New Proposed Method of Damping Temporary Overvoltages on Power System Interconnections

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Abstract: The interconnection between countries links different networks. These interconnections may be exposed to several disturbances. These disturbances (such as transient and temporary overvoltages phenomena, faults …etc.) threaten the interconnection security and reliability. This paper presents actual field measurements of transient and temporary overvoltages appearing on the Egyptian – Libyan system interconnection as an example. These overvoltages were recorded for different cases of operation. These cases were modeled and simulated using the most recent version of Alternative Transient Program (ATP) computer package to compare the results of the computational method with the actual field measurements. The comparison between the ATP output results and the actual field measurements were found less than ± 4%. Within the research activities of the Egyptian Electricity Holding Company (EEHC) temporary overvoltage phenomena on the Egyptian – Libyan interconnection network were detected. EEHC carried field measurements of the temporary overvoltage by using a special transient mobile test laboratory. This detected temporary overvoltage was due to the generated reactive power along the line on switching, in spite of this leading reactive power was compensated by connecting number of reactors at different nodes. The economical aspect has been taken into consideration to reduce the number of reactors to the network, which showed the best effect on damping the temporary overvoltage. This paper, thus, presents a proposed technique to damp the temporary overvoltage and keep the system voltage within the permissible limits by estimating the optimum number and location of reactors that must be connected to the network. [Journal of American Science. 2010;6(11):336-342]. (ISSN: 1545-1003).

Keywords: interconnection; networks; disturbances; Alternative Transient Program (ATP); Egyptian Electricity Holding Company (EEHC)

1. Introduction

Due to the very fast progress and development in the different sectors of the electrical power system all over the world, the electrical interconnection between neighboring countries have been an important goal for most countries. These interconnections are exposed to many disturbances that threaten their security, such as overvoltage phenomena and earth faults …etc.

As the Egyptian unified electrical network interconnected with the Jordan electrical network through 500/400 kV interconnection system, overvoltage studies were carried out. The overvoltage studies decided to use shunt reactors at different locations to compensate the generated reactive power of the long transmission line from Cairo to Naqab [1]. This study was based on the field measurements and EMTP output results.

Adding shunt reactors are used on many high voltage transmission lines as a means of shunt compensation to improve the performance of the line. They have the additional advantage of reducing the energization surge magnitudes. This is accomplished mainly by the reduction in temporary overvoltage [2]. All these effort were done to keep the voltage profile within the permissible level to protect the electrical equipments in the network. Therefore, when the Egyptian – Libyan power systems were interconnected, the appearing disturbance should have been studied and treated. This paper is, thus, devoted to this objective.

2. The Egyptian–Libyan Interconnection Configuration:

The Egyptian – Libyan electrical interconnection network, of 613 km from Borg Al-arab in Egypt to Tobrouk in Libya, consists of double circuit transmission line of 220 kV passing through a number of 220/66 kV sub-stations (S/S), as shown in Fig.(1).

This transmission line consists of different sectors between sub-stations. These sectors have the following lengths:

Table (1)

Sector No.	From	To	Distance (km)
1	Borg Al-Arab	Omayed	35
2	Omayed	Matrouh	215
3	Matrouh	Saloum	198
4	Saloum	Tobrouk	165

The numbers of reactors already connected to the sub-stations are as follows:

Table (2)

No	S/S	No. of reactors	Reactor rating (MVAR)	Connected to
1	Borg Al-Arab	-----	-----	-----
2	Omayed	-----	-----	-----
3	Matrouh	2	25	Bus Bar
4	Saloum	2	25	Transmission line (Saloum-Matrouh)
5	Tobrouk	2	25	Bus Bar

The reactors are not switchable; they are solidly connected to the bus bar or to the transmission line.

The Thevinen equivalent circuit of the Egyptian and Libyan Unified electrical power network, and the different sub-stations were calculated and simulated in Fig. (2).

3. Field Measurements and ATP Results:

Due to the long length of the Egyptian – Libyan electrical interconnection network (613 km) and the light loading nature of the sub-stations along the line, a leading reactive power is generated along the line. This leading reactive power distorts the voltage profile along the line.

The field measurements require advanced technology with high sensitivity and accuracy. A mobile test laboratory for overvoltage measurements in EEHC has been used for this purpose. This laboratory includes PC programmable sequence controller, computer assisted measuring and data acquisition system for registration and analysis of the test results [3].

Field measurements were carried out by the EEHC to measure the transient and temporary overvoltages for five different cases. These cases are as follows:

1- Disconnecting Tobrok 220/66 kV s/s bus coupler with two reactors connected to its bus bar.

2- Disconnecting Tobrok 220/66 kV s/s bus coupler with no reactors connected to its bus bar.

3- Disconnecting Saloum 220/66 kV s/s bus coupler.

4- Disconnecting Matrouh 220/66 kV s/s bus coupler.

5- Disconnecting Omayed 220/66 kV s/s bus coupler.

The field measurements record that the most severe case was (Case 5). Case 5 shows unacceptable temporary overvoltage due to switching off the interconnection network from Omayed 220/66 kV substation. The network configuration shown in Fig (1). This case was modeled, simulated in Fig. (2) and studied by the ATP program.

Table (3) shows the system voltage before disconnection, the maximum transient overvoltage, the temporary overvoltage and the error percentage between actual field measurements and output results of ATP.

Table (3) shows the measured voltage at different sub-stations, there voltages are as follows:

- Saloum sub-station records a maximum transient overvoltage of 1.17 p.u. and temporary overvoltage of 1.12 p.u.
- The maximum transient overvoltage at Matrouh sub-station reaches 1.25 p.u. damped to 1.2 p.u. as temporary overvoltage.
- While Omayed sub-station measuring points records 1.25 p.u. for maximum transient overvoltage and temporary overvoltage.

The average error between the actual filed measurements and output results of ATP for the system voltage before disconnection was ±1.79 %, while for the maximum transient overvoltage the error was ±3.26 % and for the temporary overvoltage the error percentage was ±3.91 %. This emphasizes the reasonable accuracy, in such cases, of the computations of ATP output results compared to the field measurements.

4. Effect of Adding Reactors:

A sensitive node analysis was done to find the more sensitive bus for reactive power compensation. In this bus a number of reactors were added one by one. A 220 kV reactor of capacity 25 MVAR was added to the most sensitive nodes. The sensitive node analysis shows that Saloum, Matrouh and Omayed sub-stations were the most sensitive buses.

Optimization studies were done to find the optimum number of reactors at sensitive buses. The output results of the optimization studies are shown in Fig. (3, 4 and 5). These figures show the system voltage, the maximum transient overvoltage and the temporary overvoltage with the number of reactors. The maximum and minimum permissible limits (±10% of the nominal voltage) assign the optimum number of reactors that gives the most acceptable temporary overvoltage. [4]

Table (3). The percentage error between the field measurements and ATP computation with the disconnection of 220kv bus coupler at Omayed 220/66kV S/S

No.	Measuring point	Phase	System Voltage Before Disconnect (kV)			Max. Transient O.V. (kV)			Overvoltage (kV)		
			Field measurements	ATP calculation	Error %	Field measurement	ATP calculation	Error %	Field measurements	ATP calculation	Error %
1	Matrouh - Saloum [I]	R	224	228	-1.79	264	267	-1.14	258	266	-3.10
		T	226	228	-0.88	275	267	2.91	262	266	-1.53
2	Matrouh - Saloum [II]	R	226	228	-0.88	264	267	-1.14	261	266	-1.92
3	Bus Bar [I]	R	227	228	-0.44	264	267	-1.14	263	266	-1.14
4	Bus Bar [II]	R	227	228	-0.44	263	267	-1.52	263	266	-1.14
5	Matrouh – Omayed [I]	T	225	228	-1.33	276	267	3.26	260	266	-2.31
6	Matrouh - Omayed [II]	R	227	228	-0.44	260	267	-2.69	262	266	-1.53
		T	224	228	-1.79	274	267	2.55	256	266	-3.91
7	Saloum- Tobrok [I]	T	224	227	-1.34	255	252	1.18	245	251	-2.45
8	Saloum- Tobrok [II]	T	225	227	-0.89	257	252	1.95	245	251	-2.45
9	Saloum- Matrouh [I]	T	224	227	-1.34	258	252	2.33	246	251	-2.03
10	Omayed – Matrouh [I]	R	225	224	0.44	274	277	-1.09	270	275	-1.85
		S	225	224	0.44	276	277	-0.36	**276**	275	0.36
11	Omayed - Matrouh [II]	S	226	224	0.88	275	277	-0.73	**275**	275	0.00
				average error	±1.79		average error	±3.26		average error	±3.91

Fig (3) shows that the optimum number of reactors at Saloum sub-station will be 2 reactors of 25 MVAR (already exist)

Fig (4) shows that the optimum number of reactors at Matrouh sub-station will be 4 reactors of 25 MVAR (2 reactors already exist and 2 reactors are to be necessarily added to damp the temporary overvoltage at this bus)

Fig (5) shows that the optimum number of reactors at Omayed sub-station will be 2 reactors of 25 MVAR (no reactors connected to this bus and 2 reactors are to be added to damp the temporary overvoltage at this bus). Adding 3 reactors will give better results for the voltage profile, but from the economical point of view adding 2 reactors is good enough.

The output results of the ATP program shown in Figs. (6, 7, 8, 9 and 10). These figures show the system voltage before disconnection, maximum transient overvoltage and temporary overvoltage after disconnection along the line (at Sloum, Matrouh and Omayed sub-stations).

Fig (6) **(solution 1)** comprises the implementation of the output results from fig (4) at Matrouh sub-station by adding 4 reactors by capacity 25 MVAR (adding 2 extra reactors to the already existing reactors). This figure shows that the temporary overvoltage was reduced from 246 kV to 232.58kV at Saloum sub-station. This means that adding 2 extra reactors reduced the temporary overvoltage by 5.46 %. This figure also shows that the temporary overvoltage was reduced from 263kV to 237.23 kV at Matrouh sub-station. This means that the temporary overvoltage was reduced by 9.8 %. This figure also shows that the temporary overvoltage was reduced from 276 kV to 245.32kV at Omayed sub-station with a reduction percentage of the temporary overvoltage by 11.12 %. Solution (1) is still considered to result in overvoltage values are over the maximum permissible limits at Omayed sub-station.

Figs. (7 and 8) were the implementation of the output results from Fig (5). Fig (7) **(solution 2)** shows the effect of adding 2 reactors of capacity 25 MVAR at Omayed sub-station. This will reduce the temporary overvoltage from 246 kV to 232.13 kV at Saloum sub-station with reduction percentage of 5.64 %. While the temporary overvoltage at Matrouh sub-station was reduced from 263 kV to 236.52 kV which means a reduction percentage of 10.07 %. Where, at Omayed sub-station temporary overvoltage decreased from 276 kV to 235.35 kV, this means that the reduction percentage at Omayed S/S is 14.73 %.

On the other hand, Fig (8) **(solution 3)** shows the best performance of voltage profile along the interconnection line due to adding 3 reactors of 25 MVAR at Omayed sub-station. There is no fluctuation between the system voltage before disconnection, transient overvoltage and temporary overvoltage. At Saloum sub-station the temporary overvoltage reached to 224.62 kV with reduction percentage of 8.69 %. While at Matrouh sub-station temporary overvoltage reached to 224.99 kV. This means that the reduction percentage is 14.45 %. At Omayed sub-station the temporary overvoltage decreased to 219.63 kV. This means that the reduction percentage 20.42 %.

Fig (9) **(solution 4)** shows the effect of adding 4 reactors at Matrouh sub-station and 2 reactors at Omayed sub-station of capacity 25 MVAR. Solution (4) reduces the temporary overvoltage from 246 kV to 217.33 kV at Saloum sub-station. This means that the reduction percentage is 11.65 %. While the temporary overvoltage at Matrouh reduced from 263 kV to 213.8 kV which means a reduction percentage of 18.71 %. At Omayed S/S temporary overvoltage decreased from 276 kV to 212.74 kV, which means reduction percentage of 22.92 %.

Fig (10) **(solution 5)** shows the effect of adding 4 reactors at Matrouh sub-station and 3 reactors at Omayed sub-station of capacity 25 MVAR. Solution (5) reduces the temporary overvoltage from 246 kV to 211.15 kV at Saloum sub-station with reduction percentage 14.17 %. While the temporary overvoltage at Matrouh reduced from 263 kV to 204.29 kV which means a reduction percentage of 22.32 %. At Omayed temporary overvoltage decreased from 276 kV to 199.51 kV by reduction percentage 27.71 %.

The output results of the ATP for the five proposed solutions, which clarify the calculated temporary overvoltages (T.O.V) and the reduction percentage (%) from the actual field measurements at Saloum S/S (246 kV), Matrouh S/S (263 kV) and Omayed S/S (276 kV) are shown in table (4).

Table (4)

Proposed solution	Saloum		Matouh		Omayed	
	T.O.V	%	T.O.V	%	T.O.V	%
Sol. 1	232.58	5.46	237.23	9.8	245.32	11.12
Sol. 2	232.13	5.64	236.52	10.07	235.35	14.73
Sol. 3	224.62	8.69	224.99	14.45	219.63	20.42
Sol. 4	217.33	11.65	213.8	18.71	212.74	22.92
Sol. 5	211.15	14.17	204.29	22.32	199.51	27.71

5. Conclusions and Recommendations:

1) Interconnection between various countries power systems can suffer from various disturbing problems, especially temporary overvoltage during operation due to the differing nature of the systems and loading conditions.

2) The performance of systems interconnection could be predicted by computations as well as by field measurements with a reasonable degree of accuracy.

3) Suggestion are presented to improve the performance of the interconnected systems, for example, which can be extended to other systems interconnections.

4) The sensitive node analysis helps to find the most effective bus for the reactive power compensation.

5) This paper shows that adding a certain number of reactors at a certain sensitive bus greatly reduces the maximum transient overvoltage, temporary overvoltage and improves the system voltage profile. This protects the electrical equipment in the network and secures the system reliability and prevents system outage.

6) Optimization technique was done to find the most optimum number of reactors at the sensitive bus. The optimum number of reactors was regulated by economical considerations. The economical considerations show that the most effective and economical solution were solutions (2 and 3) as detailed in section (4).

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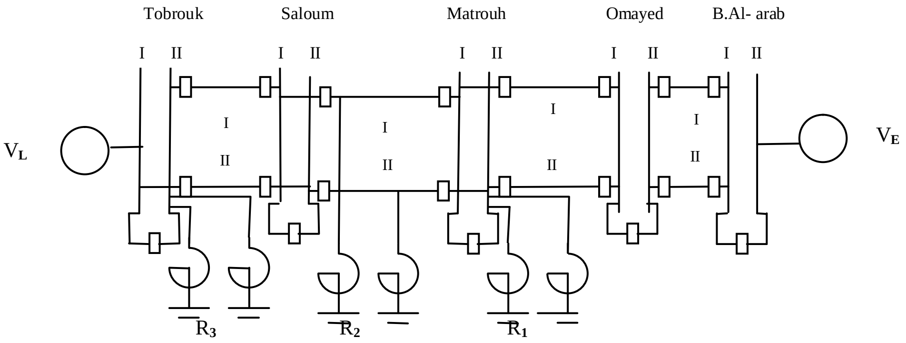


Fig (1) The network configuration when switching off Omayed bus coupler

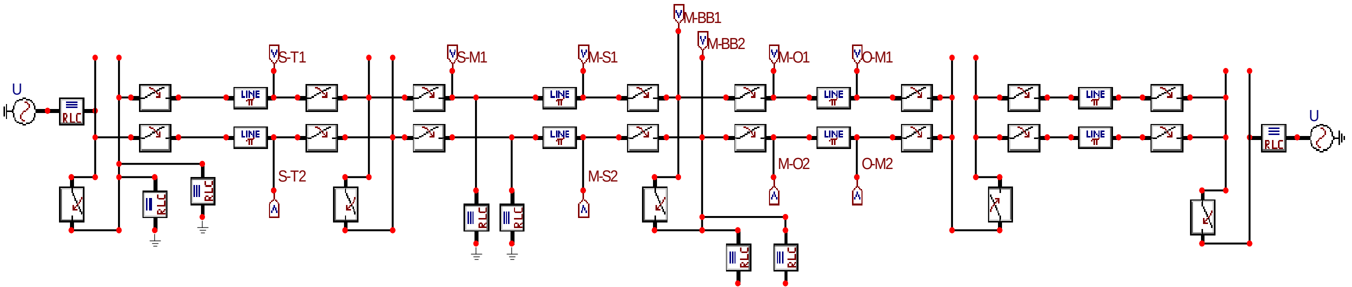
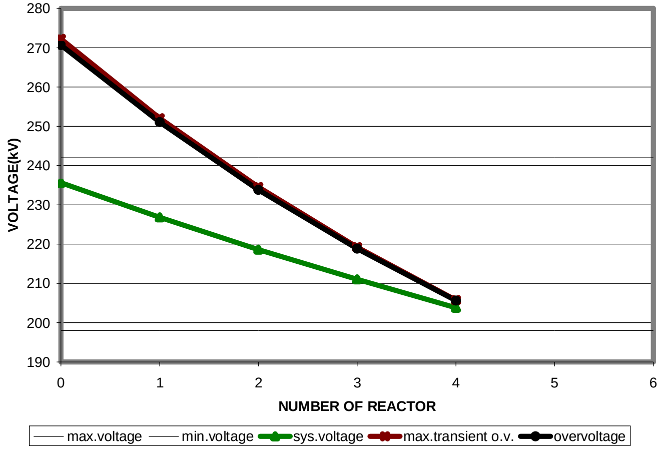


Fig (2) ATP simulation of the electrical interconnection network between Egypt and Libya



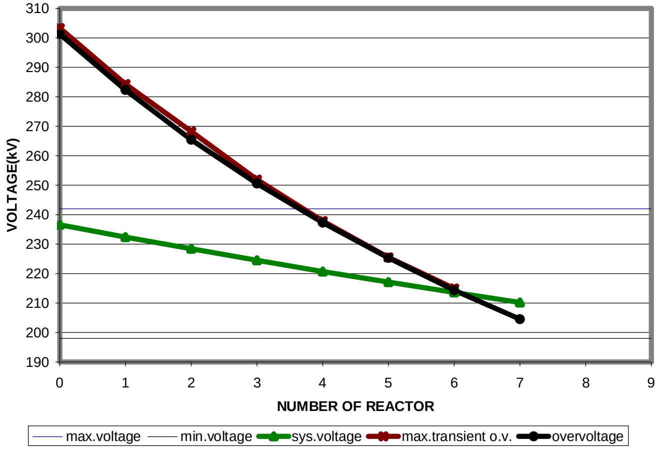


Fig (3) Number of reactor against voltage profile at Saloum

Fig (4) Number of reactor against voltage profile at Matrouh

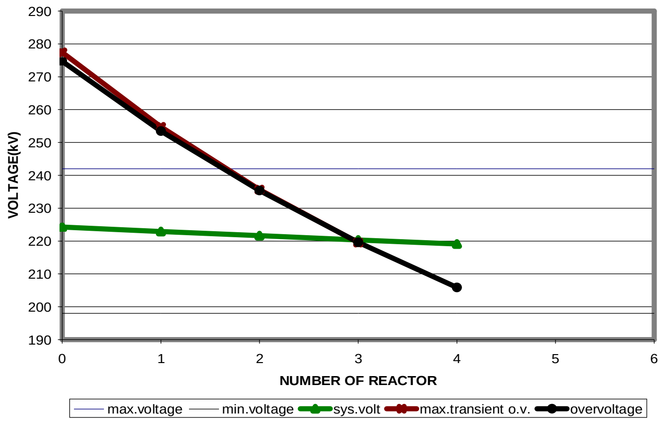


Fig (5) Number of reactor against voltage profile at Omayed

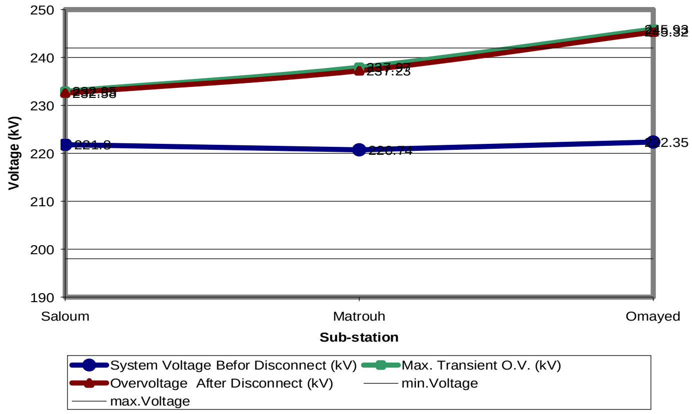


Fig (6) Voltage profile along the interconnection electrical network between Libya and Egypt after adding 4 reactors at Matrouh S/S

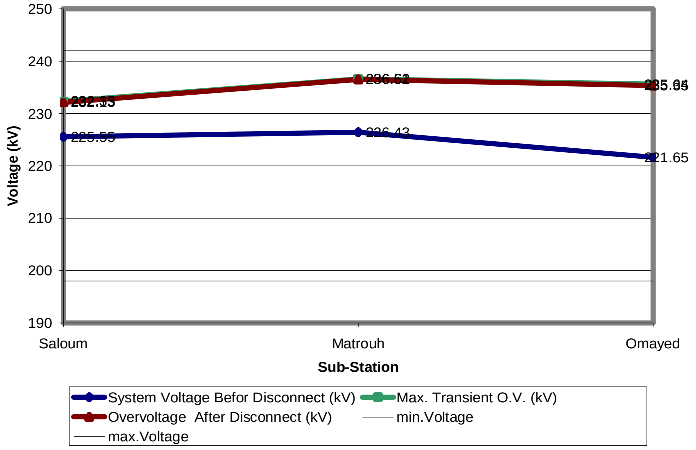


Fig (7) Voltage profile along the interconnection electrical network between Libya and Egypt after adding 2 reactors at Omayed S/S

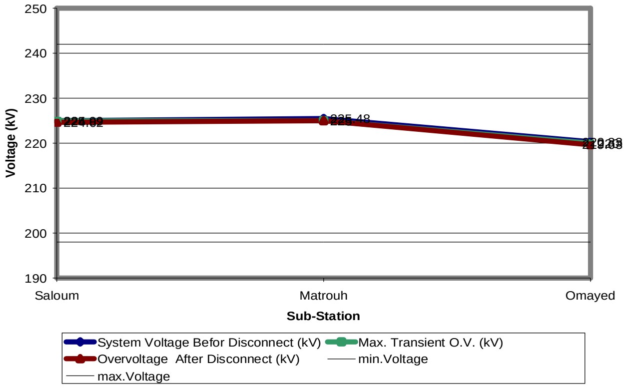
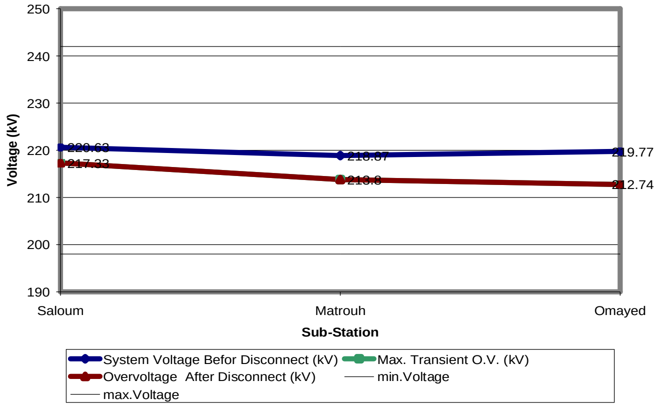


Fig (8) Voltage profile along the interconnection electrical network between Libya and Egypt after adding 3 reactors at Omayed S/S



(9) Voltage profile along the interconnection electrical network between Libya and Egypt after adding 4 reactors at Matrouh S/S and 2 reactors at Omayed S/S

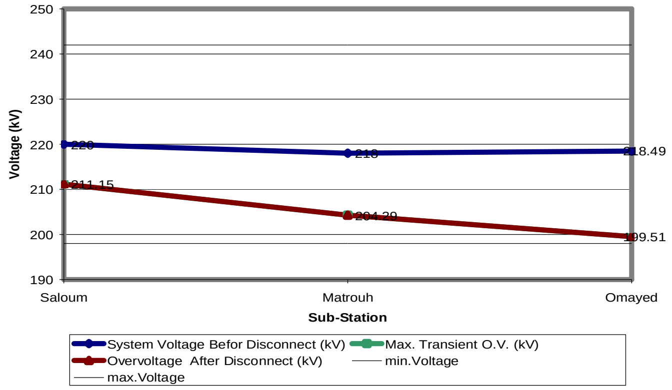


Fig (10) Voltage profile along the interconnection electrical network between Libya and Egypt after adding 4 reactors at Matrouh S/S and 3 reactors at Omayed S/S

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