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A Spectral Correlative Approach to Power Quality Improvement in Upfc Applications

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Abstract—To improvise the estimation accuracy and improve the response time faster, the conventional coding technique based on frequency analysis is developed. A modified approach for frequency based coding technique is been suggested. The approach of higher spectral coding based on finer spectral information to derive the current variation is suggested. The approach of harmonic minimization based on spectral difference for measured current pulse is been suggested. The analysis made shows a comparative higher compensation than the conventional coding approach.

Keyword—Spectral filter, Harmonic suppression, power flow controllers, spectral difference modeling.

I. INTRODUCTION

Existing Power systems are highly complex and require careful design of new devices taking into consideration the already existing equipment, especially for transmission systems in new deregulated electricity markets. This is not an easy task considering that power engineers are severely limited by economic and environmental issues. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security. In the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS) [1]. The two main objectives of FACTS are to increase the transmission capacity of ac lines and control power over designated transmission routes. The improvements in the field of power electronics have had major impact on the development of the concept itself. A new generation of FACTS controllers has emerged with improvements to Gate Turn-Of (GTO) thyristors ratings (4500 V to 6000 V, 4000 A to 6000A). These controllers are based on voltage-source inverters and include devices such as Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), and Unified Power Flow Controller (UPFC) [2]. The STATCOM is mainly used to regulate voltage in transmission systems, but can also be used to improve the dynamic stability of a system [3]. The SSSC, on the other hand, can be compared to some extent to a Thyristor Controlled Series Capacitor (TCSC), as it permits a change in the impedance of the transmission line through a voltage source in series with the line [4]. A UPFC is a device which can control transmission line impedance, voltage and phase angle. It is recognized as the most sophisticated power flow controller currently, and probably the most expensive one. This controller offers substantial advantages for the static and dynamic operation of power system, but it brings with it major challenges in power electronics and power system design, as demonstrated by the collaborative effort between the American Electric Power (AEP), the Westinghouse Electric Corporation, and EPRI to install the first UPFC in the USA [5, 6]. Emerging FACTS technologies should be supported by analytical tools to allow power engineers to determine the full potential of these controllers. Digital simulations have become increasingly reliable in assessing both steady-state and dynamic performance of power systems by means of general purpose simulation programs, providing cost effective and feasible ways to model the system. To represent the power system in a realistic manner, the simulation program has to be equipped with reliable models of all power system components. As the need for flexible and fast power flow controllers, such as the UPFC, is expected to grow in the future, there is a corresponding need for reliable and realistic models of these controllers. UPFC models have been investigated by several authors [7]. In [8], the UPFC model consists of a controllable voltage source added in series with the transmission line, plus two current sources added in shunt to balance the power flow through the UPFC. The UPFC model given in [9] is made up of two ideal synchronous voltage sources; one is inserted in series with the line, while the other one is shunt connected to the line. In [10], the steady-state model of the UPFC in a popular power system analysis software package is described. In all these approaches the controllability of variation of current wrt. time is a prime requirement to achieve higher power quality in current power systems. Although the use of a UPFC improves the power transfer capability and stability of a power system, certain other problems emerge in the field of power system protection, in particular transmission line protection [3–5]. The measured line current get Detroit due to non-linear characteristic of load applied to the power system. It is required to compensate these variations using advanced signal processing approaches. Among various techniques, wavelet based coding technique for power quality enhancement is proposed. The approach uses the spectral density of higher frequency band to achieve the distortion minimization. Though the approach is based on density , distortions based on power spectral density would result in incorporation of harmmoinc contents. this paper focus on the minimization of such harmonic content by analysis in spectral domain and performing spectral subtraction for harmonic minimization.

II. SYSTEM MODELING

The UPFC is the most versatile FACTS controller with capabilities of voltage regulation, series compensation, and phase shifting. The UPFC is a member of the family of compensators and power flow controllers. The latter utilize the synchronous voltage source (SVS) concept to provide a unique comprehensive capability of transmission system control [9]. The UPFC is able to control simultaneously or selectively all the parameters affecting power flow patterns in a transmission network, including voltage magnitudes and phases, and real and reactive powers. These basic capabilities make the UPFC the most powerful device in the present day transmission and control systems. the UPFC is a generalized SVS represented at the fundamental frequency by controllable voltage phasor of magnitude Vpq and angle injected in series with the transmission line. Note that the angle ρ can be controlled over the full range from 0 to 2π . In the UPFC, the real power supplied to or absorbed from the system is provided by one of the end buses to which it is connected. This meets the objective of the UPFC to control power flow rather than increasing the generation capacity of the system. the UPFC consists of two voltage-sourced converters, one in series and one in shunt, both using Gate Turn-Off (GTO) thyristor valves and operated from a common dc storage capacitor. This configuration facilitates free flow of real power between the ac terminals of the two converters in either direction while enabling each converter to independently generate or absorb reactive power at its own ac terminal. The series converter, referred to as Converter 2, injects a voltage with controllable magnitude Vpq and phase ρ in series with the line via an insertion transformer, thereby providing the main function of the UPFC. This injected voltage phasor acts as a synchronous ac voltage source that provides real and reactive power exchange between the line and the ac systems. The reactive power exchanged at the terminal of series insertion transformer is generated internally while the real power exchanged is converted into dc power and appears on the dc link as a positive or negative real power demand. By contrast, the shunt converter, referred to as Converter 1, supplies or absorbs the real power demanded by Converter 2 on the common dc link and supports the real power exchange resulting from the series voltage injection. It converts the dc power demand of Converter 2 into ac and couples it to the transmission line via a shuntconnected transformer. Converter 1 can also generate or absorb reactive power in addition to catering to the real power needs of Converter 2; consequently, it provides independent shunt reactive compensation for the line. It is to be noted that the reactive power exchanged is generated locally and hence, does not have to be transmitted by the line. On the other hand, there exists a closed path for the real power exchanged by the series voltage that is injected through the converters back to the line. A generic model of a UPFC unit is as shown in figure 1.

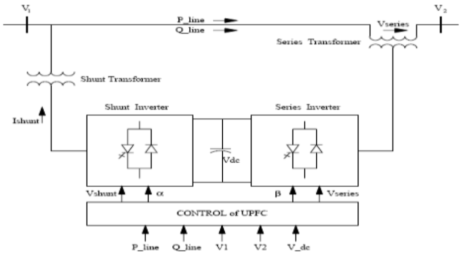

Figure 1: A generic UPFC model

III. SPECTRAL CODING APPROACH

The basic components of the UPFC are two voltage source inverters with semiconductor devices having turnoff capability (typically GTOs), sharing a common dc capacitor, and connected to the system through coupling transformers. One voltage-source inverter is connected in parallel to the transmission system via a shunt, step-down transformer, while the other is connected in series through a series transformer. A basic UPFC scheme is shown in Figure. 1. The branches can work independently of each other by separating the dc side, i.e., by supplying each branch with its own dc capacitor. In that case, the shunt-connected branch becomes a STATCOM that generates/absorbs reactive power to regulate the voltage magnitude at the ac terminal. The series branch corresponds then to a SSSC that generates/absorbs reactive power to regulate the current flow, and hence the power, of the transmission line. If these two devices are merged together through a common dc capacitor, real power can be exchanged at the ac terminals; the UPFC behaves then as an ideal ac to ac power converter in which the real power can flow freely in either direction between the controller terminals. This basically results in a controllable phase shift between the terminal voltages v1 and v2, as the two voltage-source inverters can interchange power. It should be noted that the real power is typically negotiated by the action of the series connected branch, whereas the shunt-connected branch is primarily used to feed real power from the ac system to the common dc link. The reactive power is generated or absorbed locally and independently from the real power by each branch and, therefore, it does not flow through the UPFC.

From this basic operational description, it can be concluded that the UPFC has the ability to:

1. control terminal voltage by locally generating or absorbing reactive power;
2. control power flows on the transmission line, both steady-state and dynamic, by regulating the real power flow through the controller (series capacitive/ inductive compensation and also phase shifting regulation);
3. allow secure loading of transmission lines to their full thermal capability where desirable.

From the control point of view, it is important to distinguish between the two basic types of voltage-source inverters that can be used in the UPFC [13]. One type is based on a phase control scheme, involving multi-connected out off-phase six-pulse inverters. The other type of inverters operate based on Pulse With Modulation (PWM) switching techniques, where active and reactive components of the variables can be independently controlled provided that the dc voltage is kept sufficiently high. In the only UPFC installation project so far [6], phase control is used in an eight six-pulse inverter scheme. PWM is considered uneconomical at present for transmission applications, due to the large switching losses of GTOs; however, in the near future, when developments in high power, low switching loss, semiconductor devices are exploited, this control technique would become more competitive. Many research groups, e.g. [14], use PWM controls in their UPFC studies due to simplicity and control advantages. In order to develop a fundamental frequency, balanced model of the UPFC, a power balance technique, somewhat similar to the one proposed in [13, 16] and used in [11] to develop a STATCOM model, is used here. The instantaneous power owing into the shunt inverter from the ac bus, neglecting transformer losses and assuming fundamental frequency and balanced conditions, can be represented by

$$p_{sh} = 3\,\frac{a_{sh} V_{sh} V_1}{X_{sh}} \sin\alpha$$

Where V_1 is the rms voltage of the sinusoidal receiving-end bus voltage v_1; X_{sh} is the shunt transformer equivalent reactance; ash is the transformer voltage ratio; and is the phase shift between the bus phase voltage v_1 and the corresponding output voltage of the inverter v_{sh}, as discussed in the previous section, i.e.,

$$v_1 = \sqrt{2}\,V_1 \sin(\omega t + \theta)$$
$$v_{sh} = \sqrt{2}\,V_{sh} \sin(\omega t + \theta - \alpha)$$

When > 0 (p > 0), the inverter output voltage lags the bus voltage (the capacitor charges), whereas for < 0(p < 0), the inverter ac voltage leads the bus voltage (the capacitor discharges). V_{sh} is the rms value of the inverter output voltage v_{sh}; thus, a Fourier analysis of the actual inverter voltage, yields

$$V_{sh} = \frac{1}{2\sqrt{2}}\, m_{sh} V_{dc}$$

Where V_{dc} is the average dc capacitor voltage, and m_{sh} is the amplitude modulation index of the shunt inverter. For the series branch, neglecting transformer losses, the instantaneous power owing into the series inverter under fundamental frequency, balanced conditions is represented by

$$p_{se} = 3\, a_{se} I_{ac} V_{se} \cos\gamma$$

Where a_{se} is the turns-ratio of the series transformer; I_{ac} is the rms value of the controlled ac line current i_{ac}; V_{se} is the rms magnitude of the sinusoidal inverter output voltage v_{se}; and is the phase shift of the inverter voltage v_{se} with respect to the line current i_{ac}, i.e.,

$$i_{ac} = \sqrt{2}\,I_{ac} \sin(\omega t + \phi)$$
$$v_{se} = \sqrt{2}\,V_{se} \sin(\omega t + \phi + \gamma)$$

A filtration approach to the derived current is applied to reduce the harmonic current n to this measured current to acheicve a filtered output.

IV. SPECTRAL DIFFERENTIATION APPROACH

Although the suggested approach proved very efficient in reducing high order distortion phenomena, there is still some remaining distortion which lowers the current quality. Some devices are very sensitive to this remaining residual background distortion after distortion estimation. Such as power transformer and non-linear loads. Therefore, a second distortion reduction stage is employed. From the magnitude spectrum O(k; i), output of the first distortion reduction stage, the current level is obtained by normalizing spectral autocorrelation at a lag equal to a fundamental frequency in frequency domain. At the next stage, a spectral correlator is used to find the number of peaks and the frequency bin of the peak corresponding to the highest harmonic within the auto-correlation. Each of these candidate peaks is analyzed to categorize it as a peak coming from either a harmonic or a measured value. To determine the harmonic amplitude O(h,i) and harmonic frequency in the frame , a estimation approach is developed as defined;

$$O(h,i) = max_{m\in[a,b]}(|O(m,i)|),$$

Where a = floor((signal)(f0/Sr/N)) using the sampling rate S_r and the estimated fundamental frequency f_0, and b= ceil((signal)(f0/Sr/N)). c ε [0,0:5] determines the tolerated non-harmonicity. The estimate λ_{HT} (k,i) of the distortion is then obtained by sampling the distortion spectrum in the range between the harmonic spectral peaks and by interpolation of the frequency and time from the adjacent distortion spectra in the surrounding signals. Finally, the enhanced spectral amplitude S(k,i) is achieved by spectral differentiation:

$$\tilde{S}(k,i) = O(k,i) - \lambda_{HT}(k,i).$$

This approach of spectral mapping reduces the total harmonic content resulting in higer quality improvement.

V. RESULT OBSERVATION

A generator-line-load test system introduced in [17] is Modified and used here to validate the proposed fundamental frequency model of the UPFC; the test system operates at 138 kV and is shown in Figure. 2. The generator is assumed to be an ideal voltage source behind equivalent Thevenin impedance. The transmission system is composed of transmission lines of different lengths and modeled as a distributed-parameter lines. The two parallel transmission lines in Figure 2. Have identical parameters but the lower line per unit length is assumed longer; the UPFC is placed on that line to control the power fl through it. The UPFC power fl controller is designed to maintain the power fl through the line at 0.2 p.u. The load, connected to the system through an impedance representing a step-down transformer, is modeled as an RL load. The UPFC shunt transformer is Y-Y connected and rated at 100 MVA, 138 kV/15 kV, with a leakage reactance of 14.5%. The series transformer is Y-_ connected and rated at 100 MVA, 47.81 kV/15 kV, with a leakage reactance of 6%.

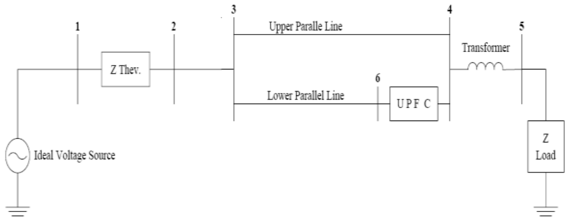

Figure 2: 5-Bus Test system for the UPFC.

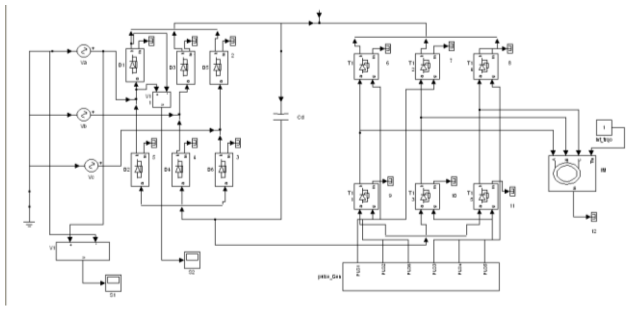

Figure 3: Simulink model for the 2-inverter logic for the UPFC model

The obtained observation is as outlined below,

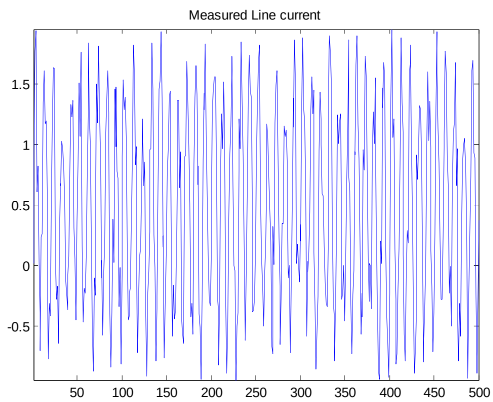

Figure 4: measured Line current for the developed system

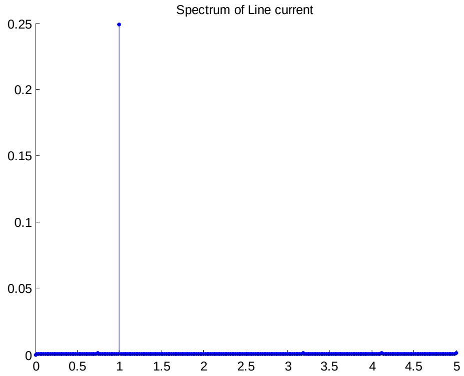

Figure 5: Measured spectral content for the line current

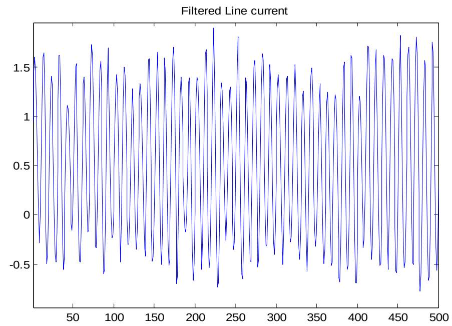

Figure 6: processed line current after spectral mapping

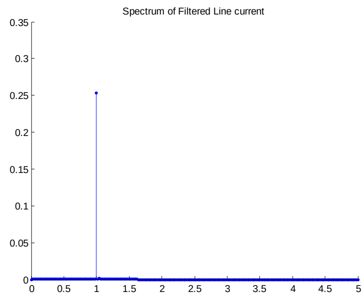

Figure 7: spectral density plot for the filtered signal

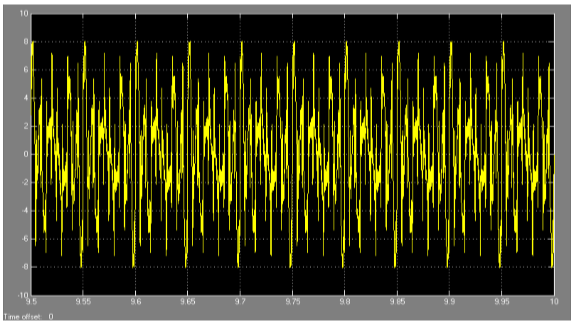

Figure 8: Measured load current without spectral correction

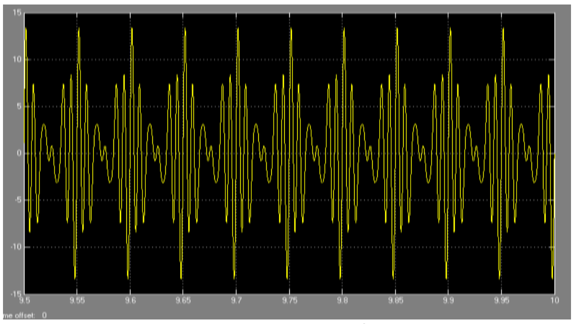

Figure 9: spectral correlated filtered output

The observation shows a decrement in the harmonic signal content in the line current, and load current.

VI. CONCLUSION

This paper presents an approach for frequency based estimation of harmonic minimization in power flow controlling. The simulation results demonstrate the validity of the proposed model, which can be used for both steady-state and transient stability studies. The model is simple and can be used in any application that has some external programming capabilities. It should be noted that the model is completely independent of the type of control used in the UPFC; the results were obtained for a PWM-based control technique, and phase control technique.

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