Real-Time Contingency Analysis with Transmission Switching on Real Power System Data

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***Abstract*—Transmission switching (TS) has shown to be an effective power flow control tool. TS can reduce the system cost, improve system reliability, and enhance the management of intermittent renewable resources. This paper addresses the state of the art problem of TS by developing an AC-based real-time contingency analysis (RTCA) package with TS. The package is tested on real power system data, taken from energy management systems of PJM, TVA, and ERCOT. The results show that post-contingency corrective switching is a ready to be implemented transformational technology that provides substantial reliability gains. The computational time and the performance of the developed RTCA package, reported in the paper, are promising.**

***Index Terms*— Power system reliability, power transmission control, real-time contingency analysis, transmission switching.**

I. Introduction

TRANSMISSION switching (TS) has been shown to provide economic benefits [1], improve system reliability [2], and enhance the management of intermittent renewable resources [3]. Given the large economic size of the electric power industry [4], it is crucial to harness the benefits of TS. The USA Department of Energy Advanced Research Projects Agency – Energy (ARPA-E) Green Electricity Network Integration (GENI) initiative has invested over $40M in power flow control technologies, including TS. Although the existing literature has shown various benefits of transmission switching, the implementation of the technology is still very limited. AC feasibility, stability analysis [5], and computational complexity [6], [7] are among the important challenges that need to be addressed before the technology can be commercialized.

An important application of TS is post-contingency corrective switching, which enhances reliability. Corrective switching is an alternative to additional reliability-motivated out-of-market corrections [8]. With corrective switching, expensive generation re-dispatch can be completely avoided at times or partially reduced by TS via power flow control.

This paper is one of the first to address the state of the art challenges of transmission switching by developing a *fast, AC-based* real-time contingency analysis (RTCA) package *with real power system data*. The tool identifies post-contingency corrective TS actions. The results are based on energy management system (EMS) data from PJM, ERCOT, and TVA and the computational time is reasonable and within the standards of the industry. Moreover, *stability analysis* on the corrective switching actions shows that post-contingency corrective switching is a viable, stable corrective action. The results demonstrate that significant savings can be achieved by incorporating TS into RTCA packages.

Section II describes the RTCA tool. The results are presented in Section III. Conclusions are drawn in Section IV.

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II. RTCA Package with TS

Fig. 1 shows the proposed RTCA tool with TS. The RTCA tool takes in a list of critical contingencies to check for potential violations. The tool makes use of an open source AC power flow package [9]. The AC-based RTCA tool iterates through the list of critical contingencies by running an AC power flow for each potential failure. The generation dispatch is adjusted for generator contingencies, based on simple participation factors, to replace the lost generation. The real power dispatch remains unchanged for transmission contingencies, with the slack bus taking up the change in losses. The RTCA assumptions are consistent with the assumptions within standard RTCA commercial packages today. In the case that post-contingency violations exist (e.g., line overloads, voltage violations), a built-in TS algorithm searches for post-contingency corrective switching actions that will either reduce the existing violations or fully eliminate all post-contingency violations. If such a beneficial solution is found, the switching action is reported to the operator. To reduce the computational complexity of TS routine, a priority list is generated that contains 100 potential post-contingency corrective switching actions. This list is created dynamically and includes candidates that are closest to the contingency. This is based on a purely topological distance metric defined as the number of branches in the shortest path connecting the two network elements. It is a common practice to limit the number of switchable lines to reduce the computational time [6]; while doing so does not guarantee a global optimum, it is essential to limit the computational time since this approach is solved in real-time. The heuristic used in this paper, 100 closest lines, is not only very fast and very effective, it is simple to implement making it a prime candidate for industry adoption. The results presented in the next section are very promising and show that even a simple heuristic can result in significant reliability improvements and, thus, significant cost savings.

III. Results

EMS snapshots were taken from PJM, TVA, and ERCOT.

The data statistics are summarized in Table I. The table shows the number of EMS snapshots tested for each system, average active and reactive power, and information regarding the size of the system such as number of buses, branches, and generators. The information is fed into the tool in PSS/E .raw format.

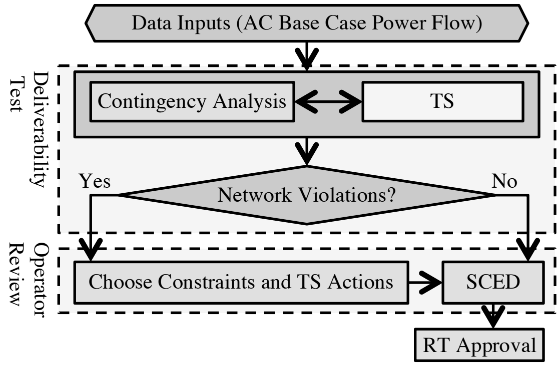

Fig. 1. RTCA package using TS combined with security-constrained economic dispatch (SCED).

Each snapshot represents the actual operational state of the system at a particular moment. For each of the snapshots, all N-1 events (transmission above 69 kV, generators) are checked for post-contingency violations. The events, which would lead to line flow or voltage violations, are identified as “critical contingencies.” These contingencies are sent to the TS routine to check whether TS can reduce the potential post-contingency violations. Table II summarizes the results. The table shows that TS would significantly reduce the number of critical contingencies by fully eliminating all post-contingency violations (while not causing any additional violations under the same contingency). The results also show that even when the post-contingency violations are not fully eliminated, there is still a substantial reduction in the post-contingency violations. In the results presented here, transmission elements with a voltage level lower than 69 kV are ignored. To gauge the performance of the heuristic, complete enumeration is performed on all potential TS actions on the TVA data; such results are minimally different from the results reported in Table II, suggesting that the proposed heuristic is very effective, at least for the TVA system.

TABLE I
DATA STATISTICS

System	EMS Snap-shots	Active Power (GW)	Reactive Power (GVAR)	Buses	Branch	Gen.
PJM	167	139	22	15.5K	20.5K	2.8K
TVA	72	24	4	1.8K	2.3K	350
ERCOT	3	57	8	6.4K	7.8K	700

TABLE II
TS-BASED RTCA RESULTS ON PJM, TVA, AND ERCOT DATA

System	Cont. Simu-lated	Critical Cont.	Reduced # of Critical Cont.	Cases with Violation Reduction	No Benefit from TS
PJM	1.4M	3862	2688 (70%)	1166 (30%)	8 (0.2%)
TVA	126K	4272	427 (10%)	3535 (83%)	310 (7%)
ERCOT	13K	40	4 (10%)	27 (68%)	9 (22%)

The average computational time for the TS-based RTCA tool, for each EMS snapshot, is listed in Table III; with a standard desktop computer, the tool handles the PJM system in 5 minutes. An industry-grade computer with 100 CPUs handles PJM in less than one minute. Therefore, the application of TS in contingency analysis is a real possibility and well within existing computational capabilities.

TABLE III
AVE. COMPUTATIONAL TIME FOR TS-BASED RTCA FOR EACH EMS SNAPSHOT IN MINUTES

	Number of CPUs				
	8	16	32	64	100
PJM	10.3	5.6	3.2	1.8	1.0
TVA	0.6	0.3	0.2	0.1	0.1
ERCOT	0.7	0.4	0.2	0.1	0.1

To confirm the corrective switching actions are stable, dynamic security assessment was performed, similar to existing industry practices and with the use of PSS/E. Dynamic data was provided by PJM.

IV. CONCLUSIONS

This paper presents a short summary on transmission switching. In particular a TS-based RTCA tool has been developed and tested on real EMS data from PJM, TVA, and ERCOT. The results showed that corrective switching can significantly improve system reliability. The number of contingencies, for which there were post-contingency violations, reduced by a factor of 70% for PJM and 10% for TVA and ERCOT. Moreover, TS is able to provide a substantial reduction in the post-contingency violations in the majority of the cases. Substantial cost savings will result from this technology. First, the investment in hardware and the maintenance costs are low since TS relies on existing circuit breakers and, furthermore, TS is also a low-cost software solution. It also enables substantial operational cost savings, which is the primary benefit, by being able to avoid costly generation redispatch by implementing a zero cost corrective switching action. The computational time for the RTCA was less than a minute for a large-scale, actual system test case with a full AC model for a standard desktop computer. In summary, the inclusion of corrective switching in RTCA applications is ripe for industry adoption.

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