CHAPTER FOUR

Reinforcement of Atbara – Portsudan Transmission Scenarios

4-1: Introduction

The voltage at receiving end of Atbara – Portsudan transmission line is below the nominal values especially during peak hours. The transmission line reactance increase the voltage drop in the line and this effect line carry-ability. Also the generated reactive power (from SVC or generating units) reduces the voltage drop at receiving terminal. All these challenge facing power system operators to find solutions and recover the voltage to its nominal value and increase line carry-ability.

4-2: Operational Problems During Off-peak

Soft-ware program is used to simulate NEC grid at the period of off-peak hours, Table 4.1 and Table 4.2 shows the data of generation, load, and losses distribution, while Table 4.4 shows the of steady-state voltages, load angles in case studied (in 6:30 am, September 13th 2016).

Table 4.1: Generation at off-peak.

POWER STATION	POWER GENERATED (MW)
ROSIERIS	173
SENNAR POWER PLANT	3.3
KOSTI	252.9
KHN	76.8
GARI	193
MWP	655.2
KHNG	0.0
ETH. INTERCAHNGE	39.2
Total	1393.4

Table 4.2: General results

P_{gen} (MW)	Q_{gen} (MVAr)	P_{load} (MW)	Q_{load} (MVAr)	P_{loss} (MW)	Q_{loss} (MVAr)
1393.382	157.236	1352.31	667.95	30.568	-1517.341

Table 4.3: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I(kA)
ATB220	ATB-POR	Line	53.968	-39.994	0.169
POR220	ATB-POR	Line	-52.061	-17.436	0.137
P_{loss} (MW)	1.9072				
Q_{loss} (MVAr)	-57.4306				
Loading (%)	19.88%				

Table 4.4: Voltage profile

500KV±5%				220KV±5%				110KV±7%			
Bus	*Voltage*	*Voltage%*	*Angle*	*Bus*	*Voltage*	*Voltage%*	*Angle*	*Bus*	*Voltage*	*Voltage%*	*angle*
ATB500-1	521.13	104.23	-7.80	POR220-1	230.99	105.00	-21.30	POR110-1	117.60	106.91	-22.60
MRK500-1	508.05	101.61	-9.40	ATB220-1	229.86	104.48	-10.50	SNJ110	113.69	103.35	-14.60
KBA500-1	506.52	101.30	-9.60	RNK220-1	226.37	102.90	-6.30	SNP110	113.30	103.00	-15.00
MWP500-1	529.94	100.94	-5.40	ROS220-1	225.89	102.68	-5.50	GDF110	112.30	102.09	-13.80
				SHN 220-1	225.47	102.49	-11.30	JAS110-1	112.10	101.90	-14.60
				HWT220-1	225.36	102.44	-12.40	NHS110-1	111.81	101.64	-16.00
				GDF220-1	224.40	102.00	-12.80	KLX110-1	111.47	101.33	-13.90
				SNG220-1	223.65	101.66	-11.80	HAS110	111.43	101.30	-16.20
				RBK220-1	222.67	101.21	-6.70	GND110-1	111.40	101.28	-16.30
				SHK220-1	221.87	100.85	-13.70	HAG110	111.21	101.10	-16.70
				GRB220-1	220.98	100.44	-14.50	AFR110-1	110.98	100.89	-14.20
				ARM220-1	220.58	100.26	-14.90	FAR110-1	110.98	100.89	-14.20
				KSL220-1	220.34	100.15	-14.90	MAR110	110.79	100.72	-17.50
				SNJ220	220.16	100.07	-13.00	SHG110-1	110.76	100.69	-15.60
				HLF220-1	219.97	99.99	-14.60	IBA110-1	110.28	100.25	-14.90
				MSH220-1	219.30	99.68	-9.80	FAO110	110.13	100.12	-17.30
				FRZ 220- 01	218.98	99.54	-11.30	IZB110-1	109.85	99.87	-15.30
				GAR220-1	218.75	99.43	-11.30	HWT 110-1	108.61	98.73	-12.40
				TND220-1	218.15	99.16	-7.30	KHN110-1	108.11	98.28	-15.60
				KBA220-1	217.97	99.08	-11.70	KUK110-1	107.71	97.91	-15.90
				DON220	217.00	98.63	-13.40	KHE110-1	107.26	97.51	-16.20
				MRK220-1	216.95	98.61	-12.30	RBK110-1	106.59	96.90	-9.00
				WAW220-1	216.12	98.24	-13.50	MSH110	106.45	96.78	-10.60
				DEB220	215.73	98.06	-11.70	IZG110-1	106.45	96.77	-16.00

500KV±5%				220KV±5%				110KV±7%			
				UMR220-1	215.52	97.97	-7.90	MHD110-1	106.01	96.38	-16.00
				JAS220-1	215.34	97.88	-12.70	GAD110	105.32	95.75	-15.30
				GAM 220-1	214.85	97.66	-12.90	BAG110	104.88	95.35	-15.40
				GAD220-1	214.80	97.64	-13.20	GAM 110-1	104.25	94.77	-19.40
				IBA220-1	214.67	97.58	-12.60	OMD 110 -1	104.04	94.58	-16.50
				KLX220	214.23	97.38	-12.90	BNT110-1	103.19	93.81	-16.60
				MHD220-1	213.90	97.23	-12.90	MUG110-1	102.06	92.78	-20.80
				MAR220	213.92	97.23	-14.30	LOM110-1	100.69	91.54	-21.50
				MWT220	213.45	97.02	-8.50				
				NHS220-1	213.31	96.96	-14.30				
				WHL220-1	213.19	96.91	-13.40				
				OBD220-1	210.97	95.90	-8.70				

As shown in Table 4.4 above:

- No voltage violation in 500kV level.
- One violated bus in 220kV level (POR).
- 2 buses violated in 110kV level (MUG, LOM).

4-3: Operational Problems During Peak Case

Also, the network is simulated during peak hour (in 3:00 pm, July 3rd 2016). The tables below shows generation, load, losses distribution, and also observe the results of portion focused in this thesis, and steady-state voltages, load angles in case studied.

Table 4.5: Generation at peak

POWER STATION	POWER GENERATED(MW)
ROSIERIS	151
SENNAR POWER PLANT	9.4
KOSTI	440
KHN + KHNG	131.6
GARI	279.4
MWP	1190.5
ETH. INTERCAHNGE	214
Total	2415.9

Table 4.6: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2401.747	989.637	2299.48	1120.73	94.279	-646.984

Table 4.7: Atbara-Portsudan portion results.

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-POR	Line	87.973	1.146	0.221
POR220	ATB-POR	Line	-82.181	-29.283	0.252
P_{loss} (MW)	5.7922				
Q_{loss} (MVAr)	-28.1369				
Loading (%)	29.64%				

Table 4.8: Voltage profile.

500KV±5%				220KV±5%				110KV±7%			
Bus	***Voltage***	***Voltage%***	***Angle***	***Bus***	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***
MWP500-1	**544.03**	**103.62**	**-4.70**	**ATB220-1**	**229.46**	**104.30**	**-13.20**	**SNP110**	**114.40**	**104.00**	**-20.70**
ATB500-1	**515.74**	**103.15**	**-8.70**	**RNK220-1**	**228.70**	**103.95**	**-7.70**	**SNJ110**	**112.28**	**102.07**	**-18.80**
MRK500-1	**479.84**	**95.97**	**-11.70**	**ROS220-1**	**227.49**	**103.40**	**-8.20**	**GDF110**	**111.05**	**100.95**	**-12.30**
KBA500-1	**475.34**	**95.07**	**-12.30**	**RBK220-1**	**225.69**	**102.59**	**-6.80**	**SNG110 -1**	**110.06**	**100.05**	**-14.40**
				TND220-1	**224.53**	**102.06**	**-8.20**	**RBK110-1**	**109.92**	**99.92**	**-9.40**
				UMR220-1	**223.60**	**101.63**	**-9.40**	**HWT110-1**	**107.62**	**97.83**	**-12.30**
				HWT220-1	**223.31**	**101.50**	**-12.30**	**HAG110**	**106.02**	**96.38**	**-22.50**
				GDF220-1	**223.08**	**101.40**	**-10.40**	**MSH110**	**105.84**	**96.21**	**-12.70**
				SHK220-1	**222.83**	**101.28**	**-12.30**	**IBA110-1**	**105.22**	**95.66**	**-22.60**
				OBD220-1	**222.22**	**101.01**	**-11.00**	**KLX110-1**	**104.50**	**95.00**	**-21.50**
				MWT220	**221.66**	**100.76**	**-11.60**	**LOM110-2**	**104.32**	**94.83**	**-21.60**
				GRB220-1	**221.63**	**100.74**	**-13.80**	**FAO110**	**104.29**	**94.81**	**-20.30**
				SHN 220-1	**221.57**	**100.71**	**-15.30**	**IZB110-1**	**104.27**	**94.79**	**-23.20**
				SNG220-1	**221.31**	**100.59**	**-13.60**	**AFR110-1**	**103.21**	**93.82**	**-22.30**
				HLF220-1	**220.99**	**100.45**	**-14.10**	**MAR110**	**103.06**	**93.69**	**-23.10**
				ARM220-1	**220.93**	**100.42**	**-14.60**	**FAR110-1**	**102.86**	**93.51**	**-22.60**
				KSL220-1	**220.84**	**100.38**	**-14.50**	**NHS110-1**	**102.53**	**93.21**	**-22.20**
				SNJ220	**216.85**	**98.57**	**-15.90**	**HAS110**	**102.14**	**92.85**	**-22.30**
				MSH220-1	**214.41**	**97.46**	**-12.00**	**KHN110-1**	**102.12**	**92.83**	**-23.90**
				DEB220	**213.96**	**97.25**	**-17.50**	**GND110-1**	**101.84**	**92.58**	**-22.60**
				FRZ 220-1	**213.96**	**97.25**	**-16.10**	**KUK110-1**	**101.18**	**91.98**	**-24.70**
				GAR220-1	**213.95**	**97.25**	**-16.00**	**JAS110-1**	**100.93**	**91.76**	**-22.10**
				WHL220-1	**212.66**	**96.66**	**-22.00**	**GAM110-1**	**100.84**	**91.68**	**-22.60**

500KV±5%				220KV±5%				110KV±7%			
				WAW220-1	**211.87**	**96.31**	**-21.70**	**IZG110-1**	**100.20**	**91.09**	**-24.80**
				KBA220-1	**211.43**	**96.10**	**-16.50**	**KHE110-1**	**100.14**	**91.04**	**-25.30**
				DON220	**209.98**	**95.44**	**-21.20**	**POR110-1**	**99.58**	**90.53**	**-34.40**
				MRK220-1	**207.47**	**94.31**	**-16.70**	**MHD110-1**	**98.77**	**89.79**	**-23.50**
				MAR220	**204.17**	**92.80**	**-18.50**	**BNT110-2**	**97.91**	**89.01**	**-24.30**
				IBA220-1	**204.14**	**92.79**	**-18.20**	**MUG110-1**	**97.24**	**88.40**	**-24.70**
				GAM 220-1	**203.06**	**92.30**	**-17.60**	**SHG110-2**	**96.44**	**87.67**	**-25.20**
				JAS220-1	**203.02**	**92.28**	**-17.40**	**SHG110-1**	**96.28**	**87.53**	**-24.20**
				MHD220-1	**202.44**	**92.02**	**-17.80**	**OMD110-1**	**96.21**	**87.46**	**-24.70**
				KLX220	**202.18**	**91.90**	**-18.70**	**LOM110-1**	**96.04**	**87.31**	**-25.40**
				GAD220-1	**201.87**	**91.76**	**-18.30**	**BNT110-1**	**95.56**	**86.88**	**-25.10**
				NHS220-1	**200.95**	**91.34**	**-19.30**	**GAD110**	**93.17**	**84.70**	**-22.30**
				POR220-1	**199.68**	**90.76**	**-32.00**	**BAG110**	**92.29**	**83.90**	**-22.50**

As shown in Table 4.8 above:

- No voltage violation in 500kV level.
- 10 buses violated in 220kV level (MRK, MAR, IBA, GAM, JAS, MHD, KLX, GAD, NHS and POR).
- 19 buses violated in 110kV level (HAS, KHN, GND, KUK, JAS, GAM, IZG, KHE, POR, MHD, BNT-2, MUG, SHG-2, SHG-1, OMD, LOM-1, BNT-1, GAD and BAG).

As shown in Table 4.4 and 4.8 during off-peak and peak operation the voltage at POR bust is under the nominal permissible limit.

In first case when load at the POR bus decreases then the voltage of POR bus (220kV) goes to sever value. Also in second case when load at the POR bus increases then the voltage of POR bus (220kV) goes to severe value.

The decrease in voltage level challenging power system operators to recover the voltage to its nominal values to keep system voltage stable in permissible limits.

4-4: Proposals and Solutions

To improve Atbara – Portsudan transmission line performance regarding voltage regulation and line current capacity the following scenarios are investigated:

1. Effect of building thermal power plant in Portsudan.
2. Installation of SVC unit in receiving end at Portsudan bus.
3. Install TCSC at ATB-POR T.L. besides SVC.
4. Install SVC at Sinkat besides Portsudan SVC.
5. Change of configuration to double-circuit line.
6. Change of configuration to double-circuit bundled line.

4-5: Effect of Building New Generating Unit in Portsudan

A 167MW, GAS turbine, power plant is built and connected to Portsudan bus POR220kV through step-up transformer. The simulation data of generation, load, and losses distribution are shown in Table 4.9 and Table 4.10. The simulation results are tabulated and given in Table 4.11 focusing in steady-state voltages, load angles.

Table 4.9: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2394.348	886.937	2299.48	1120.73	86.772	-760.789

Table 4.10: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-POR	Line	-36.872	-21.384	0.109
POR220	ATB-POR	Line	37.86	-38.302	0.138
P_{loss} (MW)	0.988				
Q_{loss} (MVAr)	-59.6861				
Loading (%)	16.23%				

Table 4.11: Voltage profile

500KV±5%				220KV±5%				110KV±7%			
Bus	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***
ATB500-1	**529.70**	**105.94**	**-4.30**	**RNK220-1**	**228.85**	**104.02**	**-3.90**	**SNP110**	**114.40**	**104.00**	**-16.80**
MWP500-1	**548.03**	**104.39**	**-1.60**	**ROS220-1**	**227.59**	**103.45**	**-4.40**	**POR110-1**	**112.77**	**102.52**	**-1.50**
MRK500-1	**482.89**	**96.58**	**-8.20**	**ATB220-1**	**226.55**	**102.98**	**-7.60**	**SNJ110**	**112.33**	**102.12**	**-14.90**
KBA500-1	**478.14**	**95.63**	**-8.70**	**RBK220-1**	**225.88**	**102.67**	**-3.10**	**GDF110**	**111.21**	**101.10**	**-8.50**
				POR220-1	**225.28**	**102.40**	**0.40**	**SNG110-1**	**110.20**	**100.18**	**-10.60**
				TND220-1	**224.72**	**102.15**	**-4.40**	**RBK110-1**	**110.02**	**100.01**	**-5.70**
				MWT220	**224.17**	**101.89**	**-8.40**	**HWT110-1**	**107.77**	**97.97**	**-8.40**
				UMR220-1	**223.80**	**101.73**	**-5.60**	**HAG110**	**106.18**	**96.52**	**-18.60**
				HWT220-1	**223.61**	**101.64**	**-8.40**	**MSH110**	**106.09**	**96.44**	**-9.00**
				GDF220-1	**223.41**	**101.55**	**-6.60**	**IBA110-1**	**105.42**	**95.84**	**-18.60**
				SHK220-1	**223.17**	**101.44**	**-8.50**	**KLX110-1**	**104.71**	**95.19**	**-17.60**
				OBD220-1	**222.43**	**101.10**	**-7.30**	**LOM110-2**	**104.53**	**95.03**	**-17.70**
				GRB220-1	**221.99**	**100.90**	**-10.00**	**FAO110**	**104.51**	**95.01**	**-16.50**
				SNG220-1	**221.59**	**100.72**	**-9.80**	**IZB110-1**	**104.47**	**94.97**	**-19.20**
				HLF220-1	**221.35**	**100.61**	**-10.30**	**AFR110-1**	**103.43**	**94.02**	**-18.40**
				ARM220-1	**221.30**	**100.59**	**-10.70**	**MAR110**	**103.30**	**93.91**	**-19.20**
				KSL220-1	**221.21**	**100.55**	**-10.70**	**FAR110-1**	**103.08**	**93.71**	**-18.60**
				SHN220-1	**220.14**	**100.07**	**-10.50**	**NHS110-1**	**102.83**	**93.48**	**-18.30**
				DEB220	**217.21**	**98.73**	**-14.20**	**HAS110**	**102.43**	**93.12**	**-18.50**
				SNJ220	**217.16**	**98.71**	**-12.10**	**KHN110-1**	**102.33**	**93.03**	**-20.00**
				WHL220-1	**216.52**	**98.42**	**-18.60**	**GND110-1**	**102.14**	**92.85**	**-18.80**
				WAW220-1	**215.69**	**98.04**	**-18.30**	**GAM110-1**	**101.47**	**92.24**	**-18.90**
				MSH220-1	**214.91**	**97.69**	**-8.20**	**JAS110-1**	**101.42**	**92.20**	**-18.30**
				FRZ220-1	**213.97**	**97.26**	**-12.00**	**KUK110-1**	**101.39**	**92.18**	**-20.70**
				GAR220-1	**213.98**	**97.26**	**-11.90**	**IZG110-1**	**100.42**	**91.29**	**-20.80**
				DON220	**213.73**	**97.15**	**-17.80**	**KHE110-1**	**100.36**	**91.24**	**-21.30**
				KBA220-1	**211.74**	**96.25**	**-12.60**	**MHD110-1**	**99.56**	**90.51**	**-19.80**
				MRK220-1	**208.72**	**94.87**	**-13.10**	**BNT110-2**	**98.56**	**89.60**	**-20.50**
				MAR220	**204.62**	**93.01**	**-14.70**	**MUG110-1**	**97.90**	**89.00**	**-20.90**
				IBA220-1	**204.47**	**92.94**	**-14.30**	**SHG110-2**	**97.10**	**88.28**	**-21.40**
				GAM 220-1	**204.11**	**92.78**	**-13.90**	**OMD110-1**	**97.03**	**88.21**	**-21.00**
				JAS220-1	**203.82**	**92.65**	**-13.60**	**SHG110-1**	**96.80**	**88.00**	**-20.40**
				MHD220-1	**203.75**	**92.61**	**-14.20**	**LOM110-1**	**96.72**	**87.92**	**-21.60**
				KLX220	**202.56**	**92.07**	**-14.80**	**BNT110-1**	**96.39**	**87.63**	**-21.30**
				GAD220-1	**202.50**	**92.05**	**-14.50**	**GAD110**	**93.51**	**85.01**	**-18.50**
				NHS220-1	**201.50**	**91.59**	**-15.40**	**BAG110**	**92.63**	**84.21**	**-18.60**

As shown in Table 4.11 above:

- One bus violated in 500kV level (ATB).
- 9 buses violated in 220kV level (MRK, MAR, IBA, GAM, JAS, MHD, KLX, GAD and NHS).
- 16 buses violated in 110kV level (GND, GAM, JAS, KUK, IZG, KHE, MHD, BNT-2, MUG, SHG-2, OMD, SHG-1, LOM-1, BNT-1, GAD and BAG)

As shown in Table 4.11, voltage at Portsudan is successfully controlled by a new generation unit. This solution useful if Atbara-Portsudan transmission line de-energized, because of load continue supplied by generating unit. But this solution fails if this unit de-energized for maintenance because it played an important role in voltage regulating and transmission losses reduction.

4-6: Energize SVC at Portsudan 110kV Bus

SVC unit is already installed and connected to Portsudan 110kV bus through (33/110 kV) transformer. The tables below show the general overview to generation, load, losses distribution, and also observe the results of portion focused in this thesis, and steady-state voltages, load angles in case of SVC incorporate at Portsudan.

Table 4.12: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2400.362	953.25	2299.48	1120.73	92.879	-672.309

Table 4.13: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-POR	Line	87.285	-22.926	0.23
POR220	ATB-POR	Line	-82.145	-12.139	0.222
P_{loss} (MW)	5.14				
Q_{loss} (MVAr)	-35.0649				
Loading (%)	38.5%				

Table 4.14: Voltage profile

500KV±5%				220KV±5%				110KV±7%			
Bus	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***
ATB500-1	**523.55**	**104.71**	**-8.60**	**RNK220-1**	**228.70**	**103.95**	**-7.60**	**SNP110**	**114.40**	**104.00**	**-20.70**
MWP500-1	**545.94**	**103.99**	**-4.70**	**ROS220-1**	**227.48**	**103.40**	**-8.20**	**SNJ110**	**112.28**	**102.07**	**-18.70**
MRK500-1	**480.63**	**96.13**	**-11.60**	**ATB220-1**	**226.17**	**102.80**	**-13.20**	**GDF110**	**111.04**	**100.94**	**-12.30**
KBA500-1	**475.95**	**95.19**	**-12.20**	**RBK220-1**	**225.71**	**102.59**	**-6.80**	**SNG110-1**	**110.05**	**100.04**	**-14.40**
				TND220-1	**224.54**	**102.06**	**-8.10**	**RBK110-1**	**109.92**	**99.93**	**-9.40**
				UMR220-1	**223.61**	**101.64**	**-9.40**	**POR110-1**	**108.97**	**99.06**	**-33.60**
				HWT220-1	**223.29**	**101.50**	**-12.20**	**HWT110-1**	**107.61**	**97.83**	**-12.20**
				GDF220-1	**223.06**	**101.39**	**-10.40**	**HAG110**	**106.01**	**96.38**	**-22.40**
				MWT220	**222.87**	**101.30**	**-11.50**	**MSH110**	**105.85**	**96.23**	**-12.70**
				SHK220-1	**222.81**	**101.28**	**-12.30**	**IBA110-1**	**105.09**	**95.53**	**-22.60**
				OBD220-1	**222.23**	**101.02**	**-11.00**	**KLX110-1**	**104.39**	**94.90**	**-21.50**
				GRB220-1	**221.61**	**100.73**	**-13.80**	**FAO110**	**104.28**	**94.80**	**-20.30**
				SNG220-1	**221.29**	**100.59**	**-13.60**	**LOM110-2**	**104.21**	**94.74**	**-21.60**
				HLF220-1	**220.97**	**100.44**	**-14.10**	**IZB110-1**	**104.13**	**94.66**	**-23.20**
				ARM220-1	**220.91**	**100.41**	**-14.50**	**AFR110-1**	**103.10**	**93.73**	**-22.30**
				KSL220-1	**220.83**	**100.37**	**-14.50**	**MAR110**	**103.05**	**93.68**	**-23.00**
				SHN 220-1	**219.84**	**99.93**	**-15.30**	**FAR110-1**	**102.76**	**93.42**	**-22.50**
				SNJ220	**216.83**	**98.56**	**-15.90**	**NHS110-1**	**102.52**	**93.20**	**-22.10**
				POR220-1	**216.40**	**98.36**	**-31.60**	**HAS110**	**102.12**	**92.84**	**-22.30**
				DEB220	**215.53**	**97.97**	**-17.30**	**KHN110-1**	**101.97**	**92.70**	**-23.90**
				WHL220-1	**214.52**	**97.51**	**-21.80**	**GND110-1**	**101.83**	**92.57**	**-22.60**
				MSH220-1	**214.45**	**97.48**	**-11.90**	**KUK110-1**	**101.03**	**91.85**	**-24.70**
				WAW220-1	**213.72**	**97.15**	**-21.50**	**JAS110-1**	**100.97**	**91.79**	**-22.00**
				GAR220-1	**213.59**	**97.09**	**-16.00**	**GAM110-1**	**100.94**	**91.77**	**-22.60**
				FRZ220-1	**213.57**	**97.08**	**-16.10**	**IZG110-1**	**100.05**	**90.96**	**-24.80**
				DON220	**211.79**	**96.27**	**-21.00**	**KHE110-1**	**99.99**	**90.90**	**-25.30**
				KBA220-1	**211.22**	**96.01**	**-16.50**	**MHD110-1**	**98.93**	**89.94**	**-23.40**
				MRK220-1	**207.73**	**94.42**	**-16.70**	**BNT110-2**	**98.01**	**89.10**	**-24.20**
				MAR220	**204.15**	**92.79**	**-18.50**	**MUG110-1**	**97.34**	**88.49**	**-24.60**
				IBA220-1	**203.92**	**92.69**	**-18.20**	**SHG110-2**	**96.54**	**87.76**	**-25.10**
				GAM 220-1	**203.23**	**92.38**	**-17.60**	**OMD110-1**	**96.38**	**87.62**	**-24.70**
				JAS220-1	**203.08**	**92.31**	**-17.30**	**SHG110-1**	**96.32**	**87.56**	**-24.20**
				MHD220-1	**202.72**	**92.14**	**-17.70**	**LOM110-1**	**96.15**	**87.41**	**-25.30**
				KLX220	**201.99**	**91.81**	**-18.70**	**BNT110-1**	**95.74**	**87.03**	**-25.00**
				GAD220-1	**201.84**	**91.75**	**-18.30**	**GAD110**	**93.15**	**84.68**	**-22.30**
				NHS220-1	**200.92**	**91.33**	**-19.20**	**BAG110**	**92.27**	**83.88**	**-22.50**

From Table 4.14 above:

- No voltage violation in 500kV level.
- 9 buses violated in 220kV level (MRK, MAR, IBA, GAM, JAS, MHD, KLX, GAD and NHS).
- 18 buses violated in 110kV level (HAS, KHN, GND, KUK, JAS, GAM, IZG, KHE, MHD, BNT-2, MUG, SHG-2, OMD, SHG-1, LOM-1, BNT-1, GAD and BAG).

As shown in Table 4.14, voltage at Portsudan is successfully controlled by a new generation unit. This solution is not useful if Atbara-Portsudan transmission line de-energized, because of load not supplied from NEC grid. Also this solution not suitable to future load increasing because with this SVC rating (Q_L=55MVAr, Q_C=15.9MVAr), voltage will not regulated efficiently.

4-7: Install TCSC at ATB-POR T.L. Besides SVC

One of the options for enhancing Atbara - Portsudan transmission line carry-ability is using of TCSC in the mid of the line beside SVC at Portsudan 110kV bus. The simulation is run and gives data in Tables 4.15 and 4.16 regarding generation, load and losses distribution. While Table 4.17 shows the results of portion focused in this thesis, and steady-state voltages, load angles in case of incorporate of SVC plus TCSC (with 50% degree of compensation, X_L= 90.12Ω, X_C= 130.75Ω, $-290 \leq X_{TCSC} \leq 130.75$).

Table 4.15: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2399.641	919.849	2299.48	1120.73	92.069	-711.083

Table 4.16: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-TCSC	Line	87.093	-38.106	0.239
POR220	TCSC-POR	Line	-82.142	-14.535	0.218

P_{loss} (MW)	4.95
Q_{loss} (MVAr)	-40.3622
Loading (%)	28.11%

Table 4.17: Voltage profile

500KV±5%				**220KV±5%**				**110KV±7%**			
Bus	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***	***Bus***	***Voltage***	***Voltage%***	***angle***
ATB500-1	**524.16**	**104.83**	**-8.60**	**ATB220-1**	**229.59**	**104.36**	**-13.10**	**SNP110**	**114.40**	**104.00**	**-20.50**
MWP500-1	**546.46**	**104.09**	**-4.60**	**RNK220-1**	**228.84**	**104.02**	**-7.50**	**SNJ110**	**112.33**	**102.12**	**-18.50**
MRK500-1	**481.92**	**96.38**	**-11.50**	**ROS220-1**	**227.60**	**103.45**	**-8.00**	**GDF110**	**111.23**	**101.11**	**-12.10**
KBA500-1	**477.31**	**95.46**	**-12.10**	**RBK220-1**	**225.87**	**102.67**	**-6.70**	**SNG110-1**	**110.21**	**100.19**	**-14.20**
				TND220-1	**224.71**	**102.14**	**-8.00**	**RBK110-1**	**110.01**	**100.01**	**-9.30**
				UMR220-1	**223.79**	**101.72**	**-9.20**	**POR110-1**	**110.00**	**100.00**	**-24.20**
				HWT220-1	**223.63**	**101.65**	**-12.10**	**HWT110-1**	**107.78**	**97.98**	**-12.10**
				GDF220-1	**223.43**	**101.56**	**-10.20**	**HAG110**	**106.19**	**96.54**	**-22.20**
				MWT220	**223.19**	**101.45**	**-11.40**	**MSH110**	**106.07**	**96.43**	**-12.60**
				SHK220-1	**223.20**	**101.45**	**-12.10**	**IBA110-1**	**105.61**	**96.01**	**-22.40**
				OBD220-1	**222.42**	**101.10**	**-10.90**	**KLX110-1**	**104.86**	**95.33**	**-21.30**
				GRB220-1	**222.02**	**100.92**	**-13.60**	**LOM110-2**	**104.68**	**95.16**	**-21.40**
				SHN 220-1	**221.90**	**100.86**	**-15.20**	**IZB110-1**	**104.66**	**95.15**	**-23.00**
				SNG220-1	**221.61**	**100.73**	**-13.40**	**FAO110**	**104.53**	**95.03**	**-20.10**
				POR220-1	**221.42**	**100.65**	**-22.20**	**AFR110-1**	**103.58**	**94.16**	**-22.10**
				HLF220-1	**221.37**	**100.62**	**-13.90**	**MAR110**	**103.32**	**93.93**	**-22.80**
				ARM220-1	**221.32**	**100.60**	**-14.40**	**FAR110-1**	**103.24**	**93.85**	**-22.30**
				KSL220-1	**221.24**	**100.56**	**-14.30**	**NHS110-1**	**102.86**	**93.51**	**-22.00**
				SNJ220	**217.18**	**98.72**	**-15.70**	**KHN110-1**	**102.53**	**93.21**	**-23.70**
				DEB220	**215.95**	**98.16**	**-17.30**	**HAS110**	**102.46**	**93.14**	**-22.10**
				WHL220-1	**215.02**	**97.74**	**-21.70**	**GND110-1**	**102.17**	**92.88**	**-22.40**
				MSH220-1	**214.88**	**97.67**	**-11.80**	**KUK110-1**	**101.60**	**92.36**	**-24.50**
				FRZ220-1	**214.44**	**97.47**	**-15.90**	**JAS110-1**	**101.39**	**92.17**	**-21.90**
				GAR220-1	**214.42**	**97.46**	**-15.80**	**GAM110-1**	**101.37**	**92.15**	**-22.40**
				WAW220-1	**214.21**	**97.37**	**-21.40**	**IZG110-1**	**100.63**	**91.48**	**-24.60**
				DON220	**212.28**	**96.49**	**-21.00**	**KHE110-1**	**100.57**	**91.43**	**-25.10**
				KBA220-1	**212.05**	**96.38**	**-16.30**	**MHD110-1**	**99.38**	**90.35**	**-23.30**
				MRK220-1	**208.44**	**94.74**	**-16.50**	**BNT110-2**	**98.46**	**89.51**	**-24.00**
				IBA220-1	**204.78**	**93.08**	**-18.00**	**MUG110-1**	**97.79**	**88.90**	**-24.40**
				MAR220	**204.66**	**93.03**	**-18.30**	**SHG110-2**	**97.00**	**88.18**	**-24.90**
				GAM 220-1	**203.94**	**92.70**	**-17.40**	**OMD110-1**	**96.84**	**88.04**	**-24.50**
				JAS220-1	**203.77**	**92.62**	**-17.20**	**SHG110-1**	**96.76**	**87.97**	**-24.00**

500KV±5%				220KV±5%				110KV±7%			
				MHD220-1	**203.46**	**92.48**	**-17.60**	**LOM110-1**	**96.61**	**87.82**	**-25.10**
				KLX220	**202.83**	**92.20**	**-18.50**	**BNT110-1**	**96.20**	**87.46**	**-24.80**
				GAD220-1	**202.57**	**92.08**	**-18.20**	**GAD110**	**93.54**	**85.03**	**-22.10**
				NHS220-1	**201.55**	**91.61**	**-19.00**	**BAG110**	**92.66**	**84.24**	**-22.30**

From Table 4.17 above:

- No voltage violation in 500kV level.
- 9 buses violated in 220kV level (MRK, IBA, MAR, GAM, JAS, MHD, KLX, GAD and NHS).
- 16 buses violated in 110kV level (GND, KUK, JAS, GAM, IZG, KHE, MHD, BNT-2, MUG, SHG-2, OMD, SHG-1, LOM-1, BNT-1, GAD and BAG).

As shown in Table 4.17, voltage at Portsudan is successfully controlled by a SVC unit and transmission line capacity increased. This solution is efficient if TCSC and SVC operate together because SVC works as voltage regulator and TCSC as a tool to enlarge the capacity of the transmission line, but in case of TCSC only, we need a tool to control the value of X_{TCSC} of TCSC.

4-8: Install SVC at Sinkat Besides Portsudan SVC

One of the options for enhancing Atbara - Portsudan transmission line carry-ability and voltage regulation is using of SVC in the mid of the line at Sinkat (new sub-station) 220kV bus. The simulation is run and gave data in Table 4.18 and 4.19 regarding generation, load, losses distribution. While table 4.20 shows the results of portion focused in this thesis, and steady-state voltages, load angles in case of incorporate of Portsudan SVC plus Sinkat SVC.

Table 4.18: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2400.02	940.348	2299.48	1120.73	92.51	-682.987

Table 4.19: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-SINKAT	Line	87.161	-29.53	0.234
POR220	SINKAT-POR	Line	-82.144	-21.258	0.223
P_{loss} (MW)	5.01				
Q_{loss} (MVAr)	-38.1896				
Loading (%)	27.53%				

Table 4.20: Voltage profile and violation

Violation			**% Voltage**		
110kV	220kV	500kV	ATB220	SIN220	POR220
18 bus	9 bus	-	226.8kV	226.6kV	219.3kV

As shown in Table 4.20, voltage at Portsudan is successfully controlled by a SVC units in (Portsudan and Sinkat) and transmission line capacity increased. This solution is efficient tow SVC operates together because Sinkat SVC works as voltage support to Portsudan 220kV bus and Portsudan SVC as a voltage regulator.

4-9: Change of Configuration to Double-circuit Line

The tables below show the general overview to generation, load, losses distribution, and also observe the results of portion focused in this thesis, in case of incorporate new circuit same to parameter of existing one (r=0.076Ω/km, x_L=0.403Ω/km, c=9.02nF/km).

Table 4.21: General results

P_{gen}(MW)	Q_{gen}(MVAr)	P_{load}(MW)	Q_{load}(MVAr)	P_{loss}(MW)	Q_{loss}(MVAr)
2397.291	935.656	2299.48	1120.73	89.773	-763.441

Table 4.22: Atbara-Portsudan portion results

Bus	Equipment	Type	P(MW)	Q(MVAr)	I (kA)
ATB220	ATB-POR-1	Line	84.534	-62.885	0.268
POR220	ATB-POR-1	Line	-82.167	-52.927	0.254
P_{loss} (MW)	2.3674				
Q_{loss} (MVAr)	-115.811				
Loading (%)	15.76% for each one				

Table 4.23: Voltage profile and violation

Violation			**% Voltage**		
110kV	220kV	500kV	ATB220	POR220	POR110
18 bus	9 bus	-	229.79kV	222.687kV	110kV

As shown in Table 4.23, voltage at Portsudan is successfully controlled by a adding a new circuit, transmission line capacity also increased and consider a secure solution if each of two circuit de-energized. But there are some remarks about this solution such as:

- Need to add a reactor in Atbara 220kV bus to absorb reactive power due to line charging (30 MVAr);
- Not useful if SVC de-energized, because of the SVC operate as voltage regulator at Portsudan.

4-10: Change of Configuration to Double-circuit Bundled Line

Atbara – Portsudan is line is built as single-conductor single circuit, if the configuration is changed to a common double circuit bundle conductor design the performance will improve. The new double circuit bundled is (r=0.067Ω/km, x_L=0.302 Ω/km, c=13.06nF/km).

The tables below show the general overview to generation, load, losses distribution, and also observe the results of portion focused in this thesis, in case of change the line to double-circuit bundled design.

Table 4.24: General results

P_{gen}(MW)	**Q_{gen}(MVAr)**	**P_{load}(MW)**	**Q_{load}(MVAr)**	**P_{loss}(MW)**	**Q_{loss}(MVAr)**
2396.919	929.982	2299.48	1120.73	89.369	-831.746

Table 4.25: Atbara-Portsudan portion results

Bus	**Equipment**	**Type**	**P(MW)**	**Q(MVAr)**	**I (kA)**
ATB220	ATB-POR	Line	84.242	-96.673	0.323
POR220	ATB-POR	Line	-82.207	-83.911	0.302
P_{loss} (MW)	2.0349				
Q_{loss} (MVAr)	-180.584				
Loading (%)	12.92% for each one				

Table 4.26: Voltage profile and violation

Violation			% Voltage		
110kV	220kV	500kV	ATB220	POR220	POR110
16 bus	7 bus	-	229.013 kV	224.889 kV	110 kV

As shown in Table 4.26, voltage at Portsudan is successfully controlled by a adding a change a line to two bundled circuit, transmission line capacity increased and consider a secure solution if each of two circuit de-energized. But there are some remarks about this solution such as:

- Need to add a reactor in Atbara 220kV bus to absorb reactive power due to line charging (45MVAr for each circuit);
- Not useful if SVC de-energized, because of the SVC operate as voltage regulator at Portsudan.

4-11: Scenarios of Increasing Portsudan Load to 150%

Atabara - Portsudan Transmission line load ability is (50 MW at 0.9678 pf lag, 140 A, to give flat characteristic V_S=V_R=1 pu). The increase in load demand requires installation of new line or upgrading of existing line capacity or using FACTs device.

The proposed solutions for future techniques to improve line carry-ability are:

- **A.** Using TCSC with Portsudan SVC.
- **B.** Using Sinkat SVC beside Portsudan SVC.
- **C.** Using double-circuit bundle line.
- **D.** Using new generating unit.

A. <u>Using TCSC with Portsudan SVC:</u>

In this scenario TCSC is installed in the mid of the line. The line delivers 82MW and 22MVAr. By installation of TCSC the line will enable the system to delivers 123MW and 33MVAr by reducing the reactance of line to 25% of existing. The simulation results are shown in Table 4.27 and Table 4.28.

Table 4.27: Atbara-Portsudan portion results

Total losses (MW)			102.334		
Bus	**Equipment**	**Type**	**P(MW)**	**Q(MVAr)**	**I (kA)**
ATB220	ATB-TCSC	Line	136.017	-9.584	0.349
POR220	TCSC-POR	Line	-123.29	-31.638	0.364
P_{loss} (MW)	12.7269				
Q_{loss} (MVAr)	6.6392				
Loading (%)	42.82%				

Table 4.28: Voltage profile and violation

Violation			**% Voltage**		
110kV	220kV	500kV	ATB220	POR220	POR110
20	10	1	225.496 kV	201.92 kV	99.37 kV

B. Using Sinkat SVC beside Portsudan SVC:

In this scenario SCV is installed in Sinkat beside SVC in Portsudan. By using two SVCs in Portsudan and Sinkat the line will be able the system to delivers 123MW and 33MVAr. The simulation results are shown in Table 4.29 and Table 4.30.

Table 4.29: Atbara-Portsudan portion results

Total losses (MW)			100.65		
Bus	**Equipment**	**Type**	**P(MW)**	**Q(MVAr)**	**I (kA)**
ATB220	ATB-TCSC	Line	135.08	-27.806	0.35
POR220	TCSC-POR	Line	-123.248	-27.794	0.336
P_{loss} (MW)	11.8313				
Q_{loss} (MVAr)	-2.6265				
Loading (%)	41.17%				

Table 4.30: Voltage profile and violation

Violation			**% Voltage**		
110kV	220kV	500kV	ATB220	POR220	POR110
18	9	-	227.393 kV	217.017 kV	107.19 kV

C. Using double-circuit bundle line:

In this scenario double circuit bundle configuration is used instead of single circuit configuration. This will increase line capacity to 123MW and 33MVAr. The simulation results are shown in Table 4.31 and Table 4.32.

Table 4.31: Atbara-Portsudan portion results

Total loss(MW)			92.945		
Bus	**Equipment**	**Type**	**P(MW)**	**Q(MVAr)**	**I (kA)**
ATB220	ATB-POR	Line	127.993	-104.286	0.417
POR220	ATB-POR	Line	-123.266	-64.838	0.356
P_{loss} (MW)	4.7264				
Q_{loss} (MVAr)	-169.123				
Loading (%)	16.68%				

Table 4.32: Voltage profile and violation

Violation			% Voltage		
110kV	220kV	500kV	ATB220	POR220	POR110
18	9	-	228.745kV	225.97kV	110kV

D. Using new generating unit:

In this scenario 120MW generated from new generation unit is built in Portsudan. The line in peak case delivered 82MW and 22MVAr. Thus scenario decrease the power delivered because of building a nearby generation. The simulation results are shown in Table 4.33 and Table 4.34.

Table 4.33: Atbara-Portsudan portion results

Total loss(MW)			87.078		
Bus	**Equipment**	**Type**	**P(MW)**	**Q(MVAr)**	**I (kA)**
ATB220	ATB-POR	Line	3.259	-28.614	0.073
POR220	ATB-POR	Line	-3.24	-35.841	0.093
P_{loss} (MW)	0.0188				
Q_{loss} (MVAr)	-64.4556				
Loading (%)	10.94%				

Table 4.34: Voltage profile and violation

Violation			% Voltage		
110kV	220kV	500kV	ATB220	POR220	POR110
18	9	-	227.165kV	223.33kV	110kV

4-12: Comparisons of Different Scenarios

Figure 4.1 summarized and compared the proposed scenarios regarding total power losses occur in the network. It is clear that scenario of building generation unit in Portsudan is the best regarding reducing total power losses.

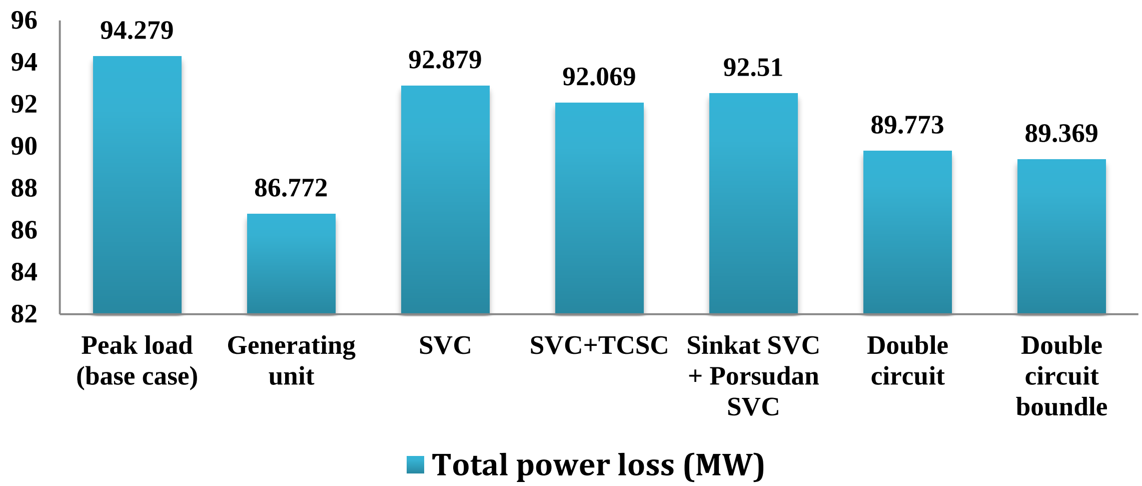

Figure 4.1: Comparison of total area loss

Figure 4.2 summarized and compared the Atbara – Portsudan line losses and line loading in all proposed scenarios. It is clear that scenario of building generation unit in Portsudan is the best regarding reducing line losses.

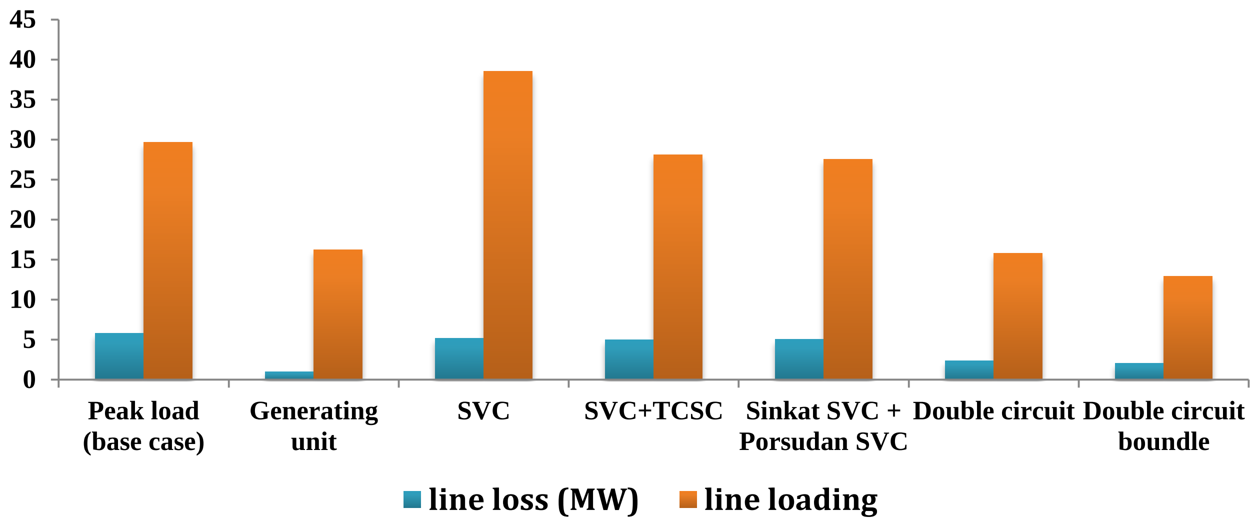

Figure 4.2: Comparison of transmission loss and loading of ATB-POR.

Figure 4.3 summarized and compared the number of violated buses in all proposed scenarios. It is clear that scenario of double circuit bundle line is the best regarding number of violated buses.

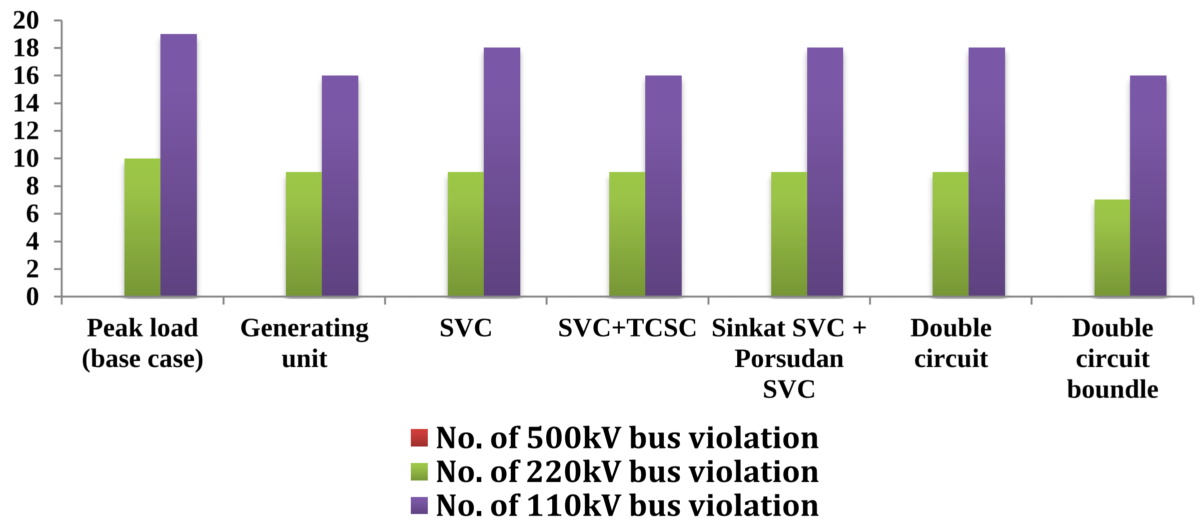

Figure 4.3: Comparison of No. of violated buses.

Figure 4.4 summarized and compared the voltages at Atbara and Portsudan buses in all proposed scenarios. It is clear that scenario of building generation unit in Portsudan is the best one.

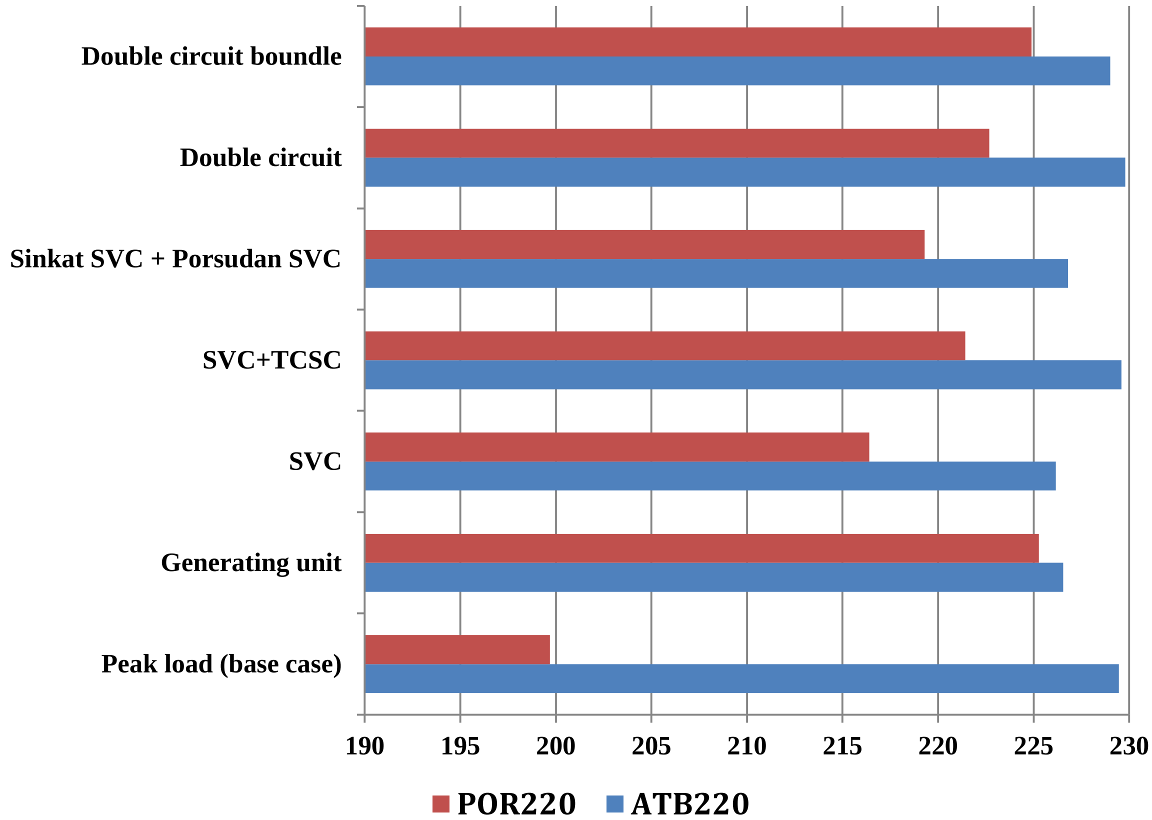

Figure 4.4: Comparison voltage profiles of ATB & POR.

Figure 4.5 summarized and compared between the scenarios of increasing line capacity. It is clear that scenario of building generation unit in Portsudan is the best one.

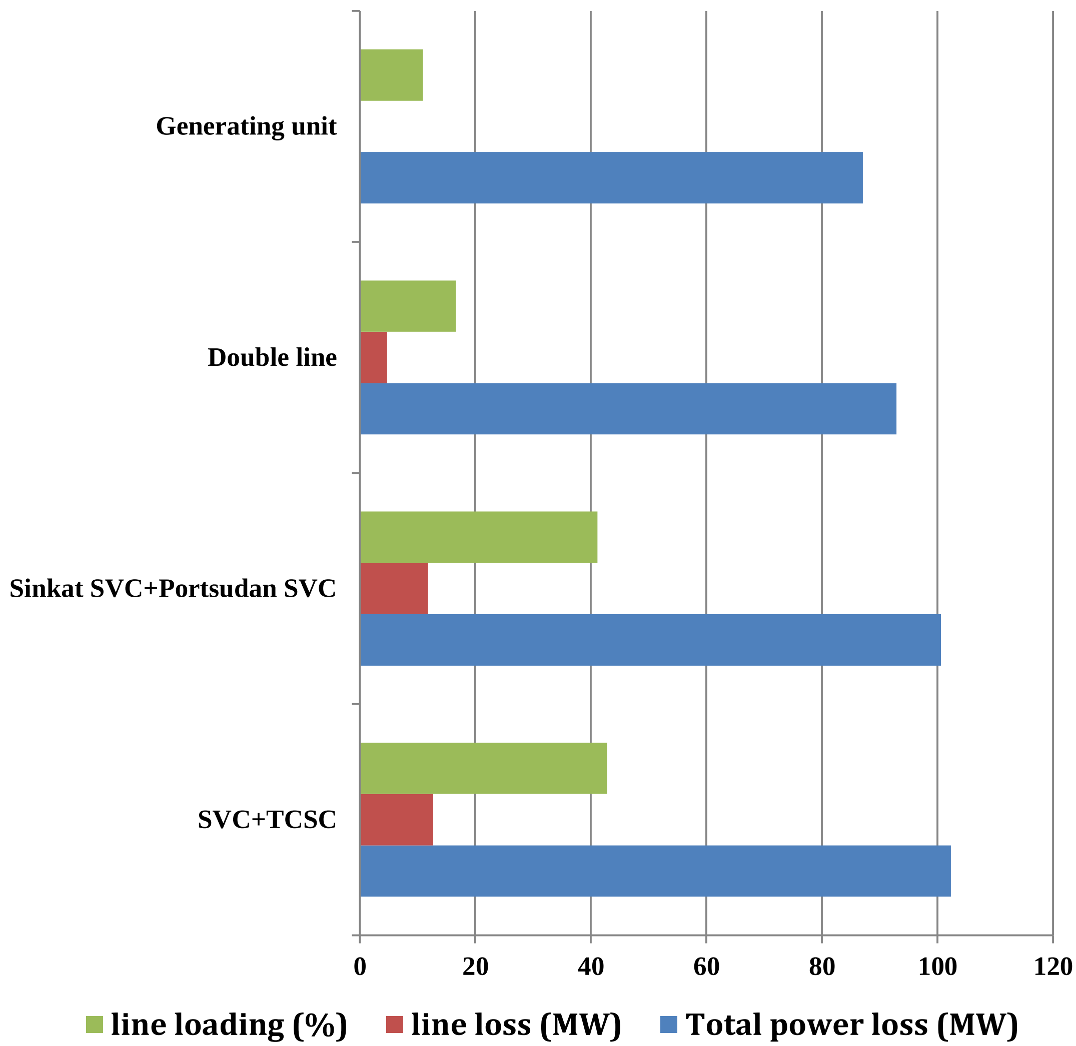

Figure 4.5: Comparison the line loading, ATB-POR transmission loss, total system loss in case of 150% load in Portsudan.

Figure 4.6 shows the voltages at Atbara and Portsudan buses in case of overloading the line. It is clear that scenario of building generation unit in Portsudan is the best one.

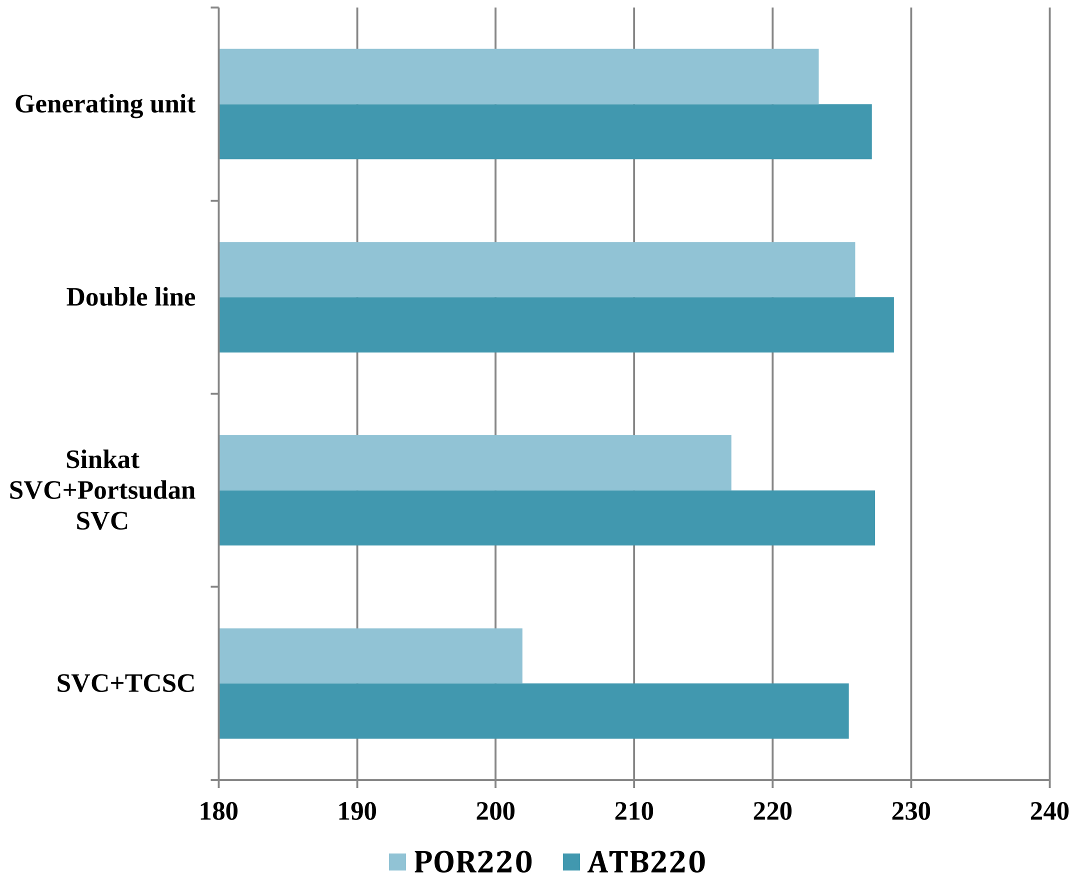

Figure 4.6: Comparison the voltage profiles of ATB220 & POR220 in case of 150% load in Portsudan.

It is observed that with the inclusion of TCSC, power transfer capacity increased with the degree of compensation. In simulations, with different degree of compensation, power level had been varied and the corresponding change in real power transfer is also observed. Also the option of line change to a new configuration is more efficient to achieve contingency of line outage, reduce transmission loss, enhance voltage profile and reduce line loading.