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A CASE STUDY ON IEEE-14 BUS SYSTEM WITH AN EMPHASIS ON OPTIMISED REACTIVE POWER COMPENSATION

[1]*Priyanka S Kole*

[1]*Assistant Professor, New Horizon College of Engineering, Bangalore*

Abstract:

Reactive Power is an important factor in the design and operation of alternating current system. Reactive power compensation is all about maintaining balance between the generated reactive power and absorbed reactive power by some of the compensating devices like shunt capacitor. Thus, the paper includes Reactive power compensation and optimization study of ieee-14 bus system using MiPower software package. The results have been obtained for different cases and satisfactory conclusion is drawn in this regard.

I.INTRODUCTION

For efficient and reliable operation of Power system, the control of voltage and reactive power is done with following objectives:

- Voltage at terminals of all the equipments in system is within acceptable limits.
- System stability is enhanced to maximize utilisation of the transmission system.
- The reactive power flow is minimised so as to reduce I^2R and I^2X losses to a practical minimum.

Since load is dynamic quantity it alters the voltage in the system which further fluctuates reactive power requirements of the system. This necessitates the compensation of reactive power as per the load conditions. Since it cannot be transmitted over long distances. Thus, certain devices are used to compensate this reactive power hence, are dispersed through the system. Some of devices are series and shunt reactors, series and shunt capacitors, synchronous condensers and SVC. In this paper passive compensation provided by shunt capacitor is discussed and the optimised uses of these shunt capacitors for reactive power compensation is an additional observation from case study.

II. DESCRIPTION AND RESULTS OF THE CASE STUDY

The case study on IEEE-14 Bus system is carried out as follows:

- The 14-Bus system is drawn in power system network editor of Mi-Power tool using built-in library components and using data as per Table.1, Table.2 & Table.3, 4.

Bus number	Bus voltage		Generation		Load		Reactive power limits	
	Magnitude (p.u.)	Phase angle (degree)	Real power (MW)	Reactive power (MVAR)	Real power (MW)	Reactive power (MVAR)	Q_{min} (MVAR)	Q_{max} (MVAR.)
1	1.060	0	114.17	-16.9	0	0	0	10
2	1.045	0	40.00	0	21.7	12.7	-42.0	50.0
3	1.010	0	0	0	94.2	19.1	23.4	40.0
4	1	0	0	0	47.8	-3.9	-	-
5	1	0	0	0	7.6	1.6	-	-
6	1	0	0	0	11.2	7.5	-	-
7	1	0	0	0	0	0	-	-
8	1	0	0	0	0	0	-	-
9	1	0	0	0	29.5	16.6	-	-
10	1	0	0	0	9.0	5.8	-	-
11	1	0	0	0	3.5	1.8	-	-
12	1	0	0	0	6.1	1.6	-	-
13	1	0	0	0	13.8	5.8	-	-
14	1	0	0	0	14.9	5.0	-	-

- Table.1: Bus data { IEEE 14 bus system}

Line number	From bus	To bus	Line impedance (p.u.)		Half line charging susceptance (p.u.)	MVA rating
			Resistance	Reactance		
1	1	2	0.01938	0.05917	0.02640	120
2	1	5	0.05403	0.22304	0.02190	65
3	2	3	0.04699	0.19797	0.01870	36
4	2	4	0.05811	0.17632	0.02460	65
5	2	5	0.05695	0.17388	0.01700	50
6	3	4	0.06701	0.17103	0.01730	65
7	4	5	0.01335	0.04211	0.00640	45
8	4	7	0	0.20912	0	55
9	4	9	0	0.55618	0	32
10	5	6	0	0.25202	0	45
11	6	11	0.09498	0.1989	0	18
12	6	12	0.12291	0.25581	0	32
13	6	13	0.06615	0.13027	0	32
14	7	8	0	0.17615	0	32
15	7	9	0	0.11001	0	32
16	9	10	0.03181	0.0845	0	32
17	9	14	0.12711	0.27038	0	32
18	10	11	0.08205	0.19207	0	12
19	12	13	0.22092	0.19988	0	12
20	13	14	0.17093	0.34802	0	12

Table.2 Line data {IEEE 14 bus system}

Bus number	Susceptance (p.u.)
9	0.19

Table.3 Shunt capacitor data {IEEE 14 bus system}

From bus	To bus	Tap setting value (p.u.)
4	7	0.978
4	9	0.969
5	6	0.932

Table.4: Transformer tap setting data {IEEE 14 bus system}

- With this network LFA (Load Flow Analysis) with FDLF (Fast Decoupled Load Flow) method is carried out and the results of such a load flow are tabulated as in Table.5. By this step most fluctuating loads are indentified where the reactive power compensation is carried out. The loads at the buses 9, 13, & 14 are taken for analysis.

Total Real Power Generation (Conventional)	272.804 MW
Total Real Power Injection (-Ve Load)	0.000 MW
Total Reactive Power Generation (Conventional)	78.873 MVAr
Generation power	0.961
Total Shunt Reactor Injection	-0.000 MVAr
Total Shunt Capacitor Injection	21.189 MVAr
Total Real Power Load	259.370 MW
Total Reactive Power Load	73.624 MVAr
Load Power Factor	0.962
Total Compensation At Loads	0.000 MVAr
Total Real Power Loss (AC+DC)	13.439753 MW
Total Reactive Power Loss	26.438631 MVAr

Table.5 Load flow results of IEEE-14 Bus system

- Now the loads at buses 9, 13, 14 are varied such that 75%, 95%, 100%, 105%, 110%,65% of the load is applied across the loads at buses 9,13 & 14.With this data optimal load flow analysis is carried out with shunt capacitor connected at the bus 9.The results of such an analysis along with shunt capacitor compensation is tabulated in Table.6 ,Table.7, Table.8 & 9 respectively. A Shunt Capacitor supply reactive power to counteract the out-of-phase component of current required by an inductive load i.e. it modify characteristics of an inductive load by drawing a leading current which counteract all lagging component of inductive load current at point of installation. Thus magnitude of source current is reduced and power factor is improved also voltage drop is reduced there by contributing voltage rise. From above table it can be noted that as percentage load increases voltage across bus9 reduces indicating less compensating MVAr requirement. And as the percentage load decreases voltage across bus 9 increases which indicate more reactive MVAr requirement by load (as shown in Table.7).

Case No.	Load Bus No.	MW	Pf	Min Compensation Mvar	Max compensation Mvar	Compensation step
1	9	45	0.7	0	50	1
	13	13.5	0.75	0	50	1
	14	30	0.75	0	50	1
2	9	45	0.7	0	50	1.5
	13	13.5	0.75	0	50	1
	14	30	0.75	0	50	1

Table.6: Reactive Power Optimization case details

%Load	65	75	95	100	105	110
Voltage(pu)	1.0713	1.0620	1.0583	1.0560	1.0537	1.0486
MVAr required	21.8071	21.6320	21.2797	21.1890	21.0973	20.8922

Table.7 Compensation for bus voltage at bus-9 by shunt capacitor

%Load	Pg(MW)	Qg(MVAr)	Pd(MW)	Qd(MVAr)	Pg(MW)	Q_l(MVAr) (inductive)	Q_cMVAr (Capacitive)
65	173.8170	19.2513	168.7215	47.8997	5.0977	-6.8399	21.8071
75	201.6557	34.5105	194.6357	55.2544	7.0204	0.8883	21.6320
95	258.3881	69.2541	246.4289	69.9522	11.9632	20.5818	21.2797
100	272.8038	78.8734	259.3696	73.6240	13.4398	26.4386	21.1890
105	287.3155	88.8781	272.3070	77.2948	15.0158	32.6807	21.0973
115	316.6449	110.2114	298.1688	84.6320	18.4760	46.4708	20.8922
Single line outage	273.0985	85.0899	259.3785	73.6270	13.7248	32.7045	21.2415
Double line out	264.9556	81.1680	259.2277	73.5764	5.7271	7.5917	0
Generator outage	275.4488	110.8861	259.0947	73.5318	16.3491	37.3526	0

Table.8 Optimal Load flow Results

Case No.	Bus No.	Final Compensation(MVAr)	Original voltage (p.u)	Final Voltage (p.u)
1.	9	-	1.056	0.9520
	13	-	1.0503	0.9836
	14	31	1.0351	0.9509
2.	9	25.5	1.056	0.9855
	13	-	1.0503	0.9931
	14	15.00	1.0351	0.9489

Table.9 Reactive Power optimization Results

- With this in view, present worth is calculated for compensating equipment i.e. shunt capacitor. Present worth of any equipment describes the present value and equivalent future value of the equipment considering its total life (in years), operation and maintenance cost. This value is very important for optimised reactive power compensation. Hence, the study further progresses by defining two cases of reactive power optimisation as given in Table.8.with each of these cases separately analysed using tool will result into content given in the Table.8. For both these cases theoretical calculations of present worth of equipment is in accordance with simulation results as shown in Table.10.

Case No.	Present Worth(in Rs) (Obtained by Simulation)	Present Worth(Rs) (Theoretical Calculation)
1	107152581.6	107152581
2	1225409.415	1225409.44

Table.10 Present Worth calculation for the Reactive power Compensating equipment (i.e. shunt capacitor)

Optimal Load Flow Data used in MiPower Tool

- Cost per MVAr (in lakh) = 5
- %Operation and Maintenance charge = 4
- %Interest charge = 15
- Loss load factor = 0.3
- Life of equipment (in years), n = 20
- Energy Charge = 2.5 Rs/kwh

Theoretical Calculations:

CaseI:

- Annual investment on capacitor banks = (Total compensation, MVAr) * (Cost per Capacitor, MVAr)* (O&M charge)/100
  = (31*5*4) / 100 = Rs 6.2 lakh
- Annual Saving(X) = (Annual income due to loss reduction) – (Annual expenditure on capacitor Banks)
  = 17738854 – 620000 = 17118854 Rs
- Present Worth of Saving = {((1+i)^n) - 1.0/(i*(1+i)^n)} * X
  (P.W) = {((1+15) ^ 20)-1/(15*(1+15)^20)}*17118854
  = 107152581.6 Rs

CaseII:

- Annual investment on capacitor banks = (Total compensation, MVAr) * (Cost per Capacitor, MVAr) * (O&M charge) /100
  = (40.5*5*4)/100 = Rs 8.1 lakh
- Annual Saving(X) = (Annual income due to loss reduction) – (Annual expenditure on Capacitor Banks)
  =20387321 - 810000 = Rs 19577321
- Present Worth of Saving= {((1+i)^n)-1.0/(i*(1+i)^n)}*X
  (P.W) = {((1+15)^20)-1.0/(1+15)^20}*19577321
  = Rs 1225409.415

It is observed that P.W for case1 is more than that for case2 hence, case2 is better for reactive power optimization since it accounts more net annual saving. Also, voltage profile is improved in case2 than in case1. Hence, providing compensation for the loads at buses 9, 13, 14 as in case 2 helps to maintain system stability by maintaining voltage profile near to constant value.

III. CONCLUSION:

This case study on IEEE-14 bus system using MiPower tool satisfactorily explains the optimized reactive power compensation as proved above. Thus this paper can be a value addition to the existing literature on reactive power optimization.

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