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Management of Power Quality in Transmission Line with Stable Voltage

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Abstract

Due to increasing interconnectivity of power systems day by day due to continuous expansion of electric power usage, the voltage stability of the system and the quality of power reaching to end consumer is affected. The magnitude of bus voltages is found to be increased after the capacitive compensation was provided at the end of transmission line. The THD level spikes in the system due to presence of non- linear loads. First the current distorts and then passes through the system impedance causing the voltage across it to be distorted. Thus, the voltage harmonics increases. The voltage profile has been improved by injection of reactive power in the line and the system becomes more resistive towards voltage instability conditions.

Index Terms— *Linear load, Power Quality, PV curve, THD, Voltage Stability*

I. INTRODUCTION

1. **Voltage Stability:** Voltage stability refers to the power system's virtue to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating point. Thesystem enters the voltage instability region when a disturbance or an increase in load demand or alteration in system state results in an uncontrollable and continuous drop in system voltage. A systemis voltage is unstable if for at least one bus in the system, the bus voltage magnitude decreases as the *reactive power injection* at the same bus is increased. It implies that if, V-Q sensitivity is positive for every bus, the system is voltage stable and if V-Q sensitivity is negative for atleast one bus, the systemis voltage unstable.

Voltage instability has been a crucial issue in power system operation since it has been the cause for many power blackouts around the world and has resulted in large monetary losses. These incidents and hence the power blackout can be prevented if early detection leading to voltage collapse and identification of weak areas are implemented. Voltage instability phenomenon has been known to be caused by *heavily loaded system* where large amounts of real and reactive power are transported over long transmission lines. This situation becomes worst in the absence of reactive power support in order to maintain normal voltage profiles at receiving end buses.

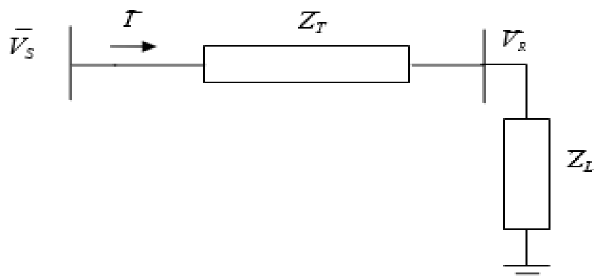

Figure 1: Two bus system with load at receiving end

P-V Curve Analysis method: P-V curve analysis is used to determine *voltage stability* of a radial system andalso a large meshed network. For this analysis P i.e real power at a particular area is increased in steps and voltage (V) is observed at some critical load buses and then curves for those particular buses will be plotted to determine the voltage stability of a system by static analysis approach.

The *nose point* at near maximum loading indicates the stability limit and power system should never be operated near this limit as it may lead to large scale blackout. Sufficient power margin should be allowed for satisfactory operation of system. For a 2-bus system shown in Figure 2, the P-V curve at constant power factor and load impedance about 1/4th of line impedance is shown in Figure 2(a). V_S and V_R are the sending and receiving end voltages respectively. Z_T and Z_L are the transmission line and load impedance respectively. The power factor is assumed 0.85.

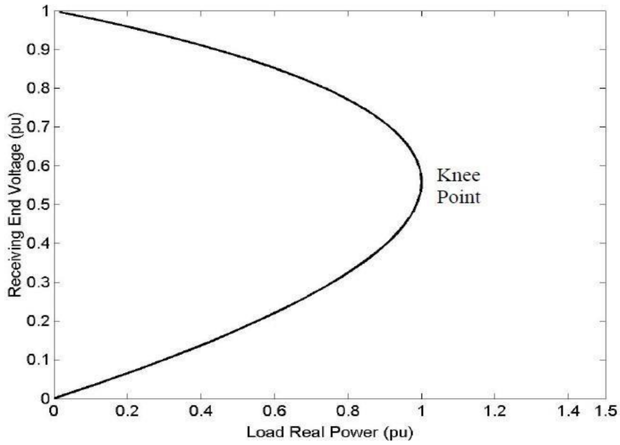

Figure 2(a): P-V curve

2. **Power Quality:** According to IEEE definition "It's the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment." In general, any power problem manifested in voltage, current, or frequency deviations that results in failures or mis-operation of consumer equipment. It is the study of how close to the ideal sinusoid the voltage and current waveforms are. The *Voltage Quality* is of most concern as it is through the terminal voltage that the devices interact.

Harmonics always originate as current harmonics and voltage harmonics are the results of currentharmonics. Current harmonics originate because of the presence of *non- linear* loads like variable speed drives, inverters, UPS, television sets, PC's, semiconductor circuits, welding sets, arc furnaces in the system. They act as harmonic current sources.

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Voltage harmonics do not originate directly from non-linear loads. The current harmonics (distorted waveforms) flow through system impedance (source and line impedances) and cause harmonic voltage drop across the impedances. This will distort the supply voltage waveform. Thus voltage harmonics are generated. One of the important power quality index for getting the idea of amount of distortion in voltage is Total Harmonic Distortion (THD).
THD is defined as the ratio of the equivalent root mean square (RMS) voltage of all the harmonic frequencies (from the 2nd harmonic onwards) over the RMS voltage of the fundamental frequency (the fundamental frequency is the main frequency of the signal. The equation below shows the mathematical definition of THD

Name is “High Voltage Transmission Line Analyzer” with model no. VPST-100HV1.The model isdivided into various sections :-

A. **Transmision Line model:** The Transmission line is considered for 180 km long. This 180 km long is divided in six sections of 30 km each. Each section is in pi model of the line. In the sections, the inductance is taken for every 30 km and the capacitance for every 15 km. The actual values of inductance, capacitance and resistance are 1.06 mh/km, 7.33nF/km and 0.03333 Ω/km respectively. The model used for practical analysis is shown in Figure 1(a).

B. **Generating Station:** It is displayed as generator model with step down transformer at end to feed the transmission line. Different ranges of voltages of 110V or 220V can be obtained. The station is provided with ammeter and voltmeter at receiving end to measure current and voltage. It is externally connected to transmission line. Generating station used for practical analysis is shown in Figure 1(b).

C. **Receiving Station:** The receiving station is provided with a step-up transformer to obtain different ranges of voltage of 110V or 220V. Ammeters and voltmeters are provided at receiving end of transmission line to measure currents and voltages. The receiving station is externally connected to the RLC loading section. The receiving station used for practical analysis is shown in Figure 1(c).

D. **R-L Loading Section:** The loading section is provided with resistive and inductive load. The loading section is also provided with an ammeter to measure the load current

THD= $n=2$ $\sqrt{\sum^{\infty}} . Vnrms^2$

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$$V_{fund\_rms}$$

and a voltmeter to measure the load end voltage. The R-L loading section used for practical analysis is shown in Figure 1(d).

Vn_{rms} is the RMS voltage of nth harmonic.
V_{fund_rms} is the RMS voltage of the fundamental frequency.

It is a measurement that tells you how much of the distortion of a voltage or current is due to harmonics in the signal. According to the IEEE 519 standard, Voltage THD should be less than 5%and individual harmonics under 3%.
The THD level spikes in the system due to presence of non- linear loads. First the current distortsand then passes through the system impedance causing the voltage across it to be distorted. Thus the voltage harmonics increases. Therefore adequate measures and equipments like filters, power conditioning equipments (Lightning and Surge Arrestor, isolation transformers etc) according to the location, magnitude and nature of power quality problem.

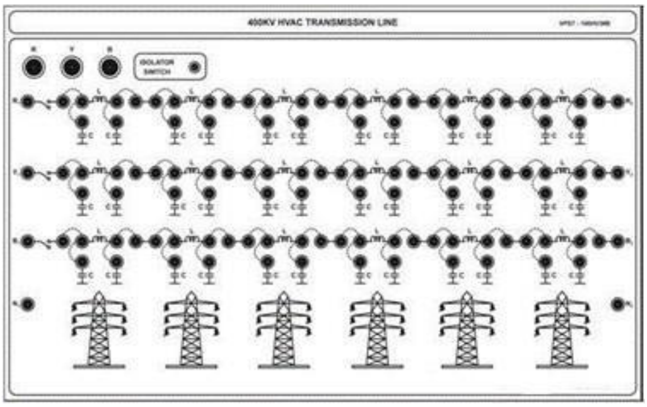
EXPERIMENTAL ANALYSIS

A. High Voltage Transmission Line Analyzer

The transmission line model along with other systems used for the purpose of voltage stability andpower quality analysis is manufactured by Vi Microsystems Pvt. Ltd. The model

E. Compensator Section: This section consists of shunt capacitors for voltage control and seriesreactor to reducethe fault current during fault conditions. The compensator section used for practical analysis is shown in Figure 1(e).

F.



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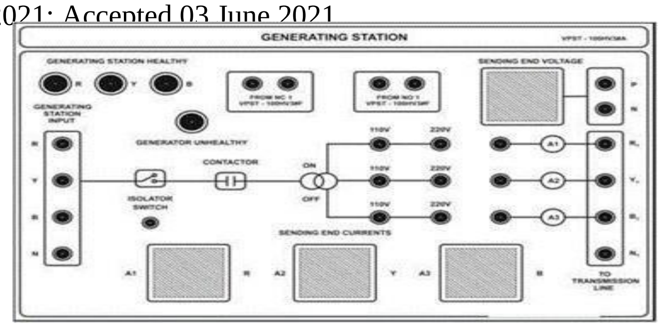

Figure 1(a): Transmission Line modelFigure 1(b): Generating Station

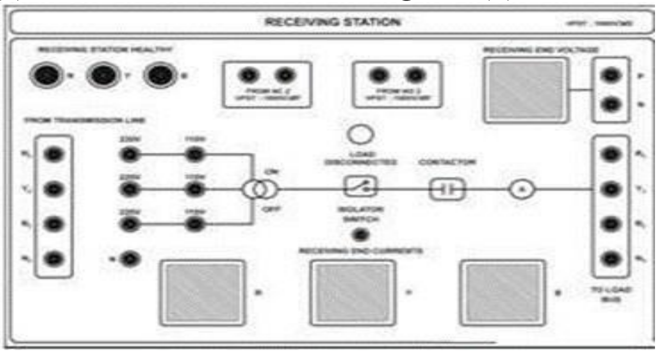

Figure 1(c): Receiving Station

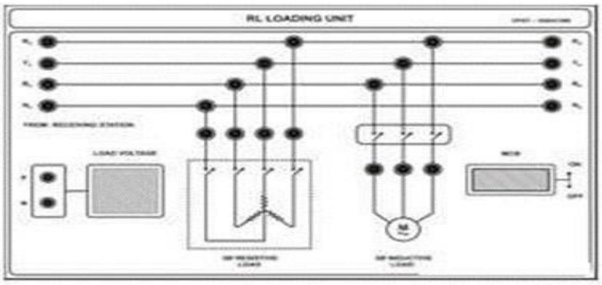

Figure 1(d): R-L Loading Unit

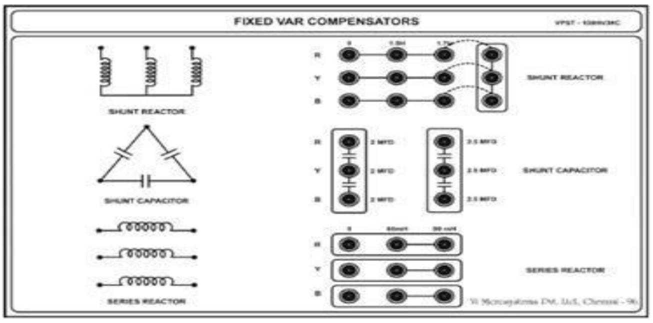

Figure 1(e): Fixed VAR compensators

B. Voltage stability analysis by PV curve method

The transmission line is loaded with linear load at receiving end. The loads used were star connected resistance (1000 Ω, 5 Amp) and induction motor (220 V). PV curves are obtained by varying the load from minimum to near maximum. The magnitude of bus voltages and the real power consumed by loads at different values were obtained with

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and without *compensation.*
The compensation used is capacitive compensation by using fixed delta connected shunt capacitance of values 2 micro farad. The observations and the corresponding PV curves are shown below. Bus voltages are V_n where n=1 to 5 from generation side to receiving end. Sending end voltage is kept fixed at 210 V.

B.1 Real power and bus voltage readings without capacitive compensation
Table 1 shows the values for real power and bus voltage and the Figure 1 shows the correspondingP-V Curve.

B.2 Real power and bus voltage readings with capacitive compensation

Table 2 shows the values for real power and bus voltage and the Figure 2 shows the correspondingP-V Curve.

Table 2

P(KW)	V1(V)	V2(V)	V3(V)	V4(V)	V5(V)
0.204	205	200	195	190	184.7
0.213	204.2	199	194	189.2	184
0.234	204	198.7	193.7	188	183.6
0.25	203	198	193.1	187.4	181.6
0.291	202	197.4	190.5	184.7	179
0.319	201.5	196	188.5	182.6	176
0.338	201	194	184.6	179.9	173.5

Table 1

P(KW)	V1(V)	V2(V)	V3(V)	V4(V)	V5(V)
0.204	200.3	192	184	174.5	165.4
0.213	200	191.6	182.8	174	165
0.234	199	190.5	182	172.3	163.2
0.25	198.6	189.3	180	171.1	161.5
0.291	197.7	187.5	177.8	168	158
0.319	197	185	176.5	167.7	157.6
0.338	196.3	182	175	166	155.8

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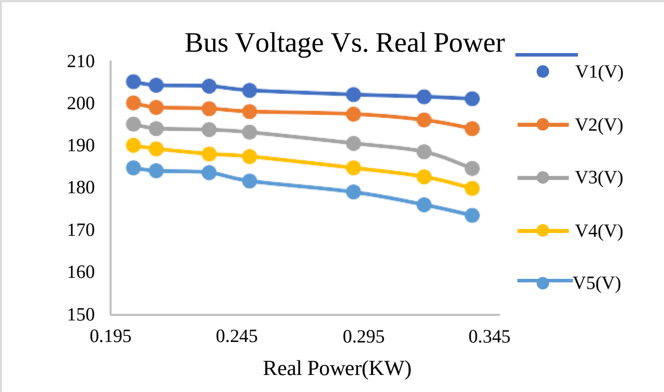
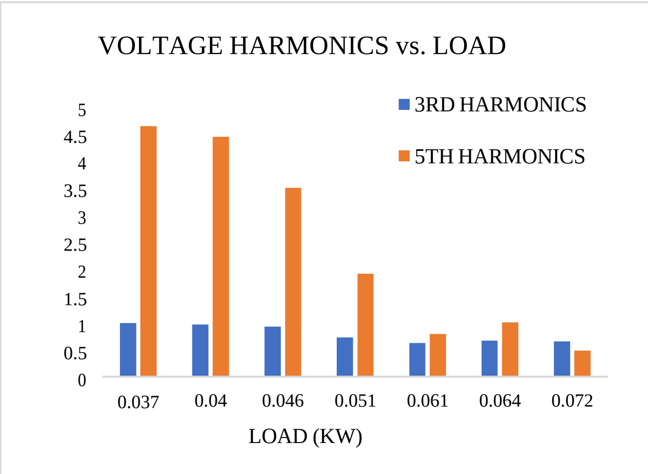


Figure 1



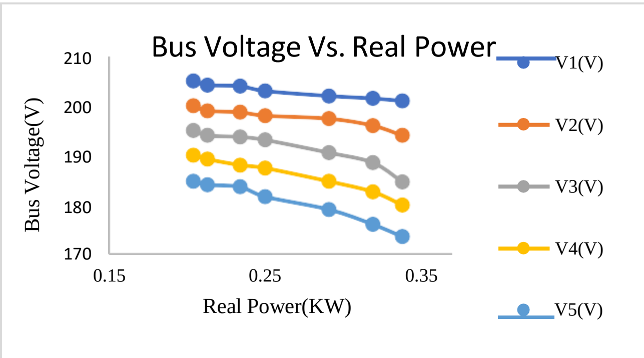


Figure 3

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Table 4 shows the load values and voltage THD associated to it. Figure 4 shows the correspondingbar graph.

Figure 2

LOAD (KW)	THD (%)
0.037	5.8
0.04	5.56
0.046	4.48
0.051	2.62
0.061	2.21
0.064	2.13
0.072	2.28

Result: The magnitude of bus voltages is found to be increased after the capacitive compensation was provided at the end of transmission line. The voltage profile has been improved by injection of reactive power in the line and the system becomes more resistive towards voltage instability conditions.

C. THD and harmonic analysis by Power Quality analyser **Loads at receiving end:** Star connected resistor, induction motor

C.1 For voltage (considering R phase)

1. Load at receiving end without compensation

Table 3 shows the values of load with 3rd and 5th voltage harmonics without compensation andFigure 3 shows the corresponding bar graph.

Table 4

THD (%)

LOAD (KW)	3RD HARMONICS (%)	5TH HARMONICS (%)
0.037	1.01	4.7

Table

0.04	0.98	4.5
0.046	0.94	3.54
0.051	0.74	1.93
0.061	0.63	0.8
0.064	0.68	1.02
0.072	0.66	0.49

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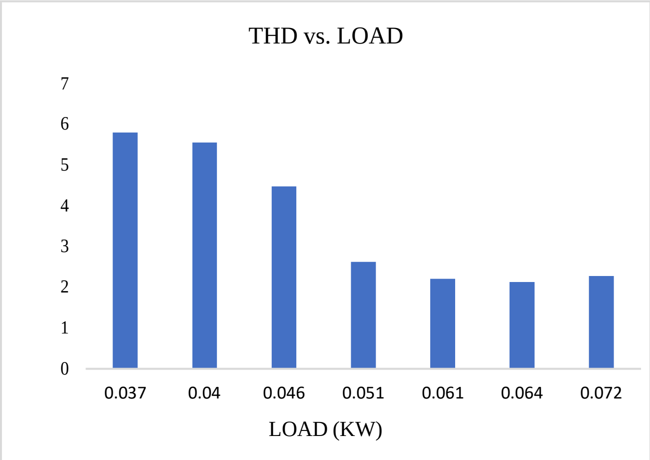

Figure 4

2. Load at receiving end with compensation (3 micro farad capacitive)

Table 5 shows the load values with 3rd and 5th voltage harmonics with compensation and Figure 5shows the corresponding bar graph.

LOAD (KW)	3RD HARMONICS (%)	5th HARMONICS (%)
0.037	2.64	1.86
0.04	2.53	1.81
0.046	2.6	1.83
0.051	2.42	2.02
0.061	1.62	2.17
0.064	1.83	2.87
0.072	1.54	2.19

Table 5

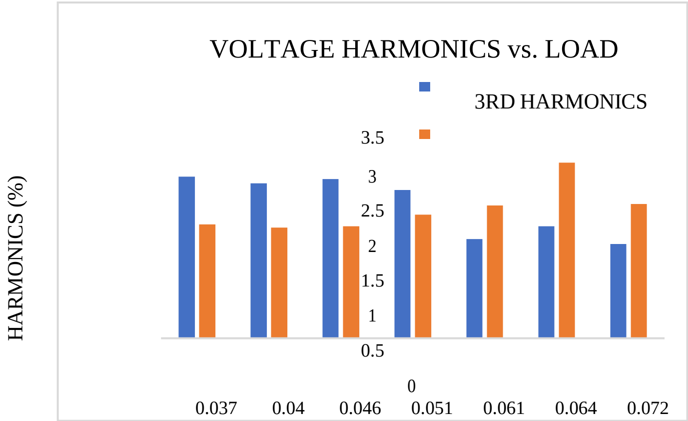

Figure 5

Table 6 shows the load values and voltage THD associated to it. Figure 6 shows the correspondingbar graph.

LOAD (KW)	THD (%)
0.037	3.26
0.04	3.11
0.046	3.21
0.051	3.2
0.061	2.73
0.064	2.84
0.072	2.7

Table 6

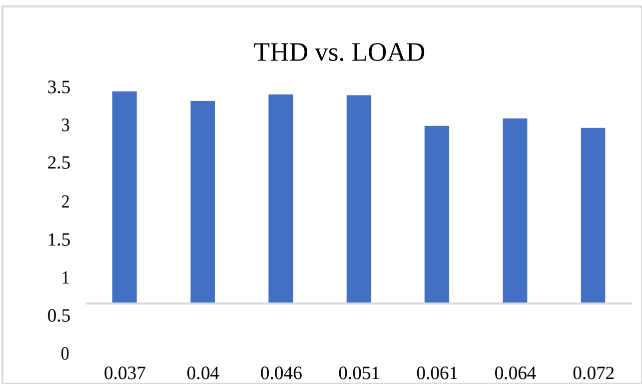

Figure 6

C.2 For current (considering R phase)

1. Load at receiving end without capacitive compensation

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Table 7 shows the load values with 3rd and 5th current harmonics without compensation and Figure 7 shows the corresponding bar graph.

LOAD (KW)	3RD HARMONICS (%)	5TH HARMONICS (%)
0.037	2.38	4.15
0.04	2.42	4.35
0.046	2.32	3.53
0.051	1.91	2.74
0.061	1.3	1.47
0.064	1.29	1.4
0.072	1.14	0.88

HARMONICS(%)

Table 7

Figure 7

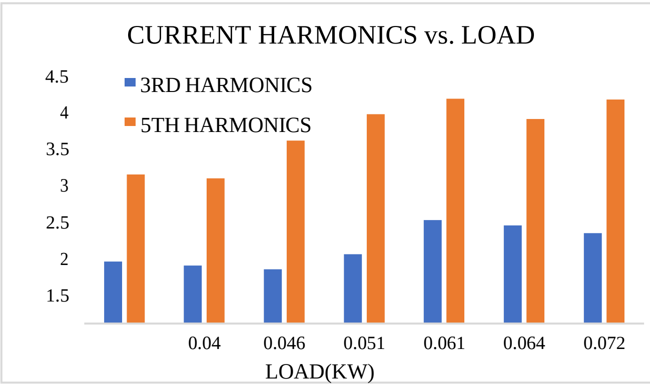

Table 8 shows the load values and voltage THD associated to it. Figure 8 shows thecorresponding bar graph

LOAD (KW)	THD (%)
0.037	5.35
0.04	5.37
0.046	4.65
0.051	3.86
0.061	2.65
0.064	2.49
0.072	2.43

Table 8

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Figure 10

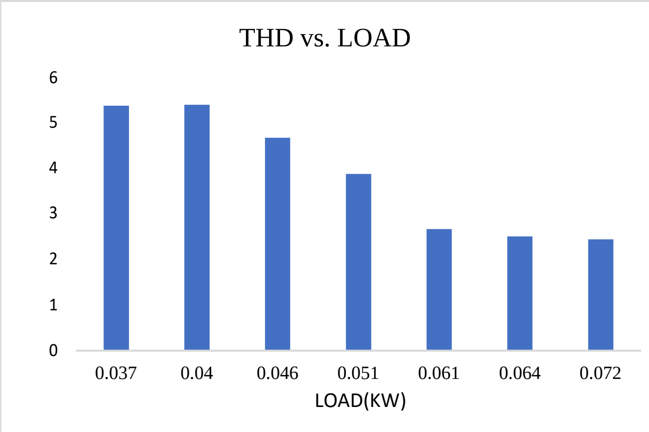

Figure 8

Table 11 shows the load values and current THD associated to it. Figure 11 shows the correspondingbar graph

THD(%)

LOAD (KW)	THD (%)
0.037	3.05
0.04	2.92
	3.95
	3.44
	4.14
0.046	
0.051	
0.072 61	4.39 62
0.064	

Table 11

2. Load at receiving end with capacitive compensation (3 micro farad):

Table 9 shows the load values with 3rd and 5th current harmonics with compensation and Figure 9shows the corresponding bar graph.

LOAD (KW)	3RD HARMONICS (%)	5TH HARMONICS (%)
0.037	1.12	2.69
0.04	1.05	2.62
0.046	0.98	3.3
0.051	1.25	3.78
0.061	1.87	4.06
0.064	1.77	3.69
0.072	1.63	4.04

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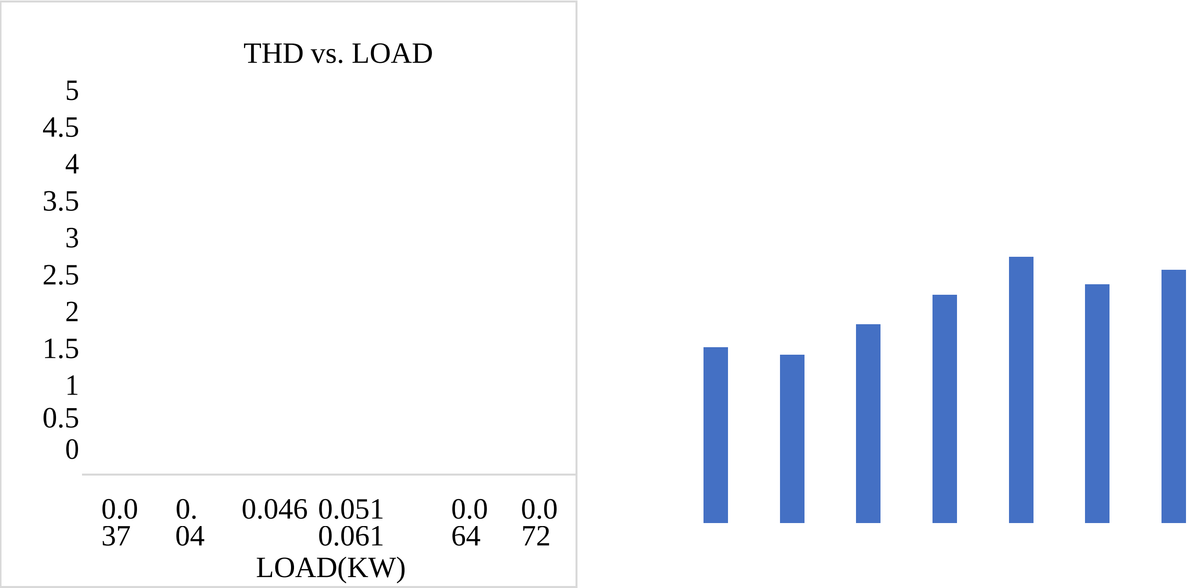

Table 10 Figure 11

Result: The graphs of harmonics and THD (Total Harmonic Distortion) for linear loads connectedat receiving end of the transmission line has been obtained with the help of PQ Analyzer.

Table 12 shows the inferences.

At receiving end	**VOLTAGE (R PHASE)**	**CURRENT (R PHASE)**
Without Compensation	*Harmonics:* -3rd and 5th harmonics are under safe limits for variousloads -3rd harmonics are much lessthan 5th harmonics. *THD:* The value of THD is also in safe limits i.e under5% deviation.	*Harmonics:* -3rd and 5th harmonics are under safe limits for various loads. But the values are higherthan the voltage counterpart. -3rd harmonics and 5th harmonics value are very closeto each other. *THD:* The value of THD is insafe limits i.e under 5% deviation.
With capacitive compensation	Harmonics (3rd and 5th) gets further reduced. THD gets further reduced.	Harmonics (3rd and 5th) gets further reduced. THD gets further reduced.

Table 12

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CONCLUSION

The voltage stability of a radial transmission line system can be improved by appropriate injectionof reactive power at the bus where voltage has dropped low enough to create the stability problem. The THD levels for linear loads connected at the end of transmission line are in the safe limits according to IEEE 519 standard. The THD levels are further reduced by appropriate compensationat load end.

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