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## Article

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## Research paper

## Voltage quality in delta Egypt network and its impact in oil industry

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## HIGHLIGHTS

- This paper studied the voltage profile in delta Egypt network.
- A relation between voltage quality and catastrophic events in oil refining industry.
- High quality grid must have voltage stability with in accepted levels at each bus.
- Network construction was performed by (DIgSILENT power factory software).
- The voltage profile was performed by proposed four different scenarios. Scenario 1: power flow (PF) study in normal operation (base case). Scenario 2: (PF) study using automatic tap changer (ATC). Scenario 3: (PF) study using (ATC)& static Var system (SVS). Scenario 4: (PF) study using (ATC), (SVS) and shunt reactive power control devices.
- A comparison between all scenarios results have done to get the optimum solution.
- The best voltage profile had achieved by using scenario 4.

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## ABSTRACT

The electrical energy is transmitted from the generating stations to the consumers through a transmission network.

The effectiveness of improving voltage profile yields high transmission network efficiency and increase the capacity of transmission lines, also decrease power losses, voltage drop and unplanned shut down in the big industrial and strategic loads like (oil refining industry).

This paper objective presents the suggested solutions for improving voltage profile in electrical network of delta Egypt to achieve a voltage quality.

The methodology of suggested solutions are applied on delta Egypt network with voltage levels (66, 11, 6.6, 0.4) kV, the simulations were performed using digital simulation and electrical network calculation (DIgSILENT power factory software) to study the voltage profile.

The validation of results was performed by comparing the voltage profile of proposed four different scenarios:

1st: power flow in normal operation (without using any voltage improving devices), 2nd: using Automatic Tap Changer (ATC) of transformers, 3rd: installing a Static Volt Ampere Reactive (VAR) System (SVS) with (ATC), 4th: installing a (SVS), (ATC) and shunt reactive power compensation devices (parallel capacitor / inductor).

The best voltage profile achieved by using scenario 4, which supported and improved the voltage profile of all system and brings the magnitudes of all buses in permissible voltage level from (0.79–0.99 P.U.) at normal operation (scenario 1) to (0.9–1.04 P.U.) at (scenario 4).

So the system can be operated with more efficiently, stability and improving the capacity of the network after applying the solution stated in scenario 4.

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## 1. Introduction

Recently due to increasing power demand and growth in the use of inductive loads in all industries which consume more reactive

power and tend to more power losses, power systems are operated to their maximum operation conditions.

A high performance network must have voltage stability and sustain with in permissible variation levels in magnitude  $\pm 10\%$  of the rated voltage at each bus (Voltage characteristics, 2005).

Increasing inductive loads cause many problems and tended to poor power quality, the most common of these problems are under voltage, sag and unbalance (voltage instability).

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### Abbreviations

DIGSILENT	Digital simulation and electrical network.
kV	Kilo volt.
P.U.	Per unit.
ATC	Automatic tap changer.
VAR	Volt ampere reactive.
Mvar	Mega volt ampere reactive.
SVS	Static volt ampere reactive system
PLC	programmable logic control.
DCS	distributed control system.
UPS	Uninterruptable power supply.
CORC	Cairo oil refining company.
MVA	Mega volt ampere.
HV	High voltage.
TCR	Thyristor controlled reactance.
TCS	Thyristor switch capacitance.
MSC	Mechanically switched capacitor.
L	Inductor.
C	Capacitor.

Voltage instability disturbance which caused malfunction or unplanned shut down in a big industrial and strategic loads like (oil refining industry) ([Kianersi and Asadi, 2015](#)), to overcome this problem several methods are available to improve voltage profile, one of commonly used methods are:

Automatic Tap Changer (ATC) of transformers, Static Volt Ampere Reactive VAR System (SVS), Shunt reactive power compensation devices (parallel - capacitor/inductor) and a combination of them.

This paper study the performance of electrical network and voltage profile by using each method to get the optimum solution and best voltage profile, all of these cases were simulated using the digital simulation and electrical network calculation (DIGSILENT power factory software).

## 2. Voltage quality and oil refining industry

A poor voltage quality leads to unscheduled electric power supply interruption to an oil refining industry and can trigger a chain of catastrophic events. This is due to the multiple interlinked chains of electrical systems and the mixture of highly flammable volatile materials on which the processes are based. Ensuring power system reliability is essential to avoid putting staff and neighboring areas at risk, and to minimize costly incidents and production stoppages.

Electric power represents one of the highest production costs in oil refining. With production facilities operating 24 h a day, 7 days a week, the continuous Electric power supply of high quality, reliable power is essential for this industry. Unscheduled power supply interruptions due to poor voltage quality can create a number of costly consequences:

### 2.1. According to oil refining industry

#### (a) Time for restarting the plant:

Costs of shutdown and restarting the entire plant after an unscheduled electric power supply failure. Costs of these restarting can be high.

#### (b) Downtime of critical units:

Unplanned power failure or disturbances which affect equipment operation leads to production stoppage costing a lot of

money. A consequence reaction leads to a sudden multiple shutdowns of plant units.

#### (c) More repairs and maintenance:

Carrying out of these sudden interventions needs expensive emergency of unplanned maintenance and time of staff or more efforts to restart the plant units.

#### (d) Equipment damage:

Unscheduled shutdown leads to unwanted operation like safety valves acts as safe fail status (full open /close), over pressure can damage equipment and increased insurance premiums.

#### (e) Neighboring companies effect:

Companies which depend on oil refining industry like distribution of oil products business need to be compensated for oil products in case of unplanned shutdown ([JM Medina, 2009](#)).

### 2.2. According to utility

Sustained under voltages or over voltages can cause the following problems:

- Less equipment efficiency operation or improper and minimized life time, like rotating machines may run slow or fast.
- Tripping and malfunction of sensitive loads, like a battery charger, programmable logic control (PLC), distributed control system (DCS) and uninterruptable power supply (UPS) may revert to battery mode during low or high voltage which leads to discharge the batteries of UPS and cause power outage to critical loads.
- Insulation damage or failure of electrical equipment due to over voltage.
- Increase of no-load losses and magnetizing current in transformers at over voltage.
- Low power factor, increasing of starting current and decreasing torque of induction motors during voltage disturbance.
- Low voltage increases power losses, utility costs, load current and temperature more than necessary transmitted current through the system ([El-HADIDY, 2008](#)).

From above discussion we can say that the voltage quality indicates the power quality which is defined as: any power problem manifested in voltage, current, or frequency deviations that results in failure or malfunction of customer equipment ([Dugan and McGranaghan, 2004](#)).

## 3. Modeling of electrical network using DigSilent power factory software

DIGSILENT power factory is a high and power system analysis tool for applications in transmission, distribution, generation, industrial, and smart grid operations. It has set standards and trends in power system modeling, analysis and simulation ([Nassar, 2016](#)).

A voltage levels at delta Egypt in this study are 66 kV for transmission network and (11,6,6,0,4) kV for distribution network which supply electrical power required for oil refining company. All of them are established and simulated using DigSilent power factory software as shown in [Fig. 1](#).

The validation of results was performed by comparing the voltage profiles of proposed four different scenarios:

scenario 1: power system in normal operation, scenario 2: by using Automatic Tap Changer (ATC) of transformers, scenarios 3: installing a Static Volt Ampere Reactive VAR System (SVS) with (ATC), scenario 4: installing a Static Volt Ampere Reactive VAR System (SVS), (ATC) and shunt reactive power compensation devices (parallel capacitive and inductive).

Four scenarios are performed to comparing the voltage profiles for each bus (only 23 buses are selected which indicate the voltage profile for all system).

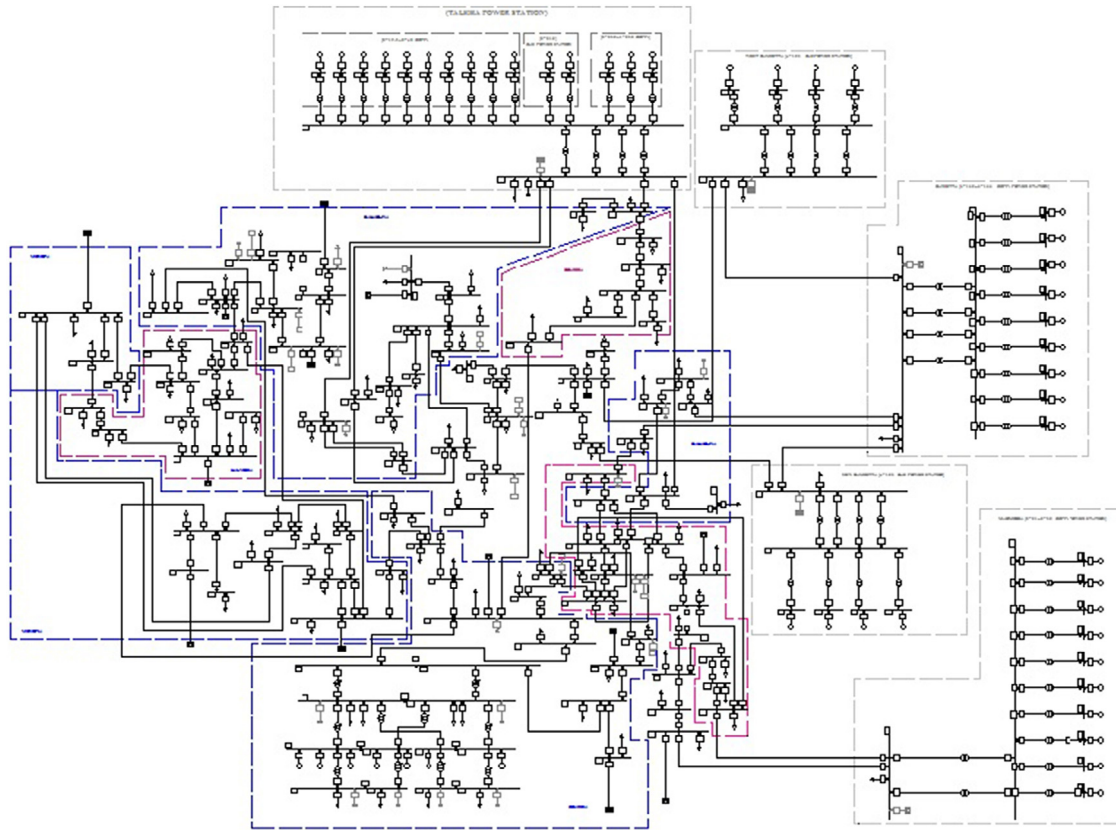


Fig. 1. A single line diagram of a 66 kV network supplying oil refining company Constructed by DigSilent power factory software.

Table 1

Voltage magnitudes in P.U. at (system normal operation).

Bus name	Voltage magnitude in P.U. (normal operation)
Abo Ghanema	0.9419348
Al Gamaliya	0.8007651
Al mandowa	0.9818294
Al mosalas	0.8360475
Al santa	0.9148444
Alborolos West	0.9559873
Albosyle	0.9628006
Alflandi	0.9725568
Almahala	0.9275878
Aolad Hamam	0.9130047
Balteam	0.7982459
Batra	0.8542577
Berkt Alsaba	0.9272687
Beyala	0.8404525
Damitta East	0.9058774
Fowa	0.9459228
Gamasa	0.9148678
Kafr Shokr	0.9553394
Sheben Alkom 2	0.9716483
Tafree el erad	0.8824861
CORC 11 kV Alzayat East	0.9930507
CORC 6.6 kV	0.9910274
CORC 0.4 kV	0.9819487

### 3.1. Scenario 1: power System in normal operation

Constructing and simulated the electrical network as shown in Fig. 1, the load flow calculations determine the Voltage magnitudes at each bus as shown in Table 1 and Fig. 2.

According to the results after load flow calculations shown in Table 1 and Fig. 2, the under voltage problem clearly notifies where The minimum voltage magnitude in the network is around 20% less than the nominal value at 66 kV at (Balteam), this value is not

in acceptable range, and should be enhanced. To improve voltage magnitude, scenario 2 is suggested.

### 3.2. Scenario 2: Using Automatic Tap Changer (ATC) of transformers

Tap-changers are devices that will vary the turns ratio of a transformer and hence regulate the voltages of that transformer (Tap-changers, 2004).

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \quad (1)$$

where:

$V_p$  = voltage on primary coil.

$V_s$  = voltage on secondary coil.

$N_p$  = number of turns on the primary coil.

$N_s$  = number of turns on the secondary coil (Electrical Science, 1992).

Eq. (1) indicates, the voltage amplitude can be easy controlled via changing the coil number of turns.

The benefits of selection this solution of tap-changers to control voltage amplitude because of this option already exist and commonly used in the distribution transformers beside it had a low cost and no need to power shut down for changing over the taps (on-line type) to achieve the required voltage amplitude.

The specifications of step down transformers installed at oil refining company (CORC) clearly shown at Table 2.

For all transformers have automatic tap changer at High Voltage (HV) side with parameters shown in Table 3.

After performing automatic tap changers at step down transformers, again the load flow calculations determine the values of voltages at each bus and make a comparison with the power system in normal operation (scenario 1), as shown in Table 4 and Fig. 3.

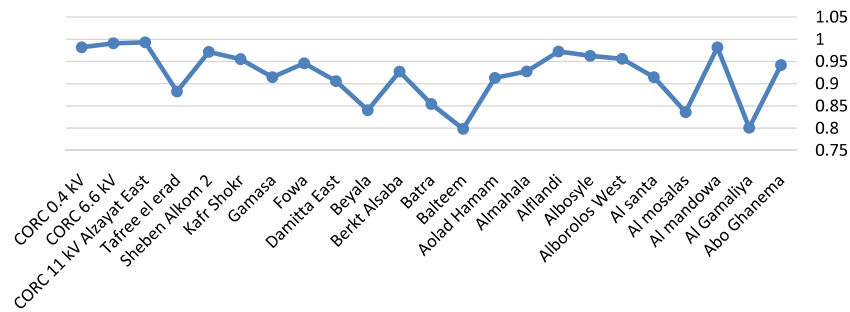


Fig. 2. Voltage magnitudes in P.U. at (normal operation).

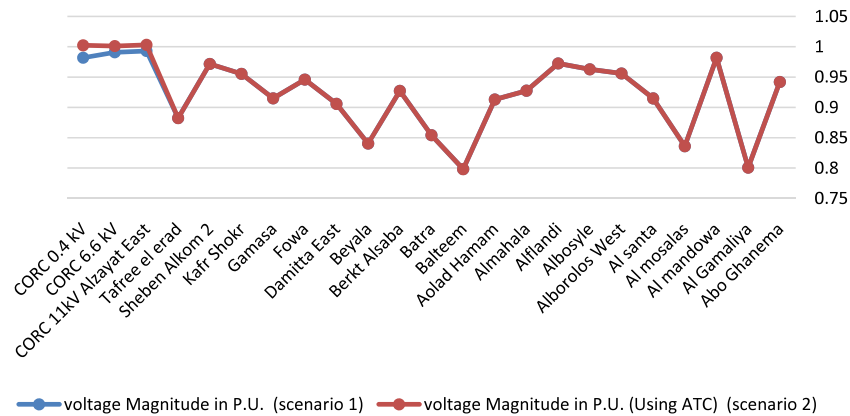


Fig. 3. Voltage magnitudes in P.U. at (normal operation) and after using ATC.

Table 2  
Transformers specifications.

Quantity	Transformer voltage ratio	Rated mega volt ampere (MVA)	Vector group	Impedance voltage %
2	66/11 kV	12.5	Dyn 11	5
2	11/6.6 kV	2.5	Dd 0	5.3
2	11/6.6 kV	4	Dyn 11	4.5
2	6.6/0.4 kV	2	Dyn 11	6.6
2	6.6/0.4 kV	2	Dyn 11	5.8

Table 3  
Transformer tap-changing parameters.

Voltage set point	1.0 P.U
Lower voltage bound	0.9 P.U
Upper voltage bound	1.1 P.U
Additional voltage per tap	1.0%
Min and max position	−10 and 10
Controller time constant	0.5 s

According to the results shown in Table 4 and Fig. 3, after using ATC the voltage profile has been improved as shown at (CORC 11 kV Alzayat East, CORC 6.6 kV and CORC 0.4 kV) Buses, but still the under voltage problem clearly notified which the minimum voltage magnitude in the network is still around 20% less than the nominal value at 66 kV at (Balteem) bus, and this is unacceptable voltage magnitude and should be enhanced, so scenario 3 shall be performed to eliminate this problem.

### 3.3. Scenario 3: Using a (SVS) with (ATC)

The static volt ampere reactive VAR compensator system (SVS) is a combination of a shunt capacitor bank and a thyristor controlled shunt reactance.

The capacitors in the capacitor bank can be switched on and off individually. The capacitors could be switched with thyristors which called thyristor switch capacitor (TSC) or could be permanently (mechanically) connected which called mechanically switch capacitor (MSC) as shown in Fig. 4 (SVS - Static Var System, 2011).

The optimum location for installing a SVS by selecting the minimum voltage amplitude buses, and apply a SVS at one of them, then run the load flow calculation and check the values of all voltage amplitudes at each bus on the network then select another one to install a SVS on it, and run the load flow calculation again and so on. Finally: the optimum location for installing a SVS which achieved the best voltage profile of the network.

The benefits of selection this solution of SVS with tap-changers to get a better voltage quality because of the Volt Ampere Reactive (VAR) or a reactive power is smoothly injected or absorbed (by using a fully controlled reactive power devices, capacitor and/or inductor), this option had a fast response with a sudden varying loads conditions and already exist at a transmission network.

The installed SVS basic data considered: thyristor controlled reactance (TCR) maximum limit is 200 mega volt ampere reactive (Mvar), thyristor switch capacitance (TSC): maximum number of capacitors is 5 (50 Mvar/Capacitor) and the amount of reactive power injected into the network is 212.9 Mvar.

Table 5 shows the final result after installed a SVS and compared voltage magnitudes at each bus with previous scenarios.



**Table 4**

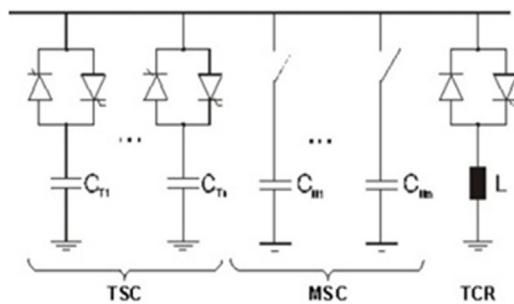
Voltage magnitudes in P.U. at (normal operation) and after using ATC.

Bus name	Voltage magnitude in P.U. (normal operation) (scenario 1)	Voltage magnitude in P.U. (Using ATC) (scenario 2)
Abo Ghanema	0.9419348	0.9419285
Al Gamaliya	0.8007651	0.8006359
Al mandowa	0.9818294	0.9818182
Al mosalas	0.8360475	0.8360274
Al santa	0.9148444	0.9148344
Alborolos West	0.9559873	0.9559797
Albosyle	0.9628006	0.9627973
Alflandi	0.9725568	0.972554
Almahala	0.9275878	0.9275876
Aolad Hamam	0.9130047	0.912958
Balteem	0.7982459	0.79823
Batra	0.8542577	0.8542488
Berkt Alsaba	0.9272687	0.9272662
Beyala	0.8404525	0.8404395
Damitta East	0.9058774	0.9058303
Fowa	0.9459228	0.9459164
Gamasa	0.9148678	0.9148636
Kafr Shokr	0.9553394	0.9553387
Sheben Alkom 2	0.9716483	0.971646
Tafree el erad	0.8824861	0.8823648
CORC 11 kV Alzayat East	0.9930507	1.003138
CORC 6.6 kV	0.9910274	1.001123
CORC 0.4 kV	0.9819487	1.00235

**Table 5**

Voltage magnitudes in P.U. at (normal operation) and after using ATC&amp;SVS.

Bus name	Voltage magnitude in P.U. [normal operation] (scenario 1)	Voltage magnitude in P.U. [using ATC] (scenario 2)	Voltage magnitude in P.U. [using (ATC & SVS)] (scenario 3)
Abo Ghanema	0.9419348	0.9419285	0.9732539
Al Gamaliya	0.8007651	0.8006359	0.8296768
Al mandowa	0.9818294	0.9818182	1.037865
Al mosalas	0.8360475	0.8360274	0.9372907
Al santa	0.9148444	0.9148344	1.005868
Alborolos West	0.9559873	0.9559797	0.9940954
Albosyle	0.9628006	0.9627973	0.9796433
Alflandi	0.9725568	0.972554	1.016776
Almahala	0.9275878	0.9275876	0.9624498
Aolad Hamam	0.9130047	0.912958	0.9275752
Balteem	0.7982459	0.79823	0.8754059
Batra	0.8542577	0.8542488	0.8811228
Berkt Alsaba	0.9272687	0.9272662	0.9702769
Beyala	0.8404525	0.8404395	0.900479
Damitta East	0.9058774	0.9058303	0.9205705
Fowa	0.9459228	0.9459164	0.9781362
Gamasa	0.9148678	0.9148636	0.9332567
Kafr Shokr	0.9553394	0.9553387	0.9830487
Sheben Alkom 2	0.9716483	0.971646	1.012042
Tafree el erad	0.8824861	0.8823648	0.9096456
CORC 11 kV Alzayat East	0.9930507	1.003138	1.001748
CORC 6.6 kV	0.9910274	1.001123	1.030972
CORC 0.4 kV	0.9819487	1.00235	1.011848

**Fig. 4.** Static volt ampere reactive VAR system model.

According to the results shown in Table 5 and Fig. 5, After using ATC & SVS the voltage had a better profile than previous scenarios (1&2), but still under voltage problem notified which the minimum

voltage magnitude in the network is around 83% of a nominal value at (Al Gamaliya) bus, and this value is still unacceptable and should be improved. To enhance voltage magnitudes, scenario 4 is suggested.

#### 3.4. Scenario 4: using a (SVS) with (ATC) & shunt reactive power compensation devices (capacitor/inductor)

Voltage is propped up with reactive power support, alternatively, if there is inadequate reactive power, the system may have voltage collapse. Therefore, electrical network require compensation for this varying reactive power.

Load compensation is the management of the reactive power to improve the voltage profile i.e. voltage quality and power factor.

In this scenario the reactive power flow is controlled by installing shunt compensation devices (capacitor/inductor) at the load end bringing about power balance between generated and consumed reactive power.

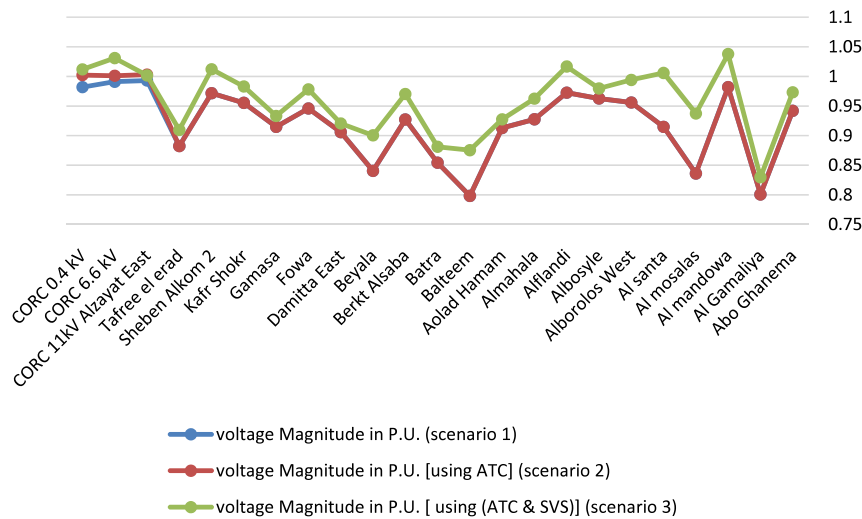


Fig. 5. Voltage magnitude in P.U. at (normal operation) and after using ATC&SVS.

The benefits of suggested this solution (shunt reactive power compensation devices (capacitor/inductor) with SVS and Tap-changer to get the best voltage profile because of using a reactive power control device (capacitor/inductor) had a lower cost than SVS beside these devices are considered the most effective solution to improve the power transfer capability of the system and its voltage stability (Rai and Hasan, 2015).

The scenario 4 procedure:

- (1) *First step:* Shunt capacitor compensation is installed at a bus which has a minimum voltage magnitude to inject a reactive power and enhance voltage profile, then run the load flow calculation and check the values of all voltage magnitudes at each bus on the network, but over voltage problem was noted at buses which they were in acceptable magnitude range before applying a shunt capacitor.
- (2) *Second step:* The shunt inductor compensation is installed to consume the reactive power and reduce over voltage problem at these buses, then run the load flow calculation again and check the values of all voltage magnitudes at each bus on the network, but under voltage problem was noted again at buses which they were in acceptable magnitude range before applying a shunt inductive device, so the first step is repeated again and so on until an acceptable voltage magnitude range at all buses in the network are confirmed.
- (3) *Finally:* by using reactive power compensation devices (capacitors/inductors) the reactive power can be controlled which influence at a voltage magnitude, the procedure flow chart shown in Fig. 6.

The discussion on the result obtained in scenario 4, after applying a (SVS) with (ATC) & shunt reactive power compensation devices (capacitor/inductor), all network voltage buses magnitudes had an acceptable range and over/under voltage problems completely eliminated and a voltage profile had improved after performing this scenario.

The best voltage profile achieved after perform scenario 4, which all voltage magnitude for all buses are in allowable range as clearly shown in the results at Table 6 and Fig. 7.

Also Table 6 and Fig. 7 discussed the comparison of voltage profiles for all previous scenarios.

#### 4. Conclusion

This paper presents and studies the voltage profile in electrical network of delta Egypt at voltage levels (66,11,6.6,0.4) kV, the

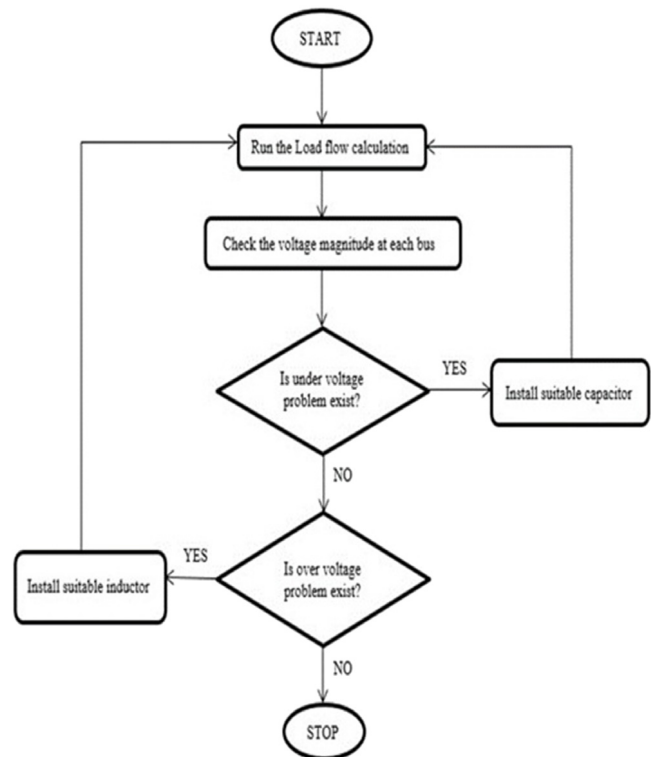


Fig. 6. Scenario 4 procedure flow chart.

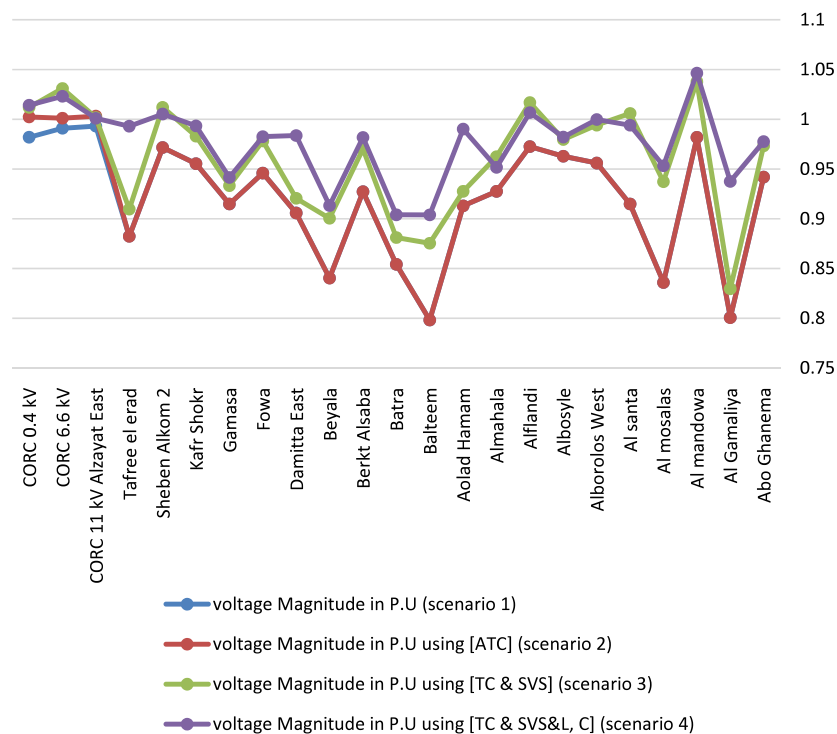
transmission network construction and simulations of delta Egypt were performed in the digital simulation and electrical network calculation (DIGSILENT power factory software) to investigate the voltage profiles at each bus in the network. The following scenarios were performed:

- (1) *scenario 1:* By applying and run the load flow calculation at normal operation (without using any voltage improving devices), under voltage problem was clearly notified at a 66 kV voltage level, so the second scenario shall be performed.
- (2) *scenario 2:* By using automatic tap changer (ATC) of transformers, this method had improving the voltage level magnitudes (11,6.6,0.4) kV, but still the 66 kV voltage level suffer

**Table 6**

Voltage magnitudes in P.U. at (normal operation) and after using ATC&amp;SVS&amp; (L, C).

Bus name	Voltage magnitude in P.U [normal operation] (scenario 1)	Voltage magnitude in P.U using [ATC] (scenario 2)	Voltage magnitude in P.U using [ATC & SVS] (scenario 3)	Voltage magnitude in P.U using [ATC & SVS&L, C] (scenario 4)
Abo Ghanema	0.9419348	0.9419285	0.9732539	0.9775659
Al Gamaliya	0.8007651	0.8006359	0.8296768	0.9375144
Al mandowa	0.9818294	0.9818182	1.037865	1.046356
Al mosalas	0.8360475	0.8360274	0.9372907	0.9532892
Al santa	0.9148444	0.9148344	1.005868	0.9939926
Alborolos West	0.9559873	0.9559797	0.9940954	0.9997634
Albosyle	0.9628006	0.9627973	0.9796433	0.9820917
Alflandi	0.9725568	0.972554	1.016776	1.006726
Almahala	0.9275878	0.9275876	0.9624498	0.9517096
Aolad Hamam	0.9130047	0.912958	0.9275752	0.9901511
Balteem	0.7982459	0.79823	0.8754059	0.9038995
Batra	0.8542577	0.8542488	0.8811228	0.9040134
Berkt Alsaba	0.9272687	0.9272662	0.9702769	0.9817663
Beyala	0.8404525	0.8404395	0.900479	0.9133325
Damitta East	0.9058774	0.9058303	0.9205705	0.9836267
Fowa	0.9459228	0.9459164	0.9781362	0.9825044
Gamasa	0.9148678	0.9148636	0.9332567	0.9415177
Kafr Shokr	0.9553394	0.9553387	0.9830487	0.9933614
Sheben Alkom 2	0.9716483	0.971646	1.012042	1.005274
Tafree el erad	0.8824861	0.8823648	0.9096456	0.9930215
CORC 11 kV	0.9930507	1.003138	1.001748	1.000929
Alzayat East				
CORC 6.6 kV	0.9910274	1.001123	1.030972	1.023106
CORC 0.4 kV	0.9819487	1.00235	1.011848	1.014193

**Fig. 7.** Voltage Magnitudes in P.U. at (normal operation) and after using ATC&SVS& (L, C).

from under voltage problem, to reduce this problem, third scenario shall be suggested.

- (3) *scenario 3*: By installing a SVS with (ATC), this solution improved the voltage profile at each bus for all voltage levels as shown at above results, but some buses still had unacceptable voltage magnitudes and need to be supported, so the final solution was applied.
- (4) *scenario 4*: By adding shunt reactive power compensation devices (capacitors/inductors), from previous results, this method supported and enhanced the voltage profile of all system and brings the magnitudes of all buses in permissible

voltage limits and the system can be operated with more efficiently, stability, reliability and high capacity of the system.

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