Renewable Generation Hosting Capacity Screening Tool for a Transmission Network

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***Abstract*—This paper outlines the methodology of an automated screening tool developed to determine the amount of renewable generation and distributed energy resource (DER) that can be accommodated in a transmission region without any network upgrades. The tool can be used to screen through a wide range of scenarios representing different load levels, network conditions, and generation dispatch to identify optimal/non-optimal regions of transmission network for future renewable generation/DER deployments. In addition, it provides understanding of where and how much these new generation resources would impact the system. The tool is developed using Siemens Power Technologies International (PTI) PSS®E bulk simulation tool and Python scripting language. Some of the key functionalities of the tool and results of case studies performed to showcase the applicability of the tool are presented in this document.**

Keywords – Renewable Generation, Distributed Energy Resources, DER, Transnmission Hosting Capacity

I. INTRODUCTION

Due to potential emission reductions, fuel cost reductions and deferral of transmission system upgrades there is a trend in increase in penetration of renewable generation worldwide. The high penetration of renewable generation presents unique challenges in the planning and operation of power systems as the generation mix changes with increasing levels of variable generation and planned retirements of fossil-fueled generation or as remaining conventional generation is displaced.

To address some of the challenges related to long-term transmission interconnection planning, the Electric Power Research Institute (EPRI) developed a high-level screening tool to support utilities in developing strategic plans to accommodate increasing penetration of renewable generation/DER while maintaining desired reliability levels. The tool is developed using widely used Siemens PTI PSS®E transmission planning software and Python scripting language. This tool will allow utilities to screen through numerous load/generation dispatch scenarios, potential renewable generation/DER deployment locations and network conditions to gauge levels of new generation resources a transmission region can host without any transmission network upgrades.

Note that this tool is not intended to replace detailed feasibility and system impact studies which are imperative to make any investment decisions. It will help transmission planners, 1) to screen through multiple interconnection requests across a larger transmission footprint allowing for a better understanding of where and how much these new generation resources would impact the system, and 2) to identify optimal versus non-optimal locations for future renewable generation deployments such that grid upgrades can be minimized.

II. TOOL FRAMEWORK

This section aims to provide a comprehensive framework employed to develop the transmission hosting capacity screening tool. Fig. 1 shows an outline of the developed analytical framework.

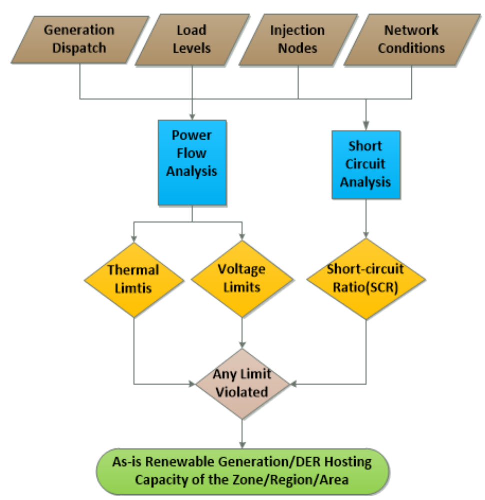

Fig. 1 Tool Framework

Through exercising this analytical framework for various system configurations, utilities could gain an understanding of how and where these new generation resource will impact the system. This may help utilities in developing strategic plans to accommodate increasing penetration of renewable generation/DER while maintaining desired reliability levels. These strategic plans may include system upgrades and new/revised interconnection requirements. The analytical framework of the tool is divided into three main components:

A. Scenario Development Module

To capture all possible bulk system impacts of high penetration of renewable generation/DER, comprehensive input scenarios to represent all possible network conditions should be developed. The hosting capacity tool allows user to input multiple:

- Base power flow cases representing different load levels (peak, off-peak, etc.)
- Generation re-dispatch schemes to accommodate different levels of renewable generation/DER.
- Network conditions representing planned or unplanned outages.
- Locations of potential future renewable generation/DER deployments. In powerflow model, DER is represented as a constant P/Q generator connected through a transformer and a line representing the distribution system's substation transformer and equivalent feeder impedance. And, the transmission-connected large scale renewable generation is represented by a constant P/Q generator connected to point of interconnection (POI) through a transmission transformer, collector system and generator step-up transformer. Again, typical values for the impedances of each component were used.

The scenario development module of the tool automatically develops a case repository of combination of these multiple inputs. For example, with 2 base cases representing peak and off-peak load levels, 10 contingencies and 2 location sets of renewable generation/DER injection nodes, the tool will generate 44 study cases in the process:

- 40 (2x10x2) powerflow cases with contingencies modeled.
- 4 powerflow base cases (system intact) for 2 load levels and 2 specified location sets

B. Analysis Module

In the analysis module, the tool iterates through all the possible combination of developed scenarios and perform powerflow and short circuit analysis using PSS®E and Python interface to evaluate limits of the renewable generation/DER levels. The process is as shown below:

- *Step 1*: Start with a solved powerflow from the study case repository.
- *Step 2*: Define total increment in renewable/DER generation and implement the generation re-dispatch to accommodate increase in penetration level of renewable generation/DER.
- *Step 3*: Calculate short circuit MVA ($S_{c,MVA}$) at the candidate POI buses using PSS®E short circuit module and rank the candidate buses according to their $S_{c,MVA.}$ Allocate the increment among the candidate based on their $S_{c,MVA}$ ranking
- *Step 4*: Check short circuit ratio SCR, defined as $S_{c,MVA}$/MW Injecton, at all candidate buses do not exceed a pre-defined value. A lower value of SCR is an indicator of a weak transmission bus w.r.t short circuit strength and may cause reactive power /voltage control issues.
    - If short circuit ratio at any candidate bus exceeds a pre-defined value, reallocate the excess generation at the constrained buses to other candidate buses in accordance with ranking based on $S_{c,MVA}$
    - If re-allocation is unsuccessful, reduce the renewable generation/DER increment level by the same amount. This sets the max allowable generation level for the case assuming there are no thermal and voltage violations for this penetration level.
- *Step 5* : If SCR is less than the pre-defined short circuit level, check for voltage and thermal violations.
    - If any violation found, set the previous increment level as the maximum hosting capacity for the case.
    - Otherwise go to *Step 2*

Repeat the same process for all powerflow cases and calculate maximum penetration level for each case.

C. Output Module

The output from post-processing of the conducted analysis can be displayed either as plots or in tabular form in the display area of the tool's GUI. In addition, these outputs are exported as .csv files and stored in the case folder for further analysis as needed. The types of output that are exported/can be plotted are:

- Maximum hosting MW for each powerflow case.
- Maximum MW per generation type (Wind/PV/DER) for each powerflow case.
- Transmission line and transformer MVA violation w.r.t. generation level.
- Voltage magnitude (p.u.) w.r.t MW generation level.

III. Case Studies and Results

To check the robustness and applicability of the tool, case studies were performed using two test systems of varying sizes. The main objective of case studies was to obtain the maximum amount of renewable generation/DER that could be added to the system without requirement of any network upgrade.

A. Synthetic Texas System

This 2000 bus test system has been constructed to statistically represent the loading level and steady state behavior of the Electric Reliability Council of Texas (ERCOT) system. It is entirely synthetic and is built from publicly available data and statistical analysis thereby bearing no relation to the actual system and contains no confidential data. The details of this system are publicly available for research purposes at [1,2].

The system, split into 8 areas, has 433 in-service generation sources with a total generation of 69 GW and total load of 67 GW and 19 GVar. Coal, nuclear, natural gas, hydro, wind and solar are the different fuel types that power the sources in this system. The base case network is comprised of 2341 in-service transmission lines and 861 in-service transformers. The additional files required for the analysis are as described below:

- Contingency file: The contingency definitions were created using the *Single contingency ranking (RANK)* functionality in PSS®E. A total of 30 most severe contingencies i.e. 20 most severe contingencies w.r.t to change in branch loadings relative to their ratings and 10 most severe contingencies w.r.t increase in reactive power losses that will have most impact on voltages were included in the contingency definition set.
- Point of Interconnection (POI): To observe the locational impact of renewable generation/DER integration, the POI location sets were defined based on the characteristics of the individual areas. Out of the eight areas, Area 5 (North Central) and Area 7 (Coast) were selected for defining the location sets candidate renewable generation/DER interconnection buses. Both areas were reasonably sized with approximately 450 buses and 600 lines each. Area 5 imports 10 GW while Area 7 imports 850 MVar, both being the maximum between all 8 areas. In each area, transmission level buses were randomly selected as POI and are shown in Table 1.
- Generation re-dispatch: Addition of new generation resources for a given load level implies that existing generation sources will either have to be backed down and/or de-committed. In this paper, it has been assumed that coal fired plants would be the first to be backed down/de-committed and thus, these plants were considered in the generation re-dispatch set. The system has 22 in service coal units with a total generation of 6.57 GW. Three re-dispatch scenarios of different GW levels were constructed as shown in Table 2. The re-dispatch is implemented according to the order and percentage specified in the table.

The analysis was conducted with a 20 MW increment step of renewable generation/DER level, short circuit ratio threshold of 10 and voltage limits of 0.9 p.u. and 1.1p.u. With these inputs, it was found that 80 MW was the maximum renewable generation/DER amount that could be hosted by the system, without requiring any network upgrades while still satisfying all voltage and flow limits for the base case and all 30 contingency cases. Due to the large number of cases considered, it is not possible to plot the results of all cases. However, Fig. 2 shows the bar graph with the maximum penetration MW of some of the contingency cases including the limiting contingency case with a maximum penetration of 80 MW.

Table 1. Point of Interconnection Location Sets

Area 5 Bus No.	Gen Type	Area 7 Bus No.	Gen Type
5026	PV	7027	PV
5028	DER	7085	PV
5054	DER	7131	DER
5079	PV	7173	PV
5083	PV	7181	WIND
5182	DER	7200	PV
5322	PV	7222	DER
5329	WIND	7261	PV
5334	WIND	7291	DER
5351	DER	7319	WIND
5398	WIND	7387	DER
5414	WIND	7390	WIND
5452	WIND	7431	PV
5457	PV		
5460	WIND		

Table 2. Generation Re-dispatch Sets

Bus	Base Case MW	Re-dispatch %		
		Set 1	Set 2	Set 3
8131	641.35	100	10	100
8129	567.6	100	10	100
8130	567.6	100	10	100
4030	535.26	80	80	100
2057	518.4	75	75	100
6110	425.23	10	100	100
4026	410	10	100	100
6078	405.59	10	100	100
6079	405.59	10	100	100
6080	405.59	10	100	100
6111	383.67	30	30	100
5360	302.4	100	25	100
8071	277.47	0	0	100
8088	269.31	0	0	100
7335	136.05	10	10	100
8117	105.51	0	100	100
8155	76.82	0	0	100
4093	28	0	50	100
4094	28	0	50	100
4095	28	0	0	100
4097	28	0	0	100
4091	23.5	0	0	100

In addition to the maximum MW level, the tool also records the total MW level of each of the different type of generation sources specified in the location set. Fig. 3 shows the split of the maximum penetration MW for multiple contingency cases among the different types of sources (blue-wind, red-PV, yellow-DER).

Also, for the limiting contingency case, the MW amount that can be added at each POI bus is extracted as shown in Table 3. For this system, the limiting case was defined by the Area 7 location set for one contingency.

In addition to calculating the maximum levels of renewable generation/DER a transmission region can accommodate, knowledge of the level of violations can provide important information regarding the magnitude of network upgrades that may be required to add more renewable generation/DER.

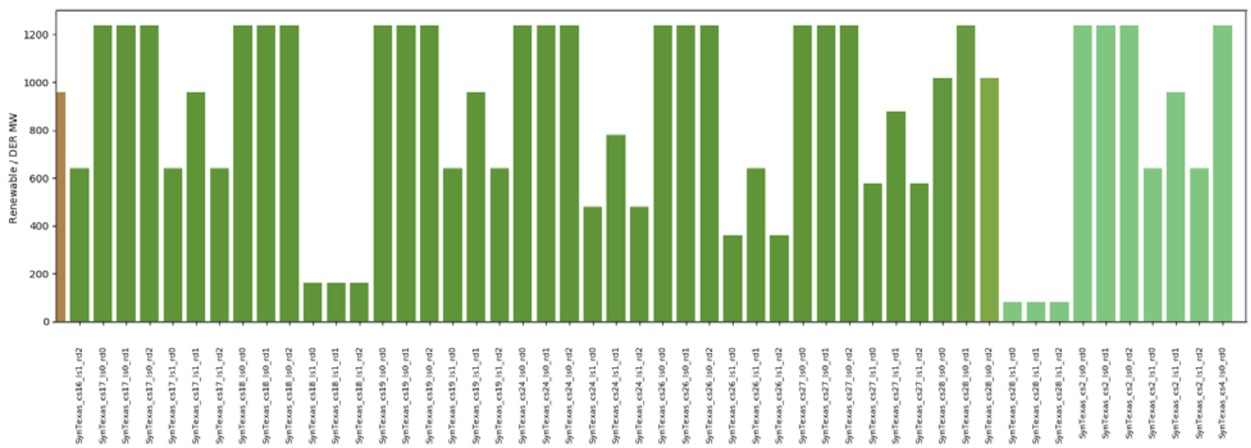

Fig. 2 Maximum Penetration Level across Multiple Contingency Cases

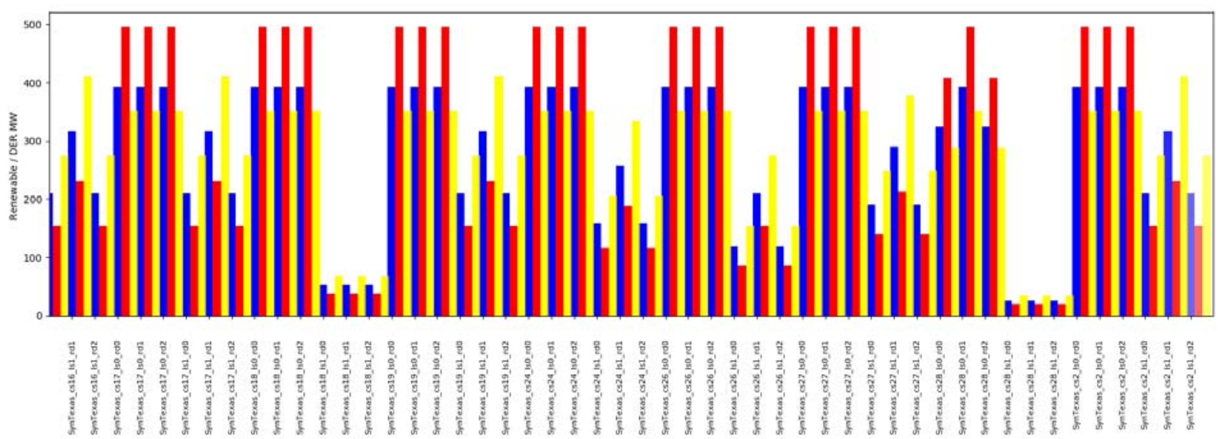

Fig. 3 Maximum Penetration Level Split up by Type of Generation Resource

Figs. 4, 5 and 6 show the delta violations in branch flow, transformer flow and voltage magnitude respectively with respect to total additional MW level of renewable generation/DER for a contingency case. For example, the branch violation plot (Fig. 4) shows that for an additional generation amount of 100 MW (80 MW being the limiting level + 20 MW increment step), a flow violation of around 2.7 MVA occurred. From these three plots, it can be inferred that if a steady state branch flow violation of around 2.7 MVA is mitigated, then the maximum hosting capacity of the system increases from 80 MW to 160 MW (as the next violation occurs as an under-voltage violation for a contingency at 180 MW).

Table 3 Bus-wise Generation Level for Limiting Penetration Level

Bus No	Gen (MW)	Bus No	Gen (MW)
7027	4.3956	7261	2.63736
7085	0.87912	7291	5.27473
7131	11.4286	7319	7.91209
7173	1.75824	7387	7.03297
7181	8.79121	7390	9.67033
7200	6.15385	7431	3.51648
7222	10.5495		

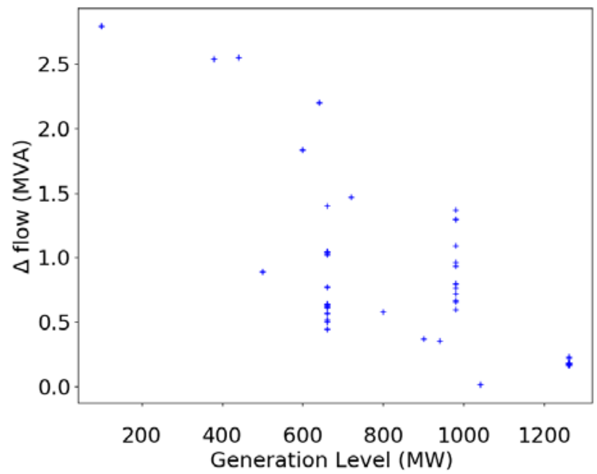

Fig. 4 Branch Flow Violations versus Generation Level

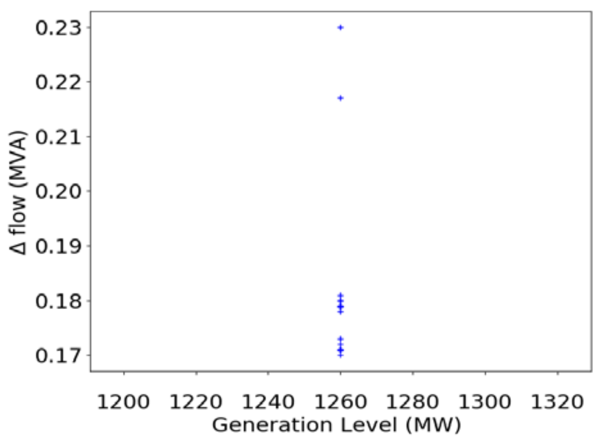

Fig. 5 Transformer Flow Violations versus Generation Level

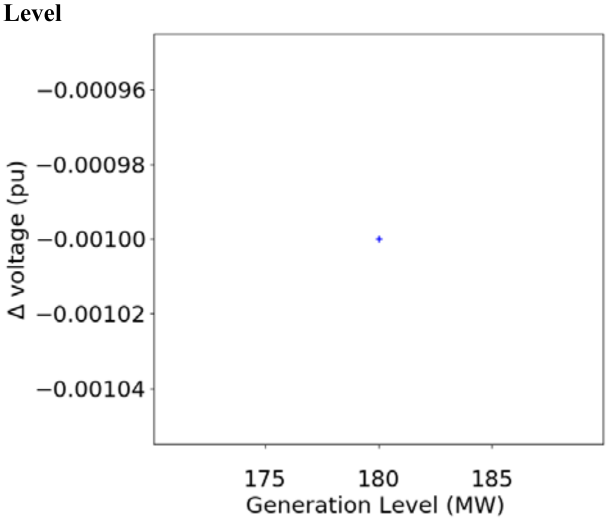

Fig. 6 Bus Voltage Magnitude Violations versus Generation Level

Furthermore, if an under-voltage magnitude violation of 0.001 p.u. can be mitigated, the maximum hosting capacity increases to around 360 MW with the next branch flow violation occurring at 380 MW.

B. Large Real System

The numerical robustness of the tool was also validated using a large interconnected system. The system comprised of approximately 37,500 buses with 3,805 in-service generators with a total generation of around 662 GW and total load of around 652 GW and 200 GVar. The base case network comprised of 38,198 in-service transmission lines, 12,586 in-service two-winding transformers and 504 in-service three-winding transformers. A contingency set with 91 contingency definitions were defined. Three point of interconnection location sets and a single re-dispatch scheme was used.

Due to the size of the system and large re-dispatch value, the hosting capacity analysis was conducted with an increment step size of 100 MW. Some of the sample results of the analysis is shown in Figs. 7 and 8 which shows a hosting capacity amount of 1000 MW was obtained for the system. The tool performed reasonably well for the large system without any convergence or data management issues.

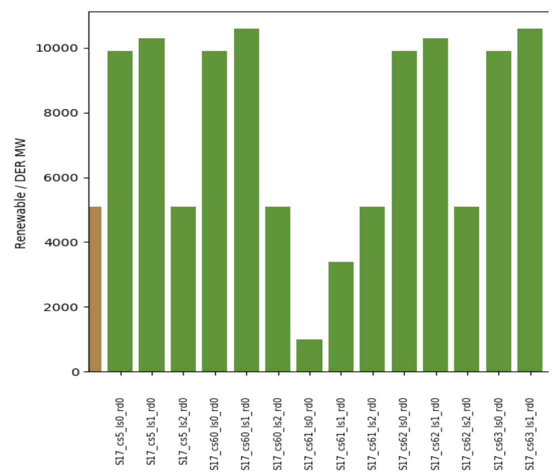

Fig. 7 Maximum Penetration Level across Multiple Cases

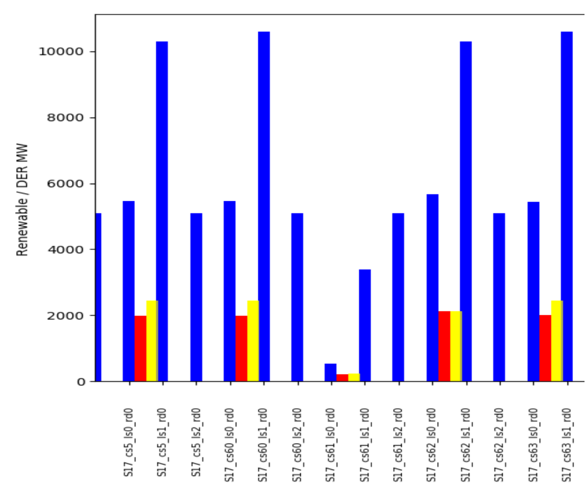

Fig. 8 Maximum Penetration Level Split up by Type of Generation source

IV. CONCLUSION AND FURTHER WORK

The screening tool provides capability to screen through a wide gamut of transmission planning scenarios and identify penetration levels a transmission region can accommodate without any upgrades. In addition, it provides an understanding on how and where these new generation resources could impact steady state performance of the bulk system and when detail impact studies are required to asses any impact in more detail. The case studies, performed so far, showcased robustness and applicability of the developed tool. In future, the tool will be validated and tested across multiple utility systems. In addition, more functionalities and features like including temporal variations of renewable generation output, ability to curtail renewable generation output during certain network conditions and assessment of dynamic performance and limits will be added to the tool as part of this on-going research effort.

V. REFERENCES

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BIOGRAPHICAL INFORMATION

V. Singhvi received the B.E. degree in Electrical Engineering in 2001 from Engineering College, Jodhpur, India and M.S. in Electrical Engineering in 2003 from Mississippi State University. He is currenlty a Technical Leader at Electric Power Research Institute. His current research activities focus on transmission system modeling and simulation. Formerly, he served as a Consultant engineer at Siemens Power Technologies International (PTI).

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