Effect of series and shunt compensation of a given 380 kV power system network

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One of the most effective units of power system network is Static-Var Compensator (SVC) if it is used as series, parallel or combined compensator. Series compensation improves system regulation and transmission load ability, whereas shunt compensation (as capacitance) reduces feeder currents and hence feeder cross-sectional area which leads to the reduction of feeder costs. These types of compensation reduce generating MVA and MVAR. The reduction in system MVAR helps electrical companies to transmit more power and absorbing more customers without expanding power network. This paper shows the maximum amount of reduction in generating MVA that can be achieved by the use of the three types of compensations on 380 kV practical power system network for electrical company of the western region of Kingdom of Saudi Arabia by the use of computer Fortran program.

إن من أهم الوحدات المستخدمة في أنظمة شبكات الطاقة الكهربائية تدعى المعادل الساكن للقدرة المفاعلية ذات التأثير على كمية الطاقة الكهربائية عند استخدامه على التوالي أو التوازي أو على الوضعين معا. فإذا استخدم على التوالي تحسنت كمية نقل الطاقة الكهربائية وقل معدل الفاقد في الجهد الكهربائي بينما لو استخدم على التوازي كمكثف فإن كمية التيار المطلوبة تقل و تقل معه مساحة مقطع الخطوط الكهربائية وبالتالي تقل تكلفة هذه الخطوط. إن استخدام هذا المعادل يقلل من الكمية المطلوبة لإنتاج الطاقة الكهربائية من المولدات ويرفع سعة الخطوط لنقل كمية أكبر من الطاقة الكهربائية وبالتالي يزيد من استيعاب عدد أكبر من المستهلكين دون الحاجة لتوسيع الشبكة. إن هذه الورقة العلمية توضح كم من الطاقة يمكن توفيرها عند استخدام المعادل في أوضاعه الثلاثة على شبكة ٣٨٠ ك ف حقيقية لشركة الكهرباء السعودية بالمنطقة الغربية باستخدام برنامج كومبيوتر مكتوب بلغة فورتران.

Keywords: SVC, Compensation, Regulation, Transmission line, Generation, Substation

1. Introduction

It is well known that the power system units are costly units though future demand can be met either by increasing the number of generating units or building new transmission systems or both [1,2]. The proposed study helps to increase the efficiency of the existing power system network to some extent. This can be done by the use of Static VAR Compensator (SVC) in different connections. The study has been classified into three types; series shunt and combined compensation. Series compensation helps in increasing transmission line load ability, shunt compensation (as capacitance) helps in improving system power factor and combined compensation helps in taking advantages of both techniques. Above all previous advantages the computer output shows good reduction in system MVA generation by implementing SVC, which means more customers can be absorbed without increasing generation input power. The load flow used by computer program is based on Newton-Raphson method.

2. Compensation techniques

The 380 kV system under investigation consists of 12 buses, 7 cables, 16 transmission lines and several generating units as shown in fig. 1. To carry out compensation techniques, the output of load flow of computer program should be compatible with the practical system load flow of the electrical company. This step has been done successfully as shown in table 1. The second step is to carry out each type of compensation on the 380 kV power system network individually. The data given by electrical company, which represents the maximum demand, is for the eleventh of September 1999 at 03.00 pm.

The three types of compensations have been achieved as follows.

2.1. Series compensation

Series compensation is usually used to compensate up to 70% of transmission line reactance to increase line load ability. It is well known that maximum power transfer can be accomplished if transmission line reactance decreased to the lowest possible value [3], fig2.

The equation, which governs this relationship can be written as:

$$P_{max} = |E1|\ |E2|\ /\ X .$$

where:

$E1$ is the voltage of generation bus,
$E2$ is the voltage of infinite bus, and
X is the transfer reactance between $E1$ and $E2$.

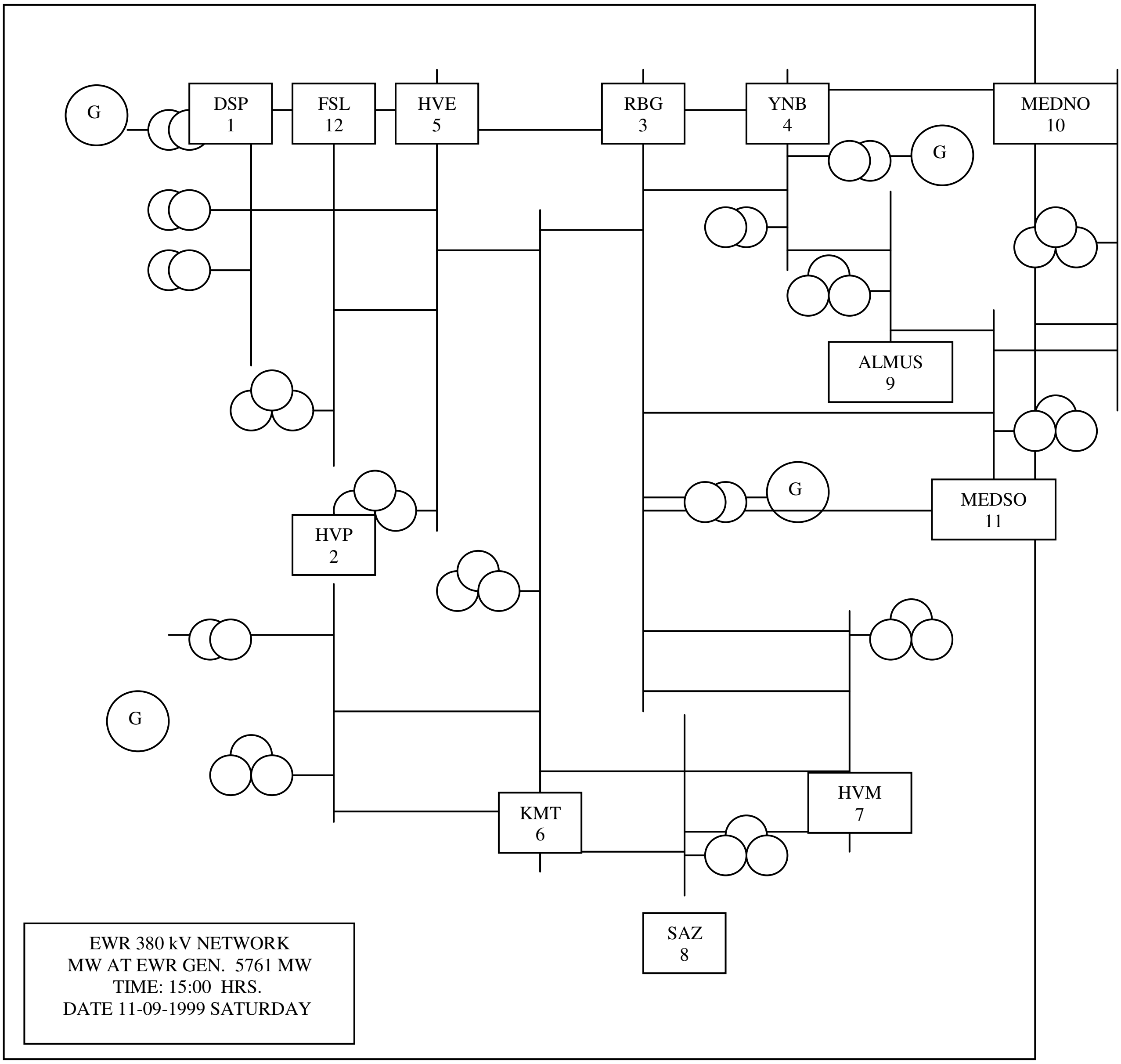

Fig. 1. 380 kV power network.

Table 1
Input/output data for 380 kV system

Buses	lines	MVA	Tolerance	
12	23	1000.0	0.0010	Test.Net

No	Bus	Bus	R	X	B
01	001	012	0.0012	0.0336	0.2639
02	001	012	0.0012	0.0336	0.2639
03	005	012	0.0004	0.0128	0.1004
04	005	012	0.0004	0.0128	0.1004
05	005	012	0.0004	0.0128	0.1004
06	002	006	0.0012	0.0312	0.2446
07	002	006	0.0011	0.0312	0.2442
08	003	005	0.0208	0.3572	0.0985
09	003	006	0.0220	0.3766	0.1039
10	003	004	0.0258	0.4709	0.1375
11	003	004	0.0258	0.4709	0.1375
12	004	009	0.0217	0.2215	0.0569
13	004	010	0.0420	0.4282	0.1100
14	006	005	0.0032	0.0549	0.0151
15	007	006	0.0080	0.1567	0.0420
16	008	006	0.0102	0.2009	0.0538
17	007	008	0.0060	0.1180	0.0316
18	003	011	0.0322	0.6659	0.1703
19	003	011	0.0322	0.6659	0.1703
20	009	011	0.0226	0.2307	0.0593
21	011	010	0.0128	0.1309	0.0336
22	003	007	0.0222	0.4112	0.1160
23	003	007	0.0222	0.4112	0.1160

Bus	Type	V	angle	PL	QL	Pg	Qg	Qmin	Qmax
01	2	.976	0.00	0.5450	0.0970	0.5660	0.0000	-10.00	00.340
02	2	.987	0.00	0.3280	0.4720	0.5310	0.0000	-10.00	00.320
03	1	1.05	0.00	0.0001	0.1290	0.0000	0.0000		
04	2	1.00	0.00	0.0620	0.3760	0.2420	0.0000	-10.00	00.165
05	3	1.00	0.00	0.4700	0.2890	0.0000	0.0000		
06	3	1.00	0.00	0.6040	0.3750	0.0000	0.0000		
07	3	1.00	0.00	0.0860	0.0060	0.0000	0.0000		
08	3	1.00	0.00	0.3100	0.1140	0.0000	0.0000		
09	3	1.00	0.00	0.0500	0.0220	0.0000	0.0000		

(b) Line Flows

Line no.	Sending end bus	Receiving end bus	Sending-end P(pu)	Sending-end Q(pu)	Receiving-end P(pu)	Receiving-end Q(pu)	Maximum I(pu)
1	1	12	0.0105	0.0162	0.0105	0.2656	0.2737
2	1	12	0.0105	0.0162	0.0105	0.2656	0.2737
3	5	12	0.2190	0.0285	0.2190	0.1226	0.2584
4	5	12	0.2190	0.0285	0.2190	0.1226	0.2584
5	5	12	0.2190	0.0285	0.2190	0.1226	0.2584
6	2	6	0.1015	-0.1030	0.1015	0.1348	0.1710
7	2	6	0.1015	-0.1025	0.1015	0.1349	0.1711
8	3	5	0.6446	0.2071	0.6354	0.1512	0.6719
9	3	6	0.5434	0.1403	0.5367	0.1339	0.5608
10	3	4	0.0552	0.0332	0.0549	0.1714	0.1799
11	3	4	0.0552	0.0332	0.0549	0.1714	0.1799
12	4	9	0.1498	0.0202	0.1493	0.0709	0.1675
13	4	10	0.1399	0.0506	0.1386	0.1421	0.2088
14	6	5	0.4924	0.2254	0.4915	0.2231	0.5552
15	7	6	0.3166	0.1145	0.3157	0.1380	0.3493
16	8	6	0.0410	0.0064	0.0410	0.0585	0.0725
17	7	8	0.3518	0.1047	0.3510	0.1203	0.3735
18	3	11	0.1233	0.0367	0.1223	0.1906	0.2344
19	3	11	0.1233	0.0367	0.1223	0.1906	0.2344
20	9	11	0.0992	0.0489	0.0989	0.1017	0.1468
21	11	10	0.0365	0.0969	0.0363	0.1258	0.1378
22	3	7	0.3804	0.0480	0.3772	0.1123	0.3902
23	3	7	0.3804	0.0480	0.3772	0.1123	0.3902

(c) Total System Flow

Generation P(pu)	Generation Q(pu)	Load P(pu)	Load Q(pu)	Losses P(pu)	Losses Q(pu)	Mismatch P(pu)	Mismatch Q(pu)
3.645	1.212	3.615	3.433	0.030	-2.220	0.000	-0.001

* Load-flow output (Newton-Raphson method conversed on 2 iterations) *

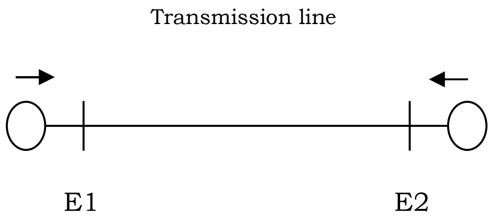

Fig. 2. Schematic diagram for load transfer.

Another advantage of series compensation is the reduction in MVA generation caused by imposing this type of compensation. The system data of fig. 1 has been run by the computer program to compensate all the sixteen lines individually to show which of the compensated line can give better reduction in MVA generation. Table 2 shows that lines between buses 3-7 (RBG-HVM) give better reduction in MVA equivalent to 0.83% (31 MVA) of the total system generation before compensation (3841MVA). Similarly, the previous process is repeated but now for each two lines simultaneously in different substations to find out the best two compensated lines give higher reduction in MVA generation. Table 2 shows that lines between buses 3-7 (RBG-HVM) and buses 3-5 (RBG-HVE) give better reduction in MVA equivalent to 1.15% (45 MVA) of the total system generation (3841MVA). For three different compensation the computer program shows that the best three lines to be compensated are 3-7, 4-10 & 3-6 or (RBG-HVM, YNB-MEDON & RBG-KMT) and the value of compensation is 1.38% (53 MVA) of the total generation. Finally, for four line compensation the computer program shows that the best four lines to be compensated are 3-7, 4-10, 3-11 & 3-6 or (RBG-HVM, YNB-MEDON, RBG-MEDSO & RBG-KMT) and the value of compensation is 1.53% (59 MVA). Brief computer results are shown in tables 3 to 6.

2.2. Shunt compensation

Shunt compensation as capacitance bank is usually used to improve system power factor, which leads to decrease generation reactive power, line currents and hence cable costs. This reduction in generating MVAR reduces the generation of system MVA, which allows electrical company to absorb more customers without increasing the number of generators. Table 7 is divided into three parts namely, stage 1, 2 & 3. Stage 1 shows the best substation gives best reduction in generating MVA in which shunt compensator can be connected. Substation no. 6 (KMT) gives better reduction equivalent to 2.31% (89 MVA) of the

Table 2
Summary of computer results for the best series compensations

Total system active power before adding capacitance (Pg) = 3.645 p u
Total system reactive power before adding capacitance (Qg) = 1.212 p u
Total system apparent power before adding capacitance (Sg) = 3.841 p u
System base voltage = 13.8 kV and system base MVA = 1000

Case No.	Line	Added Xc (pu)	Percentage of Xc	New Qg (pu)	New Sg (pu)	Δ Sg (pu)	Reduction in Sg (%)
1	3-7	0.2878	70	1.099	3.809	0.032	0.833
2	3-7 3-5	0.2878 0.1393	70 39	1.054	3.797	0.044	1.15
3	3-7 4-10 3-6	0.2878 0.2997 0.2184	70 70 58	1.017	3.788	0.053	1.38
4	3-7 4-10 3-11 3-6	0.2878 0.2997 0.3463 0.2184	70 70 52 58	0.995	3.782	0.059	1.54

Table 3
Output of series compensation on line 3-7 (70%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.647	1.099	3.615	3.433	0.032	-2.333	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 4
Output of series compensation on line 3-7 (70%) & 3-5 (39%).

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.648	1.054	3.615	3.433	0.033	-2.379	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 5
Output of series compensation on line 3-7 (70%), 3-6 (58%). & 4-10 (70%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.649	1.017	3.615	3.433	0.034	-2.416	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 6
Output of series compensation on line 3-7 (70%), 3-6 (58%). 4-10 (70%) & 3-11 (52%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.649	0.995	3.615	3.433	0.034	-2.437	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 7
Summary of computer results for the best shunt compensations

Case No.	Bus No	Added *Qc (p.u)*	New *Qg (p.u)*	New *Sg (p.u)*	*Δ Sg (pu)*	Reduction in *Sg* (%)
1	6	0.314	0.891	3.752	0.089	2.32
2	6 10	0.284 0.113	0.785	3.727	0.114	2.97
3	5 6 11	0.128 0.209 0.146	0.691	3.709	0.132	3.44

Table 8
Output of shunt compensation on bus 6 (Q_c=0.314 pu)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.645	0.891	3.615	3.119	0.030	-2.226	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 9
Output of shunt compensation on bus 6 (Q_c=0.284 pu) & 10 (Q_c = 0.113 pu).

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.644	0.785	3.615	3.036	0.029	-2.250	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 10
Output of shunt compensation on bus 5 (Q_c=0.128 pu) , 6 (q_c = 0.209 pu) & 11 (Q_c = 0.146 pu).

(c) Total System Flow

Generation P(pu)	Generation Q(pu)	Load P(pu)	Load Q(pu)	Losses P(pu)	Losses Q(pu)	Mismatch P(pu)	Mismatch Q(pu)
3.644	0.691	3.615	2.950	0.029	-2.258	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 11
Summary of computer results for the best combined compensations

	Series		Parallel					
Case No.	Line	Added *Xc (pu)*	Bus no	Added *Qc (pu)*	New *Qg (pu)*	New *Sg (pu)*	Δ *Sg (pu)*	Reduction in *Sg* (%)
1	3-7	0.2878(70%)	6	0.212	0.882	3.752	0.089	2.32
2	3-7 4-10	0.2878(70%) 0.2997(70%)	6	0.210	0.855	3.747	0.094	2.45
3	3-7	0.2878(70%)	6 11	0.194 0.140	0.733	3.719	0.122	3.18
4	3-7 4-10 7-8	0.2878(70%) 0.2997(70%) 0.0803(68%)	5 6 11	0.080 0.155 0.154	0.636	3.703	0.138	3.59

total system generation of 3841 MVA. The maximum value of shunt compensation is taken as that value which will not convert the generation power factor to be leading.

Stage 2 is for two-shunt compensation connected simultaneously at two different substations. The computer program shows that the best two substations which can give better reduction in System MVA are No. 6 & 10 or (KMT & MEDNO). The reduction is 2.96% (114 MVA) of the total system generation. In stage 3 the same process has been repeated for three substations to be compensated. The best reduction in generating MVA is found to be 3.43% (132 MVA) if the compensation are at substations 5, 6 & 11 or (HVE, KMT & MEDSO). Brief computer results are shown in tables 8-10.

3.2. Combined compensation

The aim of combined compensation is to get the advantages of both series and parallel compensations. Computer results shows that the best compensation can be achieved if parallel compensation is connected at substations 5, 6 & 11 or (HVE, KMT & MEDSO) and series compensation between substations 3-7, 4-10 & 7-8 or (RBG-HVM, YNB-MEDNO & HVM-SAZ). Table 11 shows that the highest reduction in MVA generation is 3.59% (139MVA). It is worth mentioning that substations no. 5,6 &11 and lines no. 3-7, & 4-10 which lead to the best combined compensation are the same substations which led to best parallel and series compensation individually. Complete computer results are shown in tables 12-15.

Table 12
Output of combined compensation on bus 6 (Q_c=0.212 pu) line 3-7 (70%)

(c) Total System Flow

Generation P(pu)	Generation Q(pu)	Load P(pu)	Load Q(pu)	Losses P(pu)	Losses Q(pu)	Mismatch P(pu)	Mismatch Q(pu)
3.647	0.882	3.615	3.221	0.032	-2.338	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 13
Output of combined compensation on bus 6 (Q_c=0.210 pu) line 3-7 (70%) & 4-10 (70%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.648	0.855	3.615	3.223	0.033	-2.367	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 14
Output of combined compensation on bus 6 (Q_c=0.194 pu) & 11 (Q_c = 0.140 pu) line 3-7 (70%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.648	0.855	3.615	3.223	0.033	-2.367	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

Table 15
Output of combined compensation on bus 5 (Q_c=0.080 pu) , 6 (Q_c = 0.155 pu) & 11 (Q_c = 0.154 pu) line 3-7 (70%), 4-10 (70%) & 7-8 (68%)

(c) Total System Flow

Generation		Load		Losses		Mismatch	
P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
3.648	0.855	3.615	3.223	0.033	-2.367	0.000	-0.001

* Load-flow output (Newton-Raphson method converged on 2 iterations) *

4. Conclusions

It is clear from the computer results that the use of system compensation will lead to many benefits such as increasing transmission lines load ability which enable electrical company to transmit more power with the existing transmission lines, and to absorbs more customers without increasing the number of generators. The maximum reduction in generating MVA shown by computer results is 139 MVA, which is a considerable value that relief the electrical company from adding new generators. The limits imposed for serious compensation is up to70% of line reactance and for shunt compensation is just before the system becomes leading power factor. Because of loads always variable it is recommended to use SVC rather than bank of capacitors.

5. Future studies

1. Total amount of reduction of generating MVA in one full day and hence in one full year.
2. The saving amount that can be achieved by using system compensations.
3. Comparison study between 380 kV and 110 kV systems.

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