7: Clarke transformation for Ialpha and I beta Calibration

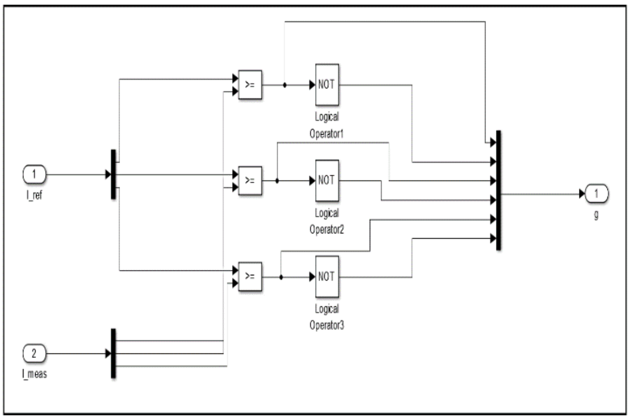


Fig. 8: Hysteresis based Ireference and Imean current comparison subsystem model

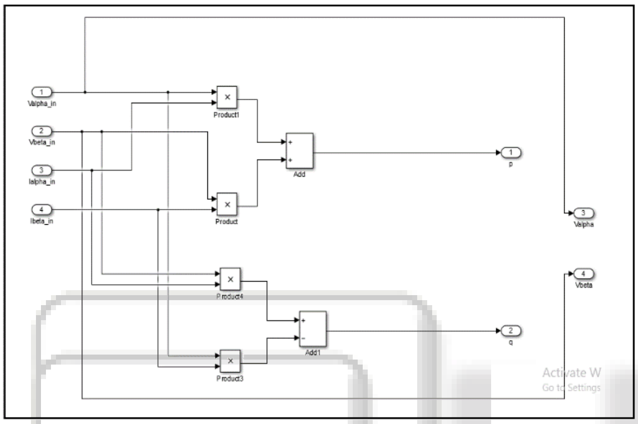


Fig. 9: P and Q components calibration subsystem model

That calibrated Valpha, Vbeta, Ialpha and Ibeta component then transfer to P and Q components calibration subsystem. The complete PQ component calibration subsystem model is shown in figure 9.

The P and Q components are calibrated in subsystem model using following formula:

$$P = (V_{alpha} * I_{alpha}) + (V_{beta} * I_{beta})$$

$$Q = (V_{beta} * I_{alpha}) - (V_{alpha} * I_{beta})$$

Then P and Q components as well as Valpha and V beta components are send to positive and negative sequence components calibration subsystem model are as follows:

$$I_{c1} = \left(\frac{-1}{V_{alpha}^2 + V_{beta}^2}\right) * \left((P_{osc} * V_{alpha}) * (Q * V_{beta})\right)$$

$$I_{c2} = \left(\frac{-1}{V_{alpha}^2 + V_{beta}^2}\right) * \left((P_{osc} * V_{beta}) * (Q * V_{alpha})\right)$$

Where,
Ic1 = Positive sequence component
Ic2 = Negative sequence component
Then again positive sequence, negative and null components of currents are then convert into phase current Ia, Ib and Ic for comparison with reference current shown in figure 9.
The phase currents are given as:

$$I_a = \sqrt{\frac{2}{3}} * \left((I_{c1}) + (0.7072 * I_{null})\right)$$

$$I_b = \sqrt{\frac{2}{3}} * \left((-0.5 * I_{c1}) + \left(\sqrt{\frac{2}{3}} * I_{c2}\right) + (0.7072 * I_{null})\right)$$

$$I_b = \sqrt{\frac{2}{3}} * \left((-0.5 * I_{c1}) - \left(\sqrt{\frac{2}{3}} * I_{c2}\right) + (0.7072 * I_{null})\right)$$

## III. MATLAB SIMULATION RESULTS

### *A. With Voltage Sag and Swell Condition*

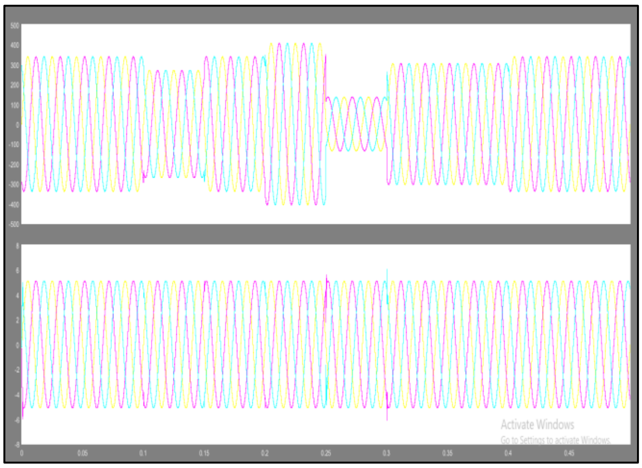

Fig. 10: Sending end three phase voltage and current of transmission line with voltage sag and swell condition

Figure 10 shows the sending end voltage and current of transmission line which contains voltage sag and swell conditions. Total simulation time is 0.5 second in which voltage swell is occurs at 0.1 sec then again voltage becomes normal at 0.15 seconds. Then again voltage well occurs at 0.2 second and then again voltage swell at 0.25 second and so on. Hence voltage fluctuations are present at sending end voltage of transmission line.

Figure 11 shows the transmission line receiving end voltage and current waveform in which x-axis shows the simulation time in second while y-axis shows the voltage and current magnitude. It is shows that transmission lone receiving end voltage at transmission line or load side is free from voltage fluctuations due to DPFC controllers.

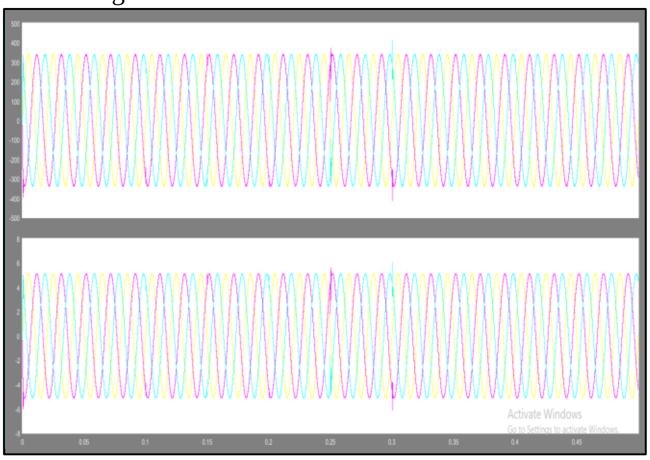

Fig. 11: Receiving end three phase voltage and current of transmission line without voltage swell and sag

### *B. With Harmonics and Momentary Interruption Condition*

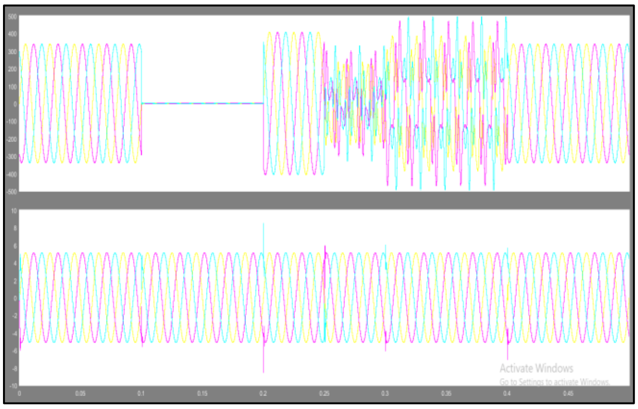

Fig. 12: Sending end three phase voltage and current of transmission line with harmonics and interruption condition

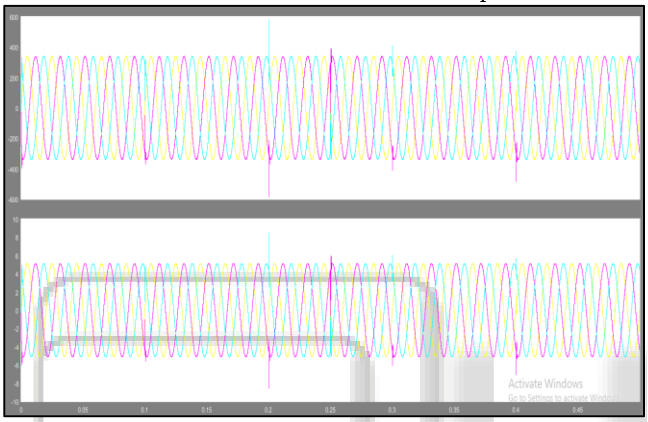

Fig. 13: Receiving end three phase voltage and current of transmission line without harmonics and interruption

## IV. CONCLUSION

The DPFC basic control is developed based on the dynamic model. The basic control stabilizes the level of the capacitor DC voltage of each converter and ensures that the converters inject the voltages into the network according to the command from the central control. The shunt converter injects a constant current at the 3rd harmonic frequency, while its DC voltage is stabilized by the fundamental frequency component. For the series converter, the reference of the output voltage at the fundamental frequency is obtained from the central control and the DC voltage level is maintained by the 3rd harmonic components. The control parameters of the basic control are determined. Both the model and the basic control are verified in Matlab Simulink.
When the DPFC is applied in power systems, the reliability issue is important. The fault tolerance of the DPFC is investigated, including the protection method for different types of failures and the use of supplementary controls, to improve system performance during converter failures.

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