Investigation of Neutral Reactor Performance in Reducing Secondary Arc Current

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***Abstract*—The majority of transmission-line faults are temporary short circuits. The short circuit arc is usually self-extinguishing after opening the transmission-line circuit breakers. High-speed reclosure of transmission-line circuit breakers can improve system stability. As the voltage level increases, arc deionization time increases as well, endangering system stability. Application of automatic single-phase reclosing makes it possible to increase system stability even for extremely high voltage transmission lines. Automatic single-phase reclosing is used to clear single-phase-to–ground faults, which are about 80% of the transient faults. In order to have successful fast reclosing, different methods are used to extinguish the arc. One of the common methods is to use a single-phase reactor in the neutral of shunt reactor, when transmission line is compensated with shunt reactors. As of now, the effect and parameters of this neutral reactor are usually determined based on the steady-state analysis without exact system and arc modeling. In this research work, the investigation of a neutral reactor application is performed for transposed and untransposed transmission lines using transient simulation with appropriate models. Then, guidelines for selecting the appropriate amount for the neutral reactor are proposed.**

***Index Terms*—Arc modeling, neutral rector, secondary arc extinction, single-phase reclosing.**

I. Introduction

IN extra- and ultra-high voltage (EHV, UHV) transmission lines, three phase reclosing system could only be used when it is very fast. Reclosing time is set based on arc deionization period in air gap between phase conductor and tower body [1]. For high-voltage transmission systems, short circuit capacity of the system usually increases as system voltage increases. The higher short circuit power results in higher short circuit current and higher ionization of the related arc. It results in higher arc extinction time so that the air gap at the fault point would be deionized before reclosing could be performed [2]. This necessitates that reclosing would be performed after some time delay. However, this delay contradicts with the lower stability margin of higher voltage systems. Therefore, application of three phase reclosing might become a nonpractical solution for EHV and UHV systems.

Application of automatic single-phase reclosing makes it possible to increase system stability limit as system voltage and short circuit level increase. About 80% of transmission-line faults are single-phase to ground faults. Moreover, a very high percentage of these faults are transient faults. Therefore, most of these faults are temporary and can be cleared using automatic single-phase reclosing. If arc is extinguished completely before first shot of reclosing, reclosing would be performed successfully.

In order to have successful fast reclosing, different methods have been applied to extinguish the arc faster. One of the common methods is to use a single-phase reactor in the neutral of the shunt reactors, when the transmission line is compensated with shunt reactors. By appropriate selection of this reactor, arc current is limited and extinguished faster [3], [4]. This method is appropriate mainly for transposed lines, whereas use of shunt reactors and neutral reactor with breakers having switching capability among shunt reactor phases and neutral reactor has been suggested for untransposed lines at very high voltage levels [4].

Appropriate value for the neutral reactor is usually determined only based on the steady-state analysis without considering exact system and arc models. Parameters of this reactor and effect of the reactor on arc extinction time are normally studied in steady-state mode while transient analysis is required to exactly determine effect of this reactor on arc extinction time and to study its transient performance. In this research work, power system and arc are exactly modeled and application of neutral reactor is studied in transient mode.

In this paper, system modeling is introduced in Section II. Traditional method for determining neutral reactor parameters and arc extinction time based on steady-state analysis are presented in Section III. Then, arc modeling using an electromagnetic based software is briefly explained in Section IV. In Section V, using exact network and arc modeling, neutral reactor performance is investigated for transposed and untransposed lines. Also based on the results obtained through transient simulations, guidelines for selection of neutral reactor are proposed for transposed and untransposed lines.

II. System Modeling

In this research, work one of the important transmission lines of the Iran national grid (400 kV Anjirak-Abbaspour) has been selected which has a three-phase 50-MVAR reactor at each end. Considering the frequency range of studies for the system under investigation, equivalent networks at two sides of the transmission line are modeled appropriately. Series impedance as well

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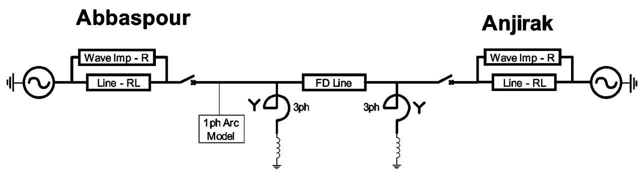

Fig. 1. Power system model.

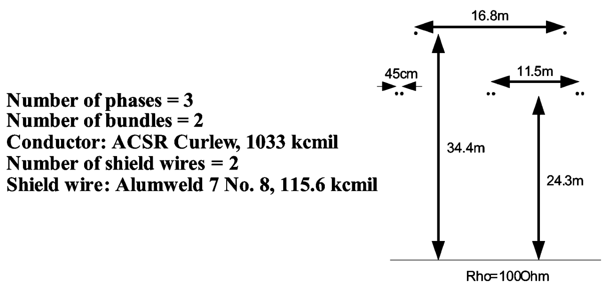

Fig. 2. Transmission-line configuration and parameters.

TABLE I
EQUIVALENT SOURCE IMPEDANCES

	Anjirak	Abbaspour
R_1 (Ω)	0.8	0.48
X_1 (Ω)	10.4	7.04
R_0 (Ω)	6.08	0.48
X_0 (Ω)	23.2	6.4

as wave impedance are used to model the networks more precisely. Fig. 1 shows a single line diagram of the network under study.

A. Transmission Line

Generally in transient studies, frequency-dependent models are used for exact modeling of transmission lines. The JMarti model is used for modeling the 264-km transmission line under study [5]. This line is transposed symmetrically. However, to be able to study the effect of neutral rector for arc suppression when transmission line is untransposed, this line would be considered to be untransposed in Section V. Fig. 2 depicts phase and earth conductor configuration for this transmission line.

B. Sources

Equivalent sources impedances have been obtained for Anjirak and Abbaspour substations using short circuit studies. Table I shows positive and zero sequence impedances for equivalent sources in these two substations. A three-phase 200-Ω resistance has been paralleled with each equivalent impedance to model the surge impedance of the sources. This resistance makes the simulations more realistic.

C. Reactors

Each 50-MVAR reactor has been modeled by a resistance of $R = 10\ \Omega$ in series with a reactance of $X = 3200\ \Omega$. Neutral reactor is modeled by a single-phase reactance. The resistance of neutral reactor is ignored due to its negligible effect.

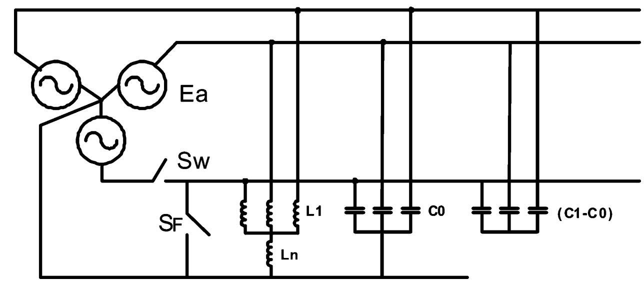

Fig. 3. Capacitive state among healthy phases and faulted phase.

III. TRADITIONAL NEUTRAL REACTOR SELECTION

In the traditional method, at first steady-state model of the network is obtained at the arc point, i.e., at the transmission-line end with higher short circuit ratio. This is the worst case which results in maximum secondary arc current. Then, an appropriate amount for reactance of the neutral reactor is selected so that the secondary arc current and voltage are minimized.

A. Secondary Arc Current

When a single-phase to ground fault occurs, the faulted phase is isolated from both ends by the related protective relays and single pole breakers. In this condition, some voltage is induced in the isolated phase due to capacitive and inductive couplings among the healthy and faulted phases. In spite of the breaker opening at both ends of the faulted phase, the induced voltage feeds current through arc in the faulted point causing arc consistency. This current, called secondary arc current, may be high enough to stop arc extinction after breaker opening. The voltage induced in the faulted phase due to capacitive and inductive coupling is known as secondary arc voltage [1].

B. Appropriate Reactance for Neutral Reactor

Fig. 3 illustrates capacitive state of the modeled network while the faulted phase is disconnected by the single-phase breaker [6], [7]. When no shunt and neutral reactors are used, in order to obtain secondary arc current at the worst case (arc resistance equals to zero Ω), switch SF is considered to be closed and capacitive current passing through it is calculated. In order to calculate this current, the equivalent circuit of Fig. 3 is simplified as shown in Fig. 4. Arc current is given as (1), where C_1 and C_0 are positive and zero sequence capacitances of the line. Since, major part of the secondary arc current is capacitive and the inductive part is negligible, only the capacitive part is considered in (1)

$$I_S = \frac{E_a \omega (C_1 - C_0)}{3}. \tag{1}$$

Consistency of the secondary arc current causes continuity of the arc and stops arc extinction. Installation of appropriate reactors (shunt reactor plus neutral reactor) when single-phase auto reclosure is used, could help arc extinction and fast deionization resulting in successful single-phase reclosing. When shunt and neutral reactors are used for compensating transmission lines, an inductive branch becomes parallel with the capacitive branch

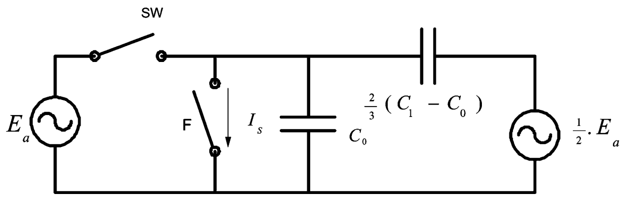

Fig. 4. Simplified circuit of Fig. 3, without considering shunt compensation.

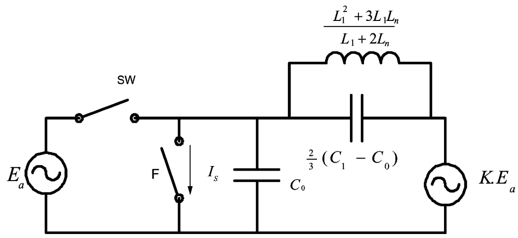

Fig. 5. Simplified circuit of Fig. 3, considering shunt compensation.

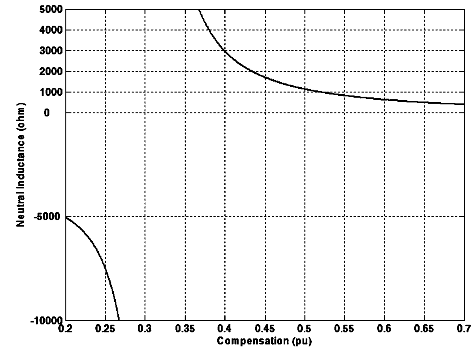

Fig. 6. Neutral reactance versus shunt compensation degree.

as shown in Fig. 5. In order to cancel out the capacitive current, inductive and capacitive branches must resonate. By satisfying this condition, the appropriate amount of neutral reactor is achieved, as calculated in (2). Installation of this reactor is appropriately effective when capacitive coupling becomes symmetrical through phase transposing [1], [6]–[8]

$$\begin{aligned} B_1 &= \omega \cdot C_1 = 9.4313\mathrm{e}^{-4}\mathrm{S} \\ B_0 &= \omega \cdot C_0 = 6.525\mathrm{e}^{-4}\mathrm{S} \\ F &= \frac{1}{X_r \cdot B_1} = \frac{1}{1600 \times 9.4313\mathrm{e}^{-4}} = 0.6627 \\ X_n &= \frac{B_1 - B_0}{3F \cdot B_1 \cdot [B_0 - (1-F) \cdot B_1]} = 463.55\Omega \end{aligned} \tag{2}$$

where

- B_1 positive sequence line susceptance (Siemens);
- B_0 zero sequence line susceptance (Siemens);
- F shunt compensation degree;
- X_r equivalent reactance of line shunt reactor;
- X_n equivalent reactance of neutral reactor.

In (2), parameters of the system under study are used and appropriate amount for the neutral reactor is calculated. As 50-MVAR reactors with 3200-Ω reactance are installed at both ends of the transmission line under study, equivalent reactance of each of the shunt reactors has been considered as $1600\ \Omega = 3200/2$ in (2). Besides, appropriate amount for the neutral reactance is obtained as 463.55 Ω using (2). This equivalent reactor can be realized using two neutral reactors installed at the neutral of both ends shunt reactors each having reactance of $2 \times 463.55 = 927\ \Omega$.

C. Secondary Arc Extinction Time

Based on the experience, some equations have been proposed in the past to estimate the arc extinction time. In the estimation of secondary arc extinction time only the stable extinction is taken into consideration, because the instantaneous extinction could happen in less than 0.15 s. According to the experiments, the arc extinction time versus secondary arc for currents about 20 A and above, and voltage about 20 to 30 kV is calculated from the equation $t_{\mathrm{b}} = 0.02 \times I_s$ [8]. Furthermore, the dead time of reclosure (t_d) must be 0.25 s more than t_{b} which results in

$$t_d = 0.25 \cdot (0.1 I_s + 1). \tag{3}$$

The exact value of arc extinction time depends on various factors and parameters of the system and could be better estimated through performing transient studies.

D. Effect of Line Parameters

Inasmuch as appropriate amount for neutral reactor depends on line parameters and shunt compensation degree, a sensitivity analysis for the amount of neutral reactor should be performed. Similar sensitivity analysis has been performed for double circuit lines in [9]. In the following, effective parameters of the transmission line and physical and economical limitations will be determined and analyzed.

1) Line Compensation Degree: Generally, high-voltage transmission lines are compensated by shunt reactors in the range of 20–70% [10]. Using (2), reactance of the neutral reactor versus various amounts of line compensation degree has been obtained and shown in Fig. 6. As shown in this figure, the higher the degree of shunt compensation, the lesser the reactance of neutral reactor.

The amount of appropriate basic impulse insulation level (BIL) for the neutral reactor is also calculated approximately from (4) by the voltage divider rule [11], [12]. The ratio of the neutral BIL to phase BIL of the shunt reactor versus the degree of line compensation is depicted in Fig. 7. As shown in this figure, the higher the degree of shunt compensation, the lesser the BIL for neutral point. For higher amount of compensation, both of the reactance of the neutral reactor and its BIL are reduced. This makes shunt and neutral reactor design easy and economical.

$$\frac{BIL_{Neutral}}{BIL_{Phase}} = \frac{X_n}{X_n + X_r}. \tag{4}$$

For the 400-kV system, BIL is considered to be 1050 kV. As such, for the neutral reactor calculated in (2), minimum acceptable BIL for the neutral point can be calculated from (4)

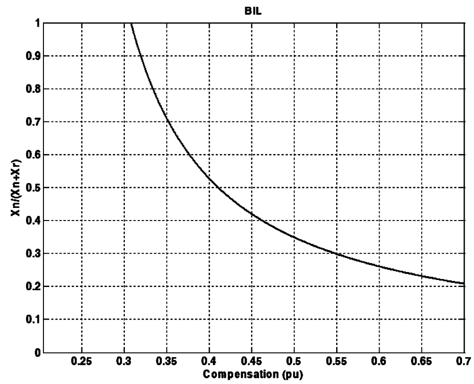

Fig. 7. Neutral to phase BIL versus shunt compensation degree.

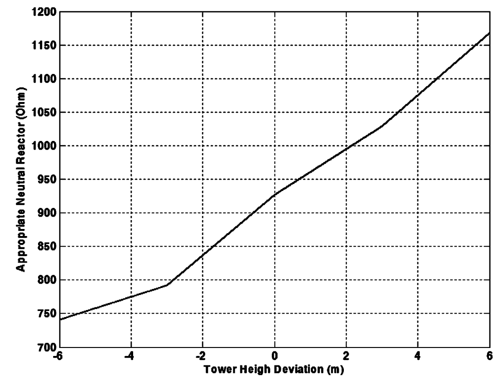

Fig. 8. Appropriate amount for neutral reactance versus tower height change.

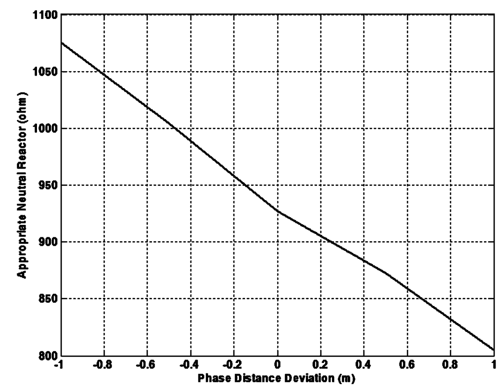

Fig. 9. Appropriate amount for neutral reactance versus phase distance change.

as $463.55/(463.55 + 1600) \times 1050\ \mathrm{kV} = 235.87\ \mathrm{kV}$. As in Iran, using 50-MVAR -132 kV reactors with 350 kV BIL for the neutral point is very prevalent, application of this kind of typical reactor has some priority due to its lower cost and simplicity in design. In the case of using lower shunt compensation degrees (less than 50%), BIL of the neutral point of shunt reactor becomes more than 350 kV. This necessitates special design and more insulation for the reactor. Therefore, the cost of shunt reactor and neutral reactor increases. Hence, it could be concluded that application of neutral reactor for transmission lines with low shunt compensation degree results in higher cost and complexity. As a result, application of special neutral reactors could not be justified for transmission lines that have no considerable effect on power system stability.

2) Positive and Zero Sequences of Line Capacitance: According to (2), the amount of neutral reactor depends on positive and zero sequence susceptances (B_1, B_0) of the line. Generally, for a transmission line different kinds of towers (suspension, tension) are used with different heights depending on the geographical state of the line path. Obtaining all of these different data and modeling them to provide exact values of B_1 and B_0 along the path are complex and tedious. In order to study sensitivity of the amount of neutral reactor to line parameters, tower height and phase distances are changed around some average values and appropriate reactance for the neutral reactor is calculated using (2) and discussed further.

Fig. 8 shows appropriate reactance of the neutral reactor versus tower height change in the range of $\pm 6\ \mathrm{m}$. As shown in this figure, the amount of reactance change is at most $\pm 220\ \Omega$ around the average value. As it will be shown in Section IV, this amount of reactance change would not have considerable effect on the arc extinction time.

Since phase distance is most often constant along the line, the amount of change in phase distance is very low. Hence, the amount of phase distance variation is considered as $\pm 1\ \mathrm{m}$. Fig. 9 shows appropriate reactance of the neutral reactor versus phase distance change. As shown in this figure, the amount of reactance variation is about $\pm 120\ \Omega$ around the average value. It will be shown in Section IV that this amount of reactance change has no considerable effect on the arc extinction time. According to a later investigation performed in this paper, the calculation of neutral inductance based on average tower model would not result in considerable error.

IV. Arc Modeling for Computer Simulation

It is very difficult to reproduce the real arc behavior by computer simulation due to the extremely random characteristic of the arc. For the accurate arc modeling, the simulation has to consider the functions describing the impulse arc characteristic as well as the recovery of the insulation following the partial extinction using electromagnetic transients analysis. Any arc model requires several input parameters which could be obtained by measurements only. Parameters extracted from measurements can be used to elaborate an arc model which reproduce quite well the main characteristic of that specific arc measurement. Such a model might give less reliable results for other arcing conditions on the same line, or completely inaccurate results for experiments carried out on other lines with different length, voltage level, and conductor arrangement [13].

However, a computer simulation of the process leading to the secondary arc extinction can be a suitable tool for sensitivity studies to identify the main influencing factors and to find the similitude invariants, which are necessary to compile generalized diagrams for the estimation of the arc extinction time [14], [15]. As the purpose of this paper is an investigation of neutral reactor effect and comparison of different amount of its reactance in the cases of transposed and untransposed lines, an appropriate arc model with three sets of typical data that leads to three different arc models (Arc1, Arc2, Arc3) is used. Typical values for the arc parameters are taken from [16]. In addition, according to Table II, three parameters u_0, l_0, and τ_0 are varied

TABLE II
ARC1, ARC2 AND ARC3 PARAMETERS

	u_0 (v/cm)	l_0 (m)	τ_0 (ms)
Arc1	12	3.5	0.714
Arc2	8	3.15	0.555
Arc3	11	3.5	0.833

around their typical values to generate three different arcs. Existing secondary arc models are based on the differential equation of the arc conductance, which describes the energy balance of the arc column as presented in (5) [13]–[17]

$$\frac{dg}{dt} = \frac{1}{\tau}(G - g) \quad (5)$$

where

τ time constant of the arc;

g instantaneous arc conductance;

G stationary arc conductance.

The stationary arc conductance can be defined as

$$G = \frac{|i_{arc}|}{(u_0 + r_0 |i_{arc}|) \cdot l_{arc}(t)} \quad (6)$$

where

$l_{arc}(t)$ instantaneous arc length;

u_0 arc characteristic voltage;

r_0 arc characteristic resistance per arc length.

Parameters τ, u_0, and r_0 can be obtained from measurements. The time constant of the arc is inversely proportional to the arc length and can be defined by the following expression:

$$\tau(l) = \tau_0 \left(\frac{l_{arc}}{l_0}\right)^{\alpha} \quad (7)$$

where

τ_0 initial time constant;

l_0 initial arc length;

α coefficient in the range of -0.1 to -0.6.

The time-dependent arc elongation $l_{arc}(t)$ is the most significant factor that influences the arc extinction and arcing duration. Since, the length of the secondary arc is highly dependent on environmental impacts like wind and thermal buoyancy, it is difficult to consider these random effects accurately in the numerical model. Nevertheless, the above arc model can be used successfully to estimate the maximum arcing duration as worst case or understand the interaction of the secondary arc with the electrical circuit.

In this research work, in order to model secondary arc model in electromagnetic transient program, appropriate tools are used. According to Fig. 10, arc resistance has been modeled as a controlled resistor between phase and ground conductors whose value is determined by solving (5)–(7). More details about the arc modeling method are presented in [14] and [15].

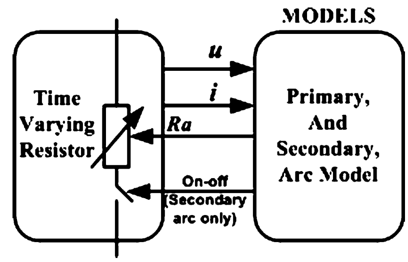

Fig. 10. Method of arc modeling.

Accuracy of the arc modeling method is validated by comparing the modeled arc with some other simulation and real arc waveforms. It was found that the developed method could model the arc with high precision [16], [17].

V. SIMULATION STUDIES

A. Transposed Lines

In order to investigate effect of the shunt and neutral reactors on arc extinction time, several simulations have been performed. In all simulations, it is supposed that a single-phase fault (Phase A to G) occurs at 0.0 s and at 0.1 s the faulty phase is isolated from both ends by opening the breakers. The arc extinction criterion is considered to be the time when the absolute amount of the arc current amplitude reduces to less than 1 A. As a result, the arc existence period is the arc extinction instant minus 0.1 s. For the modeled real power system, as the short circuit level in Abbaspour substation is more than Anjirak substation, arc extinction period in Abbaspour substation is longer than that of the Anjirak substation. Hence, in all simulations to find the worst case, arc is simulated at the Abbaspour substation end.

In Sections V-A1–V-A3 of this paper because of simplicity in explanation, any reference to the arc extinction time means arc existence period, i.e., the instant of arc extinction subtracted by 0.1 s.

1) Without Shunt Reactor: Fig. 11 shows the secondary arc current of Anjirak-Abbaspour transmission line when no shunt reactor is used. As shown in this figure, the arc extinction time is about 0.182 s and arc current is nonsinusoidal and contains harmonics. This is due to the arc nonlinear resistance. Mutual voltage from the healthy phases is sinusoidal and when mutual voltage is near to zero, the arc current is almost zero and arc is almost off. When this voltage increases and reaches to the peak of the sinusoid, secondary arc current rises suddenly (see Fig. 11). Then, by decrease in mutual voltage, due to the arc nonlinear resistance, arc resistance increases suddenly and arc current reduces considerably. This physical process results in a nonsinusoidal current containing considerable amount of harmonics.

2) Shunt Reactor With Isolated and Earthed Neutrals: Fig. 12 depicts the secondary arc current of Anjirak-Abbaspour line when 50 MVAR shunt reactors with isolated neutrals are installed at both line ends. Since in this case the line shunt reactor makes a direct electrical path among two healthy phases and the disconnected phase, secondary arc current and arc extinction time increase. In this case, the mutual sinusoidal voltage does not have zero mean and shifts the arc current to

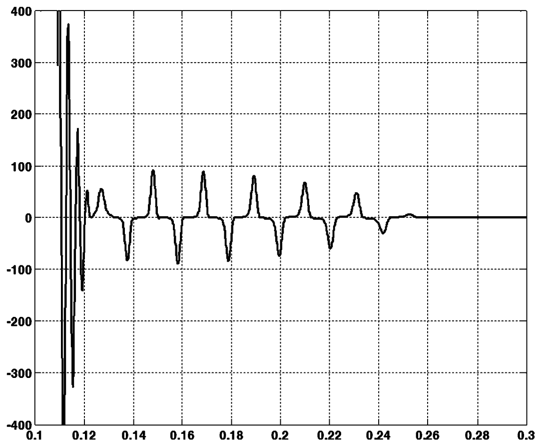

Fig. 11. Secondary arc current transposed line, without shunt compensation.

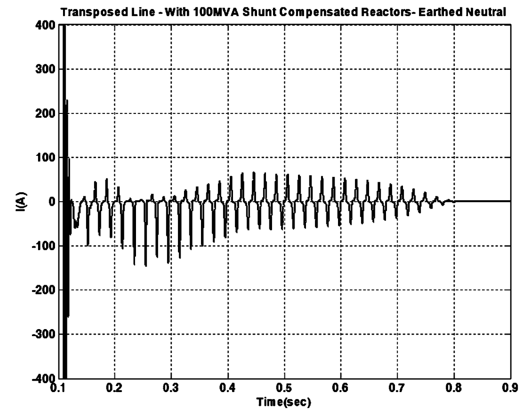

Fig. 13. Secondary arc current, transposed line, with shunt compensation and earthed neutral.

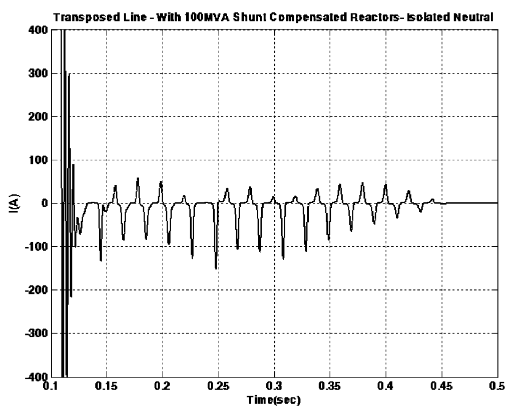

Fig. 12. Secondary arc current transposed line, with shunt compensation and isolated neutral.

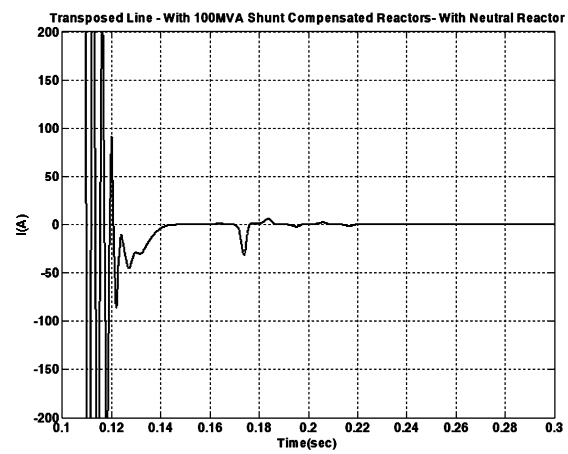

Fig. 14. Secondary arc current transposed line, with shunt compensation and with neutral reactor.

positive or negative side of the time-axis. This phenomenon happens for the shunt compensated lines with earthed neutral as well. As shown in Fig. 12, the arc extinction time is about 0.35 for transposed line with shunt compensation and isolated neutral. The arc extinction time is increased in comparison to the previous case.

Fig. 13 shows secondary arc current of the transmission line under study when 50-MVAR shunt reactors with earthed neutral are installed at both line ends. According to this figure arc, extinction time is around 0.702 s. In this case similar to the previous case, line shunt reactors make a direct electrical path among two healthy phases and the disconnected phase leading to considerable increase in the secondary arc current and arc extinction time.

3) Shunt Reactor With Appropriate Neutral Reactor: Fig. 14 shows secondary arc current of the transmission line when a 50 MVAR shunt reactor with 927 Ω neutral reactor is installed at the both line ends. The amount of neutral reactor was calculated from the steady-state analysis. According to Fig. 14, the arc extinction time is around 0.118 s showing a considerable decrease compared to the case when neutral of the shunt reactor is isolated or earthed.

Several simulations with different reactances for the neutral reactor and different parameters for the arc are performed and obtained arc extinction times are recorded. Fig. 15 depicts the arc extinction time versus the neutral reactor reactance for three different arcs. As shown in this figure, for the weak arc (Arc1) by changing neutral reactor reactance within the range of 500 to 1500 Ω, no considerable change in arc extinction time is observed. Besides, reducing the neutral reactance has more effect in increment of arc extinction time in comparison to increasing the neutral reactance. For the case of strong arc (Arc3), changing of neutral reactance within the range of 800 to 1400 Ω does not result in considerable increase in the arc extinction time.

From the above results, it could be concluded that if there is some error in calculating C_1 and C_0 of the transmission line and as a result, the appropriate amount for the neutral reactor based on the steady-state analysis is not computed quite precisely, arc extinction time would not change considerably. Furthermore, it is possible to select a neutral reactor with higher or lower reactance than what it is achieved through (2), due to simplicity in design, availability and cost. For example for the line under study, calculated reactance (927 Ω) can be replaced by 1208 Ω. This is a typical available amount for the neutral reactor at the voltage level under study and is constructed with a reasonable price by various manufacturers.

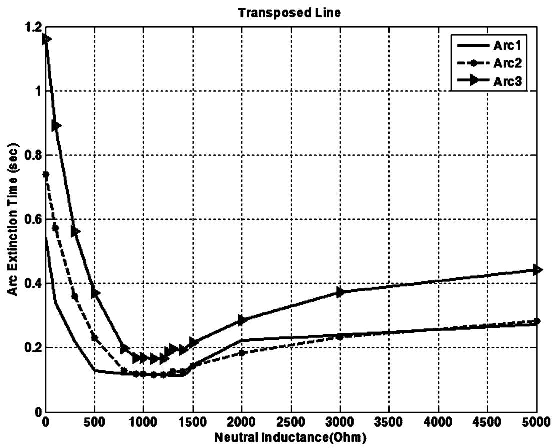

Fig. 15. Arc extinction time versus neutral reactance change for three different arcs, transposed line.

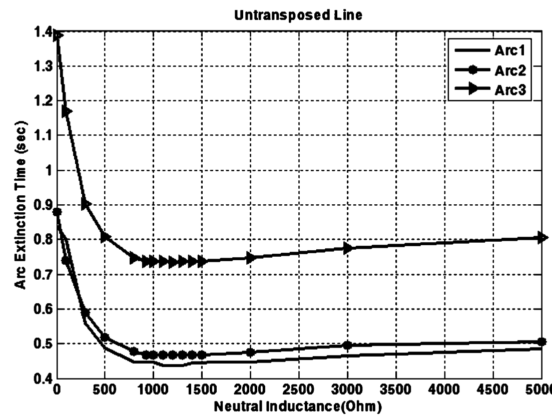

Fig. 16. Arc extinction time versus neutral reactance change for three different arcs, untransposed line.

TABLE III
COMPARISON OF ARC EXTINCTION TIME FOR TRANSPOSED AND UNTRANSPOSED LINES IN DIFFERENT CONDITIONS

Condition	Arc extinction time for untransposed line (sec)	Arc extinction time for transposed line (sec)
Without shunt reactor	0.22	0.18
2×50 MVAR shunt reactor, isolated neutral	0.52	0.35
2×50 MVAR shunt reactor, earthed neutral	0.84	0.7
2×50 MVAR shunt reactor, 2×927Ω neutral reactor	0.45	0.118

B. Untransposed Lines

In this section, it is assumed that the transmission line under study is untransposed. In order to investigate the effect of shunt and neutral reactors on secondary arc extinction time for untransposed lines, several simulations have been performed. Similar simulations are performed for both of the transposed and untransposed lines and obtained results are compared in Table III. This table compares arc extinction time for four cases: without shunt reactor, shunt reactors with isolated neutral, earthed neutral and 927 Ω neutral reactor. As illustrated in Table III, for untransposed line considerable increase in arc extinction time is observed.

Various simulations with different reactances for the neutral reactor and different parameters for the arc are performed and obtained arc extinction times are recorded. Fig. 16 depicts arc extinction time versus the neutral reactor reactance for three different arcs. As shown in this figure, arc extinction time increases severely in comparison to the extinction time of the transposed line. Meanwhile, neutral reactor could considerably reduce arc extinction time even for untransposed lines.

As illustrated in Fig. 16, for the case of untransposed line the amount of 800–2000 Ω is appropriate for reactance of the neutral reactor. Therefore, for untransposed lines, it is suggested to initially calculate neutral reactor based on the transposed line condition. Then by considering various factors such as importance of the line in system stability, arc extinction time and cost, the appropriate reactance for the neutral reactor and also BIL for the neutral point could be selected.

C. Discussion

From the above results, the following can be concluded.

- Application of line shunt reactors without neutral reactors leads to considerable increase in the secondary arc current and arc extinction time.
- The calculated amount for the neutral reactor from steady-state analysis could be chosen as the initial appropriate value for the reactance of the neutral reactor.
- Transient analysis should be performed to investigate the selected neutral reactor performance for the system under study.
- Arc extinction time could not be easily estimated from the experimental formula. It depends on various factors such as short circuit capacity of the system, application of shunt reactors and also application of appropriate neutral reactor.
- Usually changing neutral reactor reactance within a certain range has no considerable effect on arc extinction time. Therefore, the neutral reactor could generally be selected based on availability and cost. In any case, transient studies should be performed to validate selection of the proposed neutral reactor.
- Various simulations were performed to investigate the effect of line transposition. It is found that for a certain neutral reactor when the line is partially (asymmetrically) transposed, the arc extinction time would be more compared to the arc extinction time for the symmetrically transposed line. The arc extinction time of asymmetrically transposed line is less than the arc extinction time of untransposed line.
- The arc extinction time for untransposed or asymmetrically transposed lines is greater than that of the transposed lines. Although application of neutral reactors results in reduced arc extinction time for the untransposed line, however the extinction time might still be high. If there are some important transmission lines in a power system which have major effect on system stability, it might be better to transpose them to be able to reduce arc extinction time by using neutral reactors and to use single pole auto-reclosure.

VI. Conclusions

In order to perform successful fast reclosing, different methods are used to extinguish secondary arc. One of the common methods is to use a single-phase reactor in the neutral of the shunt reactor, when transmission line is compensated with shunt reactor. In this research work, traditional method for determining neutral reactor parameters and arc extinction time based on steady-state model was studied. Then, for one of the very important transmission lines of the Iran national grid, transient studies were performed and performance of neutral reactor was investigated for transposed and untransposed conditions and for different arc parameters. An appropriate method for determining basic parameters of the neutral reactor (reactance and BIL) was presented by considering shunt compensation degree and line parameters. According to the obtained results, application of neutral reactors results in reduced arc extinction time. Moreover, changing neutral reactor reactance within a certain range has no considerable effect on arc extinction time. It was also found that the arc extinction time for untransposed lines is considerably greater than that of the transposed lines.

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