An Evaluation of Flux-Coupling Type SFCL Placement in Hybrid Grid System Based on Power Quality Risk Index

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This work was supported in part by the 2016 National Key Research and Development Program of China to support Low-Carbon Winter Olympics of Integrated Smart Grid Demonstration Project under Grant 2016YFB0900500, and in part by the Beijing Natural Science Foundation under Grant 3182037.

ABSTRACT Due to the expansion of restructured electricity markets and consequently power network operation approaching dynamic and static margins, the probability of transient instability has remarkably been increased. To reduce the transient instability risk or probabilistic cost of power quality, the present study focuses on determining the optimum location of a flux-coupling type SFCL. To this end, the candidate locations with lower related transient instability risk are selected as the best locations for installing flux-coupling type SFCLs. Nowadays, the type of SFCL employed in this study, which enjoys the benefits of both resistive and inductive type SFCLs, is a suitable means for enhancing the transient stability of electrical grids. Despite being another useful approach in transient stability evaluation, the equal-area criterion is merely restricted to the analysis of the stability of a single-machine power system connected to an infinite bus and also a two-machine power system. The online approach employed in this study is based on the corrected transient energy margin (CTEM), some probabilistic factors, and the cost of transient instability. Furthermore, CTEM index is a useful tool for calculating the critical clearing time (CCT). Therefore, in recent years, this index has become more and more useful. The studies carried out on the IEEE New England 39-bus test system ascertain the high applicability of the proposed method.

INDEX TERMS Flux-coupling type SFCL, power quality stability assessment, power quality instability probability, transient instability risk, corrected transient energy margin, critical clearing time.

NOMENCLATURE
SFCL Superconducting fault current limiter
TSA Transient stability assessment
CCT Critical clearing time
FSFCL Flux-coupling type superconducting fault current limiter
PQSA Power quality stability assessment
CTEM Corrected transient energy margin
SMES Superconducting magnetic energy storage
SVC Static VAR compensator
ST Phase-shifting transformer
PEBS Potential energy boundary surface
CTKE Corrected transient kinetic energy
TPE Transient potential energy
CPEBS Corrected potential energy boundary surface
SENS\textsubscript{j} Sensitivity factor
FACTS Flexible AC transmission systems
CT Coupling transformer
MOA -\textit{R}\textsubscript{M} Metal oxide arrester
TEM Transient energy margin

I. INTRODUCTION
The stability issue is classified into two main groups: transient and steady-state Stabilities. The reason for steady-state instability, or steady-state disturbances, is long-term, small perturbations. On the other hand, sudden, severe perturbations such as short-circuits, losing large generation units and
transmission lines, outage of large-capacity loads, to name but a few are the basic reason for transient instability [1], [2]. As long as the synchronism of generators is maintained in drastic transient disturbances, a basic condition related to the operation of the system is attained. In other words, the transient stability study is generally formed by evaluating rotor synchronization preservation after the occurrence of a fault or transient disturbance. In another definition, transient stability relied on the capability of the power grid to conserve synchronism and regain stability in the condition of the abovementioned drastic transient disturbances [3]–[6]. In recent years, increasing gravitation of participants of the restructured electricity industry to higher economic profits has made power systems more disposed to transient contingencies. For instance, setting generator output power near to the maximum generation capacity for the sake of both supplying the demand and earning more profit increases the possibility of transient instability. Additionally, with expanding the capacity and complexity of power system, incidence probability and current level of short-circuiting (i.e., the main source of transient disturbances) have risen, drastically [7], and some of the vital equipment, especially circuit breakers, are disposed to failures [8]. Some factors including severe weather conditions, failures occurred in power equipment, aging of insulators, accidents, and so forth causes the faults in the existing power systems [9].

In recent years, for the sake of increasing transient stability, various devices such as static VAR compensator (SVC) [10], flexible AC transmission systems (FACTS) devices [11], phase shifting transformer (PST) [12], superconducting fault current limiter (SFCL) [13], braking resistor [14], superconducting magnetic energy storage (SMES) [15], to name but a handful have been used. Among several fault current limiting apparatus presented in the literature, which is based on power electronics development [16], FCL is a fundamental and effective solution for high levels of fault currents in both simple and intricate power systems. Nowadays, as a result of indisputable progress in superconducting technology, SFCL has become a crucial and practicable device for suppressing fault currents and improving transient behavior [17]. Some of the effective advantages of this economical device include enhancing the power balance of the system. Increasing both voltage and frequency stabilities [18], as well as distribution reliability. Considering the modern power systems requirements to be quick and on-line transient stability assessment (TSA), a fundamental tool for evaluating first-swing transient stability has been developed in [19], and it is the cornerstone of the TSA proposed in this paper. As a result of the undeniable impacts of probabilistic factors such as fault type, fault clearing time, etc., on TSA, this issue is probabilistic [20]. Therefore, in this study, some of the probabilistic factors are briefly explained and considered in the TSA. Probabilistic methods employed in [21] are not appropriate for quick and straightforward evaluation. For the sake of making economic decisions and online evaluation of the transient performance, system transient instability risk [22], [23] utilizing the linear feature of the CTEM index is appropriate. As long as consideration of both probability and cost of transient instability is concerned, this index has become more practicable, recently. CTEM is a hybrid method, and one of the most appropriate methods for TSA constitutes the basis of calculating transient instability risk in this paper. However, to reduce the disturbances that occurred in the linear parameter varying system, H∞ technique was used [24]. The capability of hybrid method evaluating transient stability considering non-linear models of loads and detailed models of generators (e.g., generators with excitors) is a remarkable advantage of these methods [25]. Also, a controller is designed to minimize the multiple disturbances developed in a non-linear system by using Lyapunov technique, which increases the gain of the system [26].

In the coming future, the CB did not exist in the power system for protecting against severe fault current. Therefore, few suggestions for protecting the power system are included like, the operation mode may be changed and in place of transformers, including series reactor and rectifying its output parameters [27]–[29].

In this paper, considering the large-scale and multi-generator IEEE New England 39-bus test system, the optimum location of an FSFCL is determined. This novel SFCL approach, which enjoys the useful characteristics of both resistive and inductive SFCLs has been presented recently. In [30], the application of FSFCL for enhancing the transient performance of the power system has been surveyed. The probabilistic approach of this paper is capable of on-line calculation of the transient instability risk of each operating condition. The remainder of this paper is organized as follows: In Section 2, the characteristics of employed SFSCF are briefly explained. Section 3 introduces some important probabilistic factors affecting TSA. In Section 4, the implication of CTEM is described. Section 5 introduces the algorithm of optimum SFSCF placement based on the transient instability risk. In Section 6, numerical results obtained from implementing the approach on the IEEE New England 39-bus test system are presented. Finally, section 7 concludes this paper.

![FIGURE 1. Electrical structure of FSFCL.](image-url)
and a superconducting core with a resistance denoted by \( R_i \) (in series connection with the secondary winding of the CT). In this figure, \( L_1 \) and \( L_2 \) are self-inductances, and \( M \) is the mutual inductance of the windings. To suppress the switching voltage produced in this structure, a metal oxide arrester (MOA) with a resistance denoted by \( R_M \) is used (in parallel connection with the primary winding of the CT).

### A. EQUIVALENT CIRCUIT PARAMETERS

To obtain the main parameters of the FSFCL, the equivalent electrical circuit has been shown in Fig. 2. Note that this equivalent circuit is obtained based on the extent of electrical relations between coupled inductors.

![FIGURE 2. Equivalent electrical circuit of employed FSFCL.](image)

It is worth mentioning that in normal condition (without any faults), the switch is in the close state, and the superconducting core has zero impedance on account of being in the superconducting state. Consequently, the impedance of FSFCL before fault occurrence is obtained using the following equation:

\[
Z_{FSFCL, normal} = \frac{j \omega \times [(L_1 + M)P(L_2 + M) - M]}{L_1 + L_2 + 2M} \tag{1}
\]

Considering the extent equations of transformation ratio and coupling \((n = \sqrt{L_1/L_2})\) the coefficient in a coupling transformer, the normal condition impedance of this \((k = M/\sqrt{L_1L_2})\) FSFCL is rewritten as follows:

\[
Z_{FSFCL, normal} = \frac{j \omega L_2(1 - k^2) \times n^2}{n^2 + 2kn + 1} \tag{2}
\]

With the assumption of using an iron core with \( k = 1 \), the normal condition impedance will be equal to 0, and the FSFCL will not modify the original power circuit. When fault befalls, an increase in the current level opens the switch, and coil fluxes cannot nullify each other anymore. Subsequently, the superconducting core turns to a high impedance state; the FSFCL impedance in fault conditions is equal to the equation (3).

\[
Z_{FSFCL, normal} = R_s + j \omega L_2 + j \omega M + (j \omega L_1 + j \omega M + R_M) \parallel (-j \omega M) \tag{3}
\]

Considering \( n = \sqrt{L_1/L_2} \) and \( k = M/\sqrt{L_1L_2} \), equation (3) is rewritten as follows:

\[
Z_{FSFCL, normal} = R_s + j \omega L_2 + \frac{(k \omega L_3)^2}{R_M + n^2 \omega L_2} \tag{4}
\]

Eventually, assuming \( R_M \geq n^2 \omega L_2 \), equation (5) is achieved:

\[
Z_{FSFCL, normal} \approx R_s + j \omega L_2 \tag{5}
\]

### B. PROBABILISTIC FACTOR OF FAULT OCCURRENCE

Attaining the probability of fault incidence based on the historical statistical information about fault rates using the following equation is a conventional process.

\[
P(E_i) = \frac{A_i}{\sum_{i=1}^{N_L} \lambda_i} \tag{6}
\]

In this equation, notation \( A_i \) signifies the mean number of faults per year. Also, \( P(E_i), N_L \) denote the probability of the event in line and \( \lambda_i \) the total number of all lines, respectively. Note that fault occurrence at each point of a specific line is possible. Therefore, to appraise the probability of fault location, it is customary that the lines are divided into several discrete parts. In this manner, the relevant probability could be achieved from historical statistic information [28]. The second approach is to use a discrete probability distribution [30]. In this method, fault probability in each part assumed to be proportional to the length of the line segment.

\[
P(E_j) = P(E_j|E_i) \times P(E_i) \tag{7}
\]

\[
P(E_j|E_i) = \frac{x_j}{\sum_{j=1}^{N_s} L_j} \tag{8}
\]

where \( P(E_i) \) denotes the probability of event \( E_i \) befallen in part of \( j \) line, and the notation \( P(E_j|E_i) \) is this probability provided that the fault location is a line \( i \). Moreover, \( L_j \) and \( N_s \) are the length of the segment \( j \) and the total number of segments, respectively. To get a better comprehension \( n \) of this approach, the division of a line \( j \) into 5 parts and the probability related to each segment is exemplified in Fig. 3.

In this figure, denotes fault \( P(x_j) \) occurrence probability assigned to the event \( x_j \) befallen in the segment \( j\)th of the line \( i \).

### C. PROBABILISTIC FACTOR OF FAULT CLEARING TIME

Considering the studies conducted in the literature, three main stages (i.e., fault detection, Operation of protection relays, and operation of breakers) [30], comprise the fault clearing process. In this regard, the first and second parts are normal distribution functions with means of 3.5 and 4 cycles, respectively. Note that the standard deviation \( \delta \) of both functions
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III. IMPLICATION OF CORRECTED TRANSIENT ENERGY MARGIN (CTEM)

In hybrid methods, by performing a time-domain simulation after fault clearance, a transient energy margin (TEM) is attained using the implication of potential energy boundary surface (PEBS) [16], [17]. It worth mentioning that the variation of hybrid TEM around its critical value against variation in some parameters of the system is non-linear and unpredictable [18]. To solve this problem, the concepts of corrected transient kinetic energy (CTKE) and transient potential energy (TPE) were presented. The subsequent problem was the fact that the sum of CTKE and TPE is not constant [15]. For the sake of addressing this problem, the functions of corrected TPE, or CTPE, and corrected PEBS, or CPEBS, were proposed, and these concepts were used for defining the CTEM index. To illuminate our point, trajectories of Fig. 5 have been illustrated and are described in this paper. According to this figure, as long as the fault is cleared in \( t_1 \) seconds, following the movement of the system on stable trajectory 1, the stable equilibrium point \( p_1 \) is obtained. With an increase in clearing time, the trajectory approaches CPEBS, and in critical trajectory 2, the amount of CTKE is the maximum value that could be absorbed by the system without losing transient stability. As clearing time violates \( t_2 \), the unstable first-swing state occurs. In other words, with clearing time equal to \( t_3 \) to, the CPEBS is cut at point C, and thereafter because of the positive accelerating power, the separation between groups of advanced and non-advanced generators rises.

The formula of the relative moving between COI of group A and group B is as follows [17]:

\[
P_{AB} = \frac{M_{eq} \omega_{AB}}{M_A} \sum_{i=1}^{n_A} (P_{mi} - P_{ei}) - \frac{M_{eq}}{M_B} \sum_{i=1}^{n_B} (P_{mi} - P_{ei})
\]

(10)

where:

\[
M_A = \sum_{i=1}^{n_A} M_i, \quad M_B = \sum_{i=1}^{n_B} M_i, \quad M_{eq} = \frac{M_A \times M_B}{M_A + M_B}
\]

(11)

\[
\omega_A = \sum_{i=1}^{n_A} \frac{M_{oi}}{M_A}, \quad \omega_B = \sum_{i=1}^{n_B} \frac{M_{oi}}{M_B}, \quad \omega_{AB} = \omega_A - \omega_B
\]

(12)

where is accelerating power between the COIs of two groups of the machines, and are output mechanical and electrical powers of synchronous generator, correspondingly.

The computation process of CTEM index is summarized in the following two steps [12]:

In the stable first-swing case, and in peak point of CTPE (specified with notation P in Fig.5) Where the sign of changes from positive to negative, a new fault is implemented to intersect the CPEBS curve at illustrated point C. In this case, the CTEM index is calculated using the following formula (note that C is intersection point):

\[
CTEM = - \int_{\alpha_{AB,C}}^{\alpha_{AB,P}} P_{AB} d\alpha_{AB}
\]

(13)
where:
\[ \alpha_A = \sum_{i=1}^{n_A} \frac{M_i \alpha_i}{M_A}, \quad \alpha_B = \sum_{i=1}^{n_B} \frac{M_i \alpha_i}{M_B}, \quad \alpha_{AB} = \alpha_A - \alpha_B \] (14)

In this equation, and are the rotor angles of synchronous generator related to the COI and the difference between rotor angles of two groups, respectively.

For unstable first-swing case, in which the value of passes through a certain minimum and positive amount, the amount of CTEM index is obtained from:
\[ CTEM = -\frac{1}{2} M_{eq} \times \omega^2_{AB} \] (15)
where \( \omega_{AB} \) denotes the value of \( \omega_{AB} \) at intersection point C.

Furthermore, using the sensitivity of CTEM, the system stability condition against variations in operation conditions will be easily predictable. Considering the first-order approximation of Taylor series around the operation point of the system, the sensitivity factor of CTEM for the \( j \)th generator is obtained as follows:
\[ SENS_j = \frac{\partial CTEM}{\partial P_j} = \frac{\Delta CTEM}{\Delta P_j} = \frac{CTEM_j - CTEM_0}{P_j} \] (16)
where \( SENS_j \) is the sensitivity factor related to the \( j \)th generator, also \( CTEM_0 \) and \( CTEM_j \) are the values of CTEM before and after deviation in the output electrical power of the synchronous generator \( j \), respectively. If the output power of several generators changes, the variation CTEM will be equal to:
\[ \Delta CTEM(P_1, P_2, \ldots, P_{N_g}) = \sum_{i=1}^{N_g} SENS_j \Delta P_j \] (17)

In this equation, \( N_g \) is the total number of generators in the system. In this regard, as the operation condition varies, given the \( SENS_j \) values of all contingencies, estimating the new amounts of \( CTEM(CTEM_{new}) \) for a certain contingency \( E \) with certain clearing time \( CT \), will be possible using the following equation:
\[ CTEM_{new} = CTEM_{E, CT} + \Delta CTEM \] (18)

If the calculated value is positive, it is estimated that the system in the new operating condition will be stable and vice versa. It is worth mentioning that are independent values from fault clearing time and operation condition (output power of generators).

IV. OPTIMUM FSFCL PLACEMENT PROCESS USING TRANSIENT INSTABILITY RISK

The main stages of the process adopted in this paper, or the proposed algorithm for optimum FSFCL placement, is explained in this Section:

1. To begin with, for FSFCLs installed in each candidate location, the CTEM curves concerning each contingency must be exploited using time-domain simulation.
2. The probable portion of fault clearing time is apportioned to parts, and the probability of \( M \) each part is obtained using (9). The more the number of parts is, the more accurate the simulation results.
3. Creating system stability condition matrix (a): This matrix is obtained using the CTEM curves of each operating condition. To this end, the 0 value is assigned to \( a_{ij} \) if the system is stable for the time part \( i \) and contingency \( j \). Otherwise, its value is equal to 1.
4. Creating a system instability probability matrix (b): This matrix is constituted using a matrix (a) and considering the probability of contingencies and time parts. Each element of matrix b is calculated using equation (19).
\[ b_{ij} = P(t_{ci(i)} < t_{ci(i)} < t_{ci(i)} \times P(E_j) \times a_{ij} \] (19)

5. Calculating the probability of transient instability for \( j \)th contingency. This probability is obtained by adding the columnar elements of matrix b, which are related to contingency \( (j) \) column summation:
\[ P(\text{instability} \mid E_j, X) = \sum_{i=1}^{M} b_{ij} \] (20)

6. Calculating the probability of system transient instability. This probability for operation Condition \( X \) equals the summation of the entries of matrix b:
\[ P(\text{instability} \mid E_j, X) = \sum_{i=1}^{M} \sum_{j=1}^{M} b_{ij} \] (21)
where \( N \) is the number of considered contingencies.

7. Cost assessment for each contingency \( C(\text{instability} \mid E_j) \). Some of the costs imposed as a result of transient instability are replacement cost \( C_R \) i.e. (the cost of replacing the tripped unit with a new unit with more expensive operation cost for several hours), repair and start-up cost \( C_{R&S} \) (i.e., the cost of repairing and starting-up the tripped unit), consumer interruption cost \( C_I \) (i.e., the cost of load shedding, applied as a result of losing a generation, to limit the frequency of the system within an acceptable range), political cost,
\[ C(\text{instability} \mid E_j) = C_{R&S} + C_R + C_I \] (22)

and social cost [18]. In this paper, only the first three types of abovementioned costs have been considered.

8. Creating the matrix of system transient instability risk (c): This matrix is obtained using Matrix band multiplying the cost of each contingency to the entries of the corresponding column. The value of each element in matrix c is calculated as follows:
\[ r_{ij} = C(\text{instability} \mid E_j) \times b_{ij} \] (23)
9. Calculating the system transient instability risk

\[ \text{RISK} (\text{instability} \mid X) = \sum_{j=1}^{N} [C(\text{instability} \mid E_j) \times b_{ij}] \]  \hspace{2cm} (24)

10. Eventually, the locations with the lowest transient instability risk are chosen as optimum locations for installing FSFCLs. The abovementioned algorithm has been illustrated in Fig. 6. In this figure, D is the number of candidate locations for FSFCL placement.

V. SIMULATION RESULTS

In the present study, the simulation outputs have been attained using MATLAB software. IEEE 39-bus New England test system, which is demonstrated in Fig. 7, has been employed to validate the applicability of the proposed method. For the sake of simplicity, merely four sever contingencies including three phases short-circuits at buses 17, 21, 26, and 28 have been simulated in this case study. Accordingly, the lines that are near these buses have more influence on reducing the destructive effects of short-circuits on transient performance; with this in mind, only the lines connected to four abovementioned buses are selected as candidate locations for FSFCL placement. Therefore, in this paper, only lines 18-17, 17-16, 27-17, 21-16, 22-21, 26-25, 29-26, 27-26, 28-26, and 29-28 are considered as the candidate locations in the procedure of FSFCL placement. The lengths of these lines have been summarized in Table 1. Also, the yearly fault rate of each bus is equal to 50% of the summation of the fault rates of the lines connected to that bus. Using equation (6), the fault rate of four buses and the incidence probability of the aforementioned sever contingencies have been demonstrated in Table 2.

| Sl No. | Line   | Length (km) |
|--------|--------|-------------|
| 1      | 18-17  | 51.36       |
| 2      | 17-16  | 55.74       |
| 3      | 27-17  | 108.36      |
| 4      | 21-16  | 84.56       |
| 5      | 22-21  | 87.7        |
| 6      | 26-25  | 202.34      |
| 7      | 29-26  | 391.52      |
| 8      | 27-26  | 92.08       |
| 9      | 28-26  | 296.92      |
| 10     | 29-28  | 94.58       |

The main simulation parameters of the FSFCL have been summarized in Table 3. In creating matrix (a) the probable
range of fault clearing time is considered virtually from 1.45 to 5.9 cycles, and this range has been apportioned to 18 segments. Note that the probability associated with each segment is calculated by integrating (9) in the relevant time interval. With the occurrence of the aforementioned contingencies, generators G1 (for contingencies at buses 17, 26, and 28) and G6 (for contingencies at bus 21) are disposed to transient instability. Some essential data for calculating transient instability cost due to the instability of these generators, and consequently, the instability cost of each contingency has been shown in Table 4.

First, for executing the proposed algorithm, we extracted the CTEM curves of these curves against variation in fault clearing time before and after installing the FSFCLs in each of the candidate lines in three-phase short-circuit conditions that occurred in buses 26 and 28 have been demonstrated in Fig.8 and Fig.9, respectively. Moreover, to make the linear property CTEM of more comprehensible, CTEM curve about the contingency occurred in bus 28 with a specific clearing time, against output power variation of generator G9 has been illustrated in Fig.10. Eventually, CTEM curves of this contingency against clearing times, for 5 different output power of generator G9 have been shown in Fig.11. In Figs. 8-11, the linear feature of CTEM the index against variation in fault clearing time and output power of generators is crystal clear. To exemplify the possibility of estimating stability condition with the variation of the operation point, the values of CTEM sensitivity SENs correspond to generators G2-G10 (note that generator G1 is the slack generator used for compensating the loss and total generation shifting) for the contingency occurred in bus 28, have been calculated and illustrated in Table 5.

The negative values obtained for CTEM sensitivities of all generators show that the reduction in output power of non-reference machines increases CTEM values and improves transient stability. After apportioning the probable portion of clearing time to M parts and constituting matrices a, b, and c based on the instructions described in the previous
FIGURE 11. CTEM curves of the contingency occurred in bus 28 against fault clearing times for different outputs of generator G9.

TABLE 5. CTEM sensitivities of The contingency occurred in bus 28 for non-reference generators.

| Sl. No. | Generators | $SENS_i$ |
|---------|------------|----------|
| 1       | G2         | $-1.093 \times 10^{-6}$ |
| 2       | G3         | $-4.329 \times 10^{-6}$ |
| 3       | G4         | $-1.75 \times 10^{-5}$  |
| 4       | G5         | $-9.297 \times 10^{-7}$ |
| 5       | G6         | $-1.638 \times 10^{-5}$ |
| 6       | G7         | $-9.609 \times 10^{-6}$ |
| 7       | G8         | $-2.103 \times 10^{-5}$ |
| 8       | G9         | $-4.794 \times 10^{-4}$ |
| 9       | G10        | $-7.386 \times 10^{-6}$ |

TABLE 6. Operation condition $x$ for the output power of generators.

| Generator | Active Power (MW) | Generator | Active Power (MW) |
|-----------|-------------------|-----------|-------------------|
| G1        | 1000              | G6        | 650               |
| G2        | 572.93            | G7        | 560               |
| G3        | 650               | G8        | 540               |
| G4        | 632               | G9        | 830               |
| G5        | 508               | G10       | 250               |

FIGURE 12. Transient instability risk values obtained for different FSFCL locations.

FIGURE 13. Voltage profile of New England system (in PU) before and after FSFCL placement.

FIGURE 14. CTEM curve for the contingency occurred on bus 26 before and after optimum FSFCL placement.

section, the values of transient instability risk corresponding to operation condition $X$ (shown in Table 6) and contingency set $E$ (including the four contingencies), before and after installing the FSFCLs in the candidate locations have been illustrated in bar diagram of Fig. 12. For evaluating the values of system static parameters such as bus voltages, the voltage profile of all buses of the New England system, before and after FSFC L placement in lines 27-26, 18-17, and 21-16, has been demonstrated in Fig. 13. In this figure, it is obvious that as expected, the optimum FSFCL placement has not had any considerable effect on voltage profile, because, in this study, the static problems have not been applied in the optimization process. Eventually, to better illustrate the transient stability enhancement through optimum FSFCL placement, the CTEM curves related to contingency occurred in bus 26, before and after the optimum FSFCL installation, have been exemplified in Fig.14.

VI. CONCLUSION

In this study, CTEM has been proposed as an applicable index for evaluating the transient system performance. One of the laudable applications of CTEM is in calculating CCT. In this paper, for the sake of addressing the costs imposed by transient instability, the transient instability risk index – a novel, quick, and on-line tool for cost-effective decisions – has been employed for optimum placement of a modified FSFCL to increase the system transient stability and decrease the costs of instability. To this end, the location whose related risk is lower is selected for FSFCL placement. This method
utilizing the theorem of conditional probability, and the useful linear features of CTEM is capable of economic assessment in the operation point. Eventually, it has been concluded that depending on whether or not the FSFCLs are installed in the optimum locations; transient behavior could be improved, which also improves the aspect of power quality. The simulation results implemented on IEEE 39-bus New England test system, and conducted using MATLAB software, ascertain the applicability and effectiveness of the proposed method for optimum FSFCL placement. Based on the numerical results, by optimum FSFCL placement, the transient instability probability reduced about 40 percent, and the probabilistic cost of instability reduced by about 0.45 million dollars.

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