MINIMIZING POWER LOSSES AND POWER QUALITY IMPROVEMENT USING FACTS CONTROLLERS USING DPFC

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Abstract: Minimizing power losses and improving power quality with optimal number of facts controllers using dpfca new component within the flexible ac-transmission system (FACTS) family, called distributed power flow controller (DPFC). The DPFC is derived from the unified power flow controller(UFPF).

Here by to improve the (PQ). A power quality disturbance is associated with the deviations in the magnitude and frequency of the sinusoidal waveform. It can take many forms, such as: voltage sag, phase unbalance and voltage swells, transient disturbances, flickers. But here we are going to concentrate on reducing voltage sag, swell and harmonics. The DPFC has the same control capability as the UPFC which comprises the adjustment of the line impedance, the transmission angle and the bus voltage.

(keyword: DPFC- distributed power flow controller, PQ-Power Quality, FACTS- Flexible AC Transmission System)

AN OVERVIEW

FACTS controllers are power electronics based system and other static equipment that have the capability of controlling various electrical parameters in transmission networks. These parameters can be adjusted to provide adaptability conditions of transmission network. There are many types of FACTS controllers such as thyristor-controlled series capacitor (TCSC), static var compensator (SVC), thyristor-controlled phase shifting transformer (TCPST), and unified power flow controller (UPFC) [1]. These FACTS controllers have been Energy Policy and Planning Office (EPPO), Ministry of Energy, Thailand proved that they can be used to enhance system controllability resulting in total transfer capability (DPFC) enhancement and minimizing power losses in transmission networks. DPFC is defined as an amount of electric power that can be transferred over the interconnected transmission network in a reliable manner while meeting all of a set of defined pre and post-contingency system conditions. DPFC can be calculated by several power flow solution methods such as linear ATC.

The maximum performance of using FACTS controllers to increase DPFC and minimize losses should be obtained by choosing the optimal types, numbers, parameter settings, and locations in transmission systems. Modern heuristic optimization techniques such as genetic algorithm (GA), evolutionary programming (EP), particle swarm optimization. POWER SYSTEM STABILITY ENHANCED BY FACTS CONTROLLERS

The improvement of power quality or reliability of the system FACTS devices like static synchronous compensator (STATCOM), static synchronous series compensator (SSSC), interline power flow controller (IPFC), and unified power flow controller (UPFC) etc are introduced. These FACTS devices are designed for the transmission system[2-8].

But now a day more attention is on the distribution system for the improvement of power quality.

The main custom power devices which are used in distribution system for power quality improvement are distribution static synchronous compensator (DSTATCOM), dynamic voltage regulator (DVR), active filter (AF), unified power flow controller (UPFC) etc. In this thesis work from the above custom power devices, DVR is used with PI controller for the power quality improvement in the distribution system. Here two different loads are considered, one is linear load and the other is induction motor. Different fault conditions are considered with these loads to analyze the operation of DVR to improve the power quality in distribution system.

FACTS DEVICES

In the late 1980s, the Electric Power Research Institute (EPRI) formulated the vision of the Flexible AC Transmission Systems (FACTS) in which various power-electronics based controllers regulate power flow and transmission voltage and mitigate dynamic disturbances. Generally, the main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes.

There are two generations for realization of power electronics-based FACTS controllers: the first generation employs conventional thyristor-switched capacitors and reactors, and quadrature tap-changing transformers, the second generation employs gate turn-off (GTO) thyristor-switched converters as voltage source converters (VSCs).

The first generation has resulted in the Static Var Compensator (SVC), the Thyristor-Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS). The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified powerflowController (UPFC), and the Interline Power Flow Controller (IPFC). The two groups of FACTS controllers have distinctly different operating and performance characteristics.

The thyristor-controlled group employs capacitor and reactor banks with fast solid-state switches in traditional shunt or series circuit arrangements. The thyristor switches control the on and off periods of the fixed capacitor andreactor banks and thereby realize a variable reactive impedance. Except for losses, they cannot exchange real power with the system[9-12].

The voltage source converter (VSC) type FACTS

FIRST GENERATION OF FACTS

Static VAR Compensator (SVC)

The svs with an auxiliary injection of a suitable signal can considerably improve the dynamicstability performance of a power system. The application of SVC for enhancing the power systems stability. Then, the low frequency oscillation damping enhancement via SVC has been analyzed [36]. It is shown that the SVC enhances the system damping of local as well as interarea oscillation modes. Self-tuning and model reference adaptive stabilizers for SVC control have been proposed and designed.
In addition, the additive and/or multiplicative uncertainty representation can not treat situations where a nominal stable system becomes unstable after being perturbed [13-17]. Moreover, the pole-zero cancellation phenomenon associated with this approach produces closed loop poles whose damping is directly dependent on the open loop system. Genetic algorithms and fuzzy logic based approaches have been proposed for SVC control. It was observed that SVC controls can significantly influence nonlinear system behavior especially under high-stress operating conditions and increased SVC gains. Thyristor-Controlled Series Capacitor (TCSC)

Many different techniques have been reported in the literature pertaining to investigating the effect of TCSC on power system stability. Several approaches based on modern control theory have been applied to TCSC controller design. However, the controller requires all system states which reduces its applicability. The impedance of the TCSC was adjusted based on machine rotorangle and the magnitude of the speed deviation. In addition, different control schemes for a TCSC were proposed such as variable structure controller.

The damping characteristics of the designed stabilizers have been demonstrated through simulation results on a multimachine power system. Robust nonlinear coordinated control approach to excitation and TCSC for transient stability enhancement. The excitation controller and TCSC controller have been designed separately using a direct feedback linearization technique.

Thyristor-Controlled Phase Shifter (TCPS)

A considerable attention has been directed to realization of various TCPS schemes. However, a relatively little work in TCPS control aspects has been reported in the literature and developed a control algorithm for TCPS using stochastic optimal control theory. In their control scheme the phase shift angle is determined as a nonlinear function of rotor angle and speed[18]. However, in real-life power system with a large number of generators, the rotor angle of a single generator measured with respect to the system reference will not be very meaningful. Also proposed a direct feedback linearization technique to linearize and decouple the power system model to design the excitation and TCPS controllers.

POWER QUALITY-INTRODUCTION

Power quality may also be defined as “the measure, analysis, and improvement of bus voltage, usually a load bus voltage, to maintain that voltage to be a sinusoid at rated voltage and frequency”. Power quality is “the provision of voltages and system design so that the user of electric power can utilize electric energy from the distribution system successfully without interference or interruption.” A broad definition of power quality borders on system reliability, dielectric selectivity on equipment and conductors, long-term outages, voltage unbalance in three-phase systems, power electronics and their interface with the electric power supply and many other areas.

POWER QUALITY STANDARDS

The ever-expanding application of power electronics loads and the increasing dependency upon information processing systems have produced serious concerns about power quality (PQ). The term Power quality broadly refers to maintaining the near sinusoidal waveform of bus voltages at rated voltage magnitude and frequency. There are several classical measures and standards of electric power quality. These are discussed in the following sub sections.

Measures of Electric Power Quality:

Total Harmonic Distortion (THD):

For a periodic wave, THD is defined as:

$$I = \text{order of harmonics},$$

$$V(i) = \text{Amplitude of } i_{th} \text{ harmonic component of voltage}$$

$$THD = \frac{\sqrt{\sum_{i=2}^{\infty} W(i)^2}}{V(1)}$$

THD has the following properties:

- THD is zero for a perfectly sinusoidal waveform
- As the distortion, increases THD becomes very large
- A commonly used THD level in distribution system in 5% THD of either current or voltage may be calculated.

Quick measure of distortion as it can be calculated easily.

Main disadvantage is that detailed information of the full spectrum is lost

Telephone Influence Factor (TIF)

$$W \text{ is (weights) reflect the response of human ear.}$$

The infinite sum is truncated for practical use. (Say to 5kHz per ANSI Standard 368). The TIF is usually applied to line currents since the nature of Electromagnetic induction is related to line current amplitude.

V.T Product

$$TIF = \frac{\sqrt{\sum_{i=2}^{\infty} W(i)^2 V(i)^2}}{V(1)}$$

THD index does not give information about the amplitude of the voltage (or current) with which it is connected. V.T index is an alternative index which incorporates the information, and in defined below. Wi's are the TIF weights and $V(1)$ the $i_{th}$ Harmonic components of line- to- line voltage V. V.T index gives a measure of audio circuit

$$I.T = \sqrt{\sum_{i=0}^{\infty} W(i)^2 I(i)^2}$$

$$V.T = \sqrt{\sum_{i=0}^{\infty} W(i)^2 V(i)^2}$$

Interference due to bus voltage interference since the bus voltage is weighted with TIF coefficients.

$$K.V.T = 1000 \times V.T$$

Similarly I.T is a measure for line currents.

$$DIN = \frac{THD}{\sqrt{1 + THD^2}}$$
Observe that TIF $V_{rms} = V \cdot T$
TIF $I_{rms} = I \cdot T$.

Distortion Index ($DIN$)
It is to be noted that neither index has any additional information from the signal frequency spectrum the other than that $DIN$ becomes unity for a highly distorted wave where as THD becomes infinite.

C - Message weights $[c]$
The $c$-message weighted index for current $i(t)$.

$$DIN = \frac{V(t)^2}{\sum_{i=0}^{\infty} c_i V(t)^2}$$

The $c$-message weight index may also be applied bus voltage. The TIF weights account for the fact that mutual coupling between circuits increases linearly with frequency, while the $c$-message weights are free of this consideration.

Flicker Factor ($F$)
If the voltage flicker (the low frequency voltage fluctuations) are sinusoidal of frequency $\omega f$ rad/s, the nominal instantaneous bus voltage, $V_{rms}(\omega f)$ may be considered as being modulated by the signal $V_{cos}(\omega_0 t)$ where $V_f$ is the flicker amplitude. Thus flicker component of bus voltage in $V_f(t) = V_{cos}(\omega f t)$, $V_{rms}(\omega f t)$.
And the total bus voltage is

$$V(t) = V_{rms} \cos(\omega_0 t) + V_f(t) = (1 + V_{rms}(\omega f t)) V_{cos}(\omega_0 t).$$

The $F = V_f/V_{rms}$

**DPFC TOPOLOGY**

By introducing the two approaches outlined in the previous section (elimination of the common DC link and distribution of the series converter) into the UPFC, the DPFC is achieved[19-24]. Similar as the UPFC, the DPFC consists of shunt and series connected converters. The shunt converter is similar as a 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 configuration
As shown, besides the key components - shunt and series converters, a DPFC also requires a high passfilter that is shunt connected to the other side of the transmission line and a transformer on each side of the line. The reason for these extra components will be explained later. The unique control capability of the upfc is given by the back-to-back connection between the shunt and series converters, which allows the activepower to freely exchange. To ensure the DPFC has the same control capability as the UPFC, a method that allows active power exchange between converters with an eliminated DC link is required.

**DPFC Operating Principle**

Active Power Exchange With Eliminated DC Link

Within the DPFC, the transmission line presents a common connection between the AC ports of the shunt and the series converters. Therefore, it is possible to exchange active power through the AC ports. 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 independent from each other and the voltage or current at one frequency has no influence on the active power at other frequencies. The independence of the active power at different frequencies gives the possibility that a converter without a power source can generate active power at one frequency and absorb this power from other frequencies.

By applying this method to the DPFC, 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, there by 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. For a better understanding, Figure 2 indicates how the active power is exchanged between the shunt and the series converters in the DPFC system. The high-pass filter within the DPFC blocks the fundamental frequency components and allows the harmonic components to pass, thereby providing a return path for the harmonic components[25-30]. The shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current.

**USING THIRD HARMONIC COMPONENT**

**Figure: Active power exchange between DPFC converters**

Due to the unique features of 3rd harmonic frequency components in a three-phase system, the 3rd harmonic is selected for active power exchange in the DPFC. In a three-phase system, the 3rd harmonic in eachphase is identical, be naturally blocked by trans- formers and these are widely incorporated in power systems (as a means of changing voltage), there is no extra filter required to prevent harmonic leakage. As introduced above, a high - pass filter is required to make a closed loop for the harmonic current and the cut off frequency of this filter is approximately the fundamental frequency.

Because the voltage isolation is high and the harmonic frequency is close to the cut off 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 transformer on the right side in Figure 2 with the ground. Because the 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 Figure 3. Therefore, the large high-pass filter is eliminated.

The objective of the shunt control is to inject a constant 3rd harmonic current into the line to supply active power for the series converters[31-36]. 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. One shunt converter and six single phase series converters are built and tested in a scaled network, as shown in Two isolated buses with phase difference are connected by the line. Within the experimental setup, the shunt converter is a single-phase inverter that is connected between the neutral point of the ground. The inverter is powered by a constant dc-voltage source.

These control functions are as shown in the control diagram and are explained below:

1. **Series Control**: Each series converter has its own series voltage source. Generally, the series voltage source is modeled as controllable, and the series control concerns the fundamental frequency 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 current for the shunt converter.

The optimization objective was chosen to minimize the average loadability on highly loaded transmission lines. UPFC/IPFC and the resulting power flow in the transmission line. This relationship was used to design two power flow control schemes that are applicable to any series-connected FACTS controller with the capability of producing a controllable voltage. The presented power flow control schemes were applied to a voltage-sourced converter-based PFC, and the resulting control performances were examined using PSCAD/EMTDC simulation package.

Fuzzy logic was used to control power flow. In the solution process, GA coupled with full AC power flow, selects the best regulation to minimize the total generation fuel cost and keep the power flows within their secure limits. OPF algorithm for corrective FACTS control to relieve overloads and voltage violations caused by system contingencies.

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**FACTS APPLICATIONS TO STEADY STATE POWER SYSTEM PROBLEMS**

For the sake of completeness of this review, a brief overview of the FACTS devices applications to different steady state power system problems is presented in this section. Specifically, applications of FACTS in optimal power flow and deregulated electricity market will be reviewed.

6.8 FACTS APPLICATIONS TO OPTIMAL POWER FLOW

In the last two decades, researchers developed new algorithms for solving the optimal power flow problem incorporating various FACTS devices [194]. Generally in power flow studies, the thyristor-controlled FACTS devices, such as SVC and TCSC, are usually modeled as controllable. However, VSC-based FACTS devices, including UPFC and SSSC, shunt devices like STATCOM, and combined devices like UPFC, are more complex and usually modeled as controllable sources. Having presented a new hybrid model for OPF incorporating FACTS devices to overcome the classical optimal power flow algorithm where load demands, generation outputs, and cost of generation are treated as fuzzy variables.

An improved genetic algorithm (GA) to solve OPF problems in power system with FACTS where TCPS and TCSC are used to control power flow. In the solution process, GA coupled with full AC power flow, selects the best regulation to minimize the total generation fuel cost and keep the power flows within their secure limits. OPF algorithm for corrective FACTS control to relieve overloads and voltage violations caused by system contingencies.

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**FACTS APPLICATIONS TO DEREGULATED ELECTRICITY MARKET**

Nowadays, electricity demand is rapidly increasing without major reinforcement projects to enhance power transmission networks. Also, the electricity market is going toward open market and deregulation creating an environment for forces of competition and bargaining. Electricity utilities
are in need to serve more loads through their networks and also maintain the system security. FACTS devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased load ability, low system loss, improved stability of the network, reduced cost of production, and fulfilled contractual requirements by controlling the power flows in the network. Generally, the changing nature of the electricity supply industry is introducing many new subjects into power system operation related to trading in a deregulated competitive market.

Commercial pressures on obtaining greater returns from existing assets suggests an increasingly important role for dynamic network management using FACTS devices and energy storage as an important resource in generation, transmission, distribution, and customer service. The roles and influences of FACTS devices on deregulated electric power systems and their technical and economical benefits have been discussed.

SHUNT AND SERIES CONVERTER (DPFC)

CONCLUSION

The project has presented a new concept called DPFC. The DPFC emerges from the UPFC and inherits the control capability of 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 converter, which is used for exchanging active power in the UPFC, is eliminated. In DPFC, the active power transmitted through the transmission line at the third harmonic frequency. The series converter of the DPFC employs the DVR concept, which uses multiple small single-phase converters instead of one large-size converter. The reliability of the DPFC is greatly increased because of redundancy of the series converter.

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