Estimation of Transmission System Power Transfer Capability at Competitive Renewable Energy Zones

Milad Javadi, Ruchi Singh
Transmission & Interconnection
Engie North America Inc.
Houston, TX, US

Di Wu
Electrical and Computer Engineering
North Dakota State University
Fargo, ND, US

Gangan Li, Guomin Ji, John N Jiang
Electrical and Computer Engineering
University of Oklahoma
Norman, OK, US

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***Abstract*—Estimation of Total Renewable Power Transfer Capability (TRPTC) out of Competitive Renewable Energy Zones (CREZ) is a critical piece of information for transmission planning assessments, generation interconnection studies and reliable operation of interconnected power grids. Over the recent years, significant decommissioning of fossil-fueled power plants and increase in interconnection of Renewable Energy Resources (RERs) have resulted in several challenges in system operations due to variations and uncertainties included in the nature of these resources. Sudden and dramatic variations in output of RERs in conjunction with lack of sophisticated/sufficient VAR support in CREZ have directly impacted the system strength at their Points of Interconnection (POIs), and consequently, the system's voltage stability. To investigate this impact, a few Short Circuit Ratio (SCR)-based methods were proposed and utilized to assess the system strength in CREZ. In this paper, we developed a SCR-based approach to estimate the TRPTC. More specifically, the newly developed Site-Dependent Short Circuit Ratio (SDSCR) methodology is utilized to estimate the TRPTC with respect to the NERC TPL-001-4 Standard. Accuracy of the TRPTC estimation using SDSCR methodology is illustrated and verified through comparative simulations studies versus other SCR-based methods.**

Keywords—Transfer capability, renewable energy, system strength, short circuit ratio, voltage stability

I. Introduction and Description of Problem

Renewable energy is a fundamental and growing piece of the world's ongoing energy transformation toward decarbonizing the electricity industry. Complexity of power systems with several Transmission Service Providers (TSPs), growing energy demand associated with environmental constraints and technical limitations of interconnection of RERs have brought new challenges to transmission planners/operators and Generator Owners (GO). The challenges mainly come from requirement of high power quality in terms of high degree of reliability and stability. On the other hand, the intermittent nature of RERs including uncertainties and variabilities due to fluctuations in weather and atmospheric conditions cannot be neglected. For instance, solar PV power generation dependents on solar irradiance and presence of clouds passing over power plants leading to generation reduction for periods of time. Clouds can lead to sudden and dramatic changes in the output of solar PV plants if they are not spread out and geographically dispersed.

Nowadays, an accurate estimation of Total Renewable Power Transfer Capability (TRPTC) out of Competitive Renewable Energy Zones (CREZ) and/or between adjacent – interconnected – TSPs is required in transmission planning, operation, and power trading activities. Transmission operators need to ensure that there exist adequate resources to accommodate substantial and dramatic variations in renewable generation to balance the system supply and demand, or renewable developers need to know if a multi-million future RER project can reliably inject power into the transmission system. The Total Transfer Capability (TTC) is traditionally used as an index to gauge the capability of system to transfer power maintaining system's $N-1$ security under NERC and other applicable regional contingencies, [1].

The TTC varies as system operating conditions change from time to time due to uncertainties included in the nature of RERs. Conventionally, there exist two typical approaches for TTC calculation. First one is based on deterministic approaches, [2],[3]. These approaches basically calculate TTC of an interface when there is no overload, voltage violation, or any other system constraint, such as stability limitation or Generic Transmission Constraints (GTC) imposed by the associated Independent System Operator (ISO). The other one is based on probabilistic approaches in which values of TTC are evaluated under various operating conditions using probabilistic models, [4]-[6]. Then, the TTC is estimated taking all calculated values into account.

To accurately estimate the TRPTC in the presence of RERs, their real impacts on transmission system performance are needed to be taken into consideration of studies. System strength is a revealing and insightful tool/measure to assess the impact of RERs on the transmission system operations and voltage stability. Potential system stability issues – particularly those related to voltage stability at CREZ – may take place when tremendous amount of RER capacities are interconnected to transmission system at weak Points of Interconnection (POIs), such as Panhandle CREZ area in North Texas, or Imperial Valley CREZ area in Southern California. Recently, SCR-based methods have been used to evaluate the system strength for RERs generation interconnection studies, [7]-[9]. Negligence of interactions among RERs and the fact that how renewable generation at a POI impacts deliverability at another – electrically close – POI leads to overestimation of the system strength. To account for the effect of these interactions, some enhanced methods such as, Composite Short Circuit Ratio (CSCR) and Weighted Short Circuit Ratio (WSCR) were proposed, [10],[11]. Based on these methods, we developed the Site-Dependent Short Circuit Ratio (SDSCR) methodology by taking into account the real electrical connectivity among RERs and rest of the power grid.

In this paper, we extend the application of SDSCR methodology into TRPTC estimation. To this end, an approach is developed to estimate the TRPTC more accurately by incorporating the SDSCR system strength measurement. This approach can be utilized by transmission planners, utility-scale renewable developers and transmission operations engineers to better understand the impact of RERs on the system's available power transfer capability from the system strength standpoint.

The rest of this paper is organized as follows. In section II, conventional methods for TTC along with the SCR-based methods for system strength evaluation are reviewed. In section III, a new SDSCR-based approach is developed for TRPTC calculation. In section IV, a comparative study is conducted to demonstrate the accuracy of proposed approach. In section V, the conclusions are drawn.

II. Conventional TTC Methods and System Strength

A. Methods for Power Transfer Capability Calculation

Several mathematical methods and heuristic algorithms are reported in literature to estimate TTC. Normally, these methods can be classified into four types, linear, Continuation Power

Flow (CPF), Repetitive Power Flow (RPF) and Optimal Power Flow (OPF)-based methods.

Linear approximation method for updating and estimating TTC is commonly used in transmission planning studies. In this method, the TTC is calculated by Power Transfer Distribution Factors (PTDFs) or Line Outage Distribution Factors (LODFs) using decoupled power flow solution. Even though such a method is easy and fast, ignorance of voltage and VAR adequacy leads to unacceptable errors under certain circumstances, [12].

CPF-based method is used for TTC calculation by increasing the loading factor in discrete steps and solving the power flow in each step. CPF method yields solutions at voltage collapse points. However, it is an iterative method and takes time to converge to a solution. Furthermore, it ignores the optimal distribution of the generation and the loading together; hence, it may result in conservative results for TTC estimation, [13],[14].

Compared to the CPF-based method, the implementation of RPF-based method is more straightforward and the time needed for convergence is less than the CPF-based one. The RPF-based method repeatedly solves the conventional power flow at a succession of points along the specified transfer directions to obtain the estimated TTC, [15].

OPF is the tool of choice for a range of optimization problems relating to real-time operations. It has been recognized and extended to the TTC calculation. As approximations are involved, the accuracy of this calculation is low. It may also yield non-converged results due to massive number of variables and equations for a real-world, large-scale power system, [16].

B. SCR Based Methods for System Strength Evaluation

(1) Current Methods for System Strength Evaluation: System strength can be defined as an index for ability of power system to maintain voltage stability and quality of load service following dramatic variations in output of RERs. The system strength of a power system has a significant impact on the AC/DC system interactions. Traditionally, the SCR was used for calibration of system protection equipment, relays configuration and threshold setting, DC link interconnection to an AC power system and so on. Recently, the concept of SCR has been used to evaluate the system strength at the POIs of inverter-based generation facilities (RERs). It is defined as the ratio of "*short circuit capacity*" of a power grid to the "*MW renewable power generation*". The SCR_i can be calculated as follows, [17],

$$SCR_i = \frac{|S_{ac,i}|}{P_i} = \frac{|V_i|^2}{P_i} \cdot \frac{1}{|Z_i|} \tag{1}$$

where, $S_{ac,i}$ is the short-circuit capacity of the system at POI *i*, P_i is the power injection of the RER, $|V_i|$ and Z_i are the voltage magnitude and Thevenin equivalent impedance at POI *i*, respectively.

However, the SCR in (1) does not take the interactions among the RERs into account for system strength evaluations. When inverter-based generation facilities are electrically close, they interact with each other and reduce the system strength at the POIs. Thus, the results of system strength evaluation obtained using *SCR* will be under/overestimated when multiple RERs are interconnected to a system in a CREZ.

To account for the interactions among RERs, some modified methods were developed. Two methods mostly adopted by the power industry are Composite Short Circuit Ratio (CSCR) developed by GE and Weighted Short Circuit Ratio (WSCR) developed by ERCOT [10],[11]. The WSCR method uses the weighted average of the short circuit capacity of all RERs to calculate a single system strength measure for the entire system, while the CSCR method is developed based on an assumption that all RERs connected POIs can be tied together to create a "*composite*" bus for system strength evaluation. The main limitation of these methods comes from their assumptions, which ignore the real electrical connectivity/interactions among all RERs. This limitation results in inaccurate or even misleading assessments regarding the system strength in transmission planning and generation deliverability/ interconnection studies. Additionally, these methods provide a single system strength evaluation for the system as a whole – not for every single POI.

(2) Newly Developed SDSCR Methodology: In order to overcome the shortcomings of the existing methods for the system strength evaluation, we developed an enhanced Site-Dependent Short Circuit Ratio (SDSCR) method by taking into account the real electrical connections among RERs to provide realistic and accurate system strength evaluations at each POI.

Based on the mathematical derivations for interconnection of single and multiple RERs in [18], the system strength at POI *i* can be formulated as follows,

$$SDSCR_i = \frac{|V_{R,i}|^2}{\left(P_{R,i} + \sum_{j\in\mathbf{R}, j\neq i} w_{ij} P_{R,j}\right)|Z_{RR,ii}|} \tag{2}$$

where, $|V_{R,i}|$ is magnitude of voltage $V_{R,i}$ at POI *i* of RER, $Z_{RR,ii}$ is the $(i, j)^{\text{th}}$ element in blocks of bus impedance matrix, $P_{R,j}$ is power injection of the RER, weight w_{ij} can be represented as,

$$w_{ij} = \frac{Z_{RR,ij}}{Z_{RR,ii}} \left(\frac{V_{R,i}}{V_{R,j}}\right)^* \tag{3}$$

This SDSCR method can be used to evaluate the system strength at each individual POI in terms of the distance between the current operating conditions to the voltage stability limit. The w_{ij} is a weight used to scale the impact of renewable power generation at POI *j* on the system strength at POI *i* (i.e., the effect of interactions among RERs).

III. A SDSCR-Based Approach for TRPTC Estimation

A. Impact of Renewable Energy Resources on TTC

Although renewable energy provides numerous advantages to power systems, it increases uncertainties in reliable operations of power systems with intermittent and stochastic performance, which has significant impacts on TRPTC.

The output of RERs are affected by modules and many external factors. For instance, unlike conventional generation, the solar PV plants are power electronic systems with no rotating parts; hence, their outputs can vary rapidly and dramatically with changes in the solar irradiance caused by movement of cloud banks over the power plant site. The consequence of this phenomenon can be severe if the change in solar irradiance occurs during system's peak hours/seasons or typical generation shortages. Furthermore, temperature variations affect the PV cells open circuit voltages and short circuit current values, resulting variations in the solar PV plants outputs, [19]. The uncertainties included in RERs power generation lead to noticeable challenges for estimating TRPTC. Inaccurate estimation of TRPTC can result in serious operational difficulties due to errors imposed to results obtained from Security Constrained Economic Dispatch (SCED) runs, or reliability concerns such as severe congestions in CREZ, voltage oscillations or flickers.

B. A SCR-Based Approach for TRPTC Estimation

Various methods have been investigated for conventional TTC calculation, but still a sophisticated method is required to take into account presence, properties and interactions among RERs assisting transmission owners and generator developers with reliable interconnection of more RERs.

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To illustrate the concept of TRPTC, consider the schematic diagram in Fig. 1, which shows a CREZ equivalenced to a solar PV plant interconnected to a power grid. The AC power grid is comprised of several synchronous generators, loads, transmission lines, transformers and other transmission and distribution equipment interconnected to the CREZ/solar PV plant at POI i. In this diagram, the TRPTC is defined as the maximum power that can be reliably transferred from a group of RERs at POI i to an interconnected power grid without compromising system security constraints.

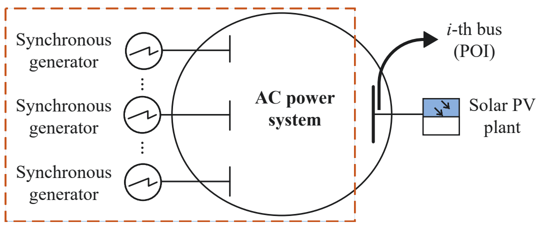

Fig.1. Schematic diagram for integration of CREZ to a power grid

Based on our previous research works on the system strength evaluation using SDSCR-based method, [18], and the basic concepts of TTC, an approach is developed to estimate the TRPTC in transmission systems interconnected to a CREZ/several RERs according to the North American Electric Reliability Corporation (NERC) TPL-001-4 Standard. Fig. 2 shows the flowchart of the proposed approach.

This is an iterative approach consists of k iterations until the TRPTC is obtained in terms of an acceptable level of system strength. It begins with the following indicative preliminaries:

- Locations of the RER facilities/CREZ POI,
- Initial output of each RER, and,
- A list of NERC contingency events: NERC P1, P2.1 and credible P7.1 contingencies for an $N-1$ assessment from operations standpoint, P3 contingencies for a more conservative assessment and P4, P5 and P6 events for EHV assets.

Based on preliminaries, the following steps are needed to be completed during each iteration:

1. Implementing each contingency event and solving the power flow,
2. Calculating the system strength at each POI,
3. Comparing the system strengths obtained from each method with thresholds of SCR-based methods,
4. Checking the new violations caused by each contingency event,
5. Increasing the output of each RER/CREZ by 1MW if there are not violations in step 4.

The power flow calculation in each iteration is based on the current outputs of RERs, as they are being increased during each iteration until the final value of TRPTC is estimated. The total output of RERs in the $k-1^{th}$ iteration is considered as TRPTC if and only if,

- The system strength assessment at each POI/CREZ is not violated following each contingency event in the $k-1^{th}$ iteration, and,
- The results of system strength assessment following each contingency violate the threshold in k^{th} iteration.

C. Voltage Range Monitoring

The TRPTC estimated by the proposed approach can be different using different SCR-based methods. To distinguish the accuracy of different SCR-based methods in TRPTC calculation, the constraint of voltage range at each POI is considered.

Typically, a post-contingency voltage magnitude of 0.9 p.u. is used as an indicator of voltage stability limit. If the magnitude of bus voltage falls below this value, it implies that the system voltage performance is not within the acceptable range.

To demonstrate the efficiency and accuracy of SDSCR method in TRPTC estimation, a comparison is performed among SCR-based methods. Following this comparison, three situations are possible to occur,

- TRPTC evaluated by SDSCR method > TRPTC evaluated by other SCR-based methods,
- TRPTC evaluated by SDSCR method < TRPTC evaluated by other SCR-based methods,
- TRPTC evaluated by SDSCR method = TRPTC evaluated by other SCR-based methods.

The TRPTC value obtained using the SDSCR method with consideration of voltage range monitoring can be the most accurate estimation if and only if,

- TRPTC evaluated by SDSCR method > TRPTC evaluated by other SCR-based methods,
- No voltage violation is observed at POIs for SDSCR method.

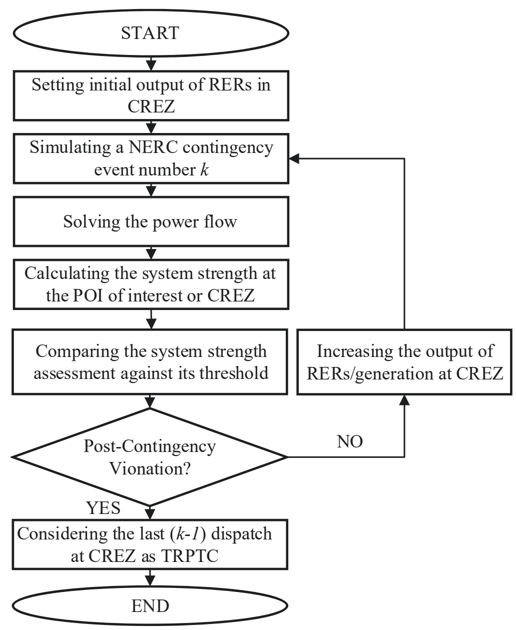

Fig. 2. Flowchart of SCR-based approach for estimation of TRPTC

In some special cases, the TRPTC value evaluated by the SDSCR method might be the same as other SCR-based methods while the constraint of voltage limit is satisfied at POIs. Then, either the result of SDSCR method or the result of other SCR-based methods are accurate.

IV. Illustrative Simulation Studies

In this section, the SCR-based methods are used to verify the accuracy and practical applicability of the proposed approach for estimation of TRPTC. The approach is utilized to estimate the TRPTC in a real-world, large-scale transmission system with over 1,000 buses, 1,500 transmission lines and 130 autotransformers. The outcome of this assessment indicates that the results obtained using the SDSCR method are more precise and accurate comparing the those obtained from other SCR-based methods. More specifically, the results from the other existing methods overestimate the system strength in areas with several RERs interconnected to transmission system in a close electrical vicinity. While, in some cases, they underestimate the

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system strength at POIs were RERs are sparsely interconnected to transmission system. Additionally, the CSCR and WSCR methods are incapable of estimating the system strength, exclusively for each POI. The accuracy and reasonability of the TRPTC estimations obtained using the proposed approach are further studied and confirmed through contingency analysis. The details on results associated with this simulation study are not presented due to release of information restrictions and confidentiality issues.

To illustrate the proposed approach, the IEEE 30-bus test system shown in Fig. 3 is used for simulation studies. In this system, synchronous generators at buses 22 and 23 are replaced by a wind farm and a solar PV plant, respectively, with an initial dispatch of 30 MW. The dispatch of each unit is increased by 1 MW for each iteration until the thresholds of SCR-based methods are reached. The following base case and contingency events scenarios are considered in our studies:

- *Base Case Scenario:* the system is in (intact) normal operating condition with all transmission equipment in-service (NERC P0),
- *Contingency Events Scenario:* each transmission line is considered out of service (one at a time) due to a contingency event (NERC P1.2, P2.1 and P7.1).

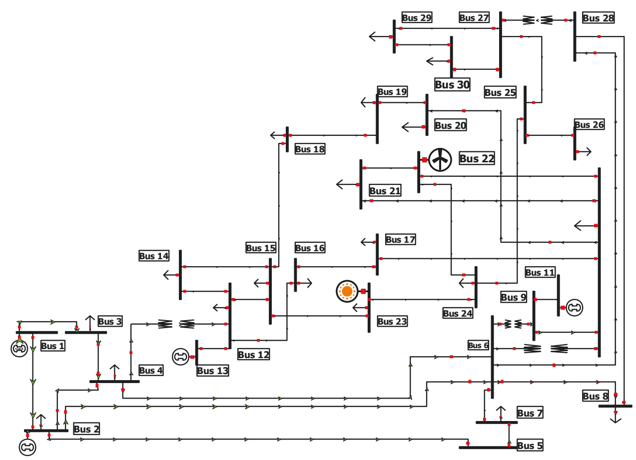

Fig. 3. One-line diagram of IEEE 30-bus system

The commonly used SCR method does not consider the interactions among the RERs and may overestimate the system strength when multiple RERs are interconnected. Hence, only the WSCR, CSCR and the newly developed SDSCR methods are used for TRPTC estimation in this study. The results obtained from each of these three methods are compared to investigate if the SDSCR method provides more accurate results in TRPTC calculation than the other methods under the base case and contingency event scenarios.

The following two constraints are considered in this study:

(1) The threshold values of WSCR and CSCR methods are chosen as 1.5 to ensure the voltage stability [10],[11]. Similar to WSCR and CSCR methods, the SDSCR method is a general representation of commonly used SCR method; and thus exhibits the same properties. In [18], we demonstrated that the value of SDSCR should be very close to 1 when the voltage stability limit is met. Considering the case that the POIs of RERs begin to become weak, the threshold value of SDSCR method should be bigger than 1. To simplify the later comparisons, the value of 1.5 is chosen as a threshold for SDSCR method as well.

(2) Similar to system strength, the voltage magnitude of 0.9 p.u. at POIs is set as another operational constraint to satisfy the transmission system voltage performance requirement.

For each scenario, we use the assumption of (RER, Load) to estimate the TRPTC by the SCR-based methods. The (RER, Load) refers to a state where generation increases in the source area/CREZ and the load increases accordingly in the sink area. Then, the maximum power transfer between the two areas is estimated subject to the constraints.

A. Base Case Scenario

In this scenario, the TRPTC value estimated using SDSCR method is compared with the TRPTC value estimated using the other two SCR-based methods when all transmission system equipment is in-service. Under the assumptions and constraints considered for TRPTC value estimation, the evaluation results are presented in Tables 1 and 2.

TABLE 1. TRPTC ESTIMATED BY SDSCR AND CSCR (BASE CASE)

Method	System Strength		Voltage (p.u.)		MW Injected Power		MW TRPTC
	Bus 22	***Bus 23***	***Bus 22***	***Bus 23***	***Bus 22***	***Bus 23***	
SDSCR	1.600	1.505	0.936	0.992	90	90	180
CSCR	1.514	1.514	0.935	0.977	55	55	110

As it can be seen in Table 1, under an operating condition where the threshold of SDSCR method is reached at one of the POIs, the voltage magnitudes at buses 22 and 23 are 0.936 p.u. and 0.992 p.u. meaning the steady-state voltage stability criterion is still maintained. Thus, the 180 MW TRPTC obtained by the SDSCR method is a reasonable and accurate estimation. While the 110 MW TRPTC estimated using CSCR is underestimating the available injection capability due to low system strength of the entire system – not at the POI of interest. Such an underestimation of TRPTC might seem to be not a criteria issue; however, in a large-scale system it can lead to fatal errors when the TRPTC is underestimated at a POI due to transmission system's low system strength value driven by system limitations – electrically – too far from the POI of interest. Moreover, the system strength values obtained by CSCR are the same at both buses 22 and 23 since this method is unable to measure the system strength at each individual POI. This comparison indicates how the SDSCR is a more accurate tool than CSCR to estimate the TRPTC more realistically without compromising the voltage stability limit.

In a same way, Table 2 presents the comparison between the TRPTC values estimated using SDSCR and WSCR methods under the base case operating condition. Prior to occurrence of voltage range violations, the TRPTC obtained by SDSCR and WSCR methods are 180 MW and 146 MW, respectively. This observation confirms that the SDCDR method provides a more accurate result compared with the WSCR method which underestimated the TRPTC value.

TABLE 2. TRPTC ESTIMATED BY SDSCR AND WSCR (BASE CASE)

Method	System Strength		Voltage (p.u.)		MW Injected Power		MW TRPTC
	Bus 22	***Bus 23***	***Bus 22***	***Bus 23***	***Bus 22***	***Bus 23***	
SDSCR	1.600	1.505	0.936	0.992	90	90	180
WSCR	1.505	1.505	0.937	0.986	73	73	146

B. Contingency Events Scenario

In this scenario, we simulated each contingency event to demonstrate how the proposed approach is accurate and effective in TRPTC estimation. The contingency list is defined based on cascading model. Specifically, the lines included in the contingency list are selected such that the least amount of load is shed following simulation of cascading line outages. The brief contingency list is defined as follows, Line 15-23, Line 23-24, Line 25-27 and Line 27-28. Same as the base case scenario, the TRPTC value is estimated and compared using SDSCR, CSCR and WSCR methods for each contingency event; and the results are presented in Tables 3 and 4.

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It can be observed on Table 3 that under the contingency events, the SDSCR method still accurately evaluates the TRPTC without voltage violations at POIs. Following each contingency, the measured voltages at the POIs are still above 0.9 p.u. when the threshold value of SDSCR method is reached. Also, the TRPTC value calculated by the SDSCR method is larger than the CSCR method for all the contingencies. According to the voltage range assessment, the result of TRPTC estimated by the SDSCR method is more accurate and the CSCR method underestimates the TRPTC following the contingency events.

The same conclusion can be drawn from the comparison between TRPTC values estimation obtained using the SDSCR and WSCR methods under contingency events presented in Table 4. This table shows that the TRPTC value estimated by the SDSCR method is always larger than that obtained by the WSCR method for each contingency without voltage violation. The results of TRPTC estimation obtained by the WSCR method are too conservative due to ignoring the real electrical connectivity of RERs, while the SDSCR method provides an accurate TRPTC estimation which is verified through performing contingency analysis.

TABLE 3. TRPTC ESTIMATED BY SDSCR AND CSCR (CONTINGENCY EVENT)

Method	System Strength		Voltage (p.u.)		MW Injected Power		MW TRPTC
Outage on Transmission Line 15 – 23							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.948	1.511	0.925	1.009	58	58	116
CSCR	1.515	1.515	0.926	1.005	53	53	106
Outage on Transmission Line 23 – 24							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.782	1.508	0.927	1.011	76	76	152
CSCR	1.504	1.504	0.928	1.001	55	55	110
Outage on Transmission Line 25 – 27							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.618	1.505	0.910	0.962	81	81	162
CSCR	1.506	1.506	0.913	0.952	54	54	108
Outage on Transmission Line 27 – 28							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.598	1.503	0.926	0.985	89	89	178
CSCR	1.501	1.501	0.926	0.971	55	55	110

TABLE 4. TRPTC ESTIMATED BY SDSCR AND WSCR (CONTINGENCY EVENT)

Method	System Strength		Voltage (p.u.)		MW Injected Power		MW TRPTC
Outage on Transmission Line 15 – 23							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.948	1.511	0.925	1.009	58	58	116
WSCR	1.505	1.505	0.926	1.007	55	55	110
Outage on Transmission Line 23 – 24							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.782	1.508	0.927	1.011	76	76	152
WSCR	1.510	1.510	0.928	1.004	60	60	120
Outage on Transmission Line 25 – 27							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.618	1.505	0.910	0.962	81	81	162
WSCR	1.500	1.500	0.912	0.959	68	68	136
Outage on Transmission Line 27 – 28							
	Bus 22	**Bus 23**	**Bus 22**	**Bus 23**	**Bus 22**	**Bus 23**	
SDSCR	1.598	1.503	0.926	0.985	89	89	178
WSCR	1.503	1.503	0.927	0.979	72	72	144

V. SUMMARY AND CONCLUDING REMARKS

In this paper, we proposed an approach to estimate the total power transfer capability of transmission system out of competitive renewable energy zones using SDSCR-based system strength assessment. Unlike the conventional methods for transfer capability estimation, the new approach provides an insight into the system strength, which is one of the most important concerns in integration of renewable energy resources. The approach is based on the principle of iteration and evaluates the system strength at POIs for continuous increase of power export out of a renewable energy zone. The total renewable power transfer capability will be the level of export for which the threshold value of the SDSCR method and the voltage range violation are reached. This method ensures reliable integration of more renewable resources to transmission system.

Several case studies are conducted to demonstrate that using the newly developed SDSCR method provides more accurate results in power transfer capability estimation when both system strength and steady-state voltage stability are concerned at the POIs. In the future works, this approach will be further improved to produce more comprehensive results of total power transfer capability estimation by taking into account the impact of economic dispatch and dynamic voltage stability.

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