Application of Transmission Line Surge Arresters to Reduce Switching Overvoltages

H. Seyedi, M. Sanaye-Pasand, M. R. Dadashzadeh

Abstract-- In this paper switching overvoltages of an actual transmission line are studied. Simulations are executed using Electro Magnetic Transients Program. Analyses are performed in two stages. In the first stage the conventional system without any arresters along the transmission line is modeled in EMTP. The results of simulations show that in this case switching overvoltages exceed the Protection Level of the transmission line insulators. Therefore the overvoltages must be reduced. In the second stage one set of surge arresters are installed along the transmission line and its impact on the switching overvoltages are analyzed in different situations.

Keywords: Switching overvoltages, transmission line surge arresters, temporary overvoltages.

I. Introduction

Switching overvoltages are among the important factors to be considered in the design of transmission lines and their overvoltage protective devices, particularly in the systems with rated voltages above 300 kV [1].

Traditionally, switching overvoltages of the transmission line are calculated in different locations of the transmission line. Afterwards, maximum switching overvoltage is compared with the Protection Level of the transmission line. If the maximum overvoltage exceeds Protection Level then it must somehow be reduced. The traditional method to reduce switching overvoltages is to install pre-insertion resistors in parallel with transmission line circuit breakers. Most companies do not use this method anymore, because in addition to its cost and complex technology its failure rate is sometimes unacceptably high. Consequently using this method, reliability of the whole system is decreased [2].

Another method to reduce switching overvoltages is controlled switching with switch synch relays [3]. The last important method, introduced in this paper, to reduce switching overvoltages is the installation of surge arresters in one or two suitable locations along the transmission line. In [4] this method has been analyzed using surge arresters at two locations along the transmission line each for switching at one end of the line.

The method proposed in this paper is to use only one set of surge arresters and then looking for the optimum point of installation by switching from both ends. Simulations of this paper are executed using EMTP, and the studied transmission line is Isfahan power plant to Soormag 400 kV, 200 km line, one transmission line from the Iranian national grid.

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II. System Modeling

The system modeled in EMTP is shown in Fig.1. Switching studies are executed on the Isfahan power plant to soormag transmission line by switching from both ends of the line.

For the transmission lines JMARTI model is used which is a frequency dependent model and thus suitable for switching transients studies [5]. All surge arresters are modeled appropriately according to their V-I characteristics.

III. Principles of Analysis

Diagram of the simulated network in EMTP is shown in Fig. 1. The modeled system includes some part of the national grid and the line under study. Principles of analysis to study switching overvoltages of the transmission line are mainly according to [1]. For each transmission line shown in Fig.1 the line circuit breaker at one end is closed while the circuit breaker at the other end of the line is open and the maximum overvoltage is obtained.

The network is divided into internal and external sections. The former comprises of the network from switching point to the next substation through all possible roots. For this section JMARTI model is used for modeling transmission lines. The latter is modeled by thevenin equivalent, parameters of which are obtained by simulation of the Iranian grid in CYMFAULT software. These parameters are listed in TableI.

TABLE I
THEVENIN EQUIVALENTS OF EXTERNAL NETWORK

Thevenin equivalent point	$R_+(\Omega)$	$X_+(\Omega)$	$R_0(\Omega)$	$X_0(\Omega)$
Chelstn	7.52	70.08	0.48	20.32
FooladM	1.6	19.68	3.84	24.96
Tiran	0.64	8.32	3.2	13.44
Karun3	0.64	6.72	0.64	4.8
IsfhanPP	0.8	13.28	0.48	17.28
Soormag	7.2	76.64	1.76	36.8

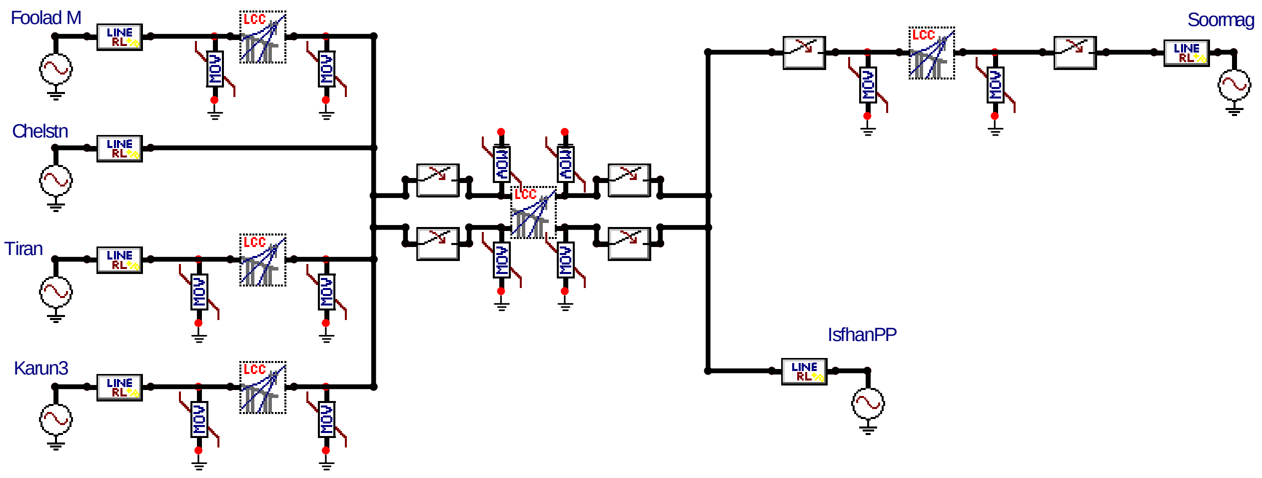

Fig. 1. Diagram of the simulated network using EMTP

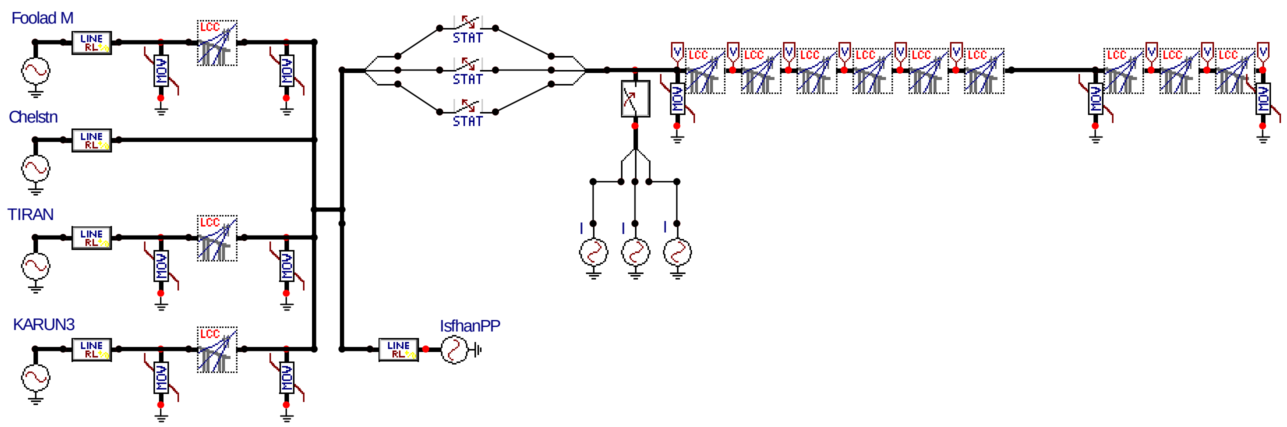

Fig. 2. Diagram of the network for switching at Isfahan power plant substation

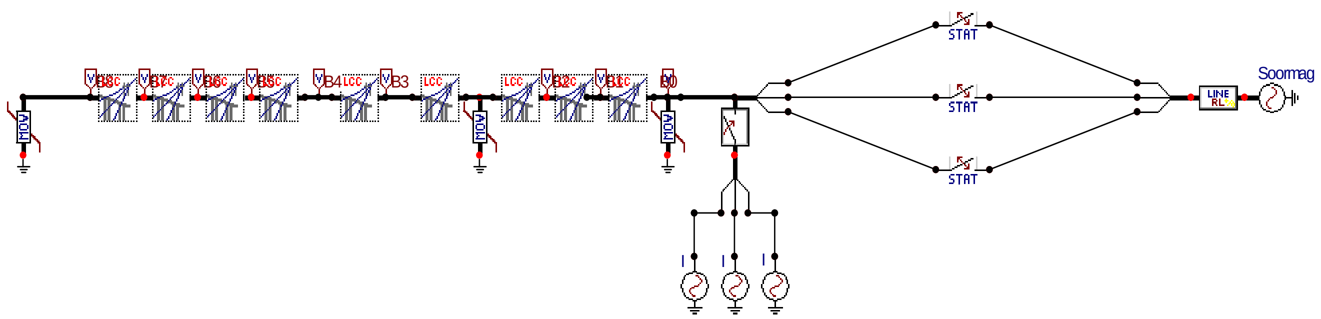

Fig. 3. Diagram of the network for switching at Soormag substation

Fig. 2 shows the network used for switching of Isfahan power plant to Soormag transmission line from Isfahan power plant substation side. Fig. 3 shows the network used for switching of the line from Soormag substation side.

The following points are also included in the modeling:

1. Three phase autoreclosure is modeled in switching in order that closing operation occurs at the instant of maximum source voltage and maximum trapped charge with opposite polarities. This way the worst case is obtained.

2. In the simulation results 1 p.u. is equal to:

$$\frac{420}{\sqrt{3}} * \sqrt{2} = 342.928 \ \ kV \qquad (1)$$

3. Switching operations are performed statistically using the statistic switch of EMTP. For each case 100 switching operations at instants of *t* are performed. *t* is a random variable with uniform distribution. Mean and Standard Deviation of *t* are according to (2).

$$\begin{aligned} Mean &= 0.05\,s \\ SD &= 0.005\,s \end{aligned} \qquad (2)$$

4. According to [1] the environmental conditions for the maximum overvoltage are obtained using (3).

$$\begin{aligned} V &= K_a K_s V_{ov} \\ K_a &= e^{m\frac{H}{8150}} \end{aligned} \qquad (3)$$

In this equation H is altitude above sea level, K_s is a safety factor usually equal to 1.05 and m is derived from the curve shown in Fig. 4.

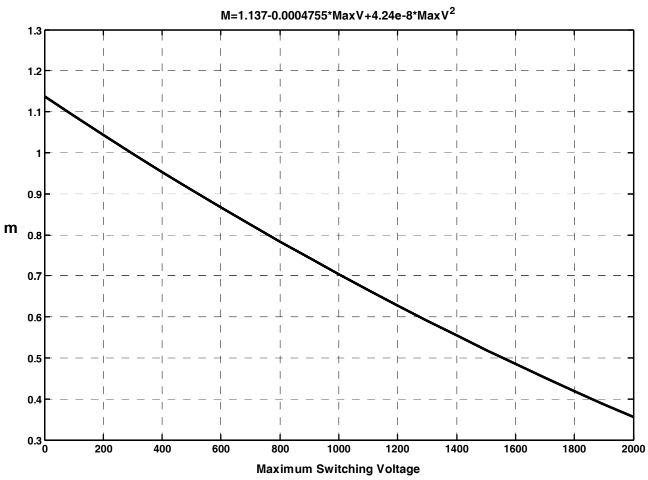

Fig. 4. Derivation of parameter m

IV. SIMULATION RESULTS

A. *Simulations Without Surge Arresters Along the Line*

In the first stage of the studies, simulations are executed without surge arresters along the transmission line. A thorough analysis is performed. Some results are shown in Table II. The overvoltages indicated in table II and other parts of the paper are 2% statistical overvoltages.

TABLE II
MAXIMUM SWITCHING OVERVOLTAGES IN STAGE A

$K_aK_sV_{0V}$ (kV)	V_{0V}(kV)	Surge arrester type
1137	929.3	EXLIM336
1176	963.69	EXLIM360
1202	987.02	EXLIM372

The surge arresters used in Table II are those installed at the ends of the transmission line. As the results of this table show, if the Protection Level of the line is considered 1050 kV (420*2.5) then maximum overvoltage exceeds the Protection Level. Therefore some efforts to reduce these overvoltages are necessary.

B. *Simulations With Surge Arresters Along the Line*

According to the extensive amount of simulations performed in this research work if a surge arrester is installed at a point along the transmission line, it results in a local minimum for the switching overvoltage at that point. Moreover, there always exist two maxima at both sides of the local minimum, one of which is absolute maximum while the other is local. The trend is to reduce the absolute maximum. The absolute maximum reaches a minimum level when the two maxima at either side of the arrester are equal. The point of arrester installation satisfying this condition is the optimum installation point for switching at one end. For switching at the other end, there is another optimum installation point which is not necessarily the same as to the previous point. The final optimum is a point between these two sub-optimums. If the maximum switching overvoltage for the final optimum point is below the Protection Level of the line it is acceptable. Otherwise, another method like two sets of surge arresters or controlled switching by switchsynch relays must be used.

C. *Simulation Results for U_r=336 kV*

Simulation studies are performed using surge arresters installed at one location along the transmission line. The rated voltages for the surge arresters used in the 400 kV national grid are 336, 360 and 372 kV. In this stage rated voltage of all arresters is considered 336 kV.

According to the results obtained, in this case the sub-optimum point for switching at Isfahan power plant substation is located at 142 km from the switching point and the sub-optimum point for switching at Soormag substation is located at 75 km from the switching point. Thus the final optimum point for this case is chosen at 137.5 km from Isfahan power plant substation.

Fig. 5 shows voltage profiles for switching at both Isfahan and Soormag substations when surge arresters are installed at 142 km from Isfahan power plant substation. K_a and K_s factors introduced in section III have been considered in this figure as well as all other voltage profiles shown in the paper. The maximum switching overvoltage increases Protection Level of the line which is considered as 1050 kV, when the line is switched from Soormag substation.

Fig. 6 shows voltage profiles for switching at both Isfahan and Soormag substations when surge arresters are installed at 75 km from Soormag substation. As shown in this figure, the maximum overvoltage approaches almost 1150 kV for switching at Isfahan substation.

Fig. 7 shows voltage profiles for switching at both substations when surge arresters are installed at 137.5 km from Isfahan power plant substation, i.e. the final selected optimum point. As shown in Fig. 7, the maximum switching overvoltage is below Protection Level of 1050 kV. A more flat voltage profile on the transmission line is obtained using the surge arresters installed at this point.

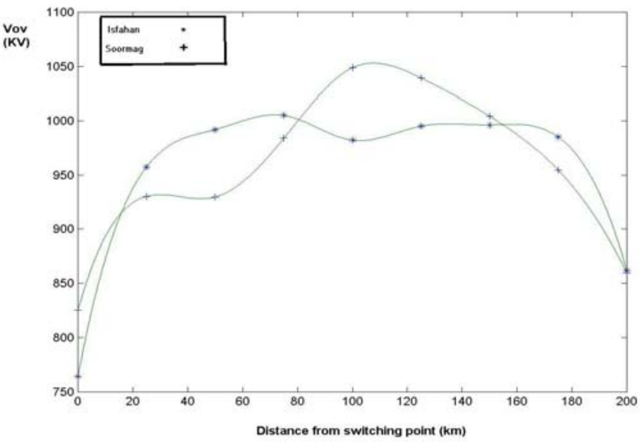

Fig. 5. Voltage profiles for surge arresters at 142 km from Isfahan power plant

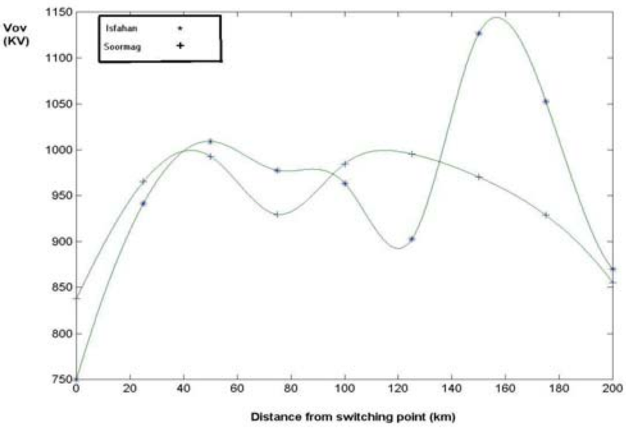

Fig. 6. Voltage profiles for surge arresters at 75 km from Soormag substation

D. Simulation Results for U_r=360 kV

In this stage rated voltage of all arresters is considered 360 kV. In this case extensive amount of simulation studies were performed. It was found that the sub-optimum point for switching at Isfahan power plant substation is located at 143 km from the switching point and the sub-optimum point for switching at Soormag substation is located at 80 km from the switching point. Thus, in this case the final optimum point is chosen at 131.5 km from the Isfahan power plant substation.

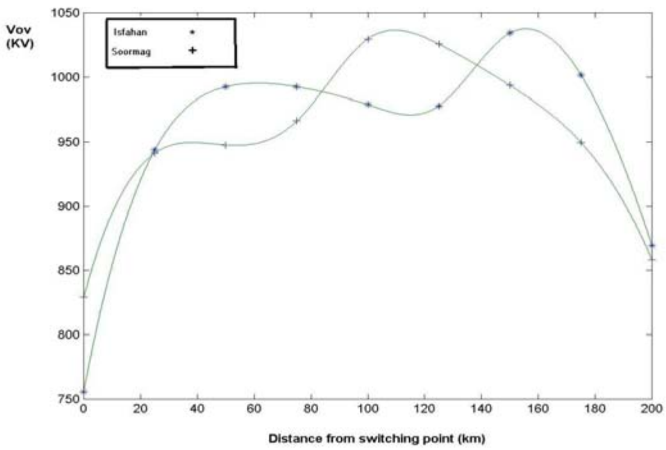

Fig.7. Voltage profiles for surge arresters installed at optimum point

Fig. 8 shows voltage profiles when surge arresters are installed at 143 km from Isfahan power plant substation for switching at both Isfahan and Soormag substations. Fig. 9 shows voltage profiles when surge arresters are installed at 80 km from Soormag substation for switching at both substations.

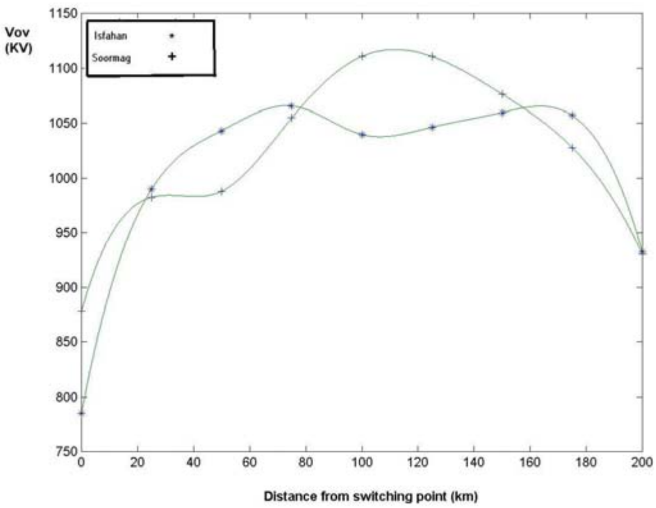

Fig. 8. Voltage profiles for surge arresters at 143 km from Isfahan power plant

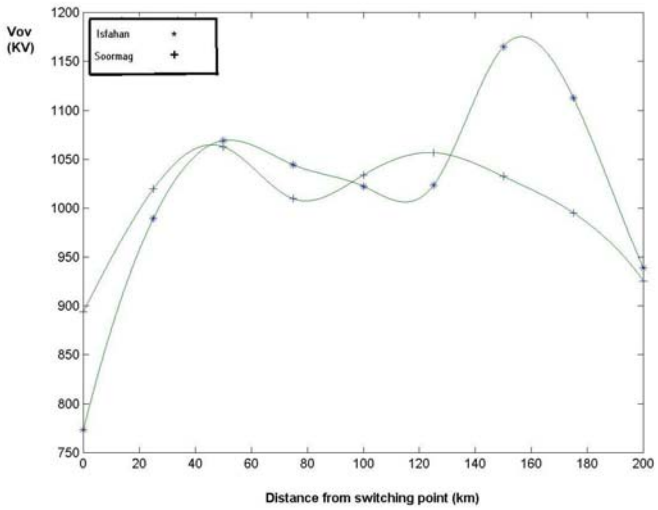

Fig. 9. Voltage profiles for surge arresters at 80 km from Soormag

Fig. 10 shows voltage profiles when surge arresters are installed at 131.5 km from Isfahan power plant substation, i.e. the final selected optimum point, for switching at both Isfahan and Soormag substations.

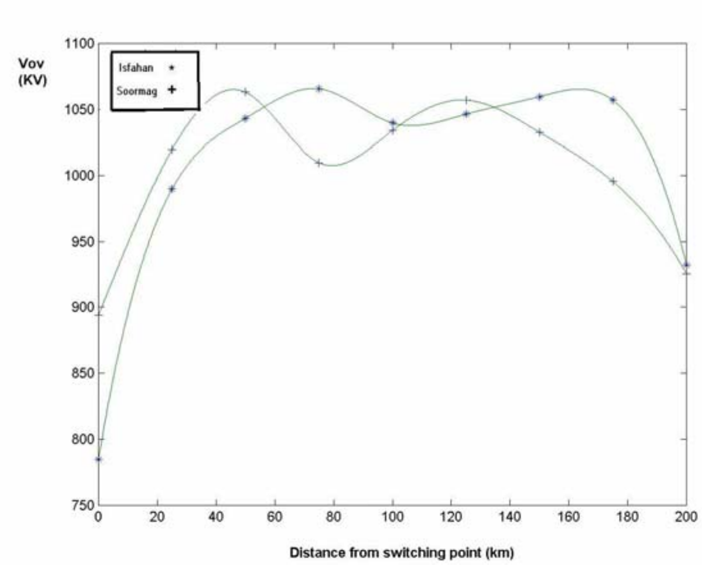

Fig. 10. Voltage profiles for surge arresters at optimum point

As shown in Fig. 10 this design is acceptable only if Protection Level of the line is designed to be above 1070 kV. Comparing Fig. 10 with Fig.7, it is found that a higher voltage profile is obtained in this case. This is due to the fact that a higher rated voltage of is selected for the arresters used in this case.

E. Simulation Results for U_r=372 kV

In this stage rated voltage of all arresters is selected 372 kV. In this case the sub-optimum point for switching at Isfahan power plant substation is located at 143 km from the switching point and the sub-optimum point for switching at Soormag substation is located at 82 km from the switching point. Thus in this case the final optimum point is located at 130.5 km from Isfahan power plant substation.

Fig. 11 shows voltage profiles for switching at both Isfahan and Soormag substations when surge arresters are installed at 143 km from Isfahan power plant substation. Fig. 12 shows voltage profiles when surge arresters are installed at 82 km from Soormag substation.

Fig. 13 shows voltage profiles when surge arresters are installed at 130.5 km from Isfahan power plant substation, i.e. the selected optimum point. Comparing Fig. 13 with Figs. 11 and 12, it is found that a more flat voltage profile is obtained by installing the surge arresters at the optimum point. However, a higher voltage profile is obtained in this case in comparison to the voltage profiles obtained in subsections C and D for them the arrester voltage was U_r=336 and U_r=360 kV, respectively. As shown in Fig. 13 this design is acceptable only if Protection Level of the line is above 1175 kV.

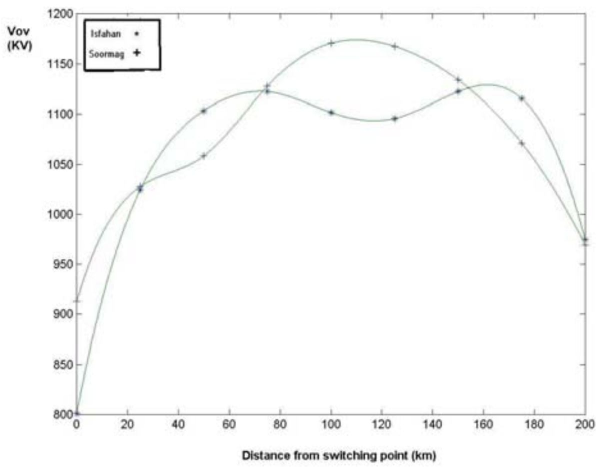

Fig. 11. Voltage profiles for surge arresters at 143 km from Isfahan power plant

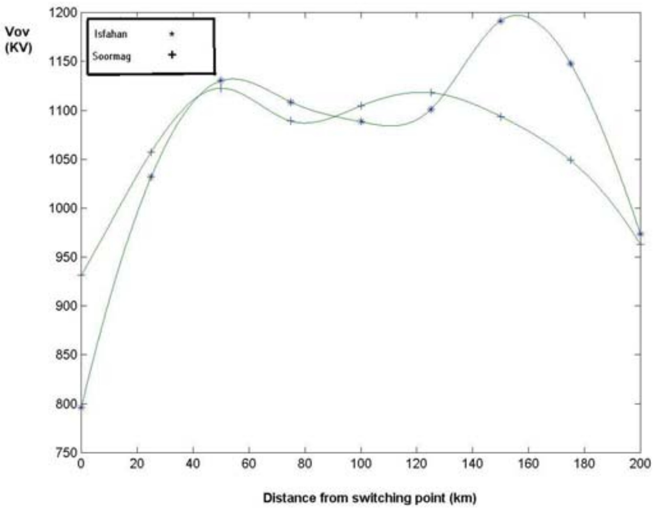

Fig. 12. Voltage profiles for surge arresters at 82 km from Soormag

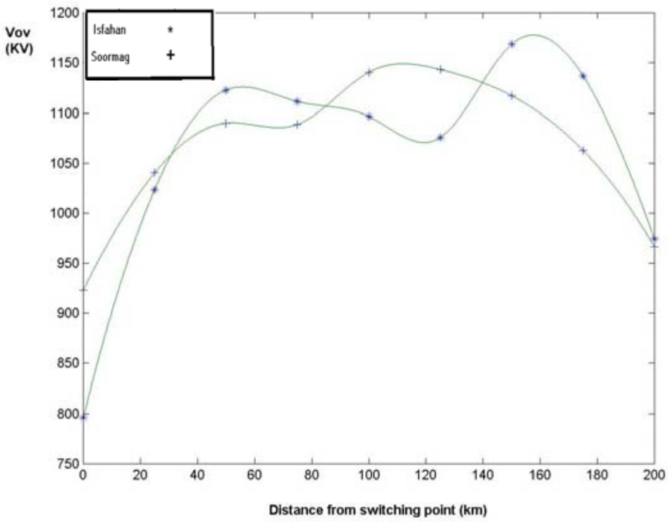

Fig. 13. Voltage profiles for surge arresters at optimum point

V. CONCLUSIONS

In this paper switching overvoltages of an actual transmission line were studied in two stages. In the first stage, simulations were performed without surge arresters along the transmission line and the necessity of reducing the overvoltages was verified. In the second stage, a set of surge arresters was installed along the transmission line at an optimum point, which is a point between two sub-optimum points for switching at both ends of the line. The effect of surge arresters in reducing switching overvoltages is verified for different types of surge arresters.

It was found that this method could provide a more flat voltage profile along the transmission line. Using this method could eliminate the necessity of installing pre-insertion resistors in parallel with transmission line circuit breakers and its associated problems. If SWIL of the line is low, two sets of surge arresters at two locations along the transmission line could be installed. The optimum installation points for these two arrester sets should be determined.

VI. REFERENCES

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