Reactive power Planning, Operation, Control and Management (Review Paper)

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Abstract

Electrical Power System is huge and complex as there is large number of generating stations, transmission lines, substations and distribution lines are interconnected to enhance reliability and security of power system. To transmit and distribute electricity with reliability and to maintain quality power supply to the stakeholders is a more challengeable job for Electrical Engineers in future. With due consideration of several regulations in power industry such as Open Access, Availability based tariff (ABT), Indian Electricity Act-2003, Indian Electricity Grid Code (IEGC), and amendment of other regulations demonstrates the need to improve power system reliability and power quality. As a developing country like India, there is a huge load growth which demands more electricity generation, transmission, and distribution. Existing power transmission lines operating under huge stress and carrying power nearer to their thermal limits results in grid disturbances and violation of various operating constraints. In this environment reactive power management is essential. Certain objectives for reactive power management are mentioned: (1) To maintain adequate voltage levels in transmission line both in normal as well as in contingency, (2) To minimize congestion of real power flows and, (3) To minimize real power losses. Also in restructuring electricity market - VAR compensation, Congestion charges, Transactive Energy, Dynamic ATCs, if not seriously thought of now, then it may affect Indian economy in future.

Keywords—*Reactive Power, Voltage Control, FACT devices, Voltage Stability*

INTRODUCTION

I. Fundamentals of Reactive Power

In alternating current (AC) system, inductors and capacitors are energy storage elements which can stores the energy in magnetic ($1/2Li^2$) and electric fields ($1/2Cv^2$) [2]. Transformers and Reactors absorb reactive power and Capacitors generates reactive power. In India majority of electric power are generated, transmitted and consumed by Alternating Current. Active Power (P=VIcosΦ) or Real Power used to do work while reactive power (Q=VIsinΦ) maintains voltage magnitudes. Real power can be transported over long distances but reactive power is difficult to transmit (As X/R >7). So there will be more IX drop in comparison to IR drop. So it can be said that reactive power should be controlled at load point. Three phase capacitor bank is the conventional approach to manage reactive power deficiency at load point.

All electrical apparatus will work only if rated voltage is provided across its terminal by utility /supplier. Less reactive power support will reduces voltage and higher reactive power will increases voltage. If more loads are connected then voltage will collapse. As voltage drops line current increases which again reduces voltage. If this continues; results in cascading failures of transmission lines and it will trip. If voltages drops too much then some of the generators will automatically disconnected. This results in uncontrollable voltage decline and all this happens because transmission lines unable to provide reactive power support!!!!!

II.Behavior of Transmission Line with reference to Reactive Power surplus/defecit.

The reactive-power behavior of transmission lines is very complicated. When connected load on transmission lines are low/negligible then all the distributed capacitance generates more reactive power than requirement and receiving end voltage becomes too much higher so needs inductive support to consume excess reactive power while highly loaded lines need capacitive reactive power support.

The thermal loading limit is the loading point (in MVA) above which real power losses in the equipment will overheat and damage the equipment. If uncompensated, these line losses reduce the amount of real power that can be transmitted from generators to loads.

Transmission-line capacity decreases as the line length increases [Fig. 1] if there is no reactive power compensation/voltage support (injection or absorption of reactive power) on the line. At short distances, the line's capacity is limited by thermal (I^2R losses) considerations; at intermediate distances the limits are voltage drop; and beyond roughly 480 Km to 560 Km, stability limits dominate.

Normally reactive power generation is almost constant, because the voltage of the transmission line is constant. Reactive power consumption depends on the load connected to the line which is generally variable. So heavily loaded lines consume more reactive power which will decrease the line voltage while lightly loaded lines – generates reactive power i.e. increasing line voltage.

Transmission lines are loaded as per Surge Impedance Loading (SIL). "When reactive power produced by line capacitance is equal to reactive power consumed by line inductance is called natural loading or surge impedance loading (SIL)"[2]. At SIL the transmission line provides the exact amount of MVAr which is needed to regulate voltage level. The balance point at which the inductive and capacitive effects cancel each other is typically about 40% of the line's thermal capacity. Lines loaded below SIL injects reactive power (Ferranti Effect- Vr>Vs) while lines loaded above SIL consume reactive power (Vr<Vs).

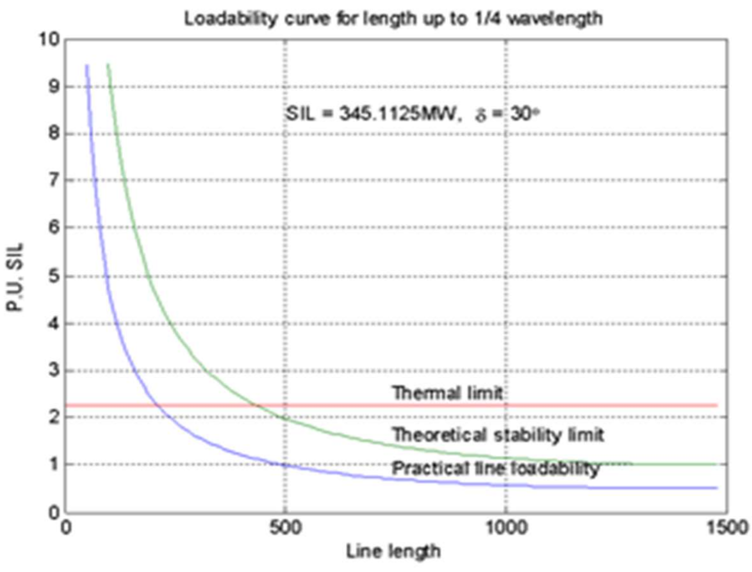

Fig. 1 Transmission line loading as function of line length (Clair Curve) [4].

III. Reactive Power Compensation by Shunt Inductors and Shunt Capacitors[2]

Normally there are two types of shunt reactors – Line reactor and bus reactor. Line reactor's functionality is to avoid the over voltages (switching overvoltage and overvoltage due to rejection of load). Bus reactors are installed on bus bars and are used to limit transient over voltage. The degree of compensation is decided by an economic point of view between the capitalized cost of compensator and the capitalized cost of reactive power from supply system over a period of time.

- **Benefits of reactive power compensation:**
  - Voltages at all points on transmission lines can be controlled as per rated voltage
  - No need to construct new overhead transmission lines
  - Easy supply of reactive power in heavily loaded condition
  - Lower reactive power demand of the transmission line during strong load condition
  - Less CO2 emission because of reduced real power losses

IV.Sources & Sinks of reactive power[5]

Sources of Reactive Power		Sink of Reactive Power
Static	Dynamic	
Shunt Capacitors	Synchronous Generators	Transmission Lines (Heavily loaded)
Filter Banks	Synchronous Condensers	Transformers & Shunt Reactors
Underground Cables	FACTS (e.g.,SVC, STATCOM)	Loads (Inductive loads)
Transmission Lines (lightly loaded)		Synchronous Machines
Fuel Cells		FACTS (e.g.,SVC, STATCOM)
PV Systems		Induction Generators (wind plants)

Table 1. Sources & Sinks of reactive power

V.Reactive Power Compensation through Series and Shunt Capacitor (Voltage Control)

Reactive power compensation through Series capacitors is usually applied to long distance transmission lines to compensate line inductance to improve transient stability. Longer transmission lines have large value of inductance. Series compensation reduces transmission line inductive reactance (X=XL-XC). At light loads series capacitors have little effect. The reactive power is proportional to the square of the load current for series capacitors thus generating reactive power whereas in shunt capacitors it is proportional to the square of the voltage.

VI.Reactive Power Control through FACT's devices

"Flexible AC transmission systems are new and emerging power electronics based static controllers which can control capacitive or inductive current from electrical power system, thereby generating/or absorbing reactive power"[1]. As there is no rotating parts; less maintenance requirements, high reliability and very fast control-response time are some of the benefits of FACT devices. Various FACT devices are available as per its connection in power system such as Shunt, Series, and combination of shunt and series. SVC-shunt connected; TCSC-series connected variable impedance type FACT devices while STATCOM and SSSC are VSC based FACT devices.

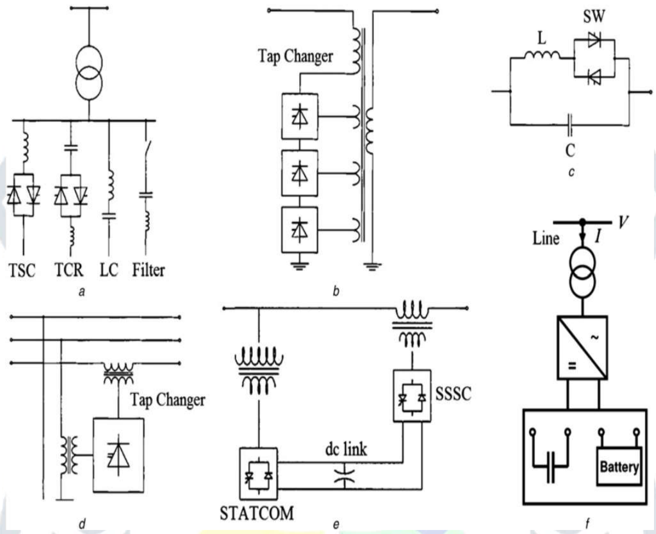

Fig.[2] FACTS devices[1]
a.SVC b .TCVR c .TCSC d .TCPST e .UPFC f .STATCOM with energy storage

CASESTUDY WITH MATLAB SIMULATION [2]

For loss less transmission line,

$$\overline{V}(x) = \overline{Vs}\cos\beta x - j\,Zo\,\overline{Is}\sin\beta x$$

,

$$\overline{I}(x) = \overline{Is}\cos\beta x - j\frac{\overline{Vs}}{Zo}\sin\beta x$$

The above equations are used to calculate voltage and current anywhere on line, at a distance of x from sending end, in terms of sending end voltage and sending end current and the line parameters.

Surge Impedance, Zo = $\sqrt{l}/c$ in Ohm
Wave number $\beta = \omega\sqrt{lc}\ \mathrm{rad/km}$
$\beta a = \omega\sqrt{lca}$ Rad/km (Electrical Length) ; Where l is the line inductances in (H/km), c is the line shunt capacitance in (F/km) of the transmission lines and a is transmission line length. From eq. we get,

$$\overline{Is} = \frac{\overline{Vs}\cos\beta a - \overline{Vr}}{jZ0\sin\beta a}$$

Sending end Power Real and Reactive Power Ps and Qs is,

$$Ps = -Pr = \frac{V^2}{Zosin\beta a} \sin\delta$$

$$Qs = Qr = V^2 cos\beta a - \frac{V^2 cos\delta}{Zosin\beta a}$$

1. Matlab/ (Simulink) Simulation Parameters:

Transmission line voltage=735KV
Line Inductance= 0.932mH/km
Line Capacitance= 12.2 nF/km
Length of transmission line=800km
Therefore, Surge Impedance Zo=276.4Ω &
Surge Impedance Loading (SIL) is given by,

$$Po = \frac{V^2 nom}{Zo} = \frac{(735x10^3)^2}{276.4} = 1954.5 \text{ MW}$$

For symmetrical line, Vs= Vr =735KV,

$$Ps = \frac{Vs}{Zosin\beta a} \sin\delta = \frac{735^2}{276.4 \sin[(\omega\sqrt{lc})800]} \sin\delta$$
$$= 2298.5 \sin\delta \text{ MW}$$
$$= 1.176 Po \sin\delta \text{ MW}$$

Load Angle(δ) δ(degree)	**Active Power(MW) Calculated as per formula**	**Reactive Power(MVAR) Calculated as per formula**
10 (Lightly Loaded)	452.77	-842.0142
20	891.79	-724.3804
30	1303.71	-532.2996
40	1676.01	-271.6080
48.56	**1954.55**	**0.0000**
50	1997.39	49.7734
60 (Heavily Loaded)	2258.09	422.0796
70	2450.17	833.9982
80	2567.80	1273.0134
90.00	2607.41	1725.7858

Table 2. Calculated Pr and Qr for different loading condition (As per formula)

2. **Simulation Model & Waveforms of sending end and Receiving End Voltages and Currents:**

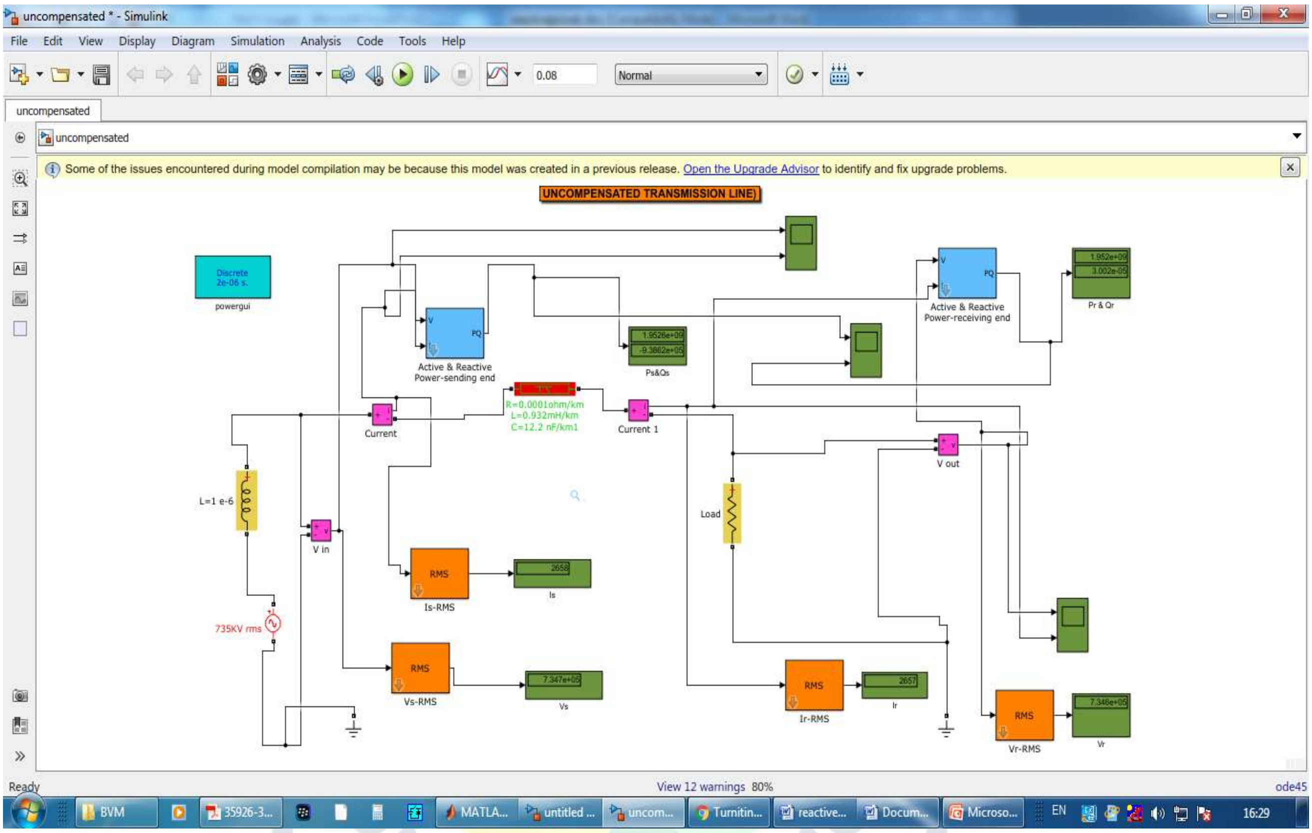

Fig. 3 Simulink model of above case study parameters without compensation-Transmission line parameters are considered as π-section (800 km) line

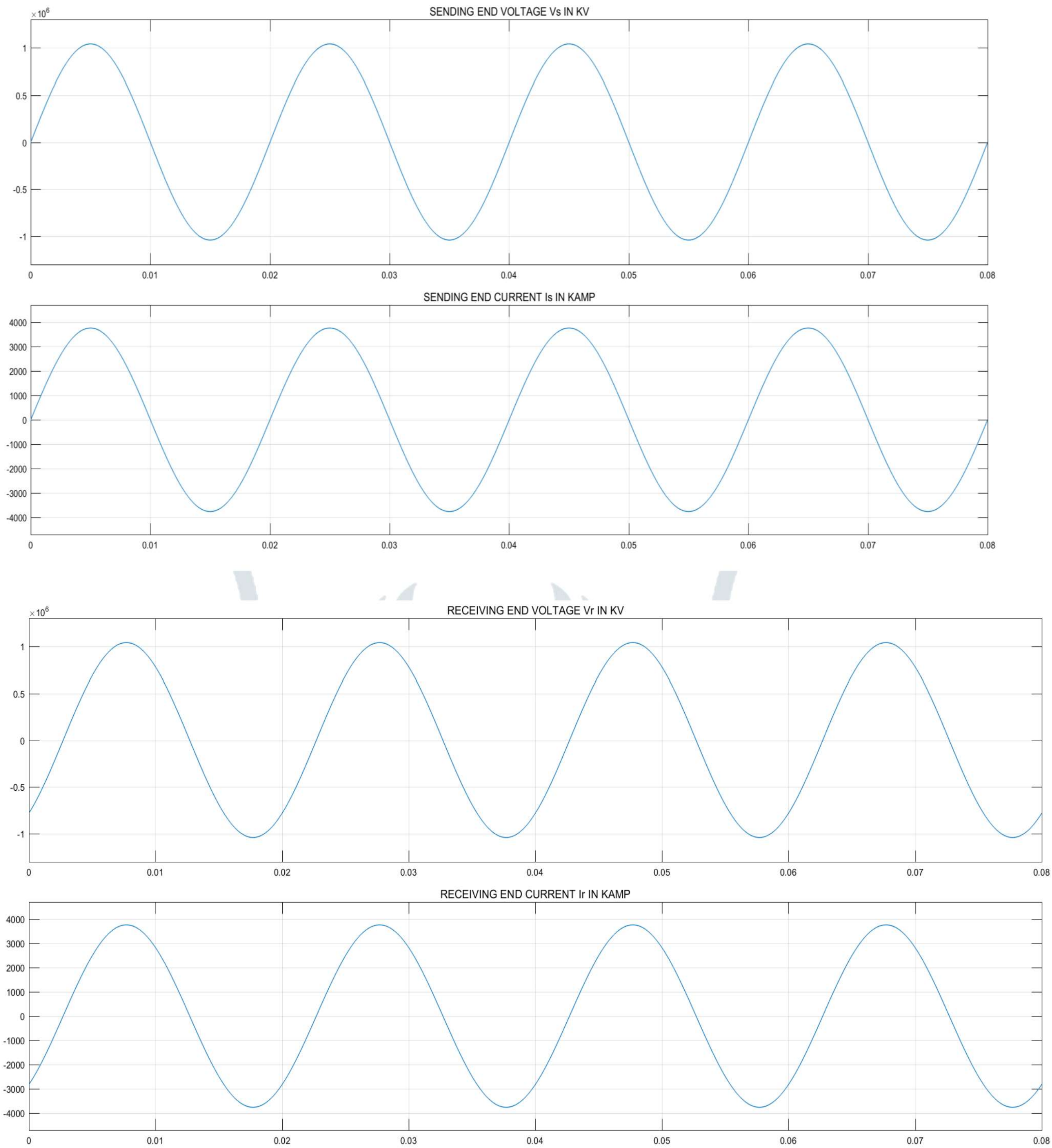

Fig. 4 Waveforms of Sending end voltage, sending end Current, Receiving End Voltage and Receiving End Current.

Simulation Results:

Vs KV	Is KA	Ps MW	Qs Mvar	Vr-KV	Ir-KA	Pr-MW	Qr-Mvar
734.7	265.8	1952.6	-93.863	**734.6**	265.7	1952	$7.262*10^{-12}$
734.7	729.7	3118.6	-4360.5	**1928**	341.2	3116	-5793
734.7	217.0	1579	221.81	**614.5**	261.3	1579	295.2

Table 3. Simulation Results for ,

1. **δ=48.56 LOAD=SIL, P=1954MW, Q=zero**
2. **δ=10 LOAD<SIL, P=452MW, Q= -841.85MVAR,**
3. **δ=60 LOAD>SIL, P=2258.28MW, Q=422.34MVAR**

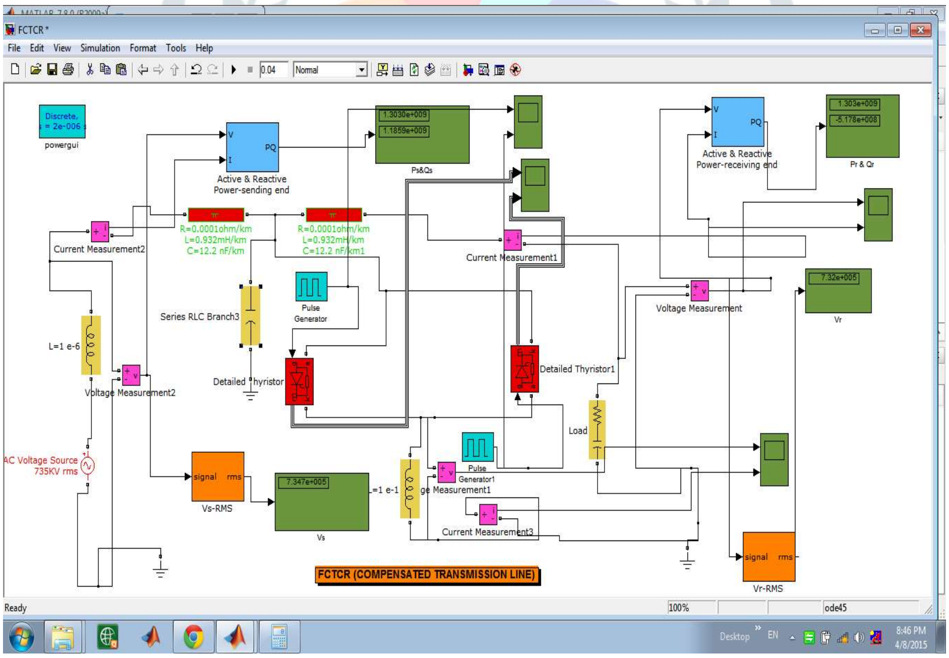

Fig. 5 Simulink model for LOAD<SIL, FCTCR is used at midpoint of transmission line (two π-section each of 400 km is considered)

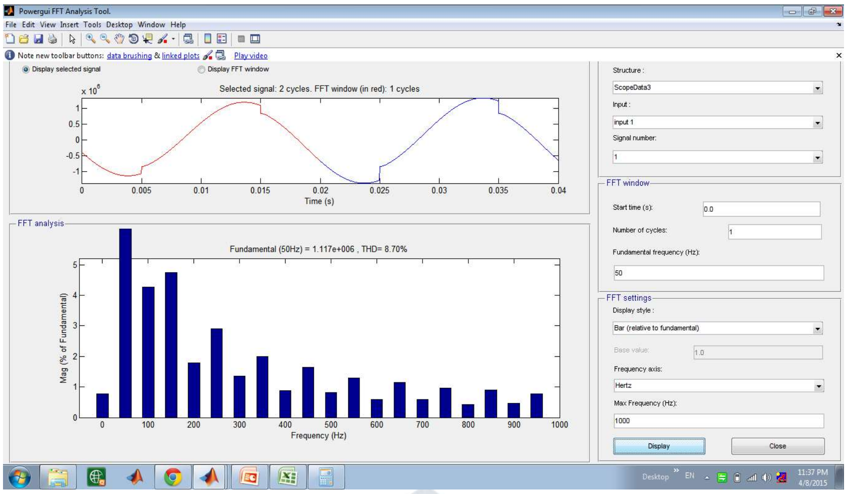

Fig. 6 FFT analysis, Total Harmonic Distortion THD is less than 10 %

CONCLUSION

Reactive power control is required to maintain rated voltages at every node on long distance high voltage transmission line. In this paper simulink model is utilized to find receiving end voltage for different loading condition. When connected load on transmission line is equal to surge impedance loading, Vs and Vr both are equal. When connected load on transmission line is below surge impedance loading, Vr is greater than Vs and shunt inductor (FCTCR is used) should be connected to consume excess reactive power. When connected load on transmission line is more than surge impedance loading then Vr drops and Shunt capacitor should be connected to increase voltages. In this research paper FCTCR is used to compensate transmission line when connected load is less than SIL. FFT analysis is done which shows THD less than 9%. Recent development in power electronics switching devices (FACTs Devices) can be used to solve reactive power control issues in high voltage long distance AC transmission line to enhance power transfer as well as voltage control.

REFERENCES

1. Hingorani, N.G., Gyugyi, L.: ‘Understanding FACTS: concepts and technology of flexible AC transmission systems’ (IEEE Press, 2000)
2. Mathur, R.M., Varma, R.K.: ‘Thyristor-based FACTS controllers for electrical transmission systems’ (IEEE Press, Piscataway, 2002)
3. Santosh Grampurohit, Rozina Surani,”Comparison of FACT devices to control reactive power in long distance transmission line”, IJERT,vol1-2,2010. ISSN 2278-0181
4. http://www.cea.nic.in/reports/committee/nrce/operational_guidelines.pdf
5. http://www.nerldc.org/Docs/webupload/NER%20REACTIVE%20POWER%20MANAGEMENT%20MANUAL%202017.pdf