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Harmonic Analysis of Pwm Based Shunt Compensator Using Dynamic Harmonic Domain

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Abstract: **-- The extended or dynamic harmonic domain method is used to obtain harmonics during steady dynamic states for static shunt compensation (STATCOM). Firing pulses used for voltage source converter (VSC) are based on pulse width modulation PWM, and the simulation results obtained during steady state are validated by prototype panel experiments. The voltage and current harmonics are observed for STATCOM VSC switching.**

I. INTRODUCTION

Flexible AC transmission techniques based on power electronics devices [1] are used in power systems to solve many power quality issues; however, they also introduce harmonics and power quality problems to these systems. Many firing schemes have been proposed for voltage source converters (VSCs) used as flexible AC transmission systems FACTS devices [2-3] [6]. [9]. [22].[26].[28] Harmonics result in a degradation of system performance. The study of the nonlinear behaviour of power electronics converters has been conducted via various methods including time and harmonic domain [5] [4] [10] [11]. These techniques have been applied to harmonic analysis of thyristor controlled reactors (TCR) [11],[21].The fixed capacitor-thyristor control reactor (FC-TCR) model in dynamic harmonic domain (DHD) is also available in [17] and the transformer DHD model is given in [19]. The extended harmonic analysis methods provide information from steady state power quality indices to those that are transient. Extended harmonics domain (EHD) is based on an orthogonal series expansion and its properties. The harmonic domain model can be used in extended harmonic domain with few or no modifications. The phase-pulse-width-modulation-based STATCOM are models in the extended harmonic domain [12] [13]. [14]. [18]. [20] [27]. Harmonic coupling can be directly calculated using a harmonic domain model [24]. Some research works have proposed hybrid methods based on time and frequency domain for harmonic analysis [8]. The DHD model of the STATCOM is simulated using selective harmonics elimination methods, or multi-pulse modulation techniques. In this study, the VSC model used as the STATCOM is simulated using a carrier-based PWM method in conjunction with a dynamic or extended harmonics domain method, and the power quality indices including RMS voltage and current are observed for a voltage source converter.DHD simulation results obtained using MATLAB® software are validated using an experimental panel. The results obtained via simulation for a VSC fired by carrier based PWM techniques are compared with experimental results for power quality analysis.

II. SWITCHING METHOD FOR VSC

Among various switching schemes available, schemes such as carrier based pulse width modulation for power quality analysis

Carrier-Based PWM

The generation of a balanced three-phase switching function reduces to a single space vector in either a static or synchronous reference frame. The resultant switching signal, sharing the fundamental period, may be expressed as its Fourier series expansion, and equivalently as a harmonic vector:

$$S_{\psi}(t) = \sum_{k \in \square} S_{\psi,k} e^{jk\omega_0 t} \quad (1)$$

$$s_{\psi}(t) = \Gamma(t) S_{\psi} \quad (2)$$

III. DYNAMIC HARMONIC DOMAIN MODELLING OF THE STATCOM

A STATCOM circuit is shown in figure 1. It has voltage source converter and capacitor connected to a transmission line through a transformer.

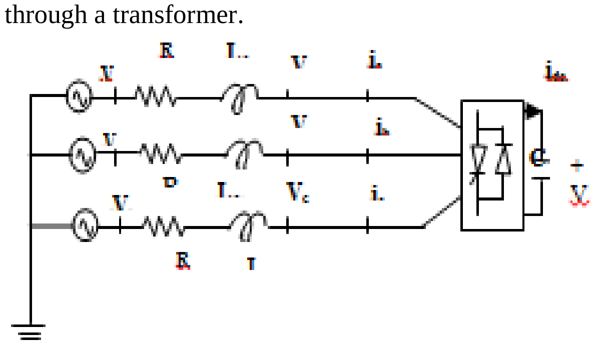

Fig. 1. STATCOM equivalent

State equation of the STATCOM

From figure 1, the DC current idc expressed in terms of capacitor voltage is given by

$$i_1 = C\frac{dv_{dc}}{dt} \qquad (3)$$

The voltage across the impedance in terms of ABC is given by

$$v_{abc} - v_{abc1} = R_{eq} i_{abc}(t) + L_{eq}\frac{di_{abc}(t)}{dt} \qquad (4)$$

Here, the Leq and Req are the inductance and resistance of the transformer, respectively, and C represents the capacitance connected to VSC. Equations 3 and 4 can then be converted into a linear time invariant system equation by means of dynamic harmonic domain as [25]

$$\begin{bmatrix} \dot{I}_{abc}(t) \\ \dot{V}_{dc}(t) \end{bmatrix} = \begin{bmatrix} -\frac{R_{eq}}{L_{eq}}U_1 - D(jH\omega_0) & -\frac{1}{L_{eq}}P_s(t) \\ \frac{1}{C}Q_s(t) & -D(jH\omega_0) \end{bmatrix} \begin{bmatrix} I_{abc}(t) \\ V_{dc}(t) \end{bmatrix} + \frac{1}{L_{eq}}\begin{bmatrix} V_{abc}(t) \\ 0 \end{bmatrix} \qquad (5)$$

The power quality indices are obtained by solving (5). Considering $\dot{I}_{abc}(t)$ and $\dot{V}_{dc}(t)$ to be zero in (5) provides the steady state solution.

IV. SIMULATION OF STATCOM MODEL

The DHD model of the STATCOM shown in equation (5) is used to examine the dynamic harmonic response for a given condition. The switching used for the voltage source converter is unipolar PWM. The capacitor voltage is assumed to be 0.4 p.u. and is considered to be constant. The reactance and resistance of the coupling transformer are Le=0.2 ×10−3 H, Re=4 × 10−2Ω, respectively, and the capacitance is C=4400 ×10−6F. The 50Hz voltages are

$$V_{Sa}(t) = \sin(\omega_0 t) \qquad V_{Ra}(t) = 0.8\sin(\omega_0 t)$$
$$V_{Sb}(t) = \sin(\omega_0 t - 120^0) \qquad V_{Rb}(t) = 0.8\sin(\omega_0 t - 120^0)$$
$$V_{Sc}(t) = \sin(\omega_0 t + 120^0) \qquad V_{Rc}(t) = 0.8\sin(\omega_0 t + 120^0) \qquad (6)$$

At 0.04 s the input voltage VRa(t) is changed;

$$V_{Ra}(t) = 0.75\sin(\omega_0 t)$$
$$V_{Rb}(t) = 0.79\sin(\omega_0 t - 120^0)$$
$$V_{Rc}(t) = 0.78\sin(\omega_0 t + 120^0) \qquad (7)$$

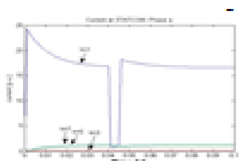

Figure 2a: Current at terminal of STATCOM (Phase A)

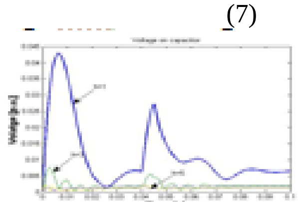

Figure2b: DC side voltage on capacitor

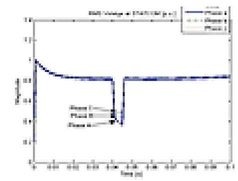

Figure 2c: STATCOM RMS voltage

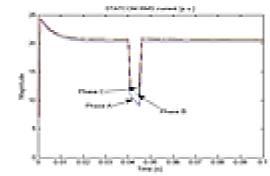

Figure 2d: STATCOM RMS current

Fig.2. : Power quality indices when a unipolar PWM technique is used

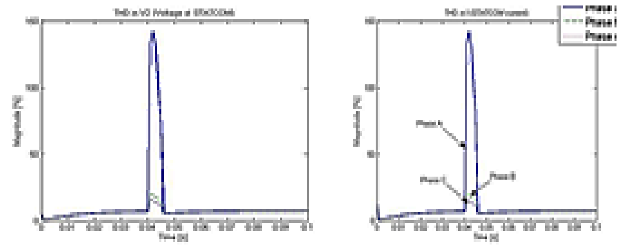

Fig. 3 : Total harmonic distortion in voltage and current

The changes are maintained upto 0.005 s.

A MATLAB code was written for the above model and the program was run using MATLAB software considering function ode(45) and harmonics in order to obtain an accurate result for analysis purposes.

The VSC current, capacitor voltage, root mean square (RMS) current at the voltage source converter, and RMS voltage at the VSC terminals, when using the carrier based switching scheme are shown in Figure 3. Observed total harmonic voltage and current distortion when the carrier based switching firing methods are used are shown in Figures4.

Figures 2a shows the current, harmonics components such as the third, fifth, and seventh harmonics in the current. The dynamic harmonic response of the capacitor voltage is shown in figure 3b when the carrier based PWM scheme is used. Figures 2b show that the capacitor voltage when the unipolar PWM scheme without using any control scheme. The non-characteristic harmonics are present in the capacitor voltage due to unbalanced nature of the disturbances.

The RMS value of voltage at the STATCOM terminal is shown in figures 2c using a more stable capacitor voltage. The RMS value of current is shown in figures 2d .

Total voltage harmonic distortion at the VSC terminal is shown in figures3a. Total current harmonic distortion is shown in figures 3b.

A. Analysis of power quality indices

The power quality indices shown in table 1 demonstrate that the THD in voltage and current is reduced and capacitor voltage is better utilized during both the steady state and transient state.

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Table 1: Power quality indices for STATCOM

	RMS value of Current	THD in current	RMS value of Voltage	THD in voltage
PWM switching	21	12%	0.8	7%

Table 5: Total harmonic distortion calculation for STATCOM

VI. COMPARISON OF ANALYTICAL AND PRACTICAL RESULTS FOR TOTAL HARMONICS DISTORTION IN VOLTAGE AND CURRENT.

The result obtained using the DHD method is compared with the experimental data for the total harmonic distortion in current and is shown figure 5 for the STATCOM. Similarly, the result obtained via the DHD method is compared with the experimental results for the total harmonic distortion in voltage and is shown in figure 6 for the STATCOM.

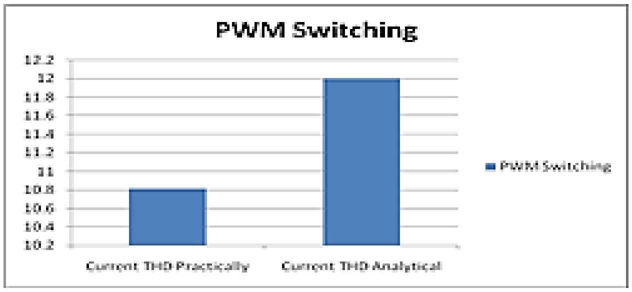

Fig. 5. ***Comparison of the experimental and analytical results for total harmonic current distortion in current for the STATCOM***

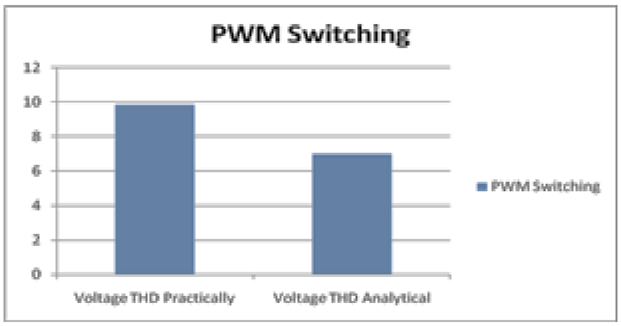

Fig. 6. ***Comparison of the experimental and analytical result for total harmonic current distortion for the STATCOM***

The y-axis in figures 5 and 6 show the total percentage harmonics distortion. From figures 5 and 6, it is observed that the analytical and practical results are in agreement with the expected values with a variation of less than 10%. This variation is primarily due to the inductive load and filtering characteristics.

VII. CONCLUSION

A STATCOM model has been simulated using PWM switching functions to study the power quality of electrical systems. The results obtained from the simulation of the STATCOM model using the DHD model with PWM techniques in order to obtain power quality indices. The power quality indices obtained by the PWM switching converter switching for VSC-based FACTS devices are compared. This comparison showed the effect of switching on the power quality indices during simulation for a VSC using DHD models, which were validated against the prototype model of transmission line and VSC-based STATCOM controller for the PWM switching using DSP 2407.

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