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Harmonics prediction of power system network in the presence of facts devices

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ABSTRACT

Flexible AC Transmission System (FACTS) devices are used in transmission system to improve voltage profiles, stability, active and reactive power flows. Basically, these devices are nonlinear. One of the present challenges facing power research groups is the harmonic study and characterization of Flexible AC Transmission System (FACTS) and their interaction with transmission and distribution networks. This kind of devices will distort the steady state voltage and current waveforms. This work is concerned with quantification of distorted voltage and current waveforms of power system network in the presence of FACTS devices. MATLAB code is developed to **assess the harmonic performance of five bus test system.**

Keywords: *FACTS, Harmonics, Distortion, Nonlinear devices, SVC, Total Harmonic Distortion*

1. INTRODUCTION

The Electrical power networks are interconnected to different kinds of generating units and load centers according to the existing plan. But load demands on the electrical system are not constant. With the increase of industrial growth and domestic load, more power is consumed by the different loads. To satisfy the load requirement, either electrical system network to be re-evaluated or the power carrying capability of the transmission line to be increased. One way to increase power carrying capability is by adding new transmission and generation. In the economic point of view, modification of existing electric network is costly. FACTS devices can enable the same objectives with no major changes to existing system. Flexible AC Transmission System (FACTS) is defined as 'Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability' [1].

Depending on the power electronic devices used in the control, the FACTS Controllers can be Variable impedance type and Voltage Source Converter (VSC) type. Static Var Compensator SVC is example for variable impedance FACTS device. Static synchronous Compensator (STATCOM) is example for VSC type. Basic elements of FACTS devices are power electronics devices. Nonlinear characteristics of Power electronics devices will distort the sinusoidal waveforms. Since harmonic distortion of voltages and currents can have negative effects on system components. The negative effects of harmonic distortion of voltages and currents usually pointed out in the literature [2] are: 'reduction in the efficiency of the generation, transmission and utilization of electric energy because of harmonic power losses, heating of system components caused by increased RMS current value, harmonic resonances resulting in excessive harmonic currents and voltages. There is a need for performing harmonic studies and developing countermeasures to compensate for it is justified in transmission network. Lot of research work on Harmonic studies of distribution system have done by many researchers. This paper focuses on harmonic studies on transmission system with FACTS devices. Voltage control problem is considered here. To regulate bus voltage magnitude dynamically in transmission system shunt connected FACTS devices (SVC, STACOM) are used. SVC is used here to control the bus voltage dynamically. As firing angle in TCR is varied, TCR current becomes non sinusoidal. Non sinusoidal current contains harmonics .these harmonics propagate throughout the network and distort the sinusoidal waveforms. The objective of this paper is to solve the network at fundamental and harmonic frequencies in the presence of nonlinear loads with a fast decoupled harmonic load flow technique. Section 2 discusses the basics of harmonics.

2. HARMONICS

The term 'harmonics' was originated in the field of acoustics, where it was related to the vibration of a string or an air column at a frequency that is a multiple of base frequency. A Harmonic component in an AC power system is defined as a sinusoidal component of a periodic wave form that has a frequency equal to an integral multiple of the fundamental frequency of the system. Harmonics in the voltage (or) current wave forms can be conceived as perfectly sinusoidal components of frequencies multiple of the fundamental frequency. Generally, AC power system network expected to operate at single frequency constant voltage. Figure (1) shows the pure sinusoidal waveform .Phasor method is used to analyze pure sinusoidal waveforms. Nonlinear devices generate harmonics which distort the pure sinusoidal waveforms. Figure (2) shows the distorted waveform. It contains 3rd and 5th harmonics. In general, even harmonics are not present in the power system network. Well known phasor method does not useful to analyze the nonsinusoidal waveforms. Nonsinusoidal waveform has been analyzed by using Fourier series analysis. Harmonic frequencies are integer multiples of the generated frequency [2] .Mathematically $f_h = hf_1$ where h is integer.5th harmonic frequency=$5f_1$,7th harmonic frequency =$7f_1$ and so on .Total Harmonic Distortion (THD) is used to know how much distorted waveform is deviate from pure sinusoidal waveform .THD is defined as ratio between sum of harmonic voltages or currents to fundamental component .If THD value is zero, it means that there is no distortion in given wave form. If THD value is more, it means that there is more distortion in waveform. Resistance is independent of frequency so it is not affected by harmonics. But it will affect on inductive and capacitive reactance. Inductive reactance is proportional to harmonics frequency and capacitive reactance is inversely proportional to harmonic frequency.

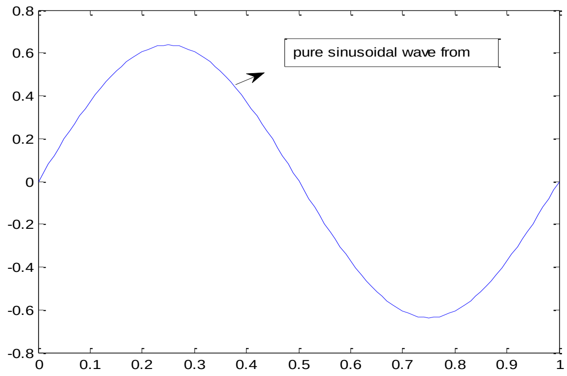

Figure (1) Undistorted Waveform

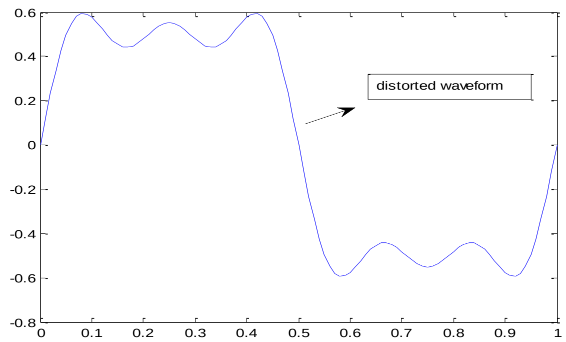

Figure (2) Distorted Waveform

3. STATIC VAR COMPENSATOR

Figure (3) shows the basic circuit diagram of SVC .It consists of a TCR in parallel with fixed capacitors. From an operational point of view, the SVC behaves like a shunt connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response. The SVC is taken to be a variable-shunt susceptance, which is adjusted in order to achieve a specified voltage magnitude while satisfying constraint conditions.

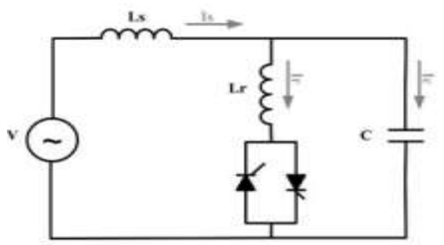

Figure (3) Basic Circuit Diagram of SVC

The overall action of the thyristor controller on the linear reactor is to enable the reactor to act as a controllable susceptance, in the inductive sense, which is a function of the firing angle. However, this action is not trouble free, since the TCR achieves its fundamental frequency steady-state operating point at the expense of generating harmonic distortion, except for the condition of full conduction'[2]. no harmonic distortion is generated by the TCR, when the thyristors are gated into conduction, precisely at the peaks of the supply voltage. When TCR conduct partially ,current becomes nonsinusoidal. Figure (4) shows voltage and current waveforms of TCR in partial conducting mode. In order to conduct harmonics analysis, frequency dependent models of various power system elements have been developed. Section 4 presents Modelling of power system elements and nonlinear elements in frequency domain.

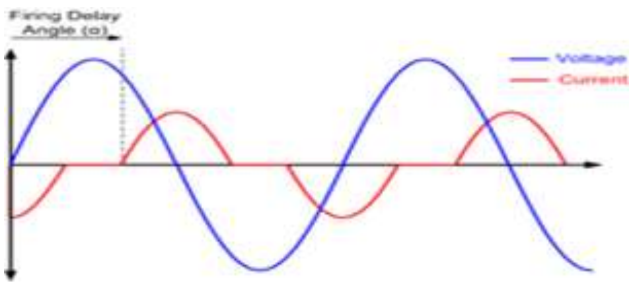

Figure (4) TCR Voltage and Current Waveforms

4. MATHEMATICAL MODELLING OF SYTEM COMPONENTS

The modelling is dependent on the network being studied. Networks vary in complexity and size and generally it is not possible to include the detailed model of every component in the study. A high-voltage grid system may incorporate hundreds of generators, transmission lines, and transformers. Thus, the extent to which a system should be modelled has to be decided. Transmission systems have higher X/R ratios and lower impedances and the harmonics can be propagated over much longer distances. [5] .Digital harmonic analysis relies on harmonic detection and prediction, respectively. The first processes in real-time data of the monitored harmonic content in the network, while the last relies on computer simulations to predict the harmonic distortion through implemented analytical models [3]. The method used in this paper belongs to second category. Accurate modelling of the power system elements will be required to prediction the harmonic response.

i). Modelling of Generator: The most important component in electrical power system is generator. Direct axis and quadrature axis reactances are equal in cylindrical rotor generator but direct axis and quadrature axis reactances are not equal in salient pole generator. Average inductance experienced by harmonic currents, which involve both the direct axis and quadrature axis reactances, is approximated Average inductance is $L_d+L_q/2$. At harmonic frequencies generator reactance is hXg.

Harmonic impedance of generator at harmonic frequency is

$$Z(h) = R + jhXg \qquad (1)$$

Admittance of generator is

$$Y(h) = \frac{1}{Z(h)} \qquad (2)$$

ii). Modelling of transmission system: Transmission line resistance(R), inductance (L), shunt capacitance(C) is obtained from datasheets. It is modelled as equivalent π model. Series harmonic impedance of line is

$$Z(h) = R + jhX \qquad (3)$$

Harmonic Admittance of line is

$$Y(h) = 1/Z(h) \qquad (4)$$

iii). Modelling of Shunt Capacitor banks: It is used to improve power factor and voltage magnitude. Steeples control is not possible. Harmonic impedance of capacitor bank can be calculated from voltage and reactive power. We can get voltage V_L from conventional power flow solution.

$$X(h) = -j\frac{VL}{hQ} \qquad (5)$$

iv) Modelling of linear loads: Different types of models are available in open literature. R-L series modelling is suitable to represent the individual loads.

v). Modelling of nonlinear loads (svc): static VAr compensator (SVC) is nonlinear device. it generates current harmonics .it is modelled as injection of current harmonics. fundamental current of SVC can calculate from power flow solution. the injected currents from SVC are assumed to known. Higher order harmonics are neglected.

Table-1: Harmonics Generated by SVC

Harmonic order	5	7	11	13	17	19	23	25
% Fundamental current	5.05	2.59	1.05	0.75	0.44	0.35	0.24	0.2

5. METHODOLOGY

This section presents the stepwise procedure to determine the harmonic voltages and currents at all buses.

Step 1: Perform power flow analysis to get fundamental voltages and angles at all buses. Create separate mfile to enter the input data. Enter bus data, line data, accuracy, max iterations in this file. Write main program in another file. These two files created for fundamental power flow solution.

Step 2: Identify weak bus from power flow solution. connect SVC to improve voltage profile.

Step 3: Power flow results is also used to calculate fundamental current of SVC and parameters of linear loads.

Step 4: Form harmonic admittance for system under consideration.

Step 5: Determine harmonic impedance for entire system.

Step 6: Solve $[V]_h=[Y_h]^{-1}[I]_h$.

Step 7: Identify dominant harmonic number.

Step 8: Calculate total harmonic distortion V_{Thd} for all buses and identify most polluted bus.

Step 9: Calculate harmonic distortion in current waveform I_{Thd}.

Step 10: Plot current and voltage waveforms at buses.

6. EXAMPLES

To illustrate the harmonic power flow method one example is presented.

6.1 Example: Figure (5) shows the test system under consideration in which it has been selected as base voltage 100 KV and base MVA is100. It has 5 buses and 7 lines. In this scheme, bus1 is taken as slack bus. bus2 is PV bus. The rest of the buses are of type PQ buses.

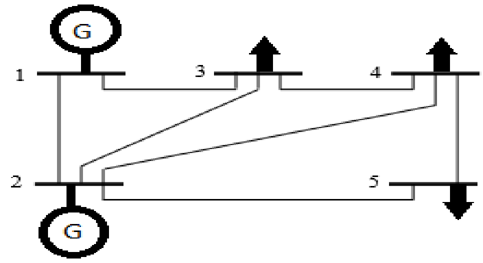

Figure (5) Single line diagram of test system under consideration

Line data and bus data presented in table 2 and table 3

Table-2: Line Data

s.no	From bus	To bus	R	X	B	Transformer taps
1	1	2	0.02	0.06	0.030	1
2	1	3	0.08	0.24	0.025	1
3	2	3	0.06	0.18	0.020	1
4	2	4	0.06	0.18	0.020	1
5	2	5	0.04	0.12	0.015	1
6	3	4	0.01	0.03	0.010	1
7	4	5	0.08	0.24	0.025	1

Table-3:Bus Data

Bus no	Type	Voltage magnitude	Phase angle	load MW	Load MVar	Generator MW	Generator Mvar	Injected MVAr
1	Slack	1.05	0	0.0	0	0	0	0
2	PV	1.0	0	0.0	0	30	0	0
3	PQ	1.0	0	45	20	0	0	0
4	PQ	1.0	0	80	30	0	0	30
5	PQ	1.0	0	50	25	0	0	0

Case 1: System analysis at fundamental frequency:

Steady state analysis with and without svc is presented in table 4 and table 5

Table -4: Power flow solution without SVC

Bus number	1	2	3	4	5
Volatge magnitude in pu	1.050	1.000	0.973	0.970	0.957
Phase angle	0.000	-2.699	-6.146	-6.839	-6.127

Table- 5: Power flow solution with SVC is connected at bus5

Bus number	1	2	3	4	5
Volatge magnitude (p.u)	1.050	1.000	0.980	0.979	0.993
Phase angle	0.000	-2.694	-6.222	-6.937	-6.708

From results it is observed that voltage at bus 5 need to be improved. It is observed that voltage at bus 5 improved by connecting the SVC. but it is nonlinear device it will inject the current harmonics. There is need to know harmonic levels at each bus harmonic power flow results presented in table no.5

Case 2: System Analysis at harmonic frequencies:

i) Most distorted Current waveform analysis: SVC is connected at bus 5, current wave form at bus 5 is most distorted. MATLAB simulated results shown in Figure (6)

From Figure (7), it is observed that 5th harmonic is dominating as compare to the other harmonic frequencies.

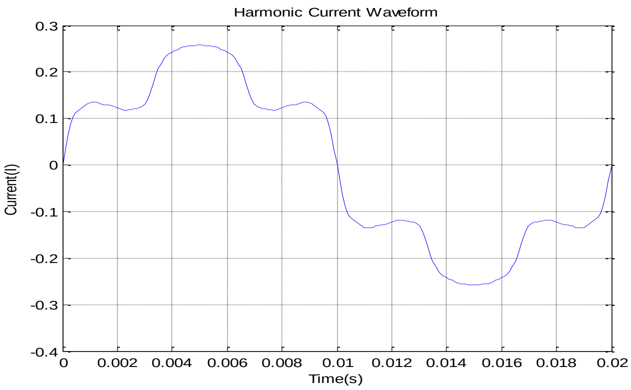

Figure (6)

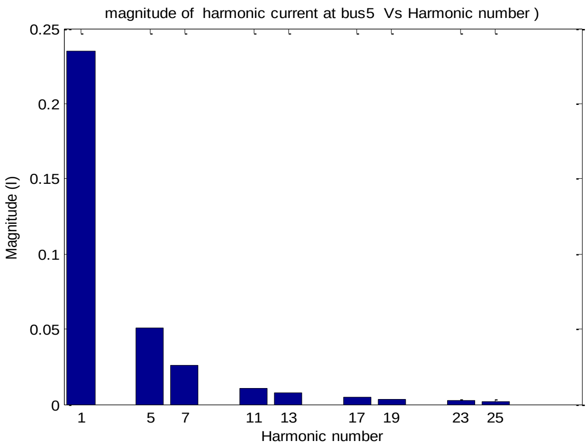

Figure (7)

ii) The most distorted voltage waveform analysis :from table 5 ,voltage waveform at bus5 is most distorted because THD value is highest of among all the buses. Figure (8) shows THD vs buses.

Table-6: Harmonic voltage distortion at various buses

Bus no	fun(p.u)	5th	7th	11th	13th	17th	19th	23rd	25th	THDv
1	1.050	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
2	1.000	0.0002	0.0002	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	0.03
3	0.980	0.0047	0.0037	0.0027	0.0022	0.0012	0.0009	0.0004	0.0003	0.72
4	0.979	0.0058	0.0045	0.0029	0.0022	0.0011	0.0007	0.0002	0.0001	0.85
5	0.993	0.0225	0.0167	0.0111	0.0096	0.0073	0.0059	0.0035	0.0027	3.35

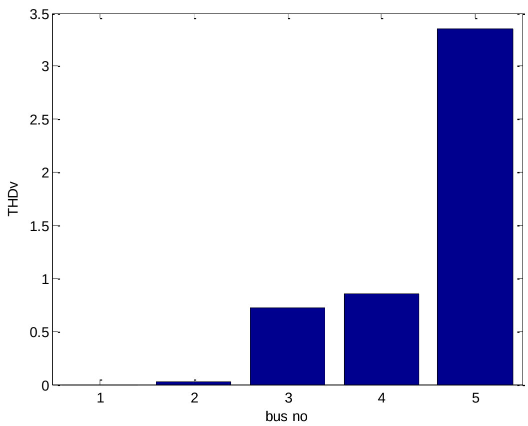

Figure (8)

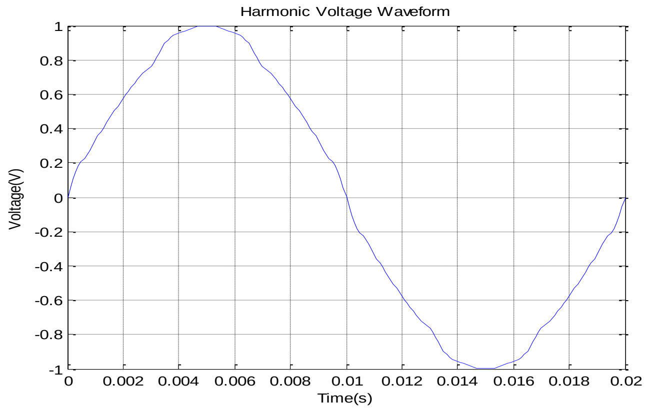

Figure (9)

Figure (9) shows distorted voltage waveform and from figure(10) it is concluded that 5th harmonic is dominating in voltage waveform also.

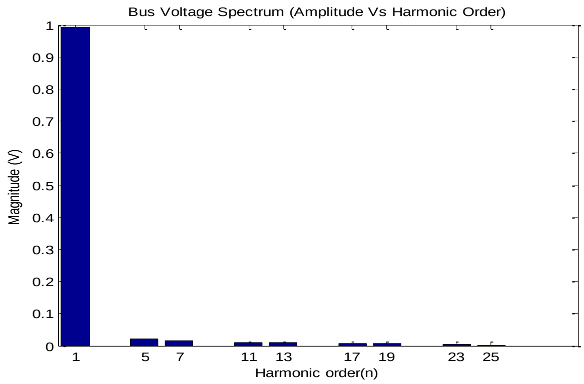

Figure (10)

7. CONCLUSION

SVC improves the voltage profile by generating current harmonics in the system before installing the SVC in practical power system network, it is better to analyses harmonic effects on performance of power system. It is concluded that voltage harmonic distortion is more at SVC connected bus. voltage distortion is less than 5%. because we have considered only one nonlinear load .practical power system may have more nonlinear loads .in that case voltage distortion more than 5 % .There is need to design the filter if THD is more the acceptable value of THD.

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