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Voltage Profile Enhancement and Losses Reduction at Future Expansion of Transmission power Systems

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Abstract

The current paper presents flexible and feasible method for enhance the voltage profile in some buses and reduction of the losses in overall transmission power system if the power system subjected to an additional resultant loads in future or current increasing of loads at one or more buses in that power system. The proposed method include estimating the injected MVARs which are required to avert voltage collapse as well as reduction the real power losses. This method is tested by computer simulation implemented on IEEE 30-bus, 41-line transmission power system using MATLAB Tool-Box (Ver. 7.5) based on fast decoupled load flow analysis and satisfactory results are obtained.

Introduction:

Power quality is one of the most important topics from electrical energy consumer's point of view. Among different power quality factors such as voltage harmonics, voltage imbalance, voltage sag, voltage swell and flicker, it is possible to say that voltage magnitude regulation and losses reduction is the most common problems.

The power produced in any power station can be carried on the line to long distances using transformers. When the electrical power is being used by loads, active and reactive powers can be drawn, depending on the type of loads. Even when the load is resistive, some reactive power is still needed for the long transmission lines, which act sometimes as inductive loads [1], in this respect an efficient control technique is needed. The main objective function of reactive power control is to: [2]

- Improve the voltage profiles.
- Minimize the system losses.

According to Dilek in [3] , the minimum and maximum values of bus voltages must be maintain at the pre-specified allowable bus voltages ($1 \pm 5\%$) per-unit value.

Several methods have been employed to avoid the voltage collapse and losses reduction in transmission systems. Some of these methods use sensitivity analysis for enhance the voltage profile and reduce the total power losses [4-7], and the other methods use artificial intelligent (AI) approaches [8-10] to identify the size and candidate nodes which are required to inject reactive power on it.

This research presents a method include increasing the load in some buses until voltage violent is occurs, then calculating the required capacitor size that must be installed in that bus with variant load levels which are computed by the same procedure.

Classical Compensation methods:

In the analysis of transmission networks for design and operational purposes it is often necessary to include a more rigorous line representation particularly where longer transmission distances are involved. This may include lumped parameters (series reactance, series resistance and shunt capacitor) or where a more exact representation is required these parameters can be distributed.

Referring to the simplified model of the uncompensated system of Figure (1) the voltage at the mid point of the line is taken to be V**M**, the real power P, exported along the line is given as:[11]

$$P = \frac{V^2}{X} Sin(\delta) \qquad (1)$$

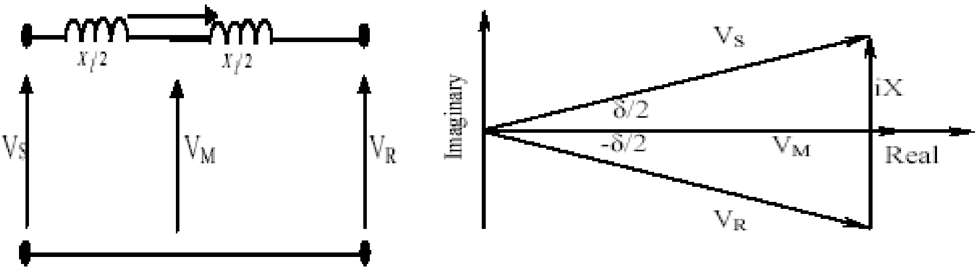

Figure (1): Simple Power system Model

Classical compensation can be summarized as:- [12]

1. Series Compensation:

Series capacitors 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 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 Figure (2) with bus-1 having a voltage magnitude V_1 at an angle δ_1 and bus-2 having a voltage V_2 at an angle δ_2 .[11]

$$P = \frac{|V_1||V_2|}{X_1 - X_2}\, Sin\,(\delta_1 - \delta_2) \qquad (2)$$

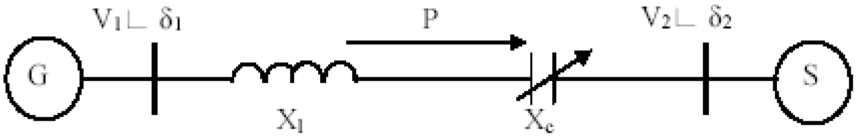

Figure (2): Simple two bus lossless system

The reactance associated with the line limits the power transfer through the system. However, the value of X_1 could be decreased, to increase the power transfer, by adding series capacitances as seen in equation 2. One of the important results of series capacitor application is the reduction of the reactive power losses in the system especially in the compensated line.

2. Shunt Compensation:

Figure (3) shows the arrangement of the ideal mid-point shunt compensator which maintains a voltage, mid-point voltage(V**M**) equal to the bus bar voltage such that sending voltage(|V**S**|) =receiving voltage(|V**R**|) = mid-point voltage(|V**M**|). It can be seen that the compensator does not consume real power since the compensator voltage; V**M** and its current I**M** are in quadrature. Clearly, the power, power transferred from sending end (S) to the mid-point is equal to the power transferred from the midpoint to receiving (R) end, and is given by:[11]

$$P = \frac{V^2}{X/2}\, Sin\,(\delta/2) \;= \frac{2V^2}{X}\; Sin\,(\delta/2) \qquad (3)$$

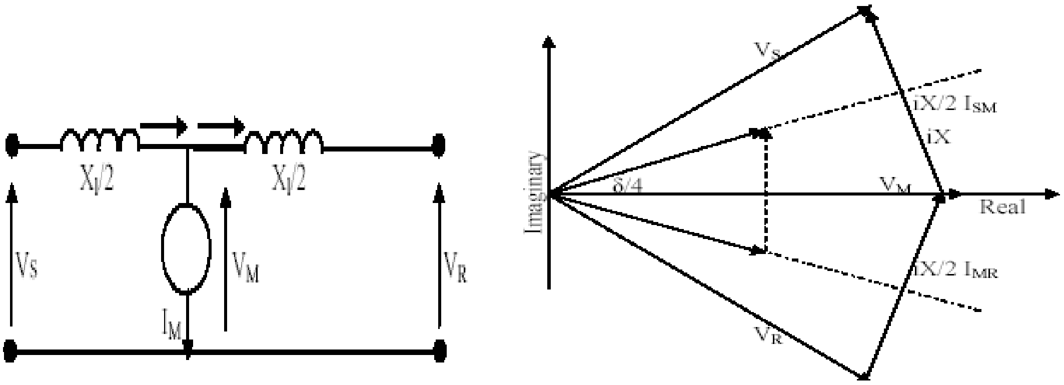

Figure (3):. Simple model with mid-point shunt Compensation

The reactive power generated by the compensator Q_P is given by:

$$Q_P = I_M V_M \qquad (4)$$

$$Q_P = \frac{4V^2}{X}(1 - Cos(\frac{\delta}{2})) \qquad (5)$$

Fast Decoupled Load-Flow Methods:-

A power flow study will provide extensive information about the system's state, weaknesses, and possible expansion opportunities. The most important information given by the power flow is the voltage and phase angle at each node. Real and reactive power may also be obtained, though the accuracy of the output depends on the system stance. Power flow systems today are simulated through computer software that can generate an output in a manner of minutes. These commercial and private software programs vary depending on the amount of buses and components allowed within a project. Power flow solutions base themselves on system constraints and assumptions.[13]

In power-Flow problem there are a number of nonlinear relation- ships between voltage and current at each bus which must be solved for all voltages and currents such that these nonlinear relationships are met. The complexity of obtaining a formal solution for Power-Flow in power system arises because of differences in the type of data specified for the different type of buses. Although the formulation of sufficient equations to match the number of unknown state variables is not difficult, the closed form of solution is not practical. [14]

There are many methods which provide digital solution to Power-Flow solutions that follow an iterative process, but the most sufficient method is the Fast-Decoupled method. This method offers a uniquely attractive combination of advantages over established methods, including Gauss Seidel and Newton-Raphson, in terms of computational speed, reliability, simplicity and storage for power flow solutions [15]. The program which was used in this study applies the Fast Decoupled method in MATLAB Language and the flow chart of this program is shown in Figure (4).

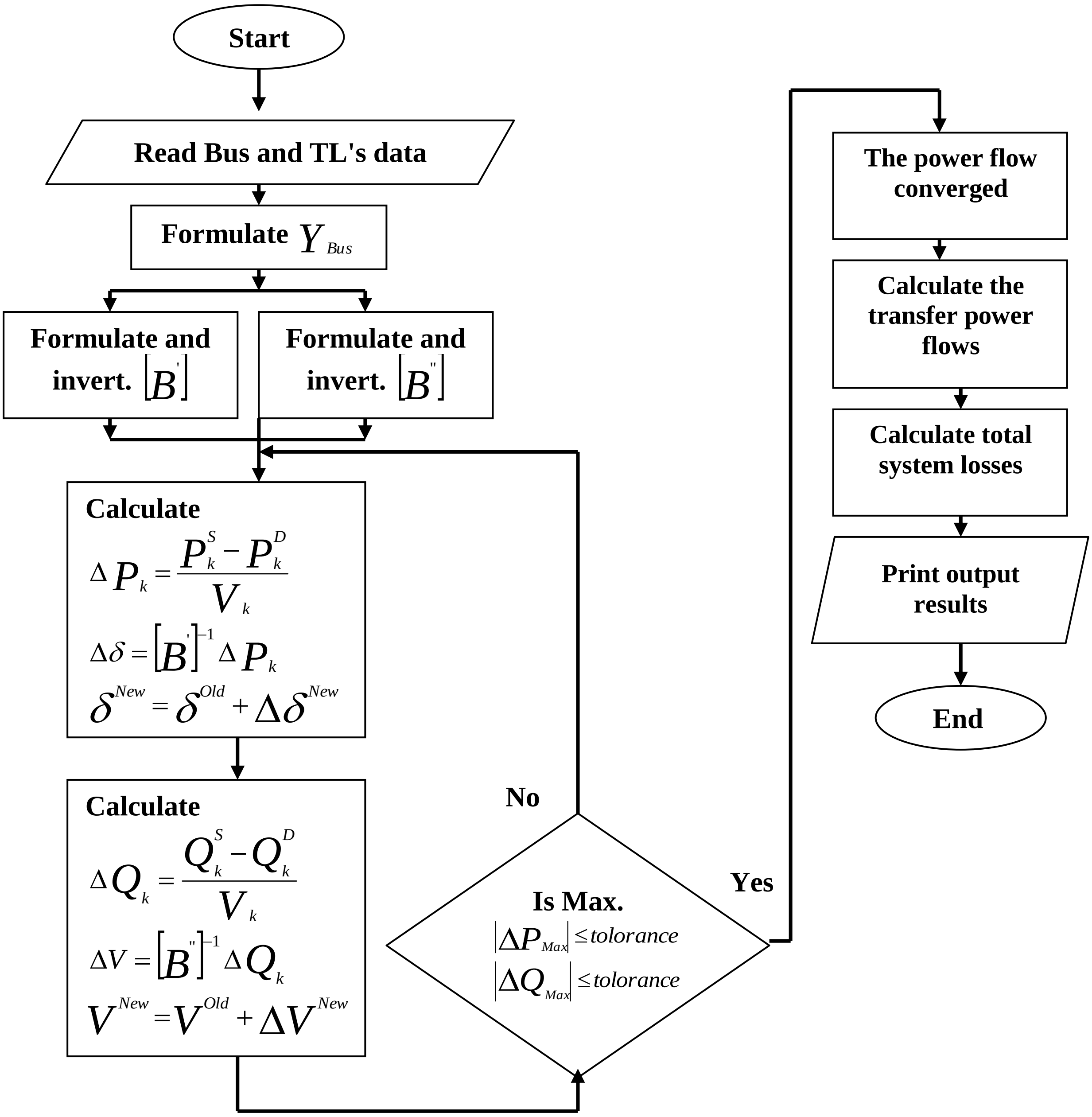

Figure (4): Flow chart for a fast decoupled power flow program

Problem formulation and Proposed Method::

The power system model is described by the power flow equations:- [16]

$$P_i = |V_i|^2 G_{ii} + \sum_{\substack{n=1\\ n\neq i}}^{N} |V_i V_n Y_{in}| Cos(\theta_{in} + \delta_n - \delta_i) \tag{6}$$

$$Q_i = -|V_i|^2 B_{ii} - \sum_{\substack{n=1\\ n\neq i}}^{N} |V_i V_n Y_{in}| Sin(\theta_{in} + \delta_n - \delta_i) \tag{7}$$

Where: G_{ii} and B_{ii} are self conductance and susceptance of bus i.

G_{in} and B_{in} are conductance and susceptance from bus i to bus n.

P_i and Q_i are active and reactive power injection at bus i.

V_i and δ_i are voltage magnitude and angle at bus i.

Y_{in} is admittance of line from bus i to bus n.

The real power losses are given as:-[16]

$$P_{Losses} = \sum_{i=1}^{N} G_i (V_i^2 + V_j^2 - 2V_i V_j Cos(\delta_i - \delta_j)) \tag{8}$$

Due to future expansion or increasing in current loads transmission power system may be subjected to voltage collapse and to avoid this situation an additional reactive power must injected. In the following the steps of algorithm that is used to avoid the voltage collapse:-

Step-1:- Perform the Load-Flow program to calculate overall real power losses in power system.

Step-2:- Increased the load in some specified buses by fixed amount according to expectant increase of load in future.

Step-2:- Perform the Load-Flow program again to know if there is voltage collapse in specified buses.

Step-4:- If there is a voltage collapse in system buses, select an appropriate value of reactive power to injected in one of these buses that required to avoid the voltage collapse, then perform the Load-Flow program to ensure correct voltage profile and to calculate the reduction in overall real power losses.

Step-5:- Select another bus from the pre-specified buses and repeat steps (2-4).

Step-6:- Repeat steps (2-5) for all specified buses.

Test Power System:

The transmission power system under consideration represents a standard IEEE 30-bus, 41-line consist of one slack bus (bus-1), five voltage controlled buses (buses of 26,27,28,29 and 30) and twenty four load bus (from bus-2 to bus-25), the data of transmission lines and buses of transmission power system are tabulated in Table (1).

Table (1): Transmission lines and buses data of test system

Transmission lines data			
From bus	To bus	R (P.U)	X (P.U)
1	26	0.0192	0.0575
1	3	0.0452	0.1852
26	4	0.0570	0.1737
3	4	0.0132	0.0379
26	27	0.0472	0.1983
26	6	0.0581	0.1763
4	6	0.0119	0.0414
27	7	0.0460	0.1160
6	7	0.0267	0.0820
6	28	0.0120	0.0420
6	9	0.0000	0.2080
6	10	0.0000	0.5560
9	29	0.0000	0.2080
9	10	0.0000	0.1100
4	12	0.0000	0.2560
12	30	0.0000	0.1400
12	14	0.1231	0.2559
12	15	0.0662	0.1304
12	16	0.0945	0.1987
14	15	0.2210	0.1997
16	17	0.0824	0.1932
15	18	0.1070	0.2185
18	19	0.0639	0.1292
19	20	0.0340	0.0680
10	20	0.0936	0.2090
10	17	0.0324	0.0845
10	21	0.0348	0.0749
10	22	0.0727	0.1499
21	22	0.0116	0.0236
15	23	0.1000	0.2020
22	24	0.1150	0.1790
23	24	0.1320	0.2700
24	25	0.1885	0.3292
25	2	0.2544	0.3800
25	5	0.1093	0.2087
8	5	0.0000	0.3960
5	11	0.2198	0.4153
5	13	0.3202	0.6027
11	13	0.2399	0.4533
28	8	0.6360	0.2000
6	8	0.0169	0.0599

Buses data						
Bus No.	V (P.U)	δ rad.	P_G MW	Q_G MW	P_L MW	Q_L MW
1	1.050	0.00	0.00	0.00	0.00	0.00
2	1.000	0.00	0.00	0.00	3.50	2.30
3	1.000	0.00	0.00	0.00	2.40	1.20
4	1.000	0.00	0.00	0.00	7.60	1.60
5	1.000	0.00	0.00	0.00	0.00	0.00
6	1.000	0.00	0.00	0.00	0.00	0.00
7	1.000	0.00	0.00	0.00	22.8	10.9
8	1.000	0.00	0.00	0.00	0.00	0.00
9	1.000	0.00	0.00	0.00	0.00	0.00
10	1.000	0.00	0.00	0.00	5.80	2.00
11	1.000	0.00	0.00	0.00	2.40	0.90
12	1.000	0.00	0.00	0.00	11.2	7.50
13	1.000	0.00	0.00	0.00	10.6	1.90
14	1.000	0.00	0.00	0.00	6.20	1.60
15	1.000	0.00	0.00	0.00	8.20	2.50
16	1.000	0.00	0.00	0.00	3.50	1.80
17	1.000	0.00	0.00	0.00	9.00	5.80
18	1.000	0.00	0.00	0.00	3.20	0.90
19	1.000	0.00	0.00	0.00	9.50	3.40
20	1.000	0.00	0.00	0.00	2.20	0.70
21	1.000	0.00	0.00	0.00	17.5	11.2
22	1.000	0.00	0.00	0.00	0.00	0.00
23	1.000	0.00	0.00	0.00	3.20	1.60
24	1.000	0.00	0.00	0.00	8.70	6.70
25	1.000	0.00	0.00	0.00	0.00	0.00
26	1.045	0.00	80.0	0.00	21.7	12.7
27	1.010	0.00	50.0	0.00	94.2	19.0
28	1.010	0.00	20.0	0.00	30.0	30.0
29	1.050	0.00	20.0	0.00	0.00	0.00
30	1.050	0.00	20.0	0.00	0.00	0.00

Simulation results:

Future expansion considered at buses 2 and 13, the expectant real load power varied in bus-2 from 5 MW to 12 MW in steps of 1MW and from 15MW to 22 MW in steps of 1MW in bus-13. The future reactive power in these buses remains constant at either 10 Mvar or 20 Mvar. The required reactive powers which are injected in the specified buses in order to remain the buses voltages at its pre-specified accepted values with the resultant real power losses reduction before and after reactive power injection are tabulated in Tables (2) and (3). Table (2) show the simulation results in case of future reactive load in specified buses equal to (10Mvar) and the simulation results in case of the future reactive load equal to (20Mvar) are tabulated in Table (3).

Figure (5) show the losses power in overall transmission power system before and after reactive power injection in that buses, while Figure (6) show the voltage profile of specified buses before and after injection.

Conclusion:

A simplified approach to estimate the appropriate required quantity of reactive power injected in some specified buses to enhance voltage profile and reduce the real power losses in transmission power systems has been presented in this study. The voltage collapse occurs in power systems as a result of the loads increasing or from future expansion, the proposed method manipulate this situation to enhance the power system performance.

The current study illustrated that the improving in voltage profile lead to significant increase in loadability of power systems, for this reason the current study represents a flexible and feasible tool to electrical engineers in planning and implementing stages of transmission power systems design.

Table (2): Simulation results when the future Q_{LOAD} = 10Mvar

Bus No.	Future P_{LOAD} (MW)	Required MVAR Injection	$\lvert V \rvert$ Before enhance (P.U)	$\lvert V \rvert$ After enhance (P.U)	P_{Losses} Before enhance (MW)	P_{Losses} After enhance (MW)
Bus No.-2	5	9.2	0.8738	0.9501	6.4513	5.7266
	6	9.8	0.8688	0.9501	6.5962	5.8384
	7	10.4	0.8636	0.9501	6.7545	5.9628
	8	11	0.8584	0.9500	6.9266	6.1000
	9	11.65	0.8529	0.9501	7.1133	6.2495
	10	12.28	0.8473	0.9500	7.3151	6.4124
	11	12.928	0.8415	0.9500	7.5330	6.5886
	12	13.62	0.8355	0.9501	7.7676	6.7784
Bus No.-13	15	12	0.8585	0.9532	6.8514	6.1599
	16	12.5	0.8540	0.9530	7.0476	6.3174
	17	12.8	0.8493	0.9512	7.2555	6.4852
	18	13.2	0.8445	0.9502	7.4756	6.6601
	19	13.8	0.8395	0.9509	7.7084	6.8417
	20	14.5	0.8343	0.9513	7.9547	7.0317
	21	15	0.8290	0.9506	8.2152	7.2317
	22	15.6	0.8234	0.9506	8.4906	7.4402

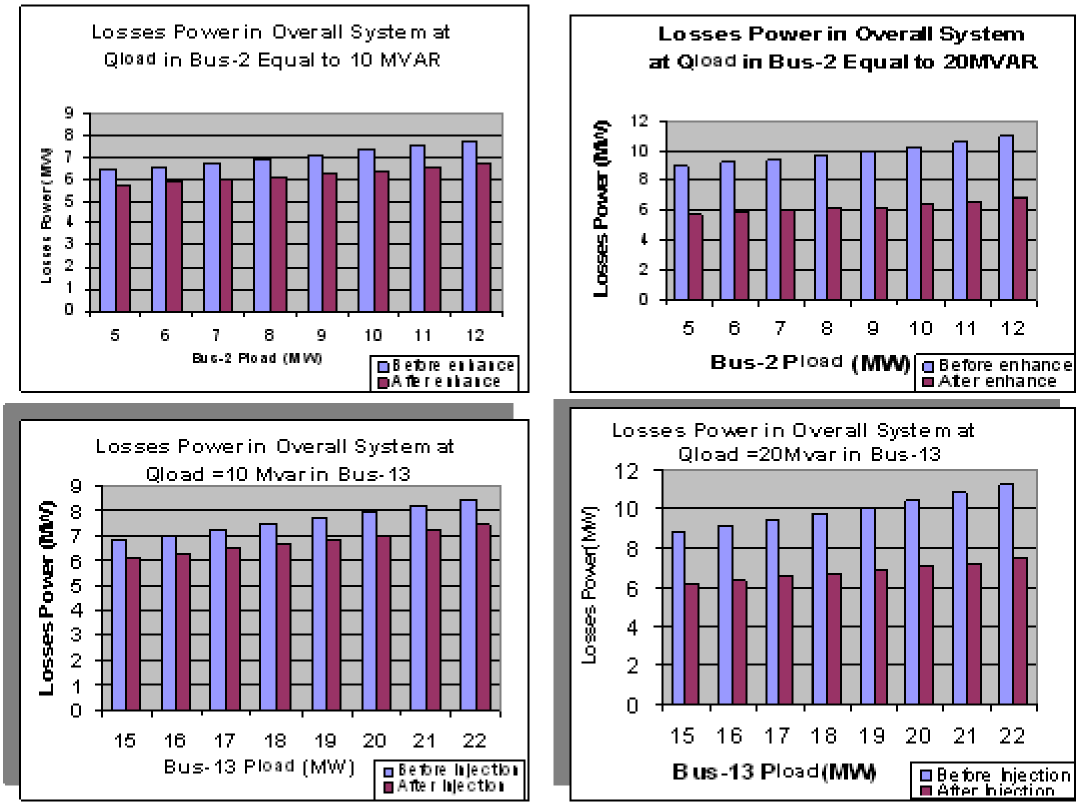

Figure (5) Losses Power in Overall Transmission Power System Table

(3): Simulation results when the future Q_{LOAD} 20Mvar

Bus No.	Future P_{LOAD} (MW)	Required VAR Injection	$\lvert V\rvert$ Before enhance (P.U)	$\lvert V\rvert$ After enhance (P.U)	P_{Losses} Before enhance (MW)	P_{Losses} After enhance (MW)
Bus No.-2	5	19.200	0.7650	0.9501	8.9547	5.7266
	6	19.800	0.7587	0.9501	9.1640	5.8384
	7	20.380	0.7521	0.9500	9.3948	5.9632
	8	21.000	0.7452	0.9500	9.9485	6.1000
	9	21.680	0.7380	0.9504	9.9270	6.2492
	10	22.400	0.7304	0.9509	10.2324	6.4118
	11	23.000	0.7224	0.9505	10.5672	6.5885
	12	23.800	0.7138	0.9514	10.9435	6.7790
Bus No.-13	15	21.800	0.7534	0.9518	8.8446	6.1623
	16	22.400	0.7473	0.9523	9.1187	6.3185
	17	22.800	0.7409	0.9512	9.4128	6.4852
	18	23.500	0.7340	0.9523	9.7349	6.6576
	19	24.000	0.7269	0.9518	10.0768	6.8403
	20	24.400	0.7193	0.9506	10.4457	7.0322
	21	25.000	0.7113	0.9506	108449	7.2317
	22	25.600	0.7028	0.9506	11.2782	7.4402

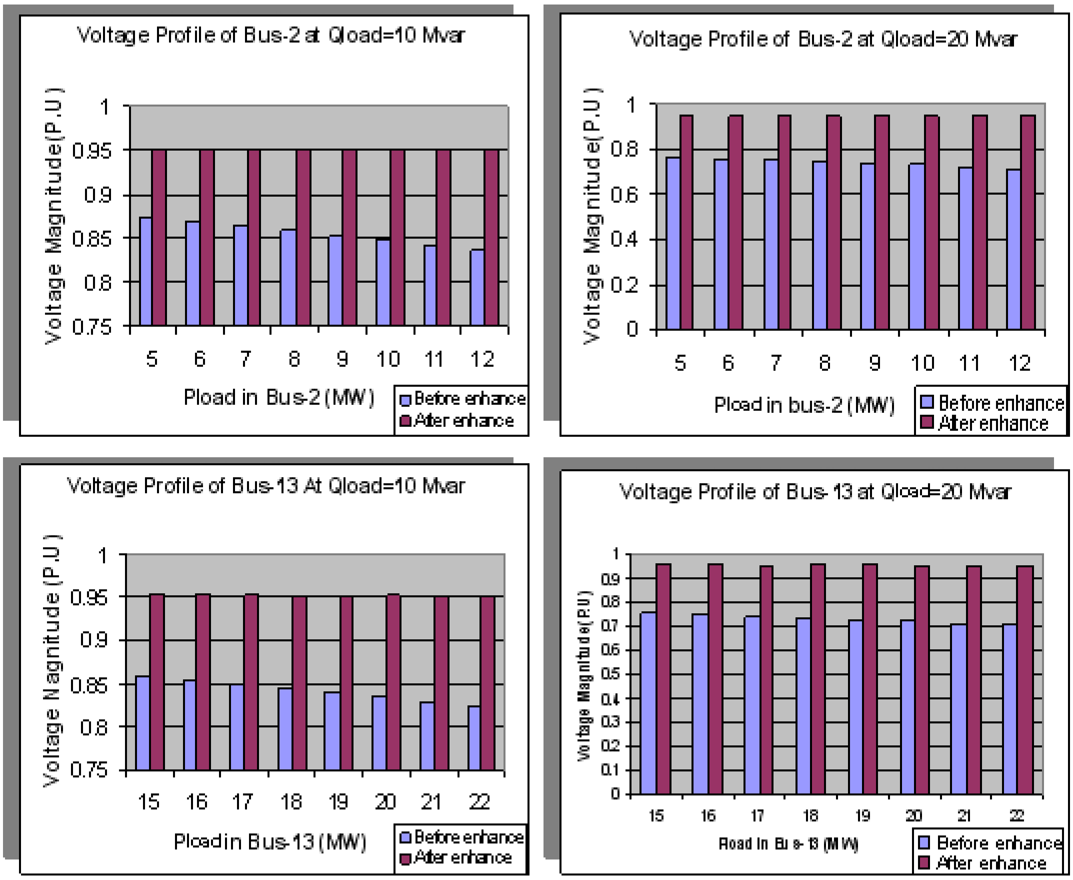

Figure (6): Voltage Profile of Specified Buses

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الخلاصة

البحث الحالي يقدم طريقة مرنة وعملية لتحسين الفولتية في بعض عموميات التوصيل الكهربائية التي تتعرض الى زيادات مختلفة من التحميل نتيجة للتوسعات المستقبلية أو زيادة الأحمال الحالية اضافة الى تقليل الخسائر الكلية في منظومة نقل القدرة الكهربائية. الطريقة المقترحة تتضمن تخمين كمية القدرة المتفاعلة المحقونة اللازمة لتفادي انهيار الفولتية ولتقليل الخسائر في المنظومة في مستويات مختلفة من التحميل, هذه الدراسة أختبرت على منظومة نقل كهربائية مؤلفة من (30) عمومي و (41) خط نقل وتم استخلاص النتائج التي بينت فاعلية الطريقة المقترحة في حل مشكلة انهيار الفولت وزيادة الخسائر.

برامج المحاكاة المقترحة بنيت بأستخدام MATLAB Tool-Box (Ver. 7.5) بالأعتماد على طريقة خفض الأقتران السريعة (Fast Decoupled load flow Method) كأحد الطرق التكرارية المستخدمة في تحليل مشكلة تدفق الحمل في منظومة القدرة الكهربائية.