Improvement Operation of Interconnected Power System

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Abstract

This paper contains a design of transmission lines, transformers and appropriate compensators for a 31-bus interconnected power system. It identifies a new pattern used to improve voltage stability and exposes several key issues that had remained as research challenges in this area. Preliminary data such as bus data, load schedule, standard transformer sizes, line distances and information associated to transmission line including type of conductors and towers has been discussed. Reorganizing the conductors of transmission lines using parallel transformers and utilizing appropriate compensators are some techniques to improve the capacity of network in order to satisfy the assigned load with a good quality of power and increase the stability and reliability of the network. Different power flows has been run accordingly to every changes in the network by using Power World Simulator software (PWS) and used the Full-Newton method power flow. Matlab software has been used to calculate the values of the line inductance and line capacitance.

Keywords: Transmission Line, Parallel Transformers, Compensators, Stability.

الخلاصة

تحتوي هذه الورقة على تصميم الامثل لنظام نقل وتوزيع الطاقة الكهربائية متكون من 31 نقطة (محطة توليد وتوزيع). والتي تمثل نمطا جديدا يستخدم لتحسين الاستقرار الجهد وقد استعرضت العديد من القضايا الرئيسية التي تمثل التحديات البحثية في هذا المجال. ناقشت ايضا البيانات الأولية مثل بيانات النقاط وجدول التحميل وأحجام المحولات المناسبة ومسافات الخط والمعلومات المرتبطة بخط النقل بما في ذلك نوع الموصلات والأبراج وإعادة تنظيم موصلات خطوط النقل باستخدام المحولات المتوازية واستخدام المعوضات المناسبة هي تمثل بعض التقنيات المستخدمة لتحسين قدرة الشبكة من أجل تلبية الحمل المتزايد وزيادة استقرار وموثوقية الشبكة. استخدمت قيم مختلفة من الطاقة المتدفقة وفقا تغييرات الحاصلة في الشبكة باستخدام برنامج Power World Simulator وباستخدام طريقة Full–Newton وايضا تم استخدم برنامج ماتلاب لحساب قيم محاثة ومتسعة الخط.

الكلمات المفتاحية: خطوط النقل، المحولات المتوازية، المعوضات، الاستقرارية.

Nomenclature:

GMD = Geometric Mean Distance or (D), ***d*** is the distance between the centre of adjacent conductor

D_{AB}, D_{BC}, D_{AC} = is the geometric distance between conductors a, b and c

GMR = Geometric Mean Radius or (D_S), ***d*** is the distance between two conductors in the group.

D_{SA}, D_{SB} , D_{SC} = is the distance between two conductors of the same phase.

L= the inductance of each phase mH/Km

XL= the inductive reactance km per phase for the line

B = capacitive susceptance per phase in mho per meter for the line.

r_A, r_B, r_C = is the radius of a conductor in the group

1. Introduction

A salient option in upgrading transmission systems instead of constructing new overhead lines due to the increasing demand is to examine the possible capacity on present sites and to use the maximum capacity of existing transmission systems. The reason is that the lead-times and costs are less than constructing new lines. In this design we tried to use more capacity of the lines by utilizing appropriate compensators (capacitors) and using parallel transformers to prevent transformers from overload situation **(**Pundir *et.al.*, 2016**)**. Using capacitors and other compensators in power systems have many advantages, capacitors especially as compensators are fast acting, reliable and have low maintenance in comparison to the other types of compensators **(**Ibe, *et.al.*, 2013; Tyll *et.al.*, 2009**)**. Low losses in these equipment's also play big role on increasing use of them in the network. They also increase the capacity and transient stability of the network **(**Murugan *et.al.*, 2013**)**. A particular interest is taken to the development of control schemes to avoid so-called voltage collapse, which can result in widespread outages. In order to achieve efficient and reliable operation of power system, the control of voltage and reactive power should satisfy the following objectives **(**Ibe *et.al.*, 2013**)**:

1. Voltages at all terminals of all equipment in the system are within acceptable limits
2. System stability is enhanced to maximize utilization of the transmission system
3. The reactive power flow is minimized so as to reduce R I^2 and X I^2 losses.

Then the types of towers and conductors have been chosen through the calculations and among the given values **(**Preeti *et.al.*, 2013**)**. Calculation of line characteristics has been done with MATLAB software, after calculating the initial values we need the first power flow results to investigate the possible design problems. Initial results show that we need to rearrange different parts of the network. In the first step of this design the network has been divided into two parts Area1 and Area2 and the last step adding compensators to the model by using bundle arrangement, adding parallel transformers and executing the last simulation, it can be seen that the system works in a stable situation.

2. Overall Single Line Diagram

Interconnected electrical power system contains 31- buses have been introduced for transmission line for upgrading analysis. Single line diagram shows electrical system configuration figure 1 and all component and their parameters have illustrated in this system.

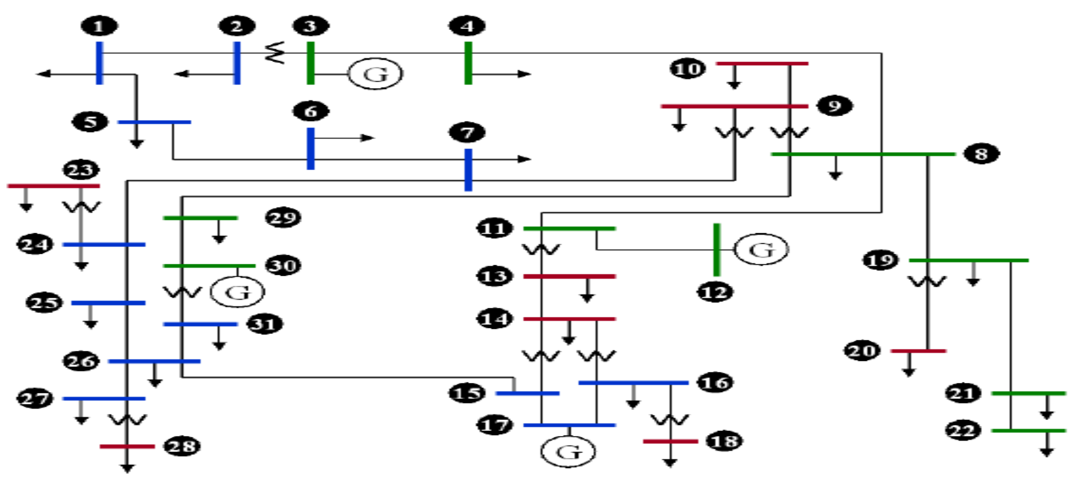


Figure 1: Overall single line diagram.

This system consists of transmission line in three voltage levels which are 69KV, 115KV, and 230KV. Four generators are installed as power generation in bus No. 03, 12, 17, and 30. Several transformers have been used for voltage step down / up of transmission lines and load substations supply in verity of MVAR.

3. Given Data

3.1. Generators data

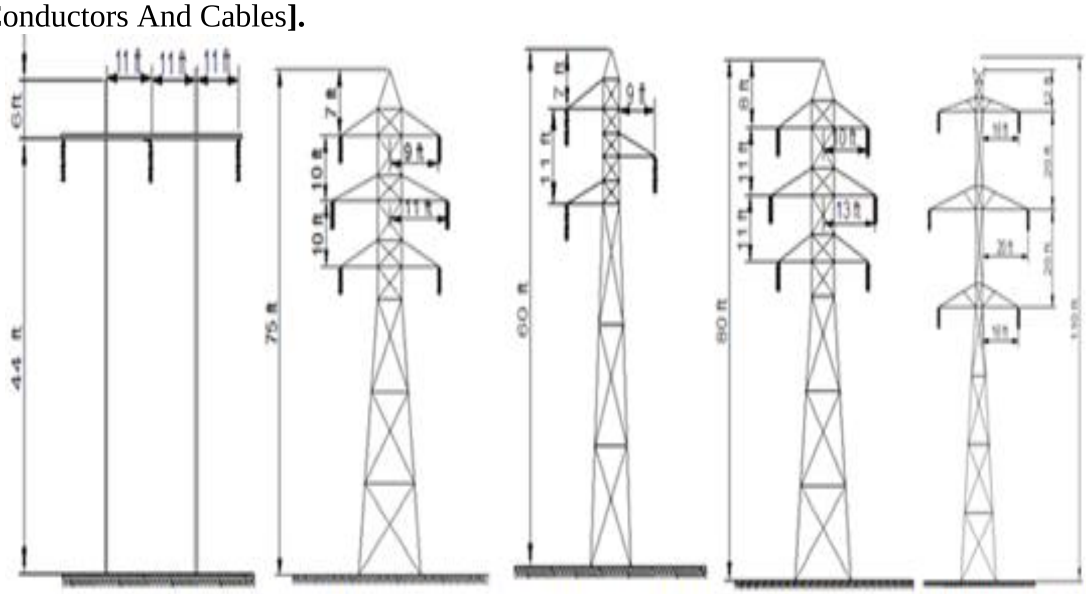
Four generators have been used in this system, maximum output power and related power factor has been given in table 1. As it shown bus no. 30 has been considered as Slack bus in the power system **(**Parul *et.al.*, 2013**)**. Slack bus is a P.U (per unit) bus in the power system, this connected to a generator and has constant voltage value.

Table 1: Generators Specification

Bus Number	bus type	Load Real Power (MW)	Nominal Voltage (Kv)	Power Factor	Maximum Generator Power output
3	PV	300	115	1	300 MW - 0.95 P.F.
12	PV	250	115	1	250 MW - 0.9 P.F.
17	PV	350	230	1	350 MW - 0.9 P.F.
30	SLACK	400	115	1	400 MW - 0.9 P.F.

3.2. Transmission lines data

Transmission lines are divided into the three voltage level. H-Frame, single circuit, and double circuit steel towers have been suggested for tower configuration of transmission line in 69Kv figure (2-a), the same configuration also introduced for 115Kv transmission line tower configurations figure (2-b), finally double circuit steel tower has been suggested for 230Kv tower configurations of overhead transmission lines figure (2-c) **(**Appendix ,2011; Al Salameh *et.al.*, 2010**)**. Several conductors and their parameters were given to choose the best and minimum acceptable conductor size in several voltage levels **(**Al Salameh *et.al.*, 2010; Molburg *et.al.*, 2007**)**. Table 2 illustrates aluminum conductor parameter **[**Catalogue as a guide to standards of Aluminium Rods Bare Conductors And Cables**].**



a- 69Kv H- Freme, 69Kv Double Circuit Steel Tower

b- 115Kv Single Circuit Steel Tower, 115Kv Double Circuit Steel Tower

c- 230Kv Double Circuit Steel Tower

Figure 2: Tower configuration of transmission line.

Table 2: Electrical Characteristics of Bare Aluminum Conductors, Steel-Reinforced (ACSR)

Aluminum Area (Kcmil)	Strands (Al/Fe)	Outside Diameter (inches)	GMR, Ds (ft.)	Approximate Current Carrying Capacity @ 75C°	A.C Resistance @25C° (ohm/ mile) small currents	A.C Resistance @50C° (ohm/ mile) 75% of current capacity
954	54/7	1.196	0.0403	1010	0.0982	0.1128
795	26/7	1.108	0.0375	900	0.117	0.1288
636	54/7	0.977	0.0329	770	0.148	0.1688
556	30/7	0.953	0.0328	730	0.168	0.1859
336	26/7	0.721	0.0244	530	0.278	0.306
266	6/7	0.633	0.00664	460	0.352	0.552

3.3. Transformers data

There are three voltage levels in the interconnected power system which is required to connect. In order to step voltage down/up, 3 sizes of transformer have been given which are chosen based on transformer loads. Minimum and maximum impedance limit in percentage of each transformer with related efficiency in appropriate voltage is the data which is shown in table 3 **(**Russell *et.al.*, 2000; Transformer Handbook from ABB Co., Switzerland**]**. Each transformer is equipped with ON-load tap changer with 2.5% steps for voltage regulating from 0.90 to 1.10 in the high voltage side of transformer.

Table 3: Transformer Specification

H.V. Winding Kv	L.V. Winding Kv	Impedance Limit in Percent		Approximate Efficiency		
		Min.	Max.	at 2 MVA	at 10 MVA	at 50 MVA
115	69	9.0	14.0	98.6%	99.12%	99.45%
230	69	12.5	18.0	98.5%	99.11%	99.44%
230	115	14.0	20.0	98.4%	99.10%	99.44%

3.4. Equations and Parameter Calculations

All parameters like transformer and transmission lines, current and voltage must fulfill margins based on the power system criteria which is between $0.95 \leq V \leq 1.05$ P.U **(**Zhang *et.al.*, 2004**)**. Some actions must be taken to change all equipment which is out of the margin.

According to the design criteria several configuration for transmission have been given to choose the best solution for transmission lines. First step has been taken to choose 69Kv transmission line configurations and the simplest configuration (horizontal configuration). Based on this configuration, all the transmission line parameters have been calculated like Gradient Mean Distance (GMD) and Gradient Mean Radius (GMR) to calculate the line reactance and capacitance is depending on types of conductors **(**Al Salameh *et.al.*, 2010**)**. Equations (1-16) were prepared for the mentioned calculation.

$$GMD = \sqrt[3]{d_{12} d_{13} d_{23}} \qquad (1)$$

$$GMD = D \qquad (2)$$

$$\longrightarrow \begin{cases} GMRl = given \\ GMRc = will\ be\ calculated \end{cases}$$

Equations 3– 6 use for GMD calculation:

$$D_{AB} = \sqrt[4]{D_{a1b1} * D_{a2b2} * D_{a1b2} * D_{a2b1}} \qquad (3)$$

$$D_{BC} = \sqrt[4]{D_{b1c1} * D_{b1c2} * D_{b2c2} * D_{b2c1}} \qquad (4)$$

$$D_{AC} = \sqrt[4]{D_{a1c1} * D_{a1c2} * D_{a2c1} * D_{a2c2}} \qquad (5)$$

$$GMD = \sqrt[3]{D_{AB} * D_{BC} * D_{AC}} \qquad (6)$$

Equations 7 - 10 use GMR calculation:

$$D_{SA} = \sqrt[2]{D_S * D_{a1a2}} \qquad (7)$$

$$D_{SB} = \sqrt[2]{D_S * D_{b1b2}} \qquad (8)$$

$$D_{SC} = \sqrt[2]{D_S * D_{c1c2}} \qquad (9)$$

$$GMR_L = \sqrt[3]{D_{SA} * D_{SB} * D_{SC}} \qquad (10)$$

$$L = 0.2 Ln \frac{GMD}{GMR_L} \frac{mH}{Km} \qquad (11)$$

$$X_L = 2\pi FL \qquad (12)$$

$$B = 2\pi FC \qquad (13)$$

$$r_A = \sqrt{rD_{a1a2}} \qquad (14)$$

$$r_B = \sqrt{rD_{b1b2}} \qquad (15)$$

$$r_C = \sqrt{rD_{c1c2}GMR_C} = \sqrt[3]{r_A r_B r_C} \qquad (16)$$

A 69Kv transmission line has been examined by hand calculation and other lines have been calculated by Matlab software due to the calculation accuracy. Therefore calculation for two circuit transmission line between buses 7 and 24 has been done at 230Kv voltage level **(**Al Salameh *et.al.*, 2010**)**. Based on conductors table 2 the last conductor has been used for calculation and appropriate data has been entered to formula (1-16). Table 4 shows parameters of all transmission line have been entered in three voltage levels.

Table 4: Transmission line parameters

From	To	R	X	B	Lim. A MVA	% of MVA
2	1	0.01629	0.02457	0.13626	366.5	44.2
1	5	0.00652	0.00966	0.05502	366.5	30.3
3	2	0.0011	0.0666	0	50	412.6
3	4	0.09127	0.09085	0.01292	91.6	175.3
4	8	0.0652	0.0649	0.00922	91.6	134.1
5	6	0.01466	0.02172	0.12381	366.5	24.9
6	7	0.01303	0.01931	0.11005	366.5	16.5
9	7	0.00336	0.1798	0	50	91.9
24	7	0.0114	0.02271	0.0963	366.5	19.4
8	9	0.00346	0.1398	0	50	80.6
11	8	0.15635	0.15575	0.02215	91.6	153.2
8	19	0.07824	0.07788	0.01107	91.6	130.2
29	8	0.14334	0.14277	0.0203	91.6	101.1
9	10	0.57805	0.80599	0.01067	55	25.1
12	11	0.16934	0.16873	0.02399	91.6	284.2
11	13	0.00346	0.1398	0	50	74.7
13	14	0.50647	0.49257	0.0093	55	118.3
14	15	0.00336	0.1798	0	50	47.3
14	16	0.00336	0.1798	0	50	91.6
15	17	0.01466	0.02172	0.12381	366.5	93.1
26	15	0.02116	0.03137	0.17889	366.5	65.8
16	17	0.02278	0.03378	0.19266	366.5	23.1
16	18	0.00336	0.1798	0	50	16.2
19	20	0.003	0.0897	0	2	41.4
19	21	0.13033	0.12979	0.01845	91.6	92.3
21	22	0.04198	0.04178	0.00594	91.6	9.1
24	23	0.00336	0.1798	0	50	4.7
24	25	0.00815	0.01207	0.06877	366.5	18.2
25	26	0.01953	0.02896	0.16511	366.5	20.9
26	27	0.01953	0.02896	0.16511	366.5	23.4
31	26	0.01792	0.02654	0.15134	366.5	20
27	28	0.00336	0.1798	0	50	4.6
29	30	0.16924	0.2309	0.02494	91.6	117.3
30	31	0.0033	0.1999	0	50	250.5

Available data for generators such as active power and power factor, we need also reactive power for this system. Equation below was used for calculation of generator's reactive power **(**Hamidreza *et.al.*, 2012**)**:

$$Q = P \times tan\ \varphi \qquad (17)$$

By using equation above we can calculate the sample reactive power for one of the generators. For instance, generator 1 works at maximum active power 300MW at power factor 0.95 then maximum reactive power of generator would be:

$$\mathrm{Q} = 300 \times \tan(\cos^{-1}(0.95)) = 145\ \mathrm{MVAR}$$

Given data related to transformer has nominal power, percentage of impedance, tap changer rating and their efficiency. Power World software version 14 needs also series reactance as same as series resistance, by taking some information from manufacturer catalogue and specifications and also using given data we can get required information for calculation **[**Cahiers Techniques**]**, also load loss of the transformer can be used in this case. Equations (18 and 19) show relation between load loss of transformer and series resistance.

$$R\%pu = \frac{P\ \text{loss full load}}{\sqrt{3}Sbase} \qquad (18)$$

$$Rreal = R\%pu * Zbase \qquad (19)$$

By calculating equations above, real parameters of resistance could be calculated based on equations below and series reactance could be calculated by equations 3 and 4.

$$X\%pu = \sqrt{(UK\%pu)^2 - (R\%pu)^2} \qquad (20)$$

$$Xreal = X\%pu * Zbase \qquad (21)$$

4. Input Data

According to load specification and single line configuration, transformer size, transmission conductor and tower configuration have been chosen, initial data has been entered in (PWS). Based on given data, generators parameters have been entered, required data for generators are maximum, minimum, nominal, active and reactive power. Other generator parameter data has been entered based on hand calculation same as generator 1. It must be mentioned that maximum output active and reactive power equals to nominal generator name plate. Also after finding transmission line parameters option by eqs. (1-16) and transformer parameter by eqs. (18-21), now could be filled in program.

5. Simulation Results

5.1. Preliminary design

After sketching the sample plan of paper in Power World software version 14 the first run was done and the output files obtained, figure 3 illustrates the designed network. As it can be seen some transmission lines and transformers are out of rating and so need to be correct, in addition the majority of the bus bars are out of desired voltage as mentioned before the voltages must be in the range of 0.9 to 1.05P.U. The data in table 5 depicts the status of the generators, nominal output MW/ MVAR and the limits of these amounts. For instance, the generator on bus 3 can deliver 300 MW active power plus 145 MVAR reactive power. However, the minimum margin to generate the reactive power is in the range of -145 to 145 MVAR. The minimum active power output is set for 50% of the generator nominal output because the efficiency of the generator under this ratio is determined that is not economic in this design. In addition, bus 30 was selected as a slack bus; generator connected to this bus manages the extra required or excess energy in the power system.

Table 5: Generator records before revision

Bus No.	Gen. MW	Gen. MVAr	AGC	AVR	Min. MW	Max. MW	Min. MVAr	Max. MVAr	Cost Model
3	300	145	YES	YES	0	300	-145	145	None
12	250	85.28	YES	YES	0	250	-82	82	None
17	350	169	YES	YES	0	350	-169	169	None
30	88.56	210.89	YES	YES	0	400	-193	193	None

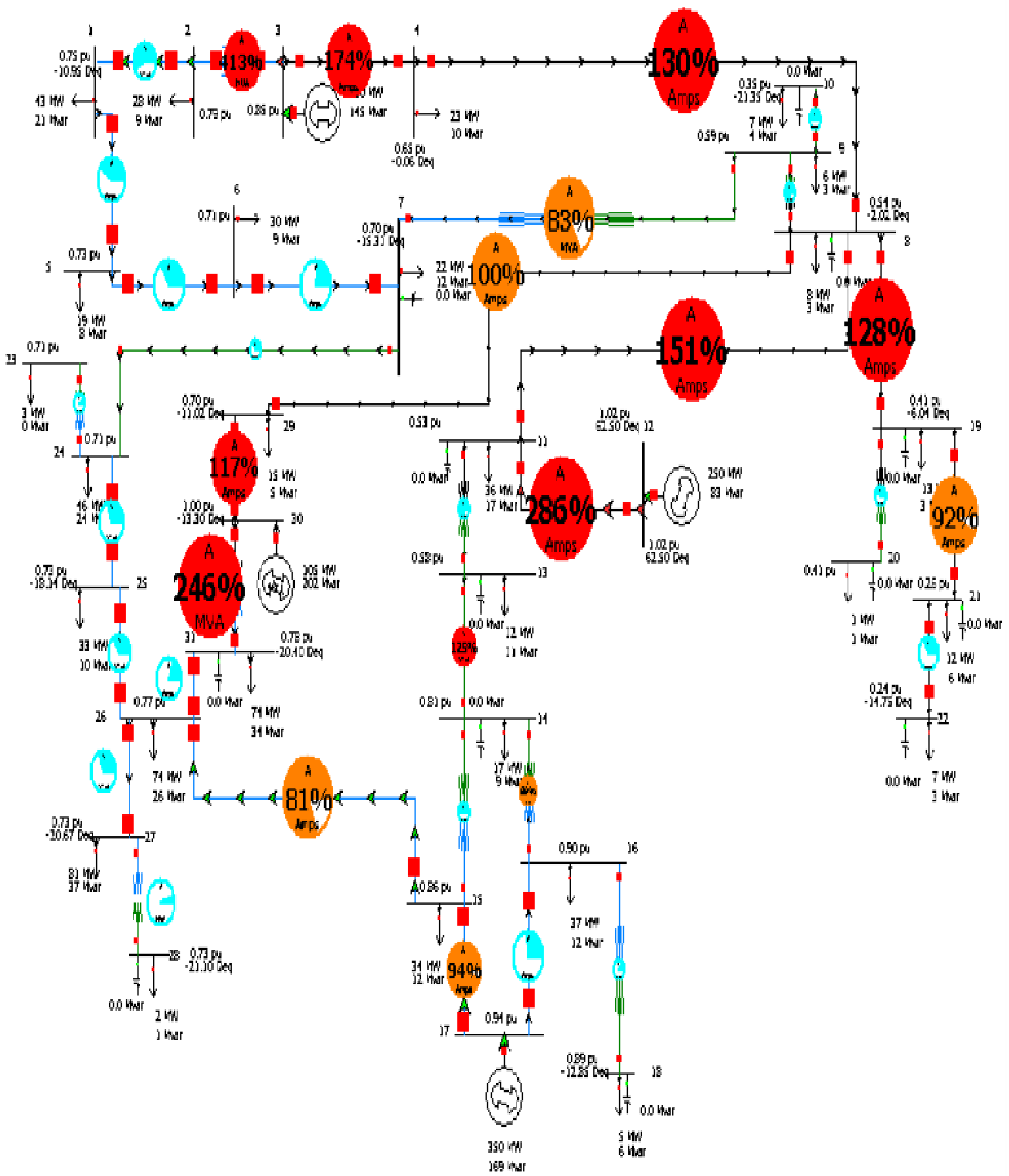


Figure 3: The single-line diagram with determined areas in preliminary design

Table 6 presents the summary of the load in this system; the interconnected buses, area, and the active and reactive power of the loads are collected in this table Similarly, bus records summary in table 7 shows the nominal, per unit, and the angle of the voltage of each bus.

Table 6: Load summary records of the plan

Bus No.	Area	Status	MW	MVAr	MVA
1	One	Closed	43	20.8	47.77
2	One	Closed	28	9.2	29.47
4	One	Closed	22.74	9.68	24.72
5	One	Closed	18.6	8.47	20.44
6	One	Closed	30	8.75	31.25
7	One	Closed	22	12.46	25.28
8	One	Closed	8.26	3	8.79
9	One	Closed	5.93	3.51	6.89
10	One	Closed	8.5	4.81	9.77
11	Two	Closed	36.61	16.67	40.23
13	Two	Closed	11.67	11.03	16.06
14	Two	Closed	16.8	8.6	18.87
15	Two	Closed	34	12.3	36.16
16	Two	Closed	37	12.1	38.93
18	Two	Closed	5.2	6.4	8.25
19	One	Closed	12.82	3.21	13.21
20	One	Closed	0.51	0.58	0.78
21	One	Closed	12.6	6.45	14.16
22	One	Closed	7.28	2.88	7.83
23	One	Closed	2.5	0.35	2.52
24	One	Closed	46	23.5	51.66
25	One	Closed	33	9.6	34.37
26	One	Closed	74	26.1	78.47
27	One	Closed	81	36.9	89.01
28	One	Closed	2.3	0.91	2.47
29	One	Closed	15.3	5	16.1
31	One	Closed	74	33.7	81.31

Table 7: Area summary records before revision

Area No.	AGC Status	Gen. MW	Load MW	Shunt MW	Inter MW	ACE. MW	Loss MW
One	ED	388.56	548.35	0	-300.49	-300.49	140.7
Two	ED	600	141.28	0	285.57	285.57	173.15

As it is known; the large interconnected systems usually have a number of control areas, each control area responsible for the operation of a particular part of the system, often a single control area corresponds to a single owner (such as an investor-owned utility), but it is usual for a single control area to have more than one owner **(**McCalley, 2000**)**. Control areas are connected to neighboring areas through tie lines. A tie line is a transmission line that has one end in one control area and the other end in another one **(**Suman *et.al.*, 2016**)**. Lines between buses 8-11 and 15-26 shown these system tie lines.The total amount of power flowing out of a control area is the algebraic sum of the power flowing out on all the area's tie lines **(**Sundaram *et.al.*, 2011**)**. Each control area is responsible for procuring enough power to meet its own load plus losses. The control area can get this power either by generating it itself or by buying it from another area, this ability to buy and sell power (i.e., power transactions) is one of the principal advantages of interconnected operation **(**Casazza *et.al.*, 2003**)**. Therefore, for this plan, two areas were considered and the required setting for this purposed area was done the dotted are as in figure 4 show the selected area 1 and 2. Table 8 presents the status of the circumstances of each area, in area 1&2 the Automatic Generating Control (AGC) and Automatic Control Energy (ACE) are activated also the summary of the generating, consumption and the losses as well.

Table 8: The records of the bus bars in the first running

Bus No.	Area	Nom. Kv	P.U Volt	Volt (Kv)	Angle Deg.	Load MW	Load MVAr	Gen. MW	Gen. MVAr	Shunts
1	One	230	0.74767	171.964	-8.91	43	20.8			
2	One	230	0.79376	182.564	-5.97	28	9.2			
3	One	115	0.85617	98.459	4.29	0	0	300	145	
4	One	115	0.65288	75.081	1.38	22.74	9.68			
5	One	230	0.73548	169.16	-9.86	18.6	8.47			
6	One	230	0.71333	164.067	-11.76	30	8.75			
7	One	230	0.70015	161.034	-12.97	22	12.46			One
8	One	115	0.54172	62.298	-0.72	8.26	3			One
9	One	69	0.59077	40.763	-9.01	5.93	3.51			
10	One	69	0.37646	25.975	-20.43	8.5	4.81			One
11	two	115	0.53669	61.719	32.54	36.61	16.67			Two
12	two	115	1.0227	117.61	63.14			250	85.28	
13	two	69	0.5715	39.433	23.79	11.67	11.03			0
14	two	69	0.78629	54.254	-11.15	16.8	8.6			0
15	two	230	0.83538	192.137	-11.35	34	12.3			
16	two	230	0.87382	200.978	-8.73	37	12.1			
17	two	230	0.90981	209.257	-8.23			350	169	
18	two	69	0.86037	59.366	-9.39	5.2	6.4			0
19	One	115	0.41516	47.744	-5.04	12.82	3.21			0
20	One	69	0.41378	28.551	-5.2	0.51	0.58			0
21	One	115	0.26557	30.54	-12.75	12.6	6.45			0
22	One	115	0.24855	28.583	-14.45	7.28	2.88			0
23	One	69	0.70478	48.63	-15.46	2.5	0.35			
24	One	230	0.70582	162.338	-14.98	46	23.5			
25	One	230	0.71593	164.663	-15.69	33	9.6			
26	One	230	0.75007	172.517	-16.41	74	26.1			
27	One	230	0.71619	164.724	-18.17	81	36.9			
28	One	69	0.71398	49.265	-18.6	2.3	0.91			0
29	One	115	0.69875	80.356	-10.38	15.3	5			
30	One	115	1	115	-13.3			88.56	210.89	
31	One	230	0.76266	175.413	-18.45	74	33.7			0

In the relation of the amount of losses and lack of co-ordination to comply with the demand, the primary design is not acceptable However, it is anticipated by compensation and clearing the mismatches in transmission lines and transformers in the first simulation, the design is to be satisfactory. Therefore, the compensation is needed to prepare the acceptable quality of power and voltage delivery.

5.2. Revision Steps

Correcting the mismatches in preliminary design need to increase the size of conductors in transmission lines and changing the tower arraignments in some cases. In addition, according to the overload percentages in transformers some of them must be re-rated. However, in relation to the limitation of selecting transformers among 2 to 50 MVA capacities some considerations must be attended.

5.2.1. Transmission Line

Table 4 presents the transmission lines parameters that must be re-rated; line MVA is shown in light red rows and the transformers is highlighted in light green. For more stability, the lines that are close to over capacity also regarded. For instance, the interconnected transmission line between buses 3-4 faced to 174% overload. In accordance with the conductor list and with regarding to the percentage of overcapacity and overdesign for future development the conductors were changed to 900A **[**Catalogue as a guide to standards of Aluminium Rods Bare Conductors And Cables**]**. Therefore, by the help of Matlab, the value of the line inductance and line capacitance are obtained and set in table 9**.** In the first step transmission lines capacities are increased by using the higher current conductors without changing the tower configuration. This measure was helpful for lines between buses 3-4, 8-19, by two –step and 19-21 by four-step increasing. However, in lines between busses 8-11, 11-12 the single circuit replaced by double circuit by increasing two and four step respectively. Moreover, the 2-conductor bundle circuit with the previous current is used for the line between buses 15-17, also line between 13-14, 4-8, 8-29 and 29-30 were corrected by the changes spontaneously. After calculation and setting the new values in Power World software the new layout is obtained in figure 4, it illustrates the new single line. Meanwhile, the new record of the line and transformer capacity is presented in table 9.

Table 9: Transmission lines and transformer's capacity after revision

From	To	R(pu)	X(pu)	B(pu)	Lim A MVA	% of MVA
2	1	0.01629	0.02457	0.13626	366.5	54.7
1	5	0.00652	0.00966	0.05502	366.5	44.1
2	3	0.0033	0.1999	0	50	75
2	3	0.0033	0.1999	0	50	75
2	3	0.0033	0.1999	0	50	75
2	3	0.0033	0.1999	0	50	75
2	3	0.0033	0.1999	0	50	75
2	3	0.0033	0.1999	0	50	75
3	4	0.01907	0.06248	0.00834	179.3	45.5
4	8	0.01512	0.07183	0.00985	145.4	42.1
5	6	0.01466	0.02172	0.12381	366.5	40.2
6	7	0.01303	0.01931	0.11005	366.5	33.4
9	7	0.00336	0.1798	0	50	78.5
24	7	0.0114	0.02271	0.0963	366.5	30.5
8	9	0.00173	0.0699	0	100	63.3
11	8	0.04212	0.08262	0.04683	290.8	60.7
8	19	0.02631	0.08619	0.01151	179.3	52.7
29	8	0.14334	0.14277	0.0203	91.6	41.1
9	10	0.57805	0.80599	0.01067	55	37.1
12	11	0.03141	0.0835	0.05332	358.5	70.9
11	13	0.00346	0.1398	0	50	70.5
13	14	0.50647	0.49257	0.0093	55	42.9
14	15	0.0047	0.1498	0	10	57.2
14	16	0.00336	0.1798	0	50	19.9
15	17	0.00253	0.01231	1.84123	1163.2	27.9
26	15	0.02116	0.03137	0.17889	366.5	61.2
16	17	0.02278	0.03378	0.19266	366.5	13.1
16	18	0.00336	0.1798	0	10	87.3
19	20	0.003	0.0897	0	2	48.1
19	21	0.03022	0.1436	0.01918	145.4	48.2
21	22	0.04198	0.04178	0.00594	91.6	53
24	23	0.0047	0.1498	0	10	25.3
24	25	0.00815	0.01207	0.06877	366.5	16.4
25	26	0.01953	0.02896	0.16511	366.5	10.7
26	27	0.01953	0.02896	0.16511	366.5	24.5
31	26	0.01792	0.02654	0.15134	366.5	20.3
27	28	0.0047	0.1498	0	10	24.8
29	30	0.16924	0.2309	0.02494	91.6	29.8
30	31	0.0033	0.1999	0	50	44.1
30	31	0.0033	0.1999	0	50	44.1

5.2.2. Transformers

In accordance with the limitation for selecting the transformers more than 50 MVA capacity, the number of transformers should increase. Therefore, added transformers must work in parallel case and the parallel considerations should be regarded. In addition, the transformers that worked less than about 50% of their nominal capacities were placed by down size transformers. For example, the transformer between buses 23-24 is working in 4.7% of capacity by referring to table 4 then; it should be replaced with a 10MVA transformer. After replacement the used capacity is changed to 25.3% this measure is taken for transformers between 14-15, 16-18, 24-23, and 27-28 buses, the objects are marked in light blue color in table 9. For temporary overloads and more stability, transforms are designed to work in 80% of their nominal capacity.

5.2.3. Voltage Regulation

According to the table 4 the buses which faced to under voltage should be improved. The usual device for this case is capacitors. In Power World both variable and fixed capacitors are available **[**Power World Simulator Version 14, 2007**]**. Then, by setting the *control regulation settings* in desired value and adjust the *control mode* he buses are equipped by capacitors. On the base of table 10, on the buses 7, 8,10,14,22, and 31 the continuous shunt capacitors were embedded, and the fixed shunt reactor to control the generator on bus 17. By this reactor the MVAR absorption of generator is decrease and generator works on steady-state. The continuous mode only adds the -71.5 MVAR to grid that causes the transformer between buses 14-15 encounters to overload and the capacity of Generator on bus 17 changes to -135 MVAR.

Table 10: The compensation records after installing the shunt switches

Bus	Control Mode	Actual MVAr	Volt High	Volt Low	Reg. Volt	Nominal MVAr
7	Continuous	120	1.05	0.95	1	120
8	Continuous	129.6	1.05	0.95	1	129.6
10	Continuous	21.25	1.05	0.95	1	21.25
14	Continuous	9.59	1.05	0.95	0.9793	10
17	Fixed	-286.2	1.05	-	0.9767	-300
22	Continuous	48.41	1.05	0.95	0.984	50
31	Continuous	27.87	1.05	0.95	0.9639	30

6. Final Design Records

In this section the final design and records are presented and discussed. Figure 4 illustrates the single line layout of the plan after revision. Table 11 presents the generator records after revision.

Table 11: Generator records after revision

Bus No.	Gen. MW	Gen. MVAr	AGC	AVR	Min. MW	Max. MW	Min. MVAr	Max. MVAr
3	300	-45.8	YES	YES	150	300	-145	145
12	250	-32.52	YES	YES	125	250	-82	82
17	286.92	59.4	YES	YES	175	350	-169	169
30	2.2	61.89	YES	YES	0	400	-193	193

Table 12 depicts the area records after revision according to the figure 4 area one receives 352.58 MW from area two. If the connected generator to bus 12 suddenly trips then other generators in area one feed the loads in area two.

Table 12: Area records after revision

Name	AGC Status	Gen. MW	Load MW	Int. MW	ACE MW	Loss MW	Auto Shunts	Auto XF
One	ED	301.44	610.3	-354.4	-352.58	45.55	YES	YES
Two	ED	536.93	147.7	354.4	352.59	34.82	YES	YES

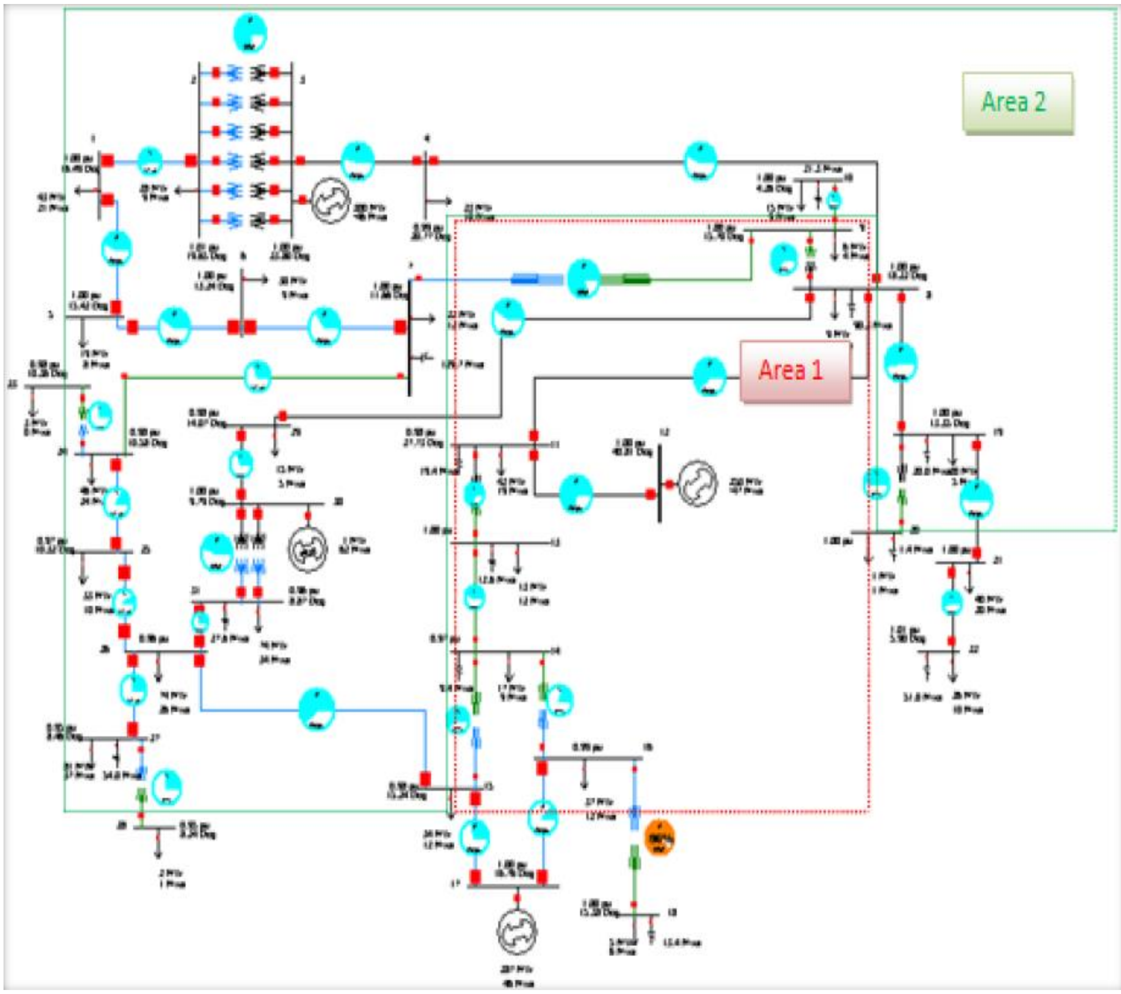


Figure 4: The single-line diagram of the plan with determined areas after revision

The values of the regulated voltage in bus bars by transformer tap changing are shown in table 13. All values are in the range of 0.95 to 1.01P.U. Table 14 shows the review of the design values nominal and actual voltage, power angle, load consumption and generation, and shunt compensation MVAR are presented in this table.

Table 13: Value of the bus voltages after regulation by tap changer of the transformers

From	To	Tap Ratio	Reg. Bus	Reg. Value	Reg. Min.	Reg. Max.	Tap Min.	Tap Max	Step Size
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
2	3	1	2	1.0135	0.95	1.05	0.9	1.1	0.025
9	7	1	9	1.00159	0.95	1.05	0.9	1.1	0.025
8	9	1	8	1	0.95	1.05	0.9	1.1	0.025
11	13	1	11	0.9721	0.95	1.05	0.9	1.1	0.025
14	15	1	14	0.9793	0.95	1.05	0.9	1.1	0.025
14	16	1	14	0.9793	0.95	1.05	0.9	1.1	0.025
16	18	1	16	0.98472	0.95	1.05	0.9	1.1	0.025
19	20	1	19	0.97861	0.95	1.05	0.9	1.1	0.025
24	23	1	24	0.98059	0.95	1.05	0.9	1.1	0.025
27	28	1	27	0.95817	0.95	1.05	0.9	1.1	0.025
30	31	1	30	1	0.95	1.05	0.9	1.1	0.025
30	31	1	30	1	0.95	1.05	0.9	1.1	0.025

Table 14: The summary of grid values after revision

Bus	Area	Nom Kv	PU Volt	Volt Kv	Angle Deg.	Load MW	Load MVAr	Gen. MW	Gen. MVAr	Shunts MVAr
1	One	230	0.99769	229.468	16.62	43	20.8			
2	One	230	1.0135	233.105	19.78	28	9.2			
3	One	115	1	115	23.92	0	0	300	-45.76	
4	One	115	0.9916	114.034	20.88	23	9.79			
5	One	230	0.99594	229.066	15.55	18.6	8.47			
6	One	230	0.99577	229.026	13.38	30	8.75			
7	One	230	1	230.001	11.81	22	12.46			120
8	One	115	1	115	18.32	9.4	3.41			129.6
9	One	69	1.00159	69.11	15.8	6.3	3.73			
10	One	69	1	69	4.36	15.2	8.61			21.25
11	Two	115	0.9721	111.791	28.3	42	19.13			0
12	Two	115	1	115	41.29			250	-33.51	
13	Two	69	0.97747	67.446	25.58	12.7	12			0
14	Two	69	0.9793	67.572	14.64	16.8	8.6			9.59
15	Two	230	1.00365	230.84	14.2	34	12.3			0
16	Two	230	0.98472	226.487	15.21	37	12.1			
17	Two	230	1.00001	230.002	15.99			286.92	-163.37	
18	Two	69	0.97267	67.114	14.67	5.2	6.4			0
19	One	115	0.97861	112.54	13.71	19.9	4.98			0
20	One	69	0.97775	67.464	13.67	0.8	0.91			0
21	One	115	0.97914	112.601	7.62	40	20.49			
22	One	115	0.98398	113.158	6.02	26	10.27			48.41
23	One	69	0.97993	67.615	10.45	2.5	0.35			
24	One	230	0.98059	225.535	10.68	46	23.5			
25	One	230	0.97421	224.069	10.37	33	9.6			
26	One	230	0.96514	221.982	10.23	74	26.1			
27	One	230	0.95817	215.78	9.08	81	36.9			0
28	One	115	0.9566	109.94	8.86	2.3	0.91			
29	One	115	0.97673	112.324	14.12	15.3	5			
30	One	115	1	115	9.79			0.44	57.33	
31	One	230	0.96388	221.691	8.88	74	33.7			27.87

7. Conclusion

Generally, reactive power compensation requires a perfect system analysis for the optimization of compensator sizes and their location in the power system. Accomplishing this goal takes numerous steps in the specified 31 interconnected bus; taking which into account the system has been simulated for examining the best power system configuration. The first step is to look for component data and parameters, for instance by choosing the transformer size and finding its parameter from famous manufacturer like Siemens and ABB, transformer data as per unit of resistance and reactance have been collected and analysed. Another step was associated to the transmission line parameter which required the transmission configuration and all parameters have been calculated after transmission line obtaining. By simulation and strengthen of design were discussed for improvements. Established on calculation tables, voltage of some busses failed to fulfill design criteria margins and also some transformers and transmission lines were faced with overload. In this cases minimum size of capacitors bank and also reactor have been chosen and several parallel transformer, two circuits, and bundle transmission line have been introduced with required changes in the critical points also used of tap changing transformer in terms of automatic voltage regulator (AVR) is to varies the tap until meet the specification of certain requirement to regulate bus voltage. In addition interconnected power system which was divided into the two areas works properly with these modification and desired responses have been taken from last simulation which was reported on detailed simulation result at index after which a precise and accurate system is presented in the end.

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