VOLTAGE STABILITY ENHANCEMENT AND LOSS REDUCTION VIA OPTIMUM LOCATION OF A SERIES CAPACITOR

Dr. Firas Mohammed Tuaimah
Electrical Engineering Department
University of Baghdad

ABSTRACT

Series compensation is frequently found on long transmission lines used to improve voltage stability. Due to the long transmission lines, voltage begins to decay as the line moves further from the source. Series compensation devices placed strategically on the line to increase the voltage profile of the line to levels near 1.0 p.u.. This paper presents a novel optimum location and optimum percentage compensation value of a series capacitor as a compensation method to enhance the voltage stability and loss reduction. The proposed method is applied to a 11-bus power system.

The load flow analysis using Newton-Raphson approach for the 11-bus test system was designed and tested using MATLAB 7 programming language.

تحسين استقرارية الفولتية وتقليل الخسائر عبر تحديد مكان امثل لوضع متسعة على التوالي

الخلاصة

غالبا ما يتم استخدام التعزيز المربوط على التوالي عبر استخدام المتسعة في خطوط النقل وذلك لتحسين الفولتية. بسب المسافات الطويلة لخطوط النقل, فأن الفولتية تبدأ بالأنخفاض كلما ابتعدنا عن المصدر. ولأجل هذا يتم استخدام متسعات موزعة وفق حسابات لتحافض على الفولتية بمستوى 1 للوحدة الثابتة (p.u.). تم في هذا البحث استخدام الية مثلى لوضع او استخدام المتسعة لتحسين الفولتية ولتقليل الخسائر. حيث تم تطبيق الطريقة على منظومة أفتراضية عالمية ذات 11 عقدة (IEEE-11BUS) .

تم استخدام طريقة الجريان نيوتن- رافسون على هذه المنظومة وأستخدمت اللغة البرمجية **MATLAB 7.**

KEYWORDS: voltage stability, loss reduction, series capacitor, load flow

INTRODUCTION

When exist the need to transmit large amount of electric power over transmission lines, it is necessary to consider a group of factors that limit the electrical energy transmission capacity. Some of these factors are: the voltage drop, the stability problem, the thermal effect on the conductors, etc. The constraints imposed by these factors may be overcome by means the construction of new transmission lines or by a transmission upgrade. These alternatives are commonly very expensive, especially in the case of long transmission lines. A more economic alternative in these cases is the series compensation.

Transmission line compensation implies a modification in the electric characteristic of the transmission line with the objective of increase power transfer capability. In the case of series compensation, the objective is to cancel part of the reactance of the line by means of series capacitors. The result is an enhanced system stability, which is evidenced with an increased power transfer capability of the line, a reduction in the transmission angle at a given level of power transfer and an increased virtual natural load.

Series compensation has been in use since the early part of the 20th century. The first series capacitor for EHV power transmission application was installed in a 245 kV line back in 1951 in Sweden [1, 2].

M. Ghandhari et.al. [3] have been proved that a controllable series capacitor with a suitable control scheme can improve transient stability and help to damp electromechanical oscillations in a multi-machine power system based on Lyapunov theory**.**

Maurício Aredes et.al. [4]discusses the possibility of using FACTS devices like small series compensation to control large quantities of active power transmitted by half-wave length transmission lines, which proves to be efficient, simple and robust.

Belkacem Mahdad et.al. [5] describes a simple approach based on logic concept. Fuzzy logic approach is described, which achieves a logical and feasible economic cost of operation without the need of exact mathematical formulation.

K. Narasimha Rao et.al. [6] presents the aspects of enhancement of ATC limited by the voltage with and without contingency by simple and efficient models of FACTS devices. The effectiveness of the proposed methods is demonstrated on IEEE-14 bus and IEEE-30 bus system and the results are compared.

Héctor J. Altuve et.al. [7] presents modern solutions to improve directional, distance, and differential element operation on series-compensated lines.

J. Miguel Gonz´alez et.al. [8] present a Complete stability analyses, including voltage, small perturbation and transient stability studies, and the associated models and controls of a Series Vectorial Compensator (SVeC).

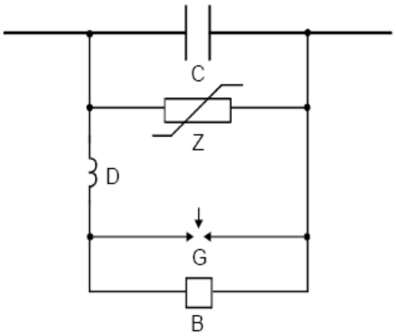
SERIES CAPACITORS (SC)

A series capacitor is not just a capacitor in series with the line. For proper functioning, series compensation requires control, protection and supervision facilities to enable it to perform as an integrated part of a power system. Also, since the series capacitor is working at the same voltage level as the rest of the system, it needs to be fully insulated to ground.

The main circuit diagram of a series capacitor is shown in Fig.1. The main protective device is a varistor, usually of Z_nO type, limiting the voltage across the capacitor to safe values in conjunction with system faults giving rise to large short circuit currents flowing through the line.

A spark gap is utilized in many cases, to enable by-pass of the series capacitor in situations where the varistor is not sufficient to absorb the excess current during a fault sequence. There are various bypass solutions available today like spark gap, high power plasma switch, power electronic device, etc. [9]

Finally, a circuit breaker is incorporated in the scheme to enable bypassing of the series capacitor for more extended periods of time as need may be. It is also needed for extinguishing the spark gap, or, in the absence of a spark gap, for by-passing the varistor in conjunction with faults close to the series capacitor (so-called internal faults).



C	**Capacitor**
Z	**Metal oxide**
D	**Discharge damping**
G	**Forced triggered spark**
B	**By-pass**

Fig.1 Main Configuration of a Series Capacitor

Series capacitors may be installed at one or both line ends. Line ends are typical capacitor locations, because it is generally possible to use space available in the substation. In turn, this reduces installation cost. Another possibility is to install the series capacitors at some central location on the line. Series capacitors located at the line ends create more complex protection problems than those installed at the center of the line. The principal applications of series compensations are [9]:

- Improves voltage regulation
- Increase power transmission capability.
- Improve system stability.
- Reduce system losses.
- Optimize power flow between parallel lines.

DEGREE OF SERIES COMPENSATION

The degree of series compensation is defined as the relation between the capacitive reactance of the series capacitor and the inductive reactance of the transmission line.

$$\text{Degree of Compensation } = \frac{X_C}{X_L} \times 100\% \qquad (1)$$

Theoretically, the degree of compensation could be 100%, however this degree of compensation may produce large currents flows in the presence of small disturbances or faults. The circuit would also series resonant at the fundamental frequency, and it would be difficult to control transient voltages and currents during the disturbance. In the other hand a high level of compensation highlight the problems in protective relays and in the voltage profile during fault conditions. A practical limitation of compensation is between 25-75%. [2]

Decreasing line reactance increases maximum active power demand, which in turn enhances the voltages at the busses as shown in Fig.2.

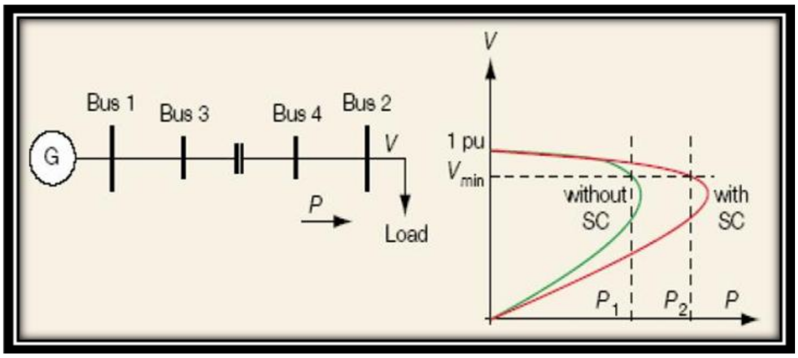


Fig.2 Series capacitor effect on voltage

Dynamically, the power transfer between two interconnected systems, as shown in Fig. 3, is defined by:

$$P = \frac{V_S V_R}{X_L} \sin\delta, \qquad \delta = \delta_1 - \delta_2 \tag{2}$$

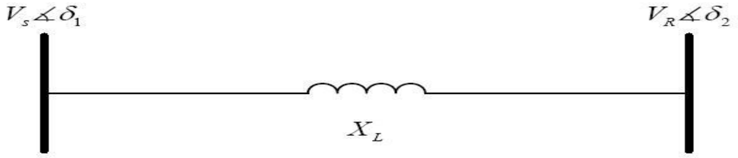


Fig.3 Equivalent network configuration for two interconnected systems

PROPOSED METHOD

The proposed method is to obtain optimal location and amount of series compensation which is used to reduce the total reactance of the transmission line, which is often the main reason for their application. This improves power system stability, reduces reactive power losses and improves voltage regulation of the transmission line. The power system is modeled using MATLAB 7 programming language and comprised of the following steps:

(i) Input all possible data of the 11-bus test system shown in Fig.4, from the line resistances, reactance's, line charging reactance's, bus voltages, active power, reactive power, angles etc.

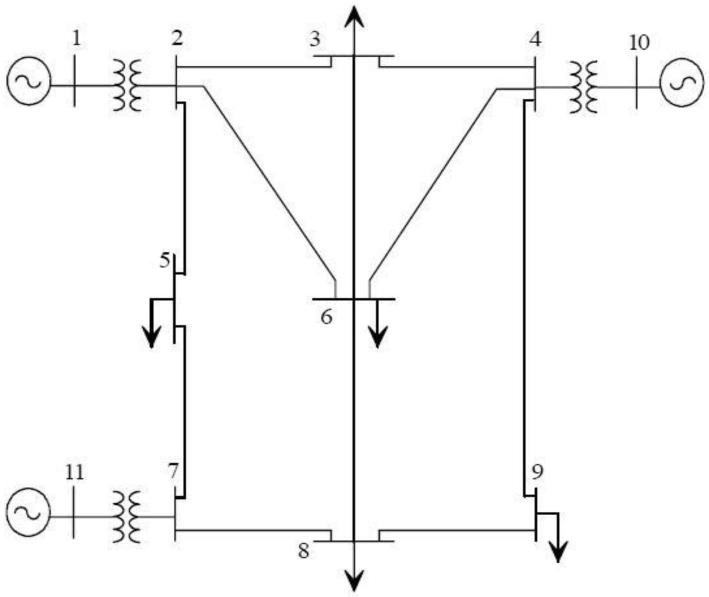


Fig.4 IEEE-11 bus test system

(ii) Perform load flow calculation using Newtom-Raphson method without using the series capacitor, then obtaining the buses voltages.

(iii)Perform load flow calculation using Newtom-Raphson method with the use of the series capacitor at each line of the system. The power flow along the transmission line is directly proportional to the difference of the phase angle and inversely proportional to the magnitude of the reactance. This concept can be demonstrated by using simple two bus lossless system as shown in Fig.5. The degree of compensation is chosen in this paper from 10% to 70% in suitable steps and then obtaining the new bus voltages. If the line is 100% compensated, it will behave as a purely resistive element and would cause series resonance even at fundamental frequency

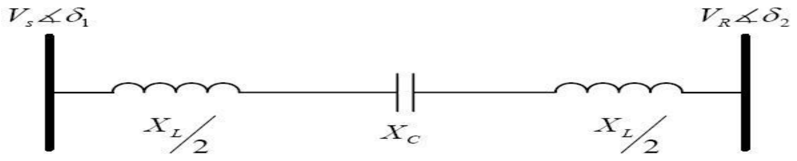


Fig.5 Equivalent system with series compensation

and hence power transferred across the transmission line is increased to:

$$P = \frac{V_S V_R}{X_L - X_C} \sin\delta \qquad (3)$$

(iv)For each compensation recalculate the active power loss and reactive power loss according to the

$$\mathrm{Re}\,active - Loss = \sum_{i=1}^{n} \left| I(i) \right|^{2} X(i) \qquad (4)$$

$$Active - Loss = \sum_{i=1}^{n} |I(i)|^2 R(i) \tag{5}$$

SIMULATION RESULTS

The following steps where performed:

- The 11-buses voltages before inserting any capacitor as a compensator in any line will be as shown in Fig.6, in which the maximum value is 1.0702 and the minimum value is 1.0252.

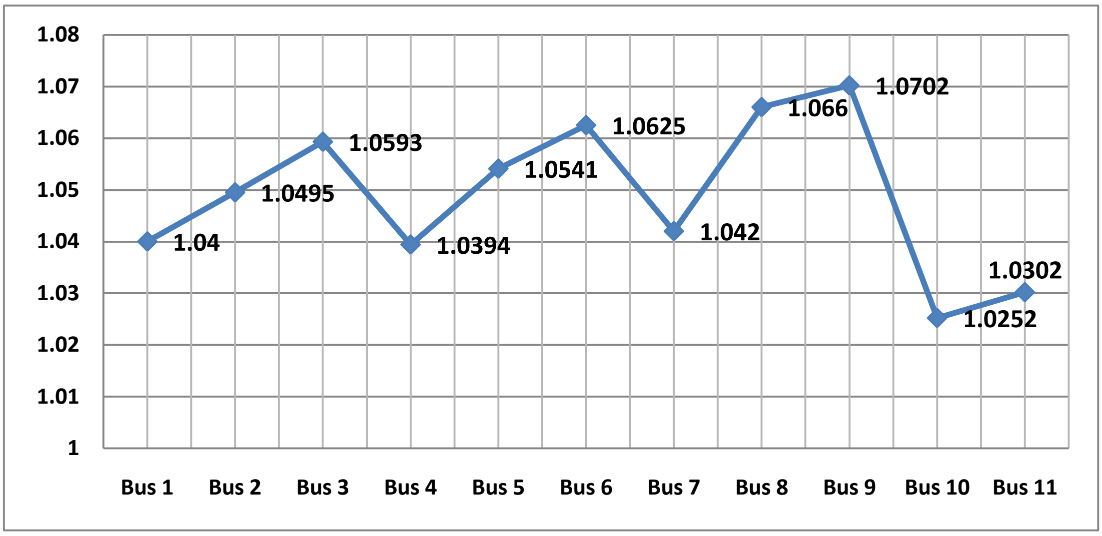


Fig.6 The 11-buses voltages before inserting a series capacitor

- A series capacitor will be inserted in the lines 1-2, 2-3, 2-5, 2-6, 3-4, 3-6, 4-9, 4-6, 4-10, 5-7, 6-8, 7-8, 7-11 and 8-9. In This paper the value of the inserted capacitor will be chosen as 10%, 30%, 50% and 70% of each line reactance.
- The proposed steps of a series capacitor will be applied on all the given lines. Next figures will show the busses voltages for each capacitor value.

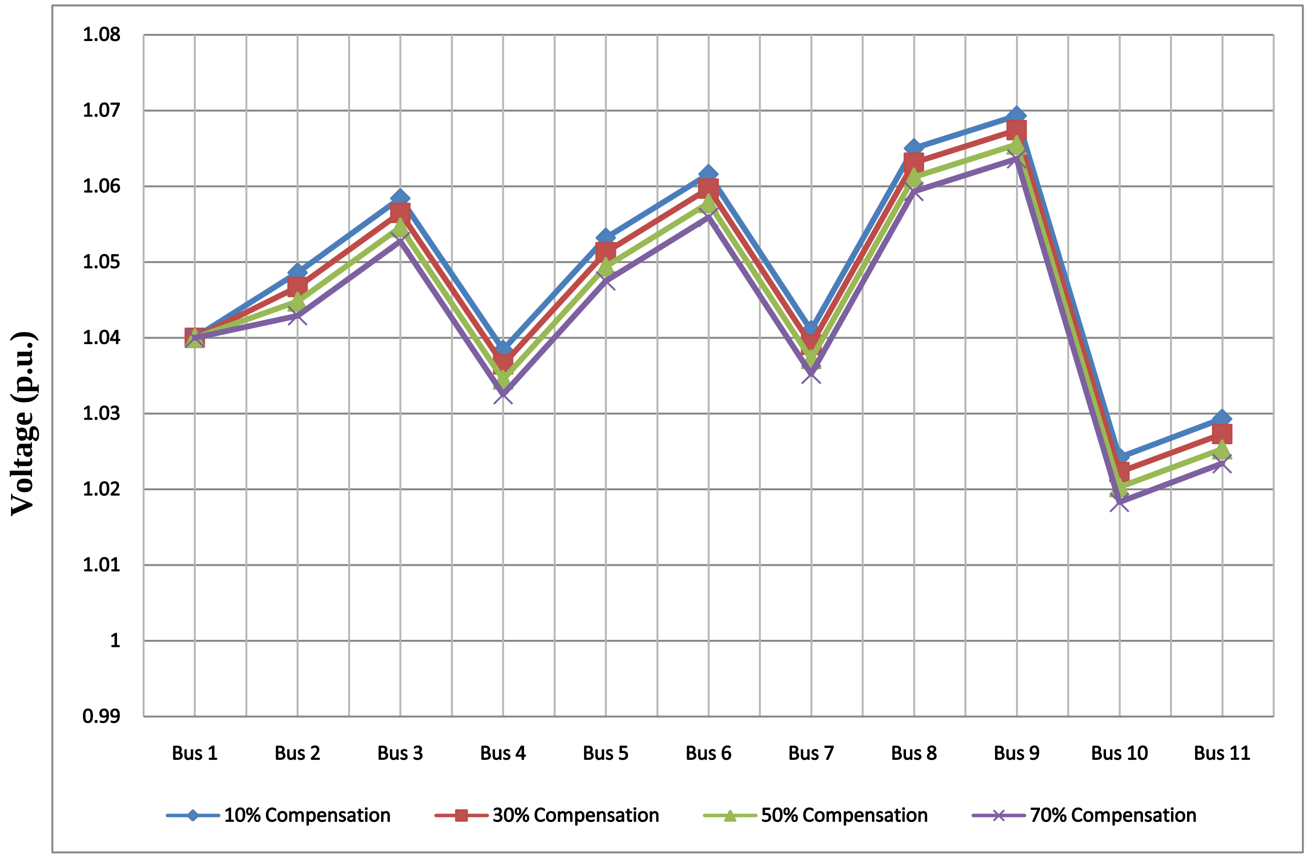


Fig.7 The effect of inserting series capacitor between bus 1 and 2 on buses voltages

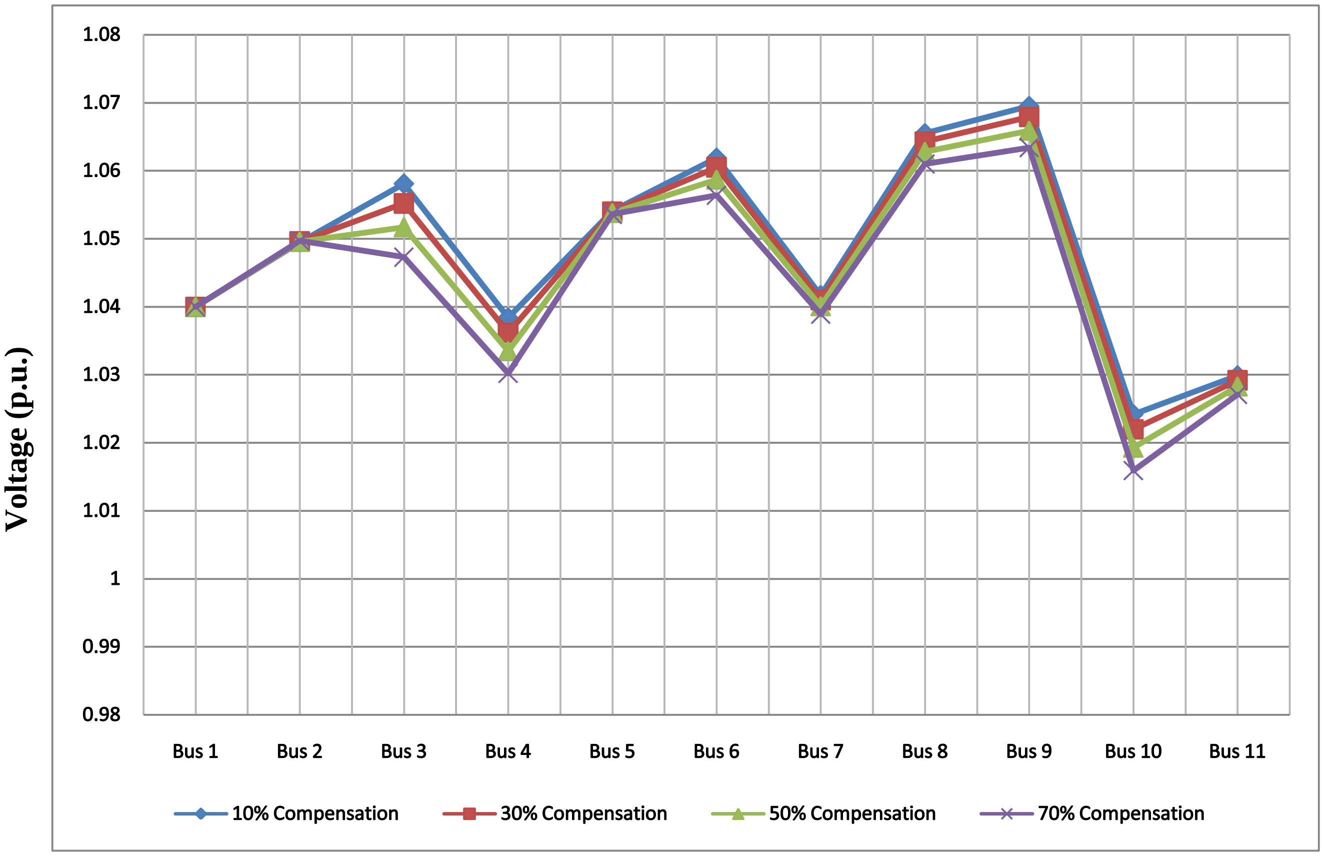


Fig.8 The effect of inserting series capacitor between bus 2 and 3 on buses voltages

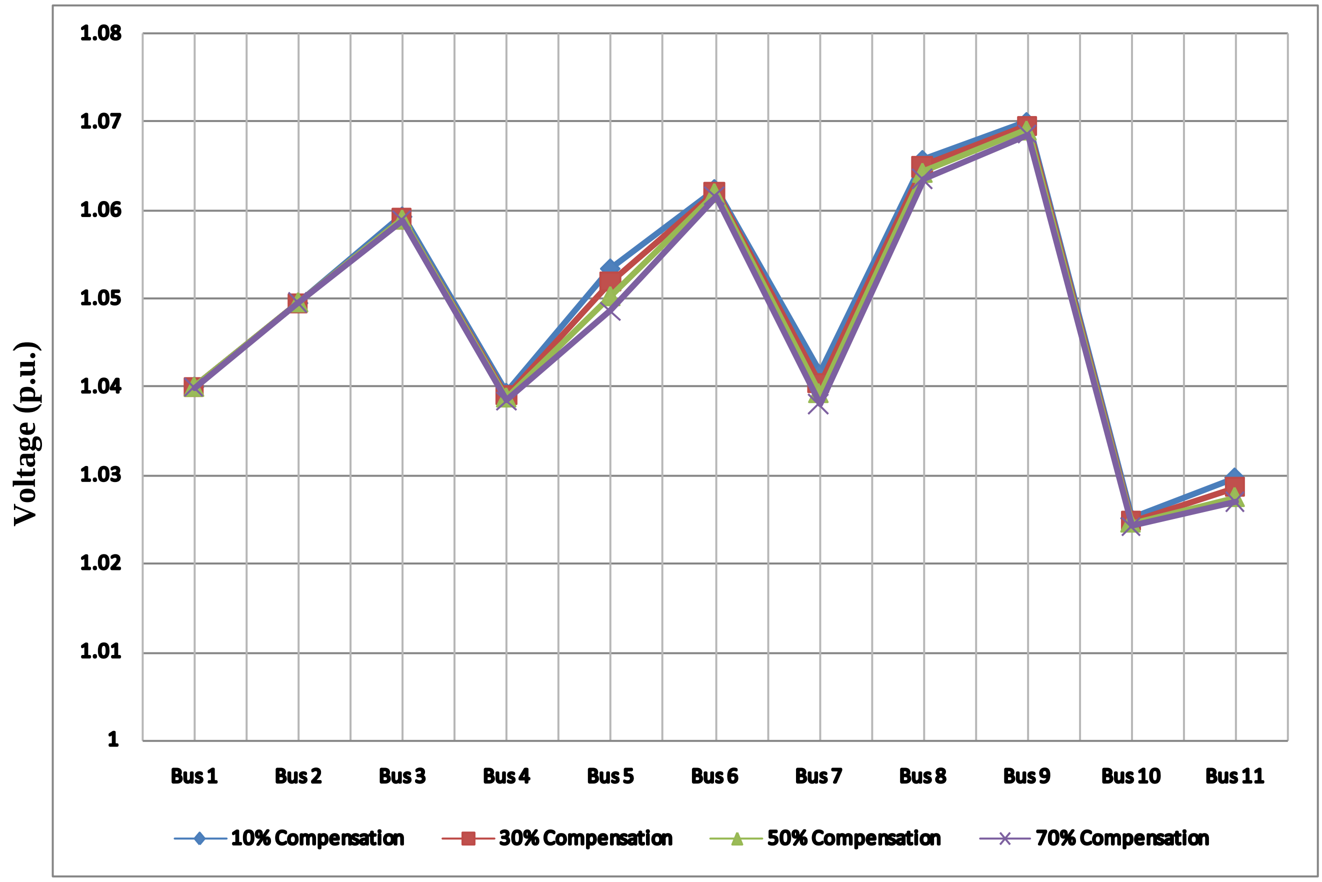


Fig.9 The effect of inserting series capacitor between bus 2 and 5 on buses voltages

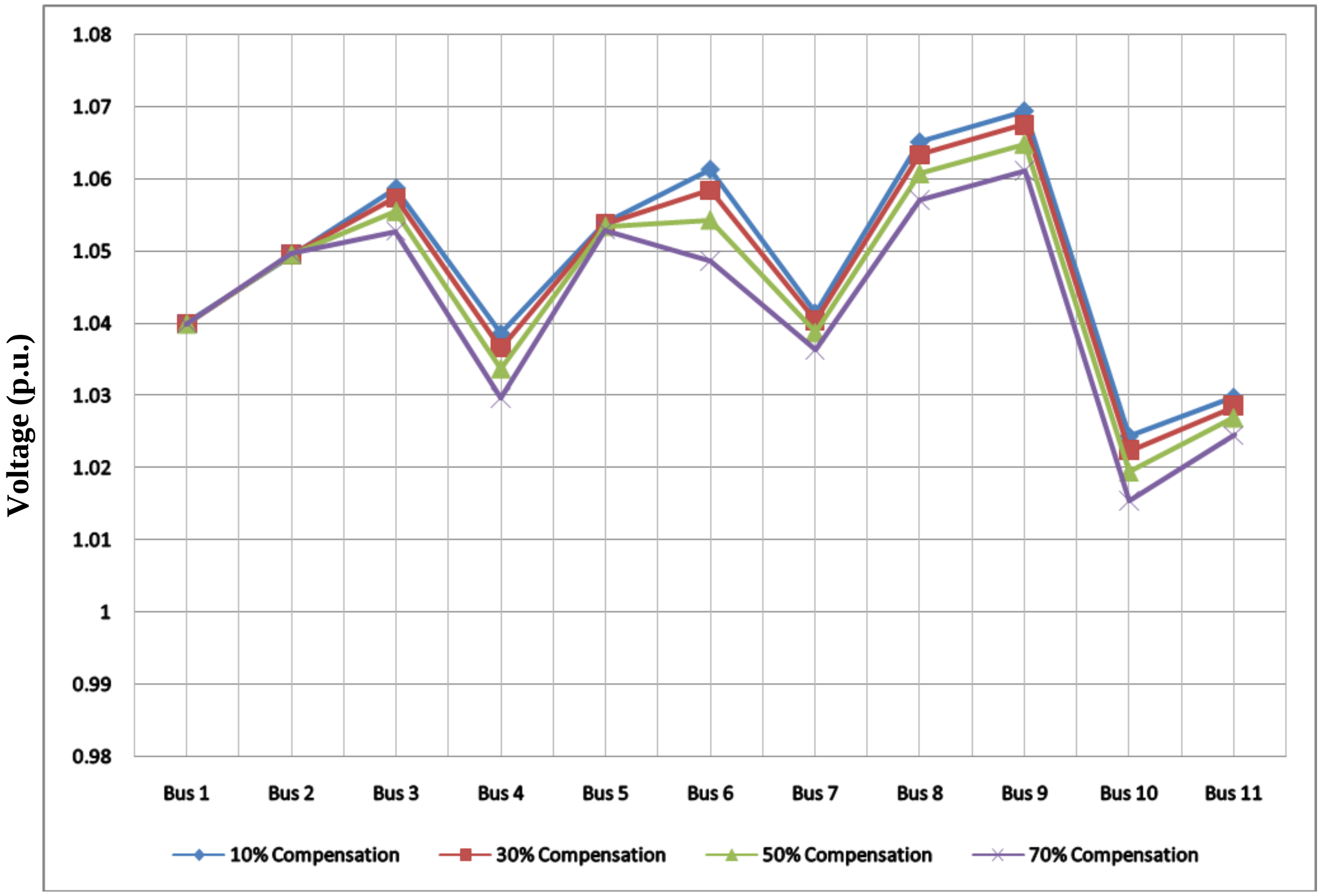


Fig.10 The effect of inserting series capacitor between bus 2 and 6 on buses voltages

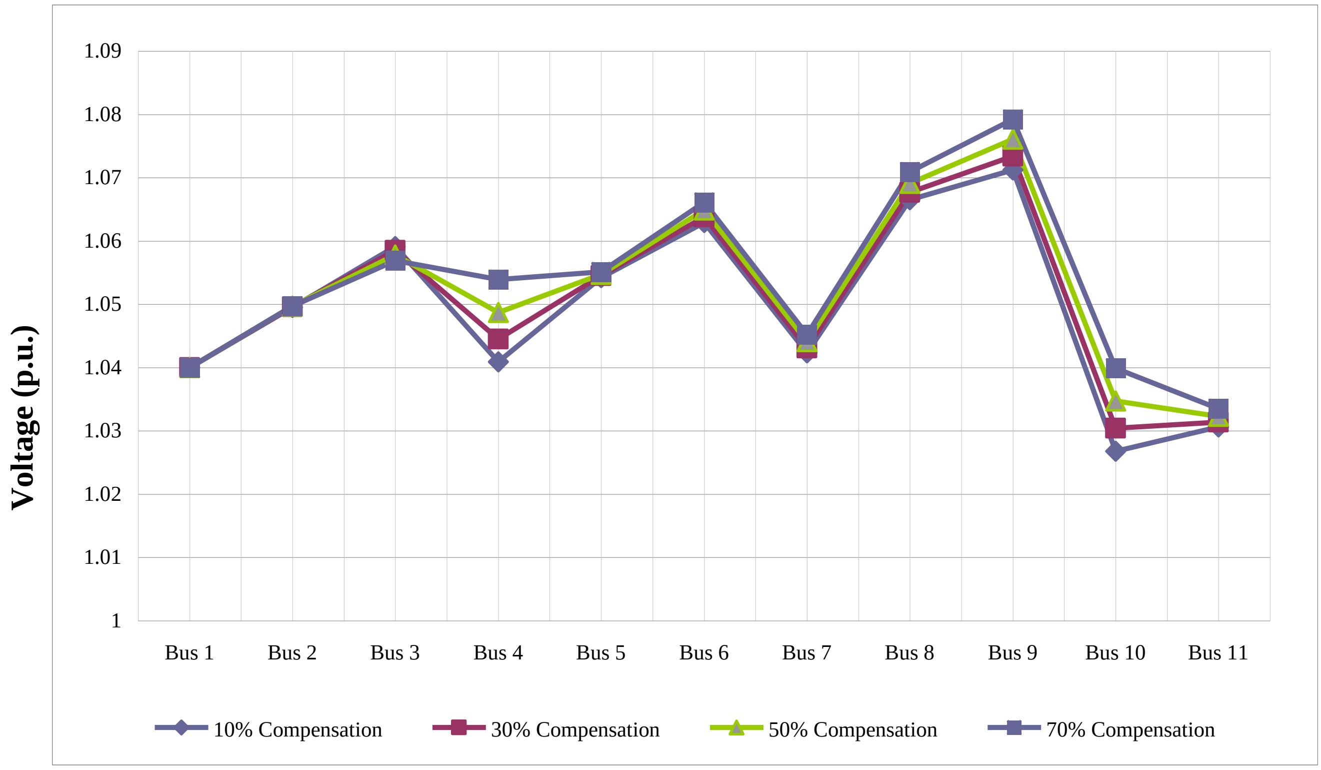


Fig.11 The effect of inserting series capacitor between bus 3 and 4 on buses voltages

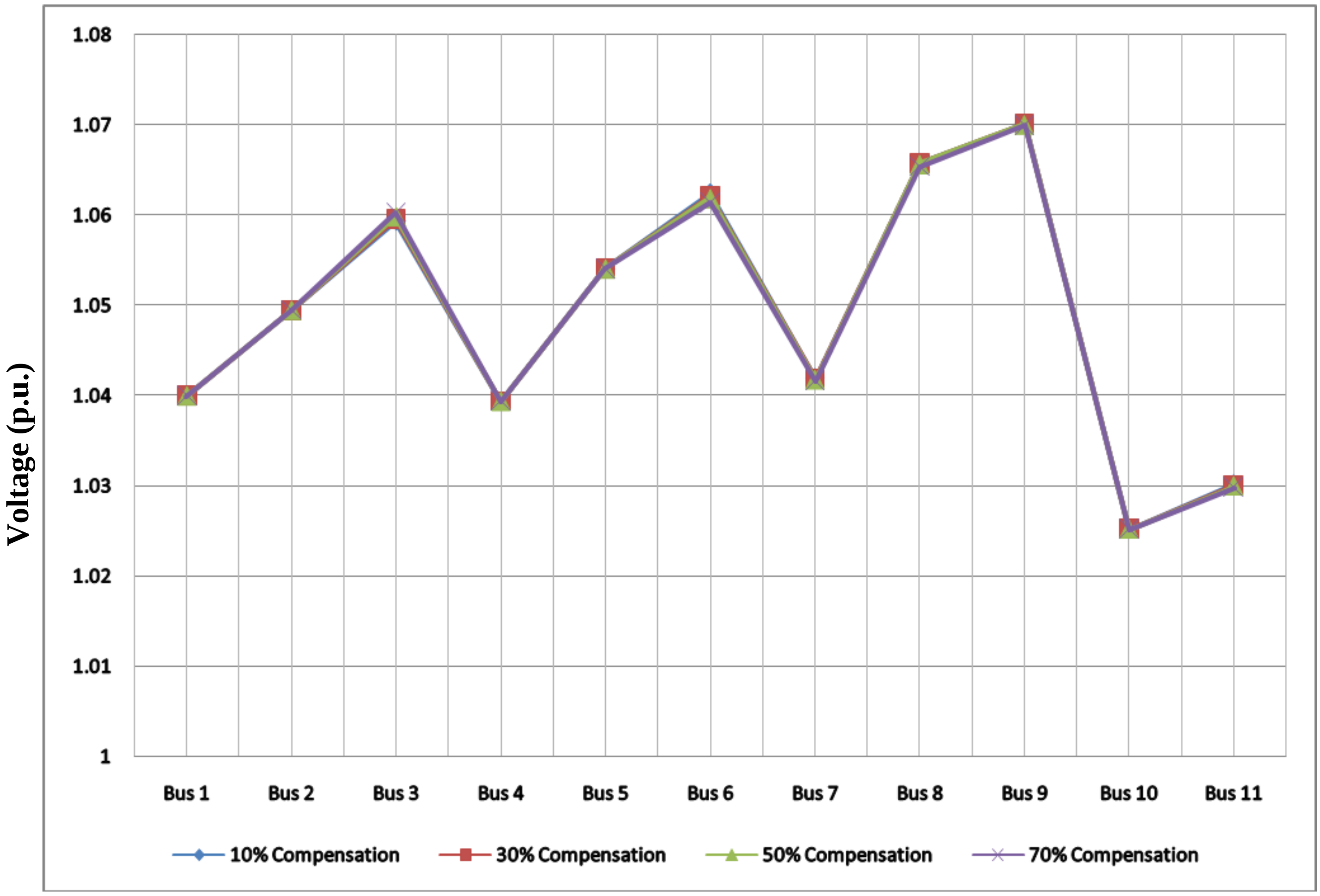


Fig.12 The effect of inserting series capacitor between bus 3 and 6 on buses voltages

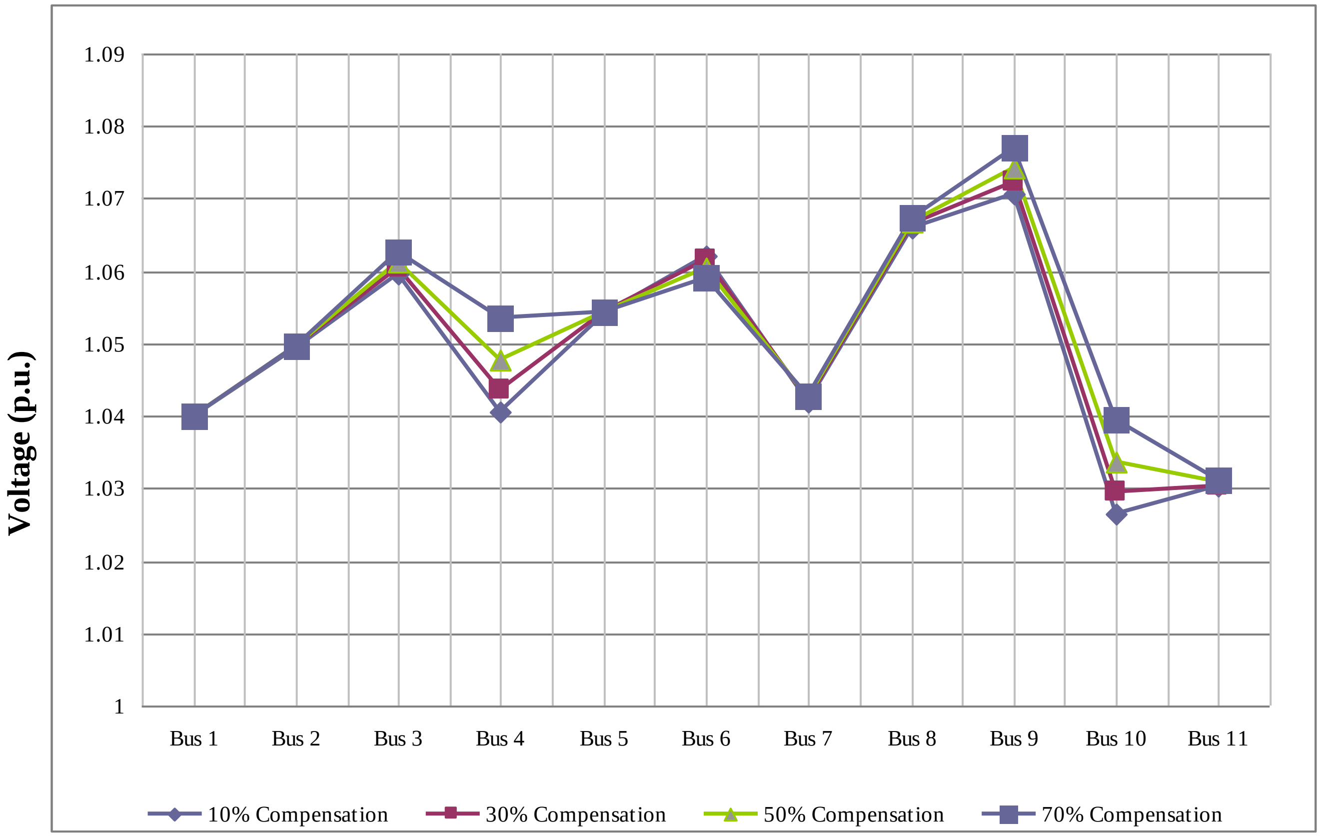


Fig.13 The effect of inserting series capacitor between bus 4 and 6 on buses voltages

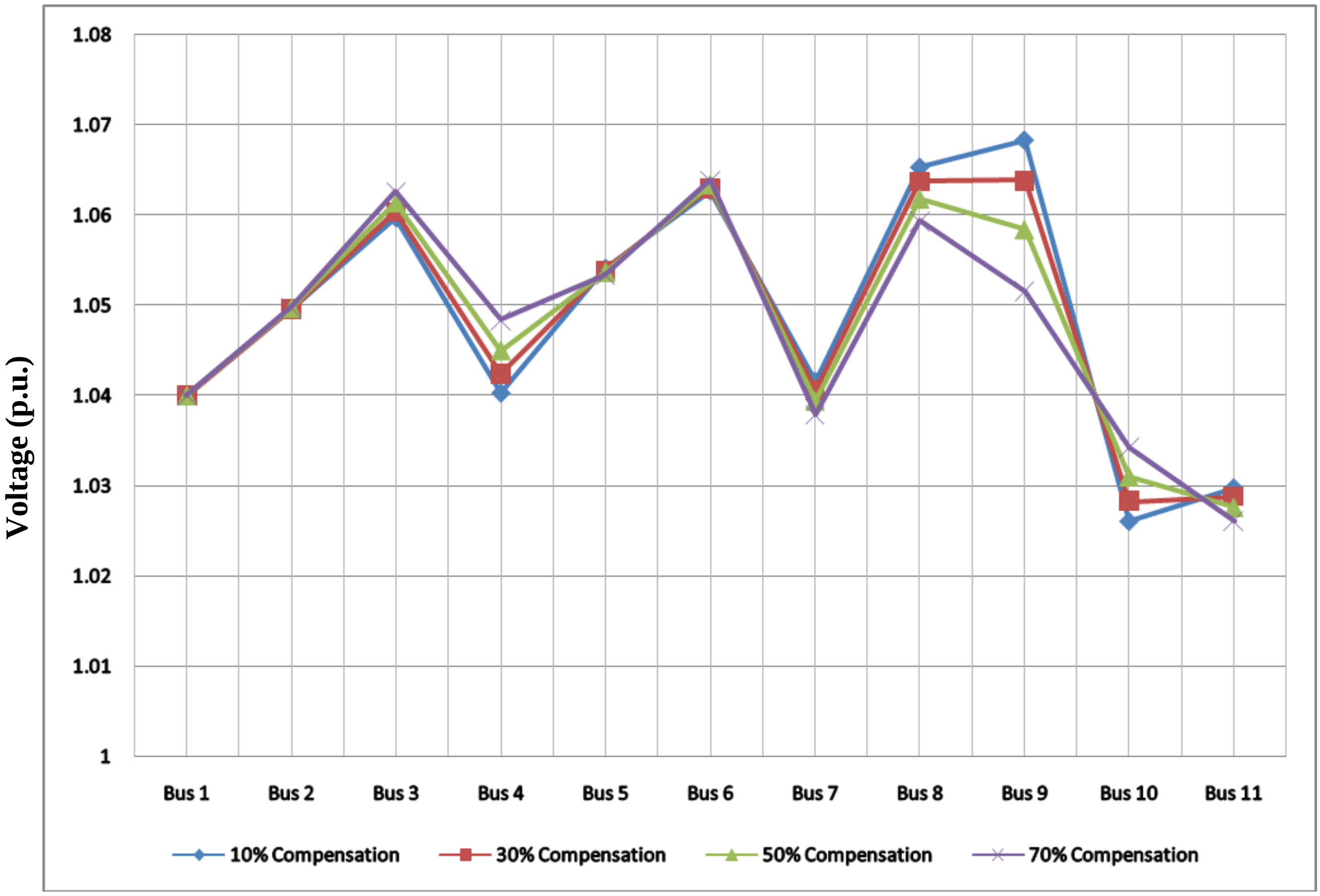


Fig.14 The effect of inserting series capacitor between bus 4 and 9 on buses voltages

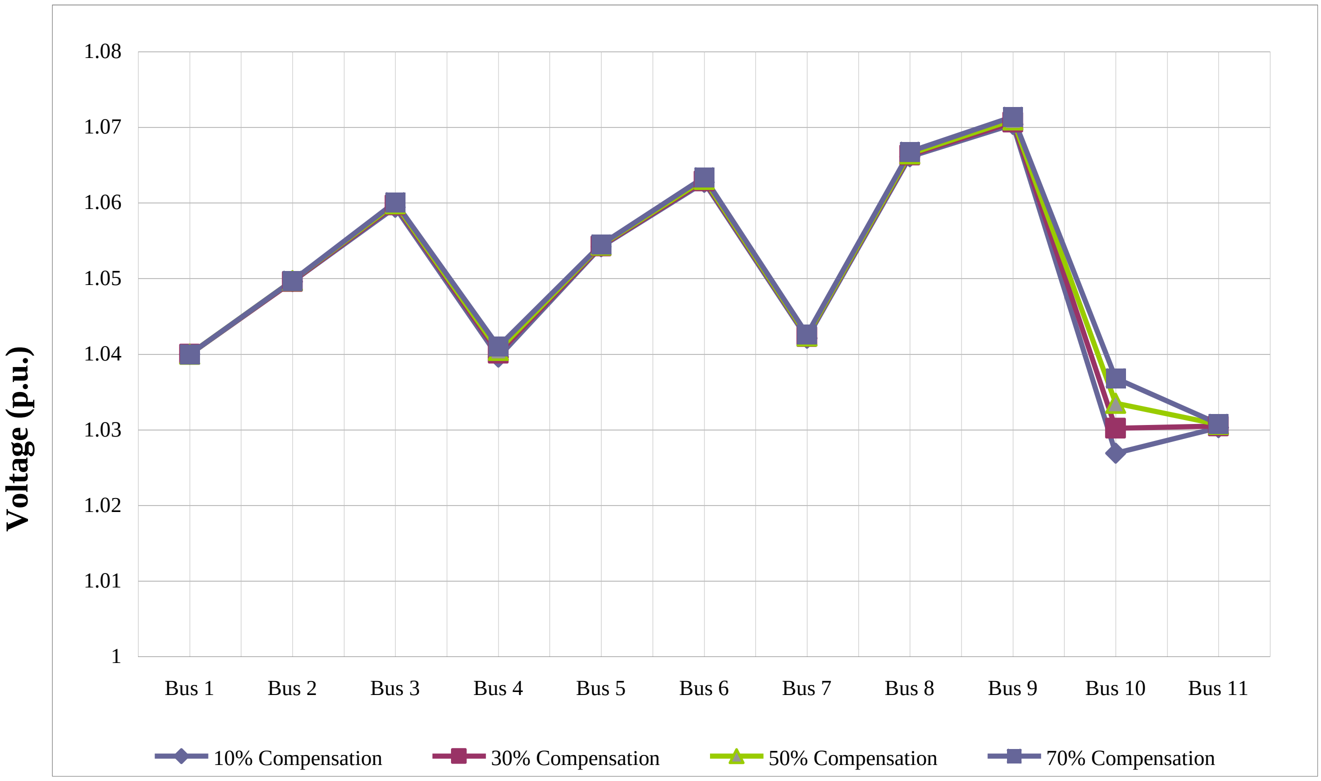


Fig.15 The effect of inserting series capacitor between bus 4 and 10 on buses voltages

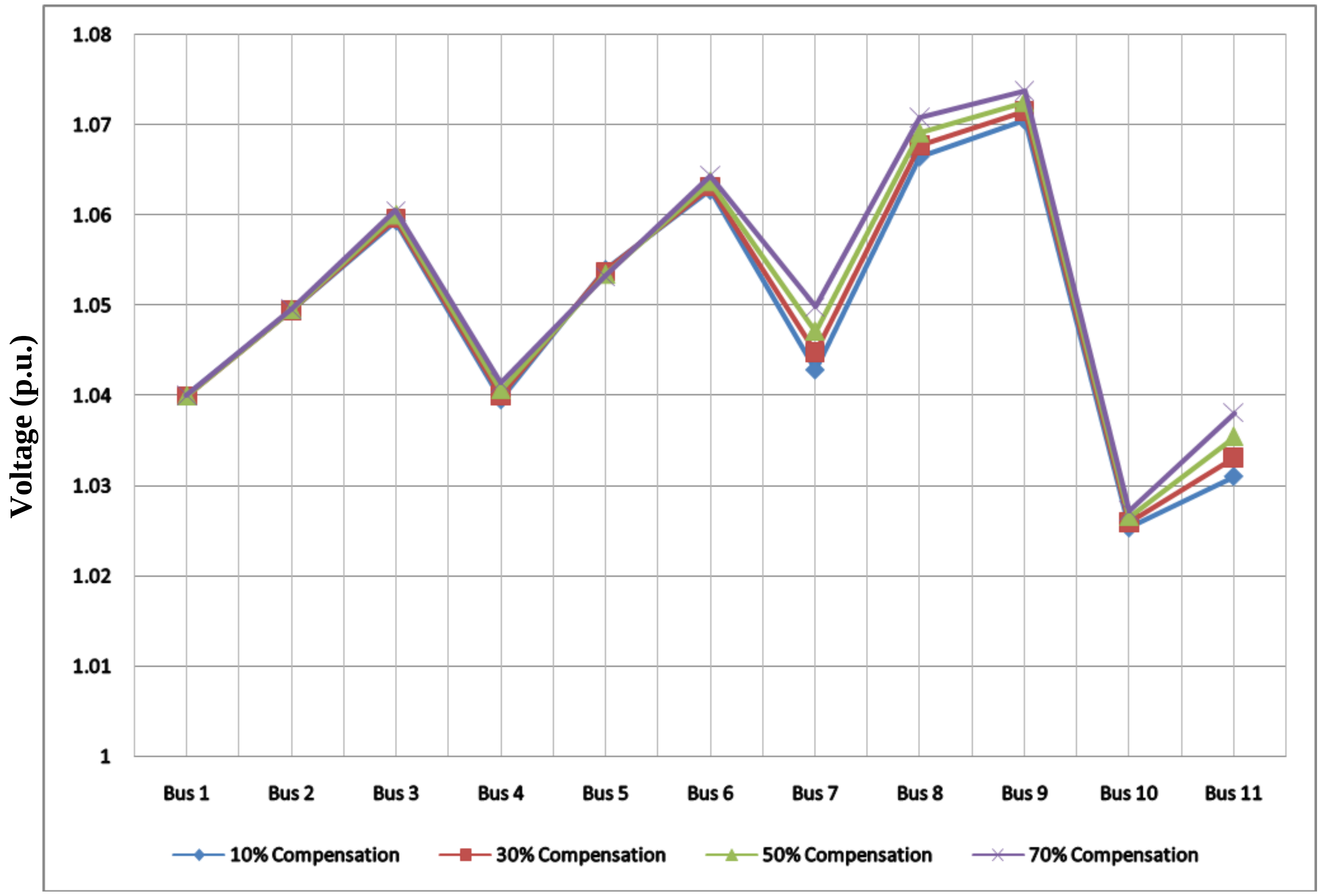


Fig.16 The effect of inserting series capacitor between bus 5 and 7 on buses voltages

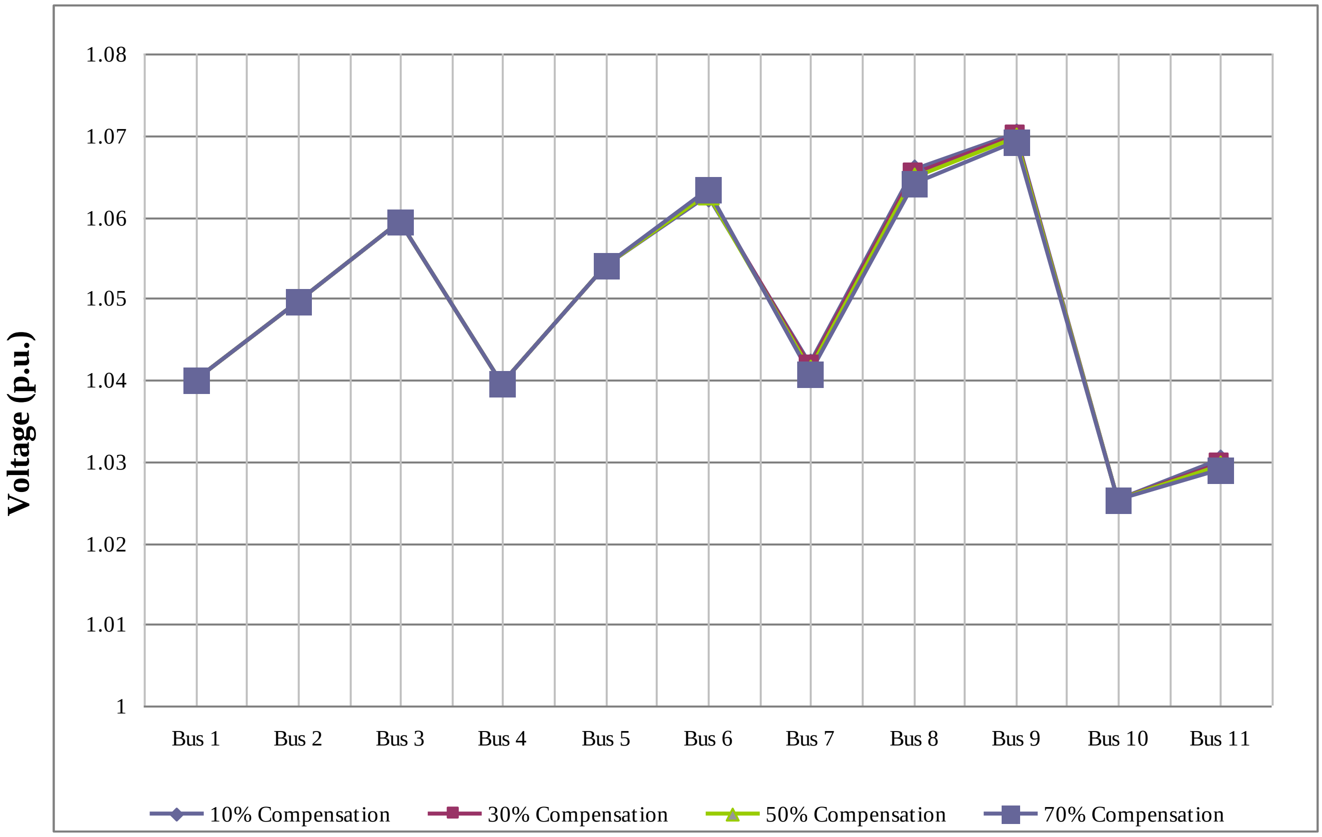


Fig.17 The effect of inserting series capacitor between bus 6 and 8 on buses voltages

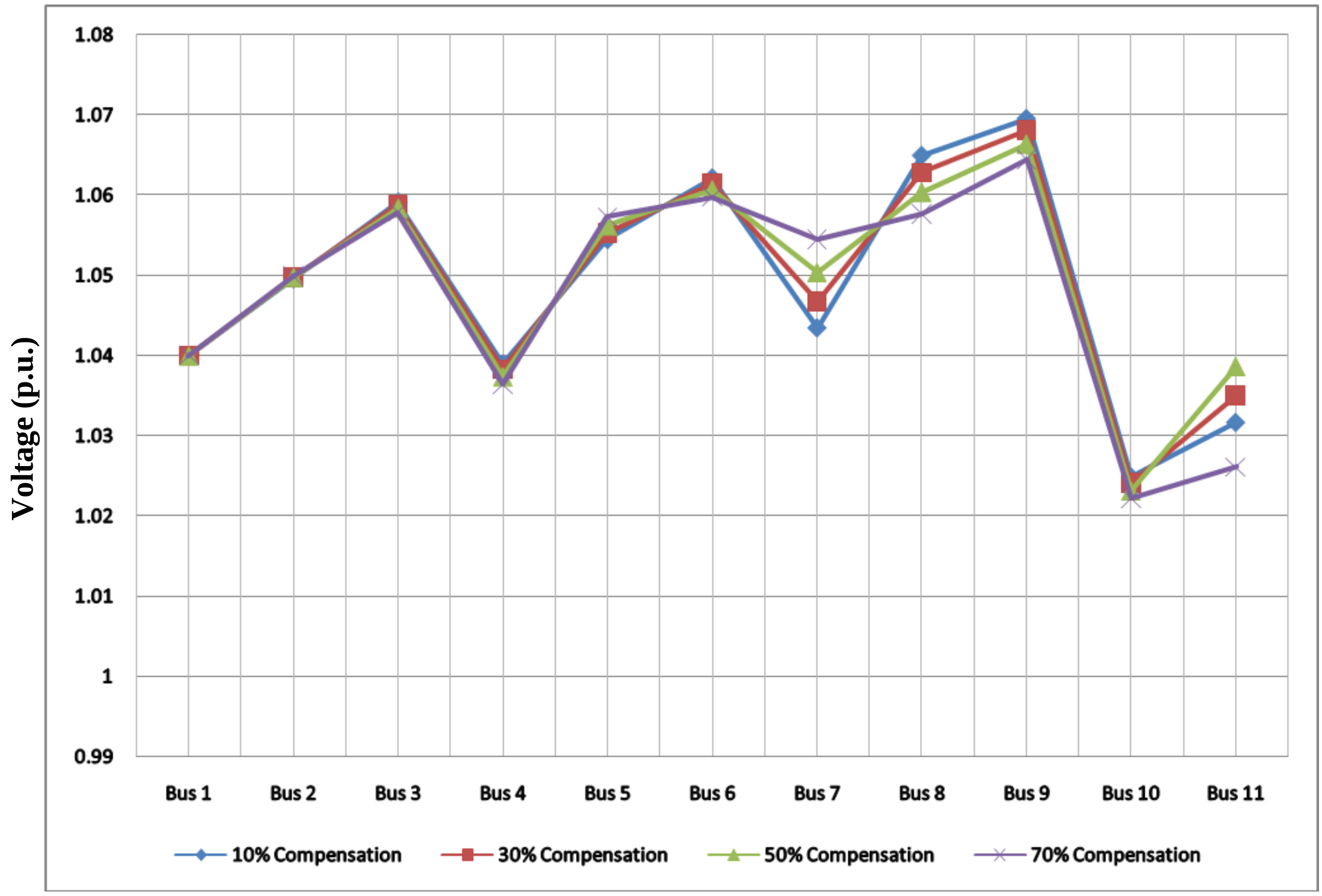


Fig.18 The effect of inserting series capacitor between bus 7 and 8 on buses voltages

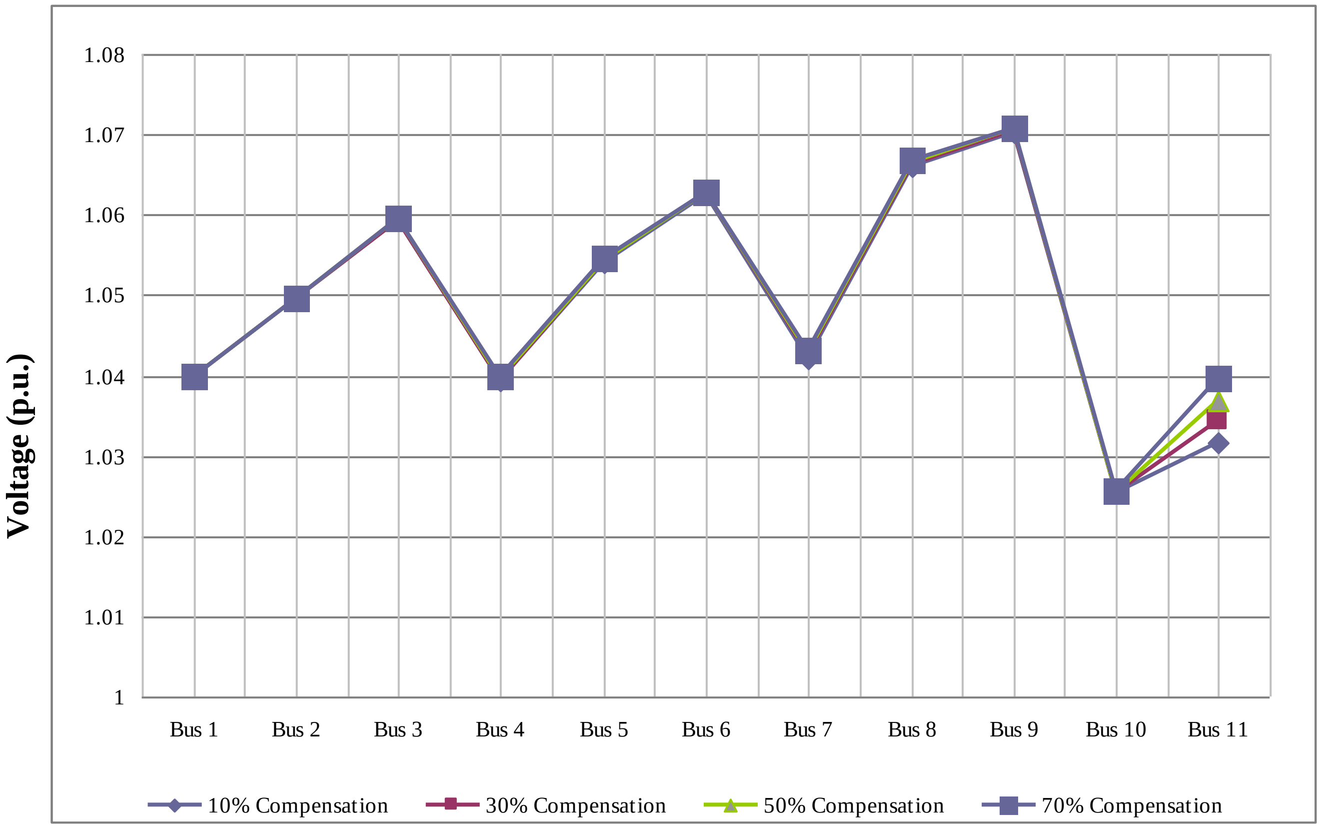


Fig.19 The effect of inserting series capacitor between bus 7 and 11 on buses voltages

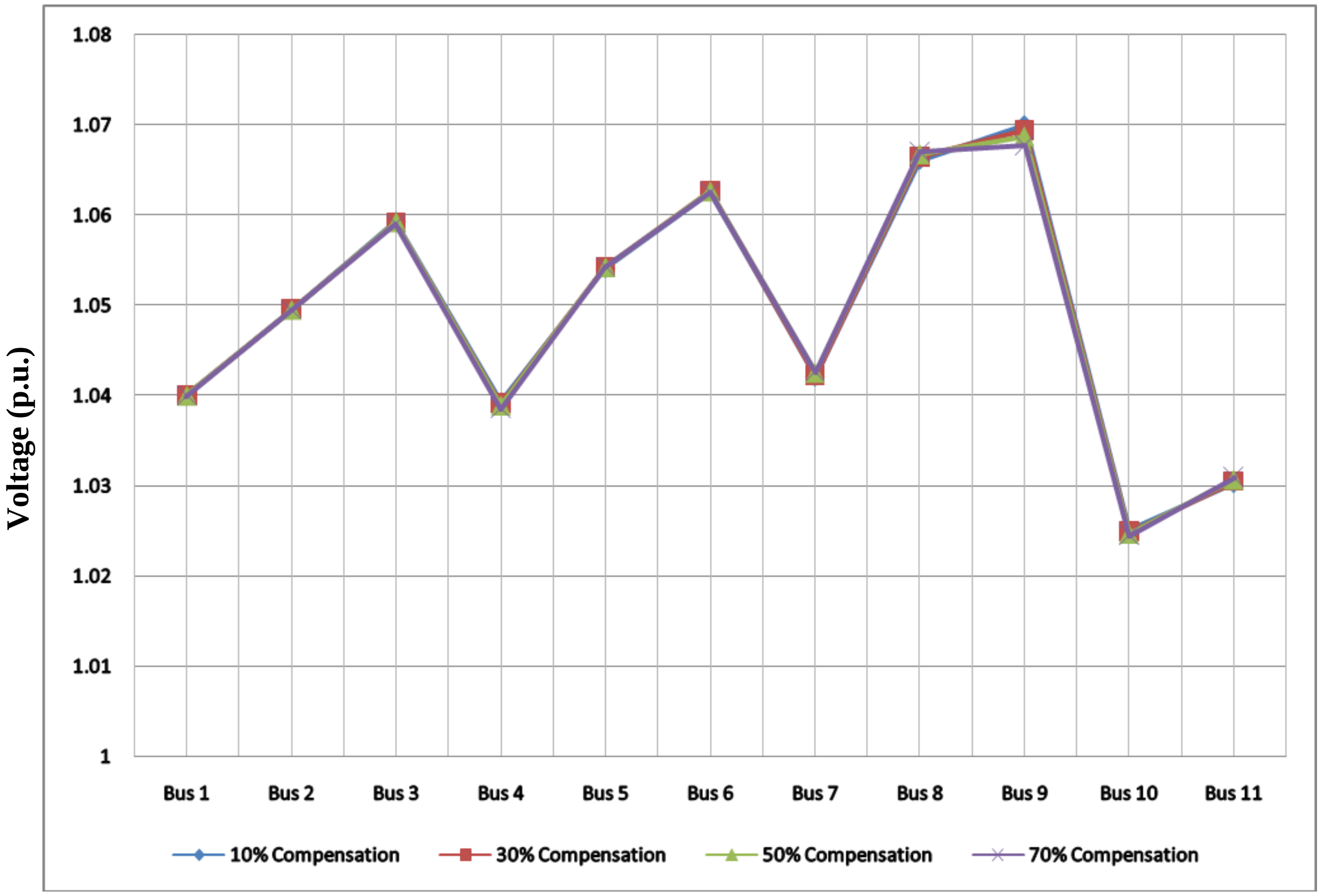


Fig.20 The effect of inserting series capacitor between bus 8 and 9 on buses voltages

- The reactive power losses and active power losses according to eq. (4) and eq. (5) can be given as shown in Fig.21 and Fig.22 respectively for 70% compensation.

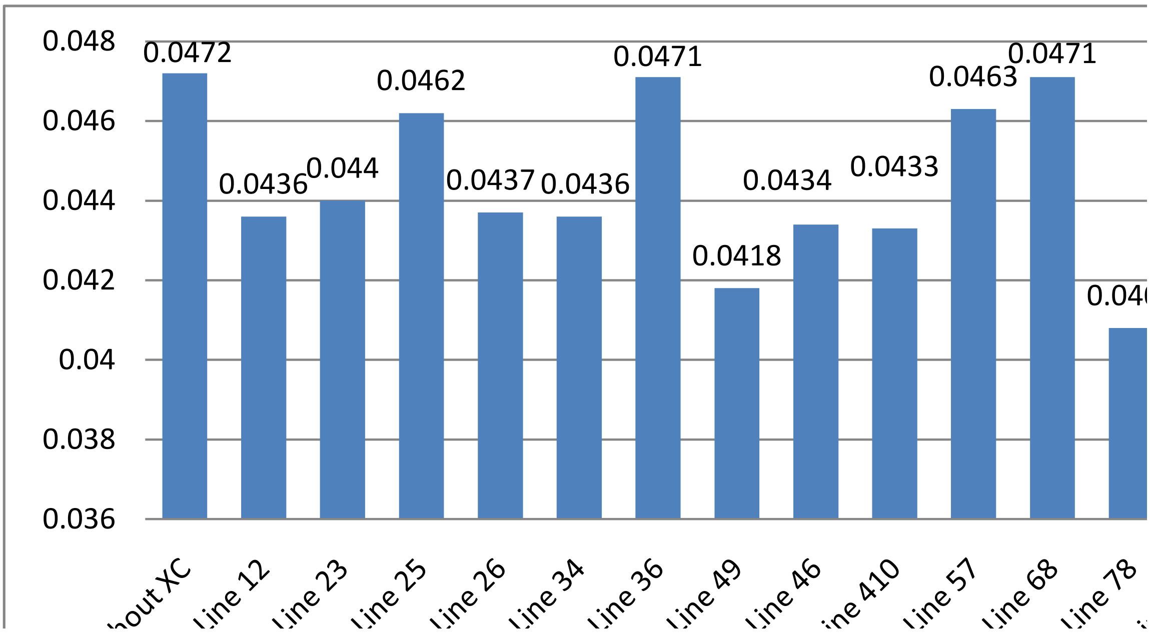


Fig.21 The reactive power losses at each line depending on 70% compensation

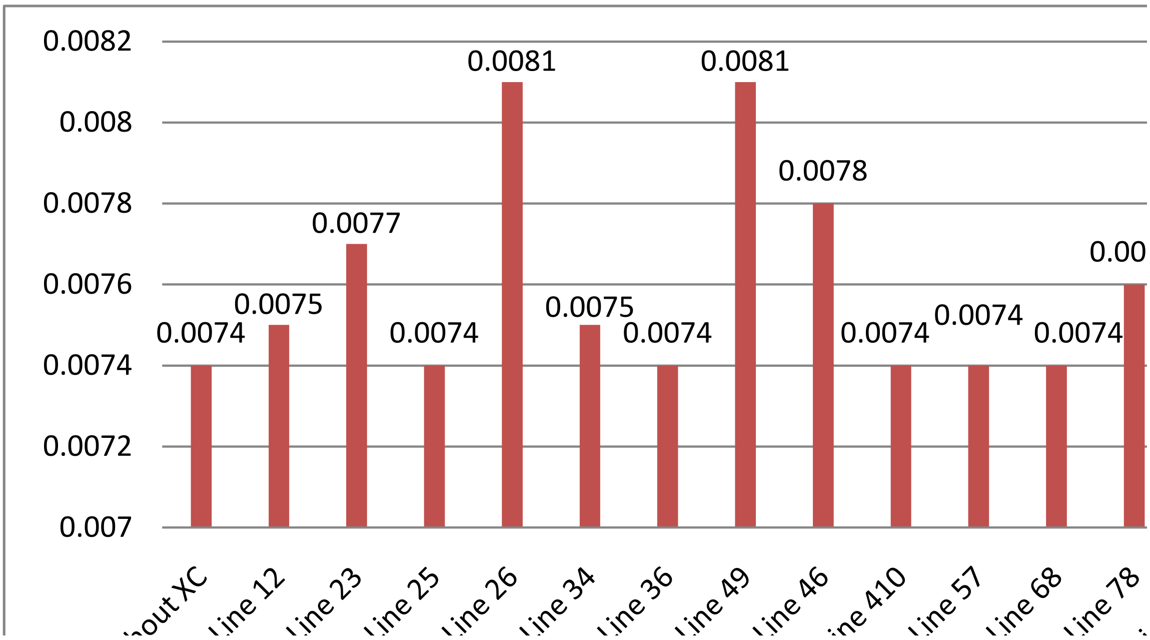


Fig.22 The active power losses at each line depending on 70% compensation

CONCLUSIONS

- It is obvious shown from Fig.7 to Fig.20 that the 70% compensation give best results for the large number of these cases. Fig.23 gives all the buses voltages cases for 70% compensation.

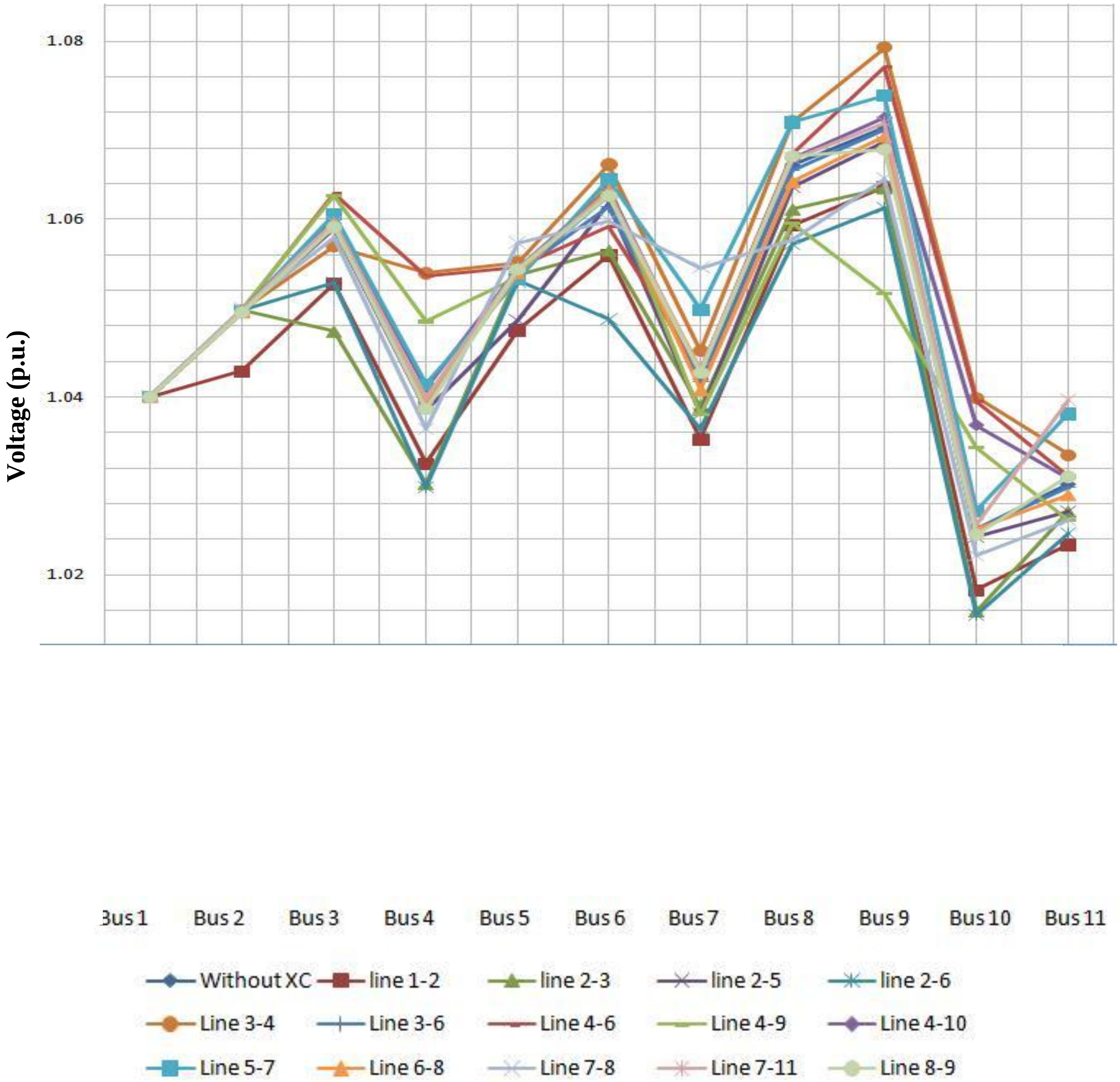


Fig.23 The 70% compensation buses voltages for all 11-bus system lines

- From Fig.23, when inserting the 70% capacitor, the best results for buses voltages exist at the lines 1-2, 2-3 and 2-6.
- One of the important results of a series capacitor application is the reduction of the reactive power losses in the system especially in the compensated line, as shown in Fig.21. Whereas there is no affective change with the active power loss, as shown in Fig.22.
- The busses voltages for the three pre mentioned cases (XC at Line 1-2, XC at Line 2-3, XC at Line 2-6), with the case of no XC and for 70% compensation can be drawn as in Fig.24.

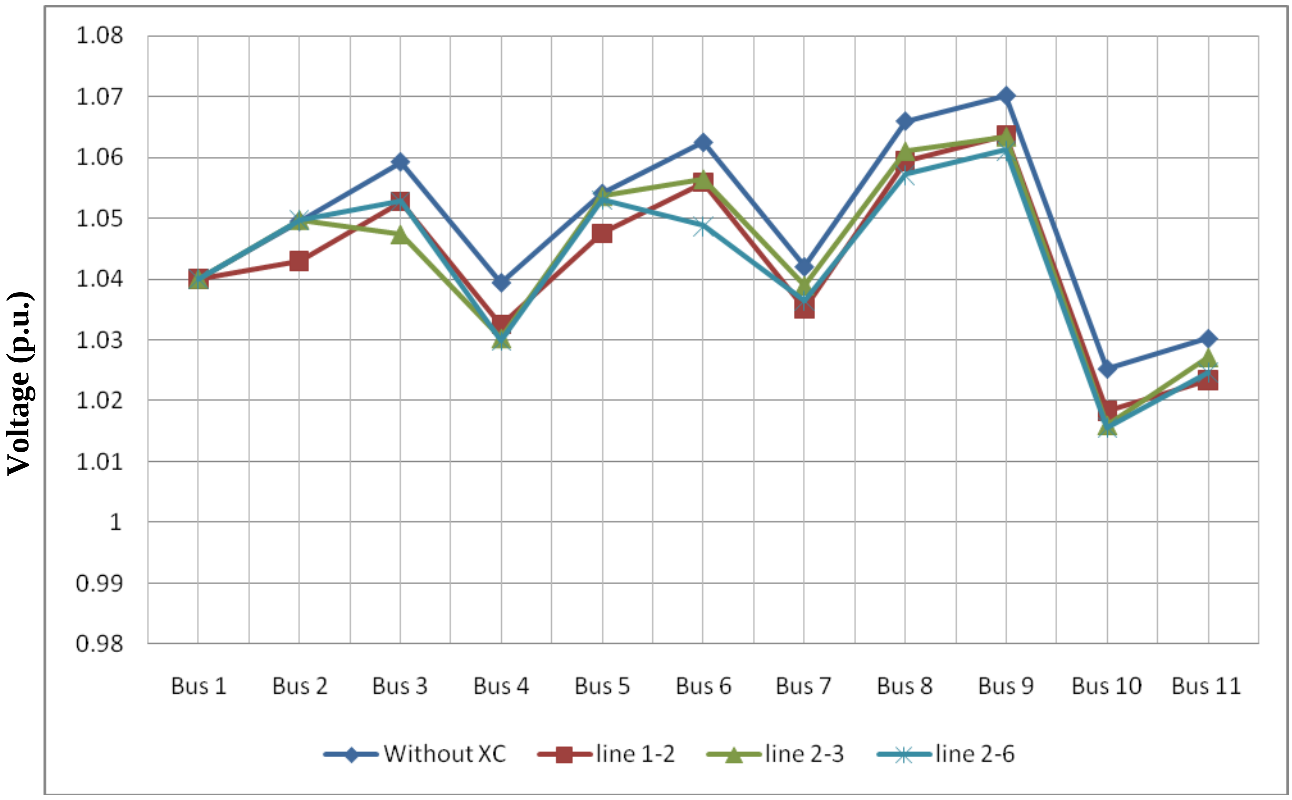


Fig.24 70% compensation for Line 1-2, Line 2-3 and 2-6

- There is no change or slight change in busses voltages when inserting a capacitor, like line 2-5, 3-6, 4-10, 6-8, 7-11 and 8-9.
- To get the optimum insertion of capacitor for the three lines (1-2, 2-3 and 2-6) the mean value of the busses voltages, which is the sum of all busses voltages over the number of busses, can be used as a criteria, as well as the minimum reactive power losses, as given in Table 1.

Table 1 Comparison for mean voltage value and reactive power loss for each line

Line	Mean Voltage Value	Reactive Power Losses
Without XC	1.0490	0.0472
XC at Line 1-2	1.0428	0.0436
XC at Line 2-3	1.0440	0.0440
XC at Line 2-6	1.0426	0.0437

- It is clearly shown from Table 1 that inserting a capacitor as a compensator in 11-bus test system, gives the optimum results for voltage enhancement and reactive power reduction, if the insertion was at **Line 1-2** or **Line 2-6**.

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LIST OF SYMBOLS

V_S	Sending voltage (volt)
V_R	Receiving voltage (volt)
P	Active power (watt)
δ	Rotor angle (degree)
X_L	Transmission line reactance (ohm)
X_C	Capacitance (ohm)