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Voltage Profile Improvement with Thyristor Controlled Series Capacitor

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ABSTRACT: In the recent years, one of the problems that found wide attention is the power system instabilities with the lack of new generation and transmission facilities and increase in the load demand of electrical power is continuously rising at a very high rate, due to rapid industrial development. Power system instability is the main problem that the industry is facing today. FACTS technology and other advanced technologies have made it possible to mitigate the power quality problems. A control strategy for the Series Compensation is developed to regulate power flow and minimize the losses in the power system. This paper describes the analysis of voltage sag/swell and harmonic distortion and compensation of these power quality problems with the Thyristor controlled series capacitor. In this paper the Thyristor controlled series capacitor is considered for the series compensation. Medium transmission line show for voltage profile and harmonic analysis when Thyristor controlled series capacitor (TCSC) is not inserted in series with the line, and then result obtained through Matlab Simulation when Thyristor controlled series capacitor is inserted in series with the transmission line. All the simulation work is carried in MATLAB/SIMULINK environment.

KEYWORDS: Power Quality, Voltage sag, Voltage swell, Harmonics, TCSC

I.INTRODUCTION

Modern electric power utilities are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. Flexible AC Transmission Systems controllers are used to control various power system problems. Power Quality in electric network is one of today's most concerned areas of electric power system [1]. The TCSC device is more effective for series compensation. Most of the available technical literature in TCSC usually deals with steady state and dynamic control and applications independently. However, to fully understand and properly utilize these types of controllers, a number of control tasks for both dynamic and steady state system improvement must be jointly considered. Since the time frames of the different control actions comprise a wide range of system responses, a hierarchical control scheme should be preferably considered for the controller. In the case of a TCSC, such a scheme should consider the different control levels acting on the same control variable, which in this paper is assumed to be the fundamental frequency equivalent impedance, as this is the control variable most commonly studied in the literature. In this kind of hierarchical control design, adverse interactions between the different control levels may be expected when not properly coordinated .The main aim is to analyse the design of a hierarchical TCSC controller for stability enhancement, taking into account interactions among the different control levels [2]. The basic Thyristor-Controlled Series Capacitor with as a method of "rapid adjustment of network impedance," It consists of the series compensating capacitor shunted by a Thyristor-Controlled Reactor [3]. Most of the available technical literature in TCSC usually deals with steady state and dynamic control and applications independently. However, to fully understand and properly utilize these types of controllers, a number of control tasks for both dynamic and steady state system improvement must be jointly considered. Since the time frames of the different control actions comprise a wide range of system responses, a hierarchical control scheme should be preferably considered for the controller. In the case of a TCSC, such a scheme should consider the different control levels acting on the same control variable, which in this paper is assumed to be the fundamental frequency equivalent impedance, as this is the control variable most commonly studied in the literature. In this kind of hierarchical control design, adverse

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interactions between the different control levels may be expected when not properly coordinated .The main aim is to analyse the design of a hierarchical TCSC controller for stability enhancement, taking into account interactions among the different control levels [2]. In this paper our objective is to analyse the voltage profile of receiving end for medium transmission line using MATLAB simulation. Simulation is done for 33kv,110km medium transmission line for the analysis of voltage sag, voltage swell and harmonic present during sag and swell. The simulation work for sag/swell and harmonic is done with and without Thyristor controlled series capacitor. Thyristor controlled series capacitor is used as series compensator.

II.POWER QUALITY

Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. Unfortunately, electronic devices are sensitive to disturbances, and thus, industrial loads become less tolerant to power quality problems such as voltage sags and harmonics [4]. Voltage sags are an important power quality problem. TCSC is an effective FACTS device to mitigate these power quality problems.
The most common Power Quality problems are:

- Reduced voltage regulation.
- Voltage Sag
- Voltage Swell
- Flickers
- Reduced Power Factor

Voltage sag (or dip):

A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0, 5 cycle to 1 minute. Voltage sag occurs on the transmission or distribution network (most of the times on parallel feeders) due to Faults in consumer’s installation. Connection of heavy loads and start-up of large motors. Voltage sag may result results in Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines.

Voltage swell:

It is Defined as the Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few a few seconds [8].

III.THYRISTOR CONTROLLED SERIES CAPACITOR

The basic Thyristor-Controlled Series Capacitor scheme, proposed in 1986 by Vithayathil with others as a method of "rapid adjustment of network impedance," is shown in Figure 1. It consists of the series compensating capacitor shunted by a Thyristor-Controlled Reactor. In a practical TCSC implementation, several such basic compensators may be connected in series to obtain the desired voltage rating and operating characteristics. A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance Specific dynamical issues in transmission systems are addressed by Thyristor Controlled Series Capacitors (TCSC). In case of large interconnected electrical systems it increases damping. It also overcomes the problem of Sub- Synchronous Resonance (SSR). Sub-Synchronous Resonance is a phenomenon that involves an interaction between large thermal generating units and series compensated transmission systems. The high speed switching capability of TCSC provides a mechanism for controlling line power flow. This permits increased loading of existing transmission lines, and also allows for rapid readjustment of line power flow in response to various contingencies. Regulation of steady-state power flow within its rating limits can be done by the TCSC. The TCSC resembles the conventional series capacitor from a basic technology point of view. All the power equipment is located on an isolated steel platform, including the Thyristor valve which is used for controlling the behaviour of the main capacitor bank. Similarly the control and protection is located on ground potential along with other auxiliary systems. This arrangement is similar in structure to the TSSC and, if the impedance of the reactor, X_L, is sufficiently smaller than that of the capacitor, X_C, it can be operated in an on off manner like the TSSC. However, the basic idea behind the TCSC scheme is to provide a continuously variable capacitor by means of partially cancelling the effective compensating capacitance by the TCR. The TCR at the fundamental system frequency is continuously variable reactive impedance; controllable by delay angle α, the steady-state impedance of the TCSC is that of a parallel *LC* circuit, consisting of a fixed capacitive impedance, X_C, and variable inductive impedance, $X_L(\alpha)$, that is[5]

$$X_{TCSC} = \frac{X_c X_L(\alpha)}{X_L(\alpha) - X_C} \qquad (1)$$

$$X_L(\alpha) = X_L \frac{\pi}{\pi - 2\alpha - \sin\alpha} \quad , \; X_L \le X_L(\alpha) \le \infty \qquad (2)$$

X_L=ωL, and α is the delay angle measured from the crest of the capacitor voltage (or, equivalently, the zero crossing of the line current). Fig.1 shows the Basic Thyristor controlled series capacitor.

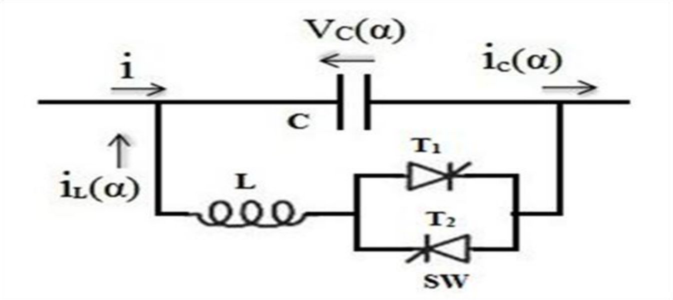

Fig.1 Basic Thyristor Controlled Series Capacitor

The TCSC thus presents a tune able parallel LC circuit to the line current that is substantially a constant alternating current source. As the impedance of the controlled reactor, $X_L(\alpha)$, is varied from its maximum (infinity) toward its minimum (ωL), the TCSC increases its minimum capacitive impedance, X_{TCSC}.min = X_C = 1/ωC, (and thereby the degree of series capacitive compensation) until parallel resonance at $X_C = X_L(\alpha)$ is established and X_{TCSC}.max theoretically becomes infinite. Decreasing $X_L(\alpha)$ further, the impedance of the TCSC, $X_{TCSC}(\alpha)$ becomes inductive, reaching its minimum value of $X_L X_C / (X_L - X_C)$ at α = 0, where the capacitor is in effect bypassed by the TCR. Therefore, with the usual TCSC arrangement in which the impedance of the TCR reactor, X_L, is smaller than that of the capacitor, X_C, the TCSC has two operating ranges around its internal circuit resonance: one is the $\alpha_{Clim} \le \alpha \le \pi/2$ range, where $X_{TCSC}(\alpha)$ is capacitive, and the other is the $0 \le \alpha \le \alpha_{Clim} \le \pi/2$ range, where $X_{TCSC}(\alpha)$ is inductive, as illustrated in Figure 1 [5]. An appropriate value for capacitor and inductor of a TCSC device is based on the net reactance of transmission line and expected power demands in future. Capacitor value is chosen by a degree of series compensation. Sub section gives an idea of selecting degree of series compensation. Choice of inductor depends on the length of operating area required for inductive and capacitive region. It is perfectly decided by a factor 'ώ', given by shifting the position of resonance region. The FACTS devices have low switching frequency of once a cycle in the converters and hence the have low losses. The thyristor can be also used to simply bridge impedances in the valves [6].

IV. SIMULATION RESULT

A three phase 33kv, 110km long transmission is considered as a case study for improving the voltage profile at receiving end and hence improving the power transfer capability. All the simulation work has been done in MATLAB/SIMULINK environment. Fig.4 shows a MATLAB/SIMULINK model. Model-1 shows a substation without TCSC in series with line and Model-2 shows a substation with TCSC . Our aim is to analyse the voltage profile (sag, swell and harmonics) at receiving end with and without TCSC. Simulation has been done for 33kv, 110km long transmission line. Voltage sag, voltage swell and harmonics are described here. The complete simulation model is shown in fig.3. First the simulation results are obtained for system without TCSC, and then for a system with TCSC implemented.

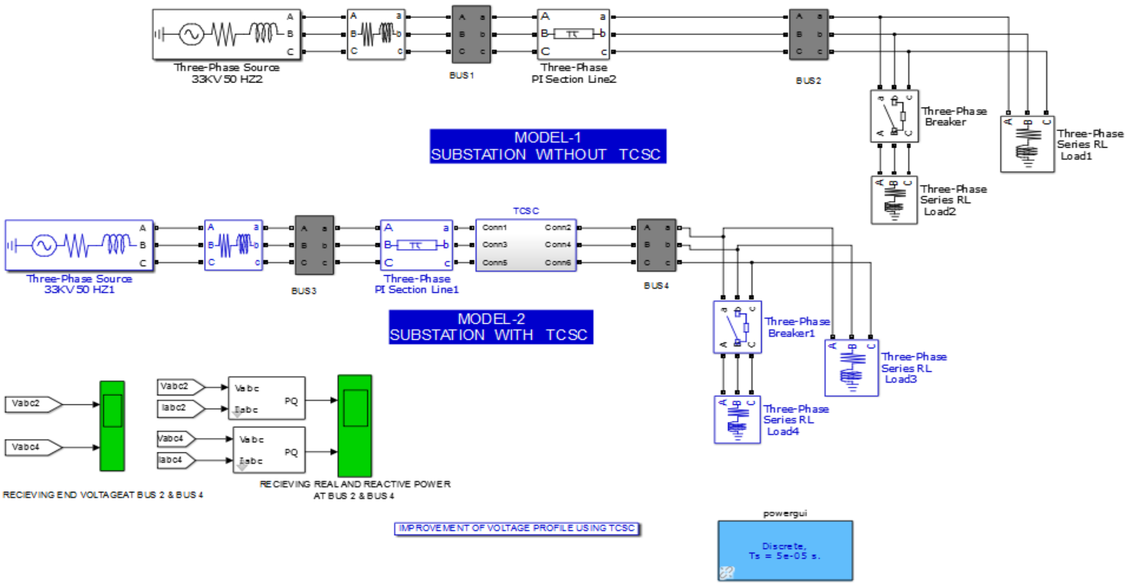

Fig.2 complete simulation model for voltage profile analysis

Voltage Profile Analysis:

i. Consider a 33kv, 110km long transmission line, at bus-2 (receiving end) we found 14.5% voltage sag during switching on of heavy loads or during fault condition as shown in fig.5. X-axis shows the time and Y-axis shows the magnitude of the voltage in rms. This is shown in fig.3.

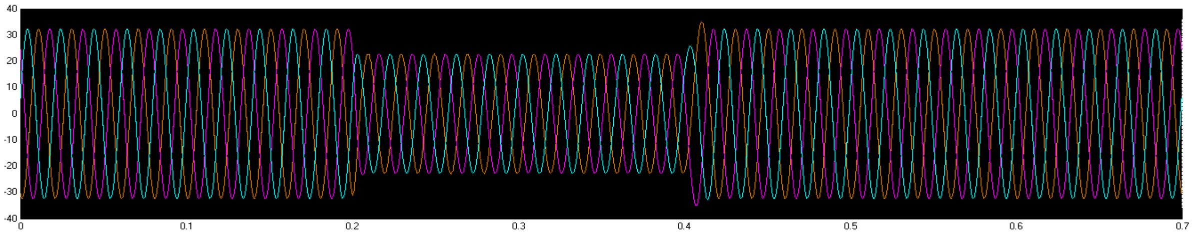

Fig.3 Three phase Voltage sag(without TCSC) in 33KV transmission line

ii. For 33kv 110km long transmission line we found 14.5%voltage sag(Bus-2) which has been compensated(Bus-4) to 3.36 as shown in fg.4.

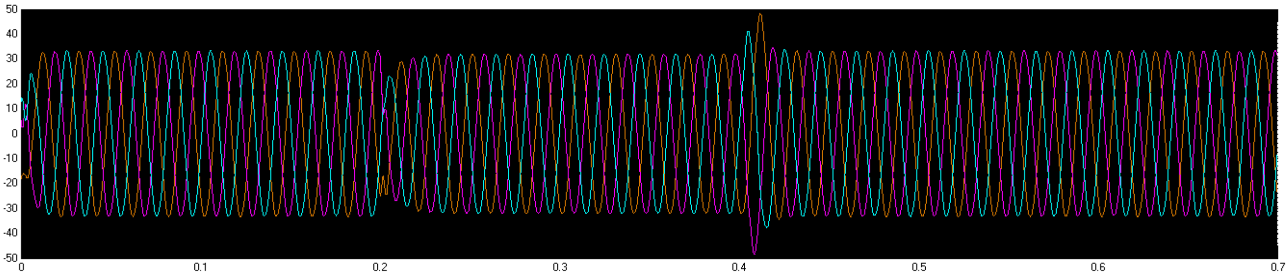

Fig.4 Sag compensation (with TCSC) for 33kv transmission line

iii. For a 33kv, 110km long transmission line we found 14.56% voltage swell at bus-2 (receiving end) during sudden switching-on of the large load as shown in fig.5.

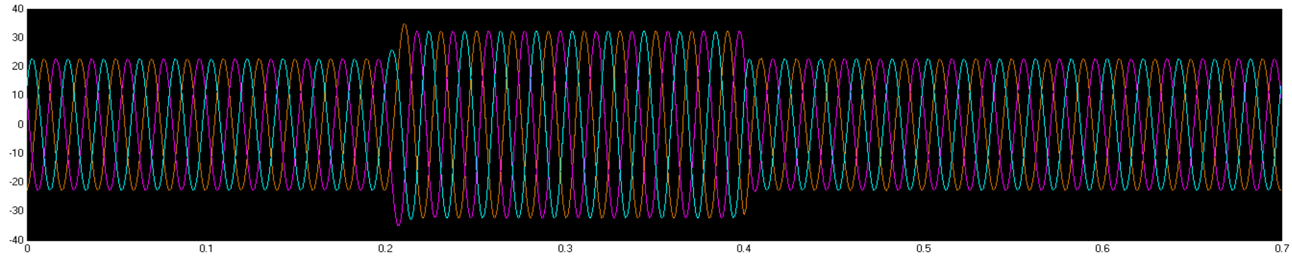

Fig.5 Three phase Voltage swell(without TCSC) in 33KV transmission line

iv. For 33kv, 110km long transmission line 14.56% voltage swell was found, which is reduced to 0.31% as shown in fig.6.

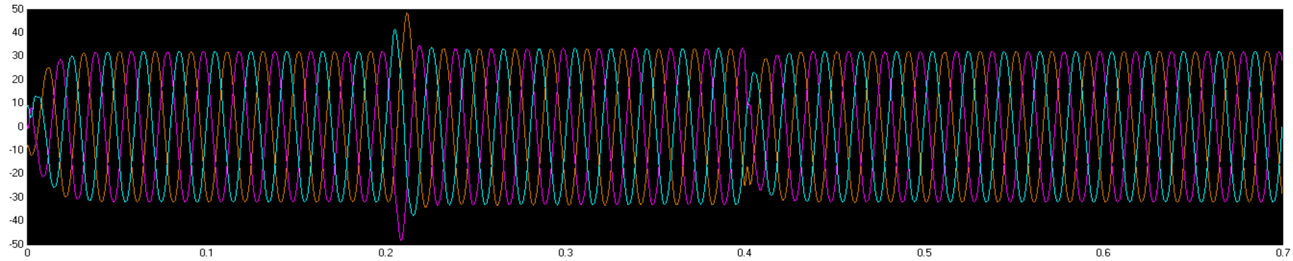

Fig.6 phase Voltage swell compensation (with TCSC) in 33KV transmission line

Harmonic Analysis:

Harmonic distortion levels are described by the complete harmonic spectrum with magnitude and phase angle of each individual harmonic component. It is also a common to use a single quantity, the total harmonic distortion (THD) as measure of effective value of harmonic distortion. Here Harmonic analysis are shown for a voltage profile (Sag & Swell) with and without TCSC.

i. 16.61% Harmonic distortion present in receiving end voltage of 33kv, 110km transmission line during voltage sag condition. This is shown in fig.7.

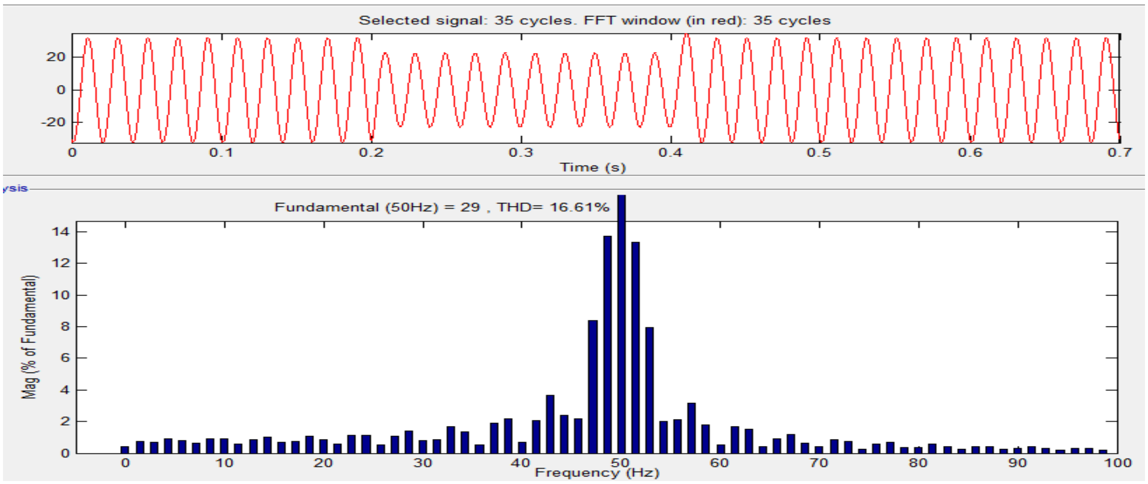

Fig.7 Harmonic distortion in 33kv, 110km line during voltage sag without TCSC

ii. For 33kv, 110km long transmission line 16.61% harmonics was found during voltage sag, which has been reduced to 7.00% as shown in fig.8.

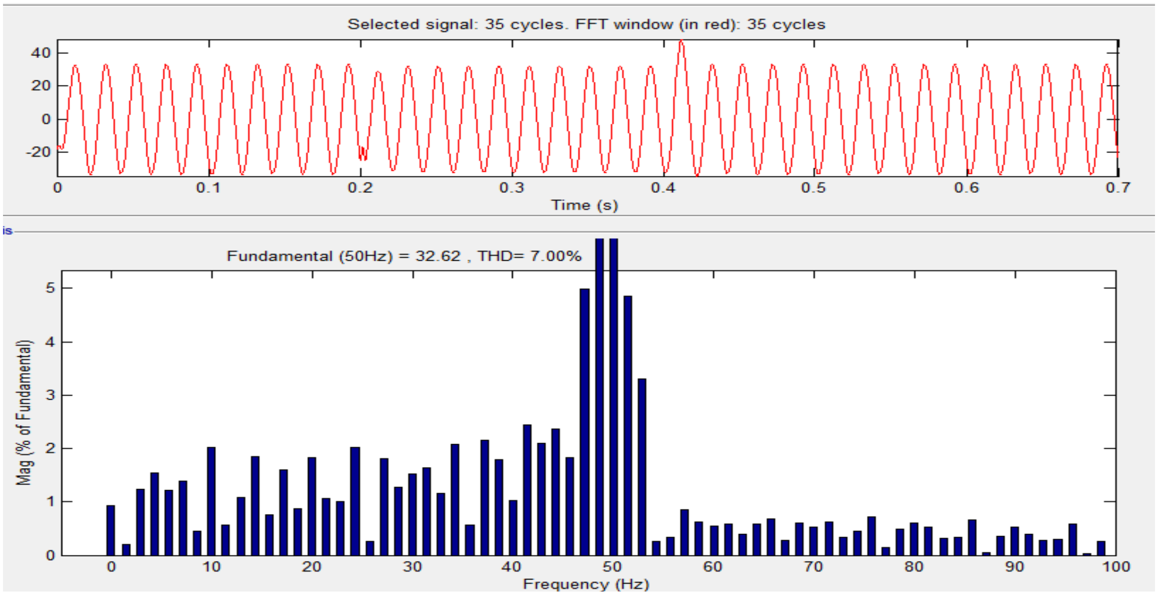

Fig.8 Harmonic distortion during voltage sag with TCSC

iii. 19.03% Harmonic distortion present in receiving end voltage of 33kv, 110km transmission line during voltage swell condition. This is shown in fig.9

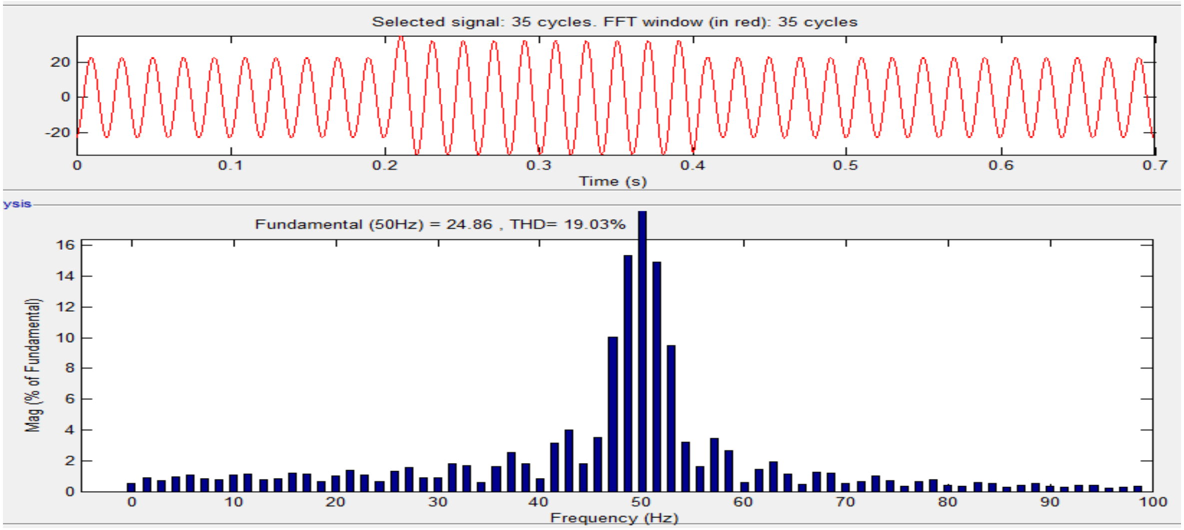

Fig.9 Harmonic distortion during voltage swell without TCSC

iv. For 33kv, 110km long transmission line 19.03% harmonic distortion was found during voltage swell, which has been reduced to 8.77% as shown in fig.10

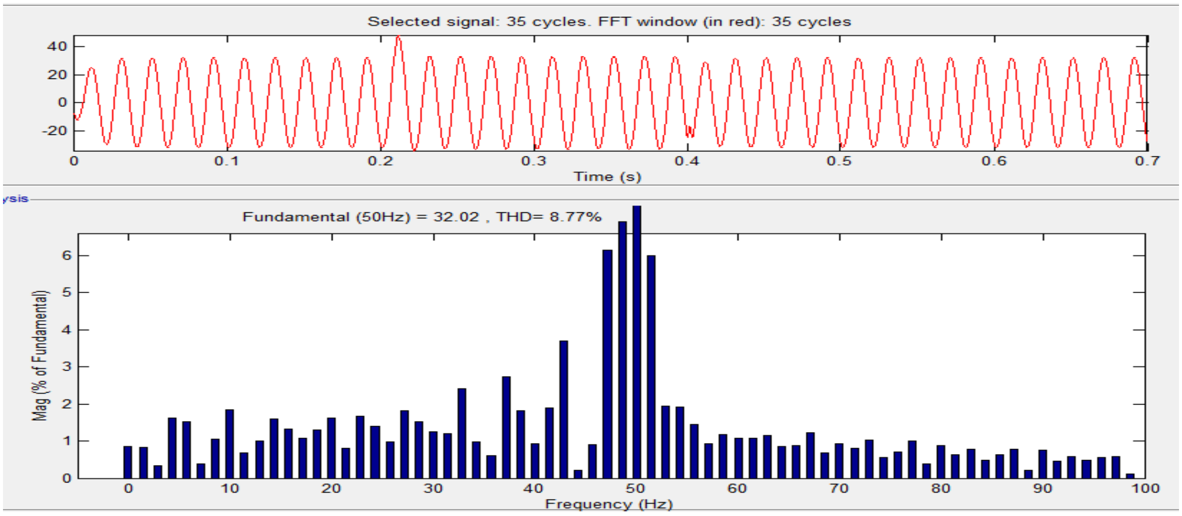

Fig.10 Harmonic distortion during voltage swell with TCSC

All the simulation results has been carried in MATLAB/SIMULINK environment. The summary for all the results with and without TCSC is shown in Table.1

Table No.1 Summary of results obtained with & without TCSC

S.No.	**Sag/Swell Analysis**				**Harmonic Analysis**	
	Sending End Voltage in KV	Voltage Sag/swell type	Voltage sag % without TCSC	Voltage sag % with TCSC	Harmonic % Without TCSC	Harmonic % with TCSC
1	33	Sag	14.5	3.36	16.61	7.00
2	33	Swell	14.56	0.31	19.03	8.77

V. CONCLUSION

Simulation has been done for 33kv 110 km medium transmission lines. During the power flow from sending to receiving end the losses of power and voltage drop appear and our objective is to minimize that drops and improve power transfer capability of the system. In this paper we can see that the voltage sag and swell is generated during sudden switching on/off of heavy loads, when TCSC is not inserted. These sag/swell has been compensated with the use of TCSC as described above. Harmonic analysis is also done for both the conditions of voltage sag and voltage swell. Finally we conclude that with the use of series compensator the sag/swell and harmonics can be compensated, and hence the power transfer capability of line can be improved.

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