Power Quality Enhancement and Mitigation of Voltage Sag using DPFC

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ABSTRACT:

The Distributed power flow controller is mainly used to control the power flow and also used to mitigate voltage and current waveform deviations and improves the quality of power in the matter of few seconds. The structure of DPFC is identical to the UPFC. In DPFC the dc capacitor link between series and shunt converter is terminated. DPFC consists of a single shunt converter and several small independent single phase series converters are employed. The operating function of shunt converter is like a STATCOM and series converter employs a Distributed- FACTS concept. The exchange of active power between the series and shunt converter is through the transmission line. The DPFC has the ability to control the transmission line parameters such as line impedance Z, transmission angle Θ, and bus voltage magnitude |V|. The problems obtained with power quality issues such as voltage sag and swell can be mitigated by using DPFC. The DPFC is installed in between transmission lines and connected to a single machine infinite bus power system which is simulated in MATLAB/SIMULINK in order to determine the performance of DPFC in the power system.

Key words: Power quality improvement, Mitigation of voltage and Current waveform deviations, Distributed power flow controller.

1 INTRODUCTION

The power system mainly incorporates with generation, transmission, distribution, and consumption. The power system mainly deals with the problem i.e. increase in power demand and also with the power quality related problems such as voltage, current & frequency distortions. Electrical apparatus will be affected due to power quality related problems. The power quality problems are obtained due to appearance of short circuits in the grid, to faster switching operations, high inrush magnetizing currents are obtained with the starting of large machines. Power electronic based system is used to control the ac transmission system parameters and to increase power transfer capability and also to improve the power quality. The most serious threats for sensitive electrical equipment in grids are voltage sag and swell. These voltage sag and swell are mitigated and improves the power quality by using DPFC. In this paper DPFC is represented as a new FACTS device which is determined from UPFC and has the same controlling capability but with less cost and higher reliability. DPFC is used to compensate the unbalanced voltage and currents in transmission system. It can also be used to compensate zero and negative sequence unbalanced currents in transmission line. The structure of DPFC is derived from the UPFC and has the same control capability. The DPFC consists of single shunt converter and multiple small independent series converter. The operating performance of shunt converter is like a STATCOM. The main function of shunt converter is to inject a constant third harmonic component current into a transmission line. The series converter consists of PWM controlling technique and it is a single phase converter. The main function of series converter is to maintain capacitor dc voltage by the use of third harmonic frequency components. Within the DPFC each converter consists of own DC capacitor in order to maintain the required dc voltage. DPFC also contains a high pass filter and shunt connected to the line in order to extract the harmonics.
II. DPFC OPERATING PRINCIPLE

The main advantage of DPFC is elimination of DC-link between shunt and series converter and using third harmonic current to exchange the active power.

Active power exchanged in lines with eliminated DC link:

In DPFC the dc & ac terminal of shunt converter and series converter are connected to the transmission line. The exchange of active power between two converters can be done through transmission line, as the dc link is eliminated. The power exchange in the DPFC is done based on theory which is nothing but power theory of non-sinusoidal components. According to Fourier series analysis, the sum of non-sinusoidal voltage or current can be represented as sum of the sinusoidal components at different frequencies with different amplitude. The obtained active power from non-sinusoidal voltage and current can be defined as the product of voltage and current mean value. All the cross product with different frequencies and their integrals are zero; the active power can be represented by the equation:

\[ P = \sum_{i=1}^{\infty} V_i I_i \cos \varphi_i \quad \text{Eq (1)} \]

Where \( V_i \) and \( I_i \) are the \( i \)th harmonic voltage and current and \( \varphi_i \) is the angle between the voltage and current at same frequency. The above equation expresses the active power at different frequency components. The active power generated from the grid at fundamental frequency is absorbed by the shunt converter and injects current back into the grid at a third harmonic frequency. The obtained third harmonic current will flows through the transmission line. Due to the amount of active power required from shunt converter at fundamental frequency, the required amount of voltage is generated by series converter at the third harmonic frequency, and the active power is absorbed from harmonic components. The active power exchange between the shunt and series converter is shown in the fig. By assuming a lossless converter, the active power generated at fundamental frequency is equal to the active power absorbed at third harmonic frequency.

By the selection of third harmonic component:

The current flowing in a transmission line at higher frequencies provides high impedances which results raise in voltage level of series converters. The third harmonic current is the smallest harmonic order frequency with less impedance so the obtained voltage level of converters is also less. The third harmonic current component is similar to the zero-sequence current and the zero-sequence current in three phase system can be naturally blocked in Y–Δ transformers.

In power system the voltage levels can be changed by the use of Y–Δ transformers. Extra filter is not required in order to prevent harmonic leakage current. Therefore highpass filter is eliminated. The main advantage of using third harmonic component is active power can be exchanged, grounding the Y–Δ transformers in order to route harmonic current into a network. The 3rd, 6th, 9th harmonic frequencies these are all zero sequence harmonic frequencies. These
harmonic frequencies can also be used to exchange active power. The transmission line capacity can be determined by line impedance; the impedance of transmission line is inductive and is proportional to the frequency. Therefore higher frequency of transmission line will cause high impedance. The lower frequencies are offered by the zero sequence harmonic components, Therefore third harmonic component is selected.

Advantages of DPFC:

The DPFC has some advantages when compared to UPFC, the following advantages are:

1) Low cost: In DPFC there is no phase to phase voltage isolation required by series converter. Each converter power rating can be easily produced in series production line.

2) Higher control capability: The DPFC can control impedance of line Z, transmission angle θ and bus voltage magnitude[r] these are all the parameters of power system. DPFC consists of higher control capability. Therefore DPFC can be used to improve system stability and can also be used to improve the power quality related problems such as voltage sag and swell, low frequency power oscillation damping, balancing asymmetry etc.

3) Higher reliability: Due to the redundancy of the series converter gives an improved reliability of the converter. Since both the shunt and series converter are independent. If the failure has been occurred at one converter another converter will not influenced.

III. STEADY STATE ANALYSIS OF DPFC

In this following section, the steady-state analysis and also the behavior of the DPFC are analyzed, and the DPFC controlling capability is specified in parameters of the network and the DPFC. To simplify the performance of DPFC, the converters of DPFC are placed in series with controllable voltage sources. Each converter in DPFC generates the voltage at two different frequencies at the fundamental and third harmonic frequency; here in this paper we are assuming that the converters and the transmission line are lossless, the total generated active power will be zero at the two frequency voltage sources. The multiple number of series converters is represented by single large converter with the voltage, which is equal to the sum of the voltages for all series converter.

Control strategies of DPFC:

There are three control strategies they are as follows:
- Central control
- Series control
- Shunt control

![Fig.4: DPFC control block diagram](image-url)

a) **Central control**: The main function of central controller it controls both series and shunt controller and sends the reference signals to both controllers.

b) **Series control**: In DPFC each single phase series converter has its own control through the line. The inputs of series controller are capacitor voltages, line current and series voltage reference in rotating dq-frame. Series controller consists of low pass filter and 3rd pass or high band pass filter is required inorder to create fundamental and third harmonic current. Series controller also consists of two single-phase phase lock loop (PLL) which is used to maintain the frequency and phase information from network. The series controller maintains the capacitor dc voltage of its own converter by utilizing third harmonic frequency components and to generate voltage at fundamental frequency that is obtained by the central control.
IV. POWER QUALITY ENHANCEMENT

The system model consists of a source which is of three phase is connected to the non linear three phase RLC load which is connected through a parallel transmission lines (i.e, line1 and line2) which are of same line length. The DPFC is incorporated in between the transmission lines, the shunt converter is connected in parallel to the transmission line through a Y−Δ transformer and series converter is connected in series to the transmission line.

The system parameters are listed in TABLE. In order to simulate the dynamic performance of DPFC a fault is created near the load. The time duration of fault is 0.5sec (500-1000milli seconds).

In this system the fault occur between the time 500ms to 1500ms. During this fault time the voltage is goes to sag position as shown in figure. The voltage magnitude is reduced by 0.65 percent of its nominal value during this fault time.

Table: Simulation system parameters

V. FLC Implementation in DPFC

Fuzzy logic controllers are formed by simple rules such as If A and B then C. These rules are defined by persons experience and also by the Knowledge of systems behaviour. The system performance is improved by these rules. Each rule defines one membership function which is the function of FLC. More control mechanism of FLC can be provided by the number of membership functions. In this work, the input of the fuzzy system consisting of 7 membership functions, so the fuzzy system rules is...
formed in 49 rules. Based upon these rules the controller performs its functions.

The basic rule such as if-then rule are defined as “If (error is small and rate of change of error is small) then output”. The signals error and change of error or error rate is described as crisp variables in the FLC such as large negative (LN), Large positive (LP), medium negative (MN), Medium positive (MP), Small negative (SN), Very small (VS), Small positive (SP).

These are shown in Fig.7. The input values of the fuzzy controller are connected to the output vales of fuzzy controller i.e. crisp values by the if-then rules. The relationship between the input and the output values can be obtained easily by using Center of gravity type of inference method. The output values or fuzzy values are characterized by memberships and named as crisp variables such as Zero(Z), negative big (NB), negative medium (NM), negative small (NS), positive medium (PM), positive small (PS) and positive big (PB). The membership functions of output variables and the FLC rules are shown in Table I.

<table>
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<tr>
<th>c/Ae</th>
<th>LP</th>
<th>PB</th>
<th>PB</th>
<th>PS</th>
<th>Z</th>
<th>NS</th>
<th>NM</th>
<th>LN</th>
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<td>Z</td>
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<td>PB</td>
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<td>PM</td>
<td>PS</td>
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<td>NM</td>
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<tr>
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<td>PB</td>
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<td>PS</td>
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<td>NM</td>
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<td>NB</td>
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</tbody>
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Fuzzy logic algorithm:

1. Defines the terms and also linguistic variables (initialization)
2. Construct the membership functions (initialization)

Results

Fig.5.1: Output Voltage during fault condition

Figure 5.1 shows the simulation result for output voltage during fault. In this fault period a sag condition occurs in the output voltage.

Fig.5.2: Output Current during Fault Condition

During this fault time the load current raises its magnitude around 1.2% per unit as shown in figure
THD value for a system is 12.36% and it is reduced by using DPFC controller

A PI controller based DPFC controller is used for that system and now the THD value is reduced to 3.88%

Now the PI controller is replaced with fuzzy controller the THD value is reduced to 3.65%

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Name</th>
<th>THD value</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Load voltage without DPFC</td>
<td>12.36%</td>
</tr>
<tr>
<td>2</td>
<td>Load voltage with DPFC(PI)</td>
<td>3.88%</td>
</tr>
<tr>
<td>3</td>
<td>Load voltage with DPFC(Fuzzy)</td>
<td>3.65%</td>
</tr>
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TABLE 1: Comparison of THD values

THD values for load voltage without DPFC, load voltage with DPFC using PI controller and load with DPFC using fuzzy controller are compared and listed in above table.
Future Scope:

The DPFC is a new FACT device and has lower cost and more reliable when compared to the UPFC. Moreover, the DPFC also require modification in future research orientation, which are classified as

- Series converter weight reduction: The series converters on transmission line are huge which results in extra pressure to the towers. So a light weight series converter unit is desirable.
- Third harmonic current management: The third harmonic component within the DPFC leads to extra losses in transformers and in transmission lines. In this project third harmonic current within the DPFC is set at a constant value. The magnitude of third harmonic current can be managed by the amount of active power required. So the losses of the DPFC can be reduced.
- Communications: Since the series converters operate outdoors, wireless or PLC is required for communication purpose between the central control and series control. The communication should be reliable to continue the operation if any disturbances have been occurred such as lightening or storm.

CONCLUSION

A concept to controlling the power quality issues i.e. DPFC is implemented in this paper. The proposed theory of this device is mathematical formulation and analysis of voltage dips and their mitigations for a three phase source with linear load. In this paper we also proposed a concept of fuzzy logic controller for better controlling action. As compared to all other facts devices the DPFC based Fuzzy has effectively control all power quality problems and with this technique we get the THD as 3.65% and finally the simulation results are shown above.

REFERENCES


Mandava Bindu Sahithi received the B.Tech degree in Electrical and Electronics Engineering from Vijaya institute of technology for women in 2014 and pursuing M.Tech in Power system control and Automation at Prasad V Potluri Siddhartha Institute of Technology. Research includes Power Quality improvement using FACTS device.

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