21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2017 Grid of the Future Symposium

Dominion's Blackstart Restoration Plan Study

Y. WANG, H.-M. CHOU, R. SUN, M. K. THOMAS
Dominion Energy
USA

SUMMARY

To withstand various system failures and contingencies, the power system is planned and operated in the most reliable manner. However, events caused by human mistake or severe weather conditions may occur and lead to a blackout of the Bulk Electric System (BES). The system operator needs to restore the system and re-establish the integrity of the interconnection in the least amount of time to reduce the huge economic losses. A blackstart is the process of restoring the power system to operation without relying on external transmission networks. Dominion Energy is following the System Restoration Plan (SRP) for restoring bulk electric system facilities. To study the feasibility of the current SRP, steady state analysis and dynamic analysis are performed to check if there exist a feasible equilibrium point and whether the system is able to reach that point. Simulation results validate that all the existing paths in the current SRP are feasible and have no dynamic issues stability issues.

KEYWORDS

Blackstart, steady state analysis, dynamic simulation, RTDS

ywang139@vols.utk.edu

Introduction

Of all the threats that a disaster plan should consider, a blackout is one of the most realistic and the most likely to occur. When a power grid fails, a substantial geographic area can be without power for hours, days, or even weeks, which will have a large impact on the society and draw intense public scrutiny. In 2003, the Northeast blackout left 55 million people in Canada and the U.S. without power; in some cases, blackout lasted for more than 2 days. In 2005, Louisiana and surrounding areas dealt with the aftermath of Hurricane Katrina that left 2.6 million people without power. In 2008, a fire in a substation in Florida caused a cascading failure, which made Miami dysfunctional at that time.

Once a blackout occurs, the system operator is responsible for promptly assessing the situation and responding accordingly with a priority of restoring the system and re-establishing the integrity of the interconnection of the whole system [1]. A prompt restoration procedure that takes the least possible time is needed to avoid huge economic losses. A blackstart is the process of restoring the power system to operation without relying on the external transmission network. Normally, the electric power used within the plant is provided from the station's own generators. If all of the plant's main generators are shut down, station service power is provided by drawing power from the grid through the plant's transmission line. However, during a wide-area outage, off-site power from the grid is not available. In the absence of grid power, a so-called blackstart needs to be performed to bootstrap the power grid into operation [2].

Because the old blackstart units are being retired, new blackstart units are being installed, and the electric transmission system changes, restoration paths need to be updated and validated regularly. However, a blackout study cannot be performed in a real grid. Therefore, computer simulations are used to validate the restoration paths.

To successfully execute the system restoration path requires validating a series of system operations, which relies on the comprehensive understanding of blackstart characteristics. Steady state analysis is the fundamental study. The load flow algebraic equations of the system that is being restored are solved step by step through the restoration procedure to ensure the path is feasible. However, dynamic simulations are needed to check whether after each switching step, the system can reach the new equilibrium point. In this work, Real Time Digital Power System Simulator (RTDS) is used to perform dynamic simulations, because RTDS gives a deeper insight into the system dynamics. The RTDS consists of big number of calculators that work in parallel, in order to numerically simulate a network, virtually built in its software environment. The digital and analog simulated quantities are available by means of software-to-hardware interface systems, based on digital/analog converters. Moreover, voltage and current amplifiers can amplify these quantities in order to reach the correct level to send signals to protection and control devices [3-4]. This type of hardware-in-the-loop simulation can thoroughly and efficiently test embedded devices such as relays in a virtual environment.

This paper studies the feasibility of Dominion's blackstart restoration plan. In section II, the system restoration plan is briefly introduced. Section III presents the steady state analysis in PSS/E. Dynamic simulation results in RTDS are shown in section IV. Section V concludes the existing results and draws attentions to the future work.

Dominion's Blackstart System Restoration Plan

The blackstart strategy that Dominion Energy uses is Core Island Approach, which is also the most common approach. First, units that have the blackstart capability are selected.

Restoration paths are pre-determined followed by NERC standard and PJM manual. The restoration begins with a single path restoration. Power stations, transmission lines, substations and loads are being started individually and gradually being reconnected to each other in order to form an interconnected core island. When couple of core islands are established, system operators can synchronize the core islands when appropriate. Figure 1 shows the formation of a core island and Figure 2 shows the synchronization of multiple core islands.

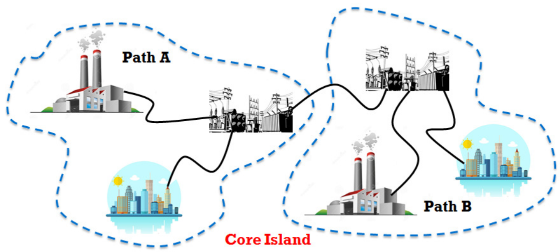

Figure 1. Formation of a core island

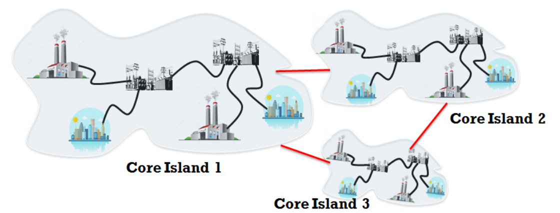

Figure 2. Synchronization of multiple core islands

This approach can develop larger island quicker and provide the system with more stability. As the island grows, it allows for larger block of load restoration and enables the under frequency relays sooner. Compared to the other approaches, it has higher controllability, which takes less time to restore the system.

Figure 3 represents the geographical information of some restoration paths in Dominion's SRP. There are two major paths to start the nuclear power plants. Additional cranking paths are energized to bring back the big power stations. After these paths are energized, three core islands are established. The final synchronization is performed between these three core islands.

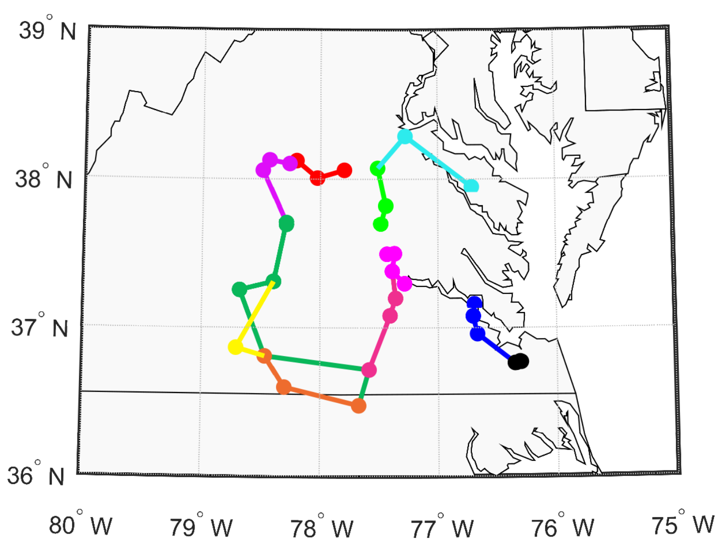

Figure 3. Synchronization of multiple core islands

Steady-state Analysis in PSS/E

The steady state analysis is conducted in PSS/E to check the following problems:

1) Over/under-voltage issue at any system nodes – generator terminal voltage can vary usually from +5% to -5% of nominal value while transmission line voltage should be kept between in 90% - 105% of nominal value.

2) Over/under-voltage may occur when long transmission line is energized and high line charging VAR is injected, incorrect LTC settings for transmission transformers, too much/few loads are energized through the restoration, and so on.

3) Generator operating requirement and reserve satisfaction issue – if there are enough blackstart generation and loads in the path to maintain the stability of the island, as well as meet the operating requirement and reserve requirement of the units.

As an example, power flow results of Path A after the energizing step 1 are shown in Table I and Table II. Table I shows the bus status in restoration Path A. Voltage magnitude and angle are obtained at each step. Also the difference between the voltage magnitude and the nominal voltage (1 p.u.) are calculated to check if there is an over/under voltage issue. Table II shows the machine status in the same path. This table gives the information of the generators restoration sequence and as well as the total power reserve.

Two conclusions can be made after energizing Path A. Firstly, Cranking path A is feasible according to load flow simulation. All voltages are maintained within 1±0.05 p.u. for energized system nodes. Also, system lines and transformers are operated well below their thermal limits. Secondly, the total load/generation in the island is 94.369/144MW. More loads can be picked up after the whole path is fully energized.

The same analysis has been done for all the paths in the SRP. Note that, in some restoration paths, high voltage magnitudes throughout the island are detected due to the energization of the long transmission lines. The high voltage issue is mitigated by adjusting the transformer LTC on that line and energizing loads along the path.

In summary, all of the paths are validated and the steady state analysis results show that the restoration paths are feasible.

Dynamic Analysis in RTDS

Dynamic analysis is performed in RTDS to make sure that the system can reach successfully its new equilibrium point. RTDS simulation provides system level frequency response and dynamic voltage/current response by solving differential equations of the power grid, including the dynamics of transmission line, generator and load model. This dynamic analysis is capable of validating system reliability for: 1) The accuracy of the system models; 2) The frequency response of restoring the blackstart path –the frequency should remain within 59.5 Hz to 60.5 Hz; 3) The voltage response of restoring the blackstart path –the voltage should remain within the same acceptable limits in the steady state.

The system model for one single path in RTDS is converted from PSS/E. For some paths, the excitation system and governor model parameters are modified to make the model more accurate. Figure 4 shows the system diagram of Path B in RSCAD. There are nine breakers in this path and they are closed following the sequence showing in the diagram; the dynamic response is captured during each closing moment of each breaker.

From the dynamic simulation results shown in Figure 5 and 6, several conclusions can be drawn: 1) The frequency is remained within the limits (59.5 Hz to 60.5 Hz); 2) Frequency deviation occurs when the load is brought back into the system and more accurate load switching strategy can be taken to reduce the deviation during the transient state; 3) All voltages are maintained within 1±0.05 p.u. for energized system nodes.

Table I. Bus status in restoration Path A

Bus	Base (kV)	Step 1-2		Step 3-4		Step 5-7	
		Voltage (p.u.)	Angle (deg)	Voltage (p.u.)	Angle (deg)	Voltage (p.u.)	Angle (deg)
1	13.8	1.0087	-51.29	1.0087	-51.29	1.0087	-51.29
2	230	1.0087	-53.53	1.0087	-54.01	1.0087	-54.28
3	230	1.0082	-53.81	1.0082	-54.29	1.0082	-54.56
4	230	1.0075	-53.95	1.0075	-54.43	1.0075	-54.7
5	500	1.0327	-53.95	1.0327	-54.43	1.0327	-54.7
6	230	1.0087	-53.53	1.0086	-54.05	1.0087	-54.32
7	230	1.0087	-53.53	1.0085	-54.07	1.0087	-54.35
8	13.8	1.0047	-53.48	1.0126	-50.67	1.0025	-50.89
9	230	-	-	1.0083	-54.13	1.0087	-54.42
10	230	-	-	1.0071	-54.4	1.0086	-54.73
11	115	-	-	1.0016	-54.19	1.0018	-54.47
12	230	-	-	1.007	-54.43	1.0086	-54.76
13	230	-	-	1.0075	-54.43	1.0105	-54.81
14	230	-	-	-	-	1.0111	-54.84
15	230	-	-	-	-	1.0116	-54.89
16	115	-	-	-	-	1.0048	-54.94
17	230	-	-	-	-	1.0116	-54.89

Table II. Machine status in restoration Path A

Machine	Base (kV)	PMax (MW)	Step 1-2		Step 3-4		Step 5-7		Power Reserve (MW)
			PGen (MW)	QGen (MVAR)	PGen (MW)	QGen (MVAR)	PGen (MW)	QGen (MVAR)	
1	13.8	72	33.214	-0.2089	40.342	-0.0849	44.369	0.011509	27.631
2	13.8	72	0.6	-3.3915	50	3.4845	50	-5.04305	22

Conclusion and Future Works

As a conclusion, Dominion’s current blackstart restoration plan is feasible in both steady state analysis and dynamic analysis. Future work includes automation of the steady state analysis for the next version of SRP and further improvement of the system dynamic parameters using PMU data. In addition, more work can be done for the protection validation and test of synchronization of the multi-islands.

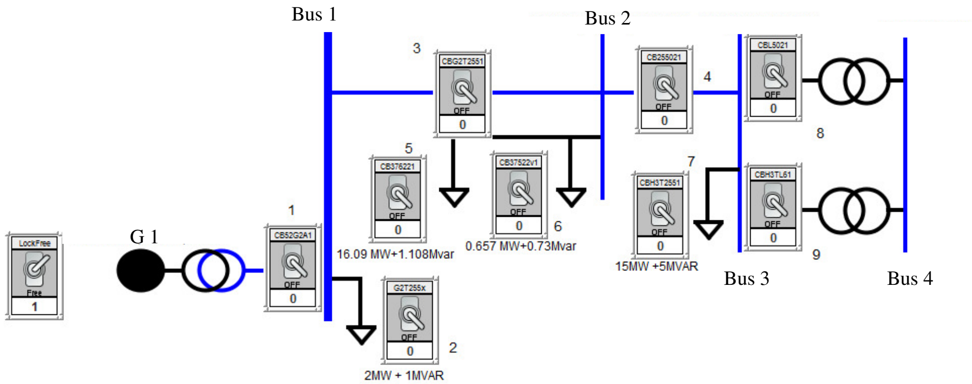

Figure 4. System diagram of Path B in RSCAD

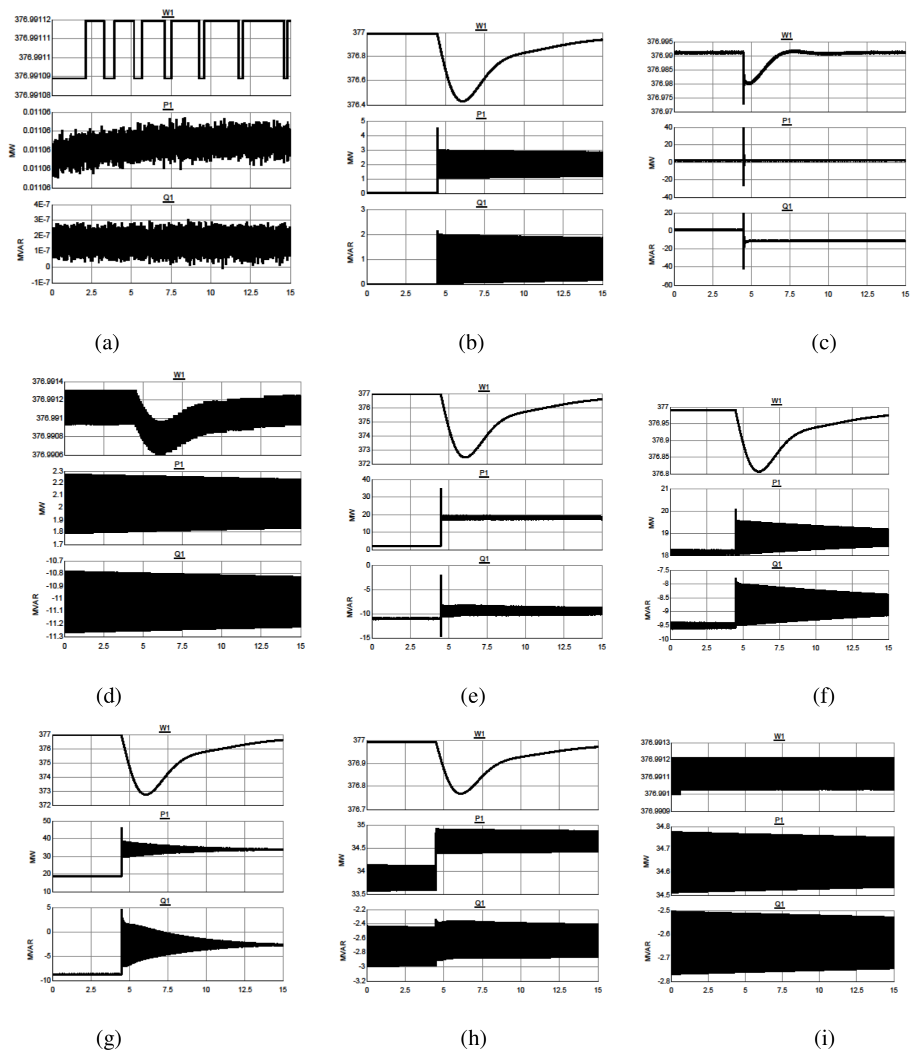

Figure 5. Generator speed, active and reactive power output at each breaker closing moment (a)-(i) for breaker 1-9

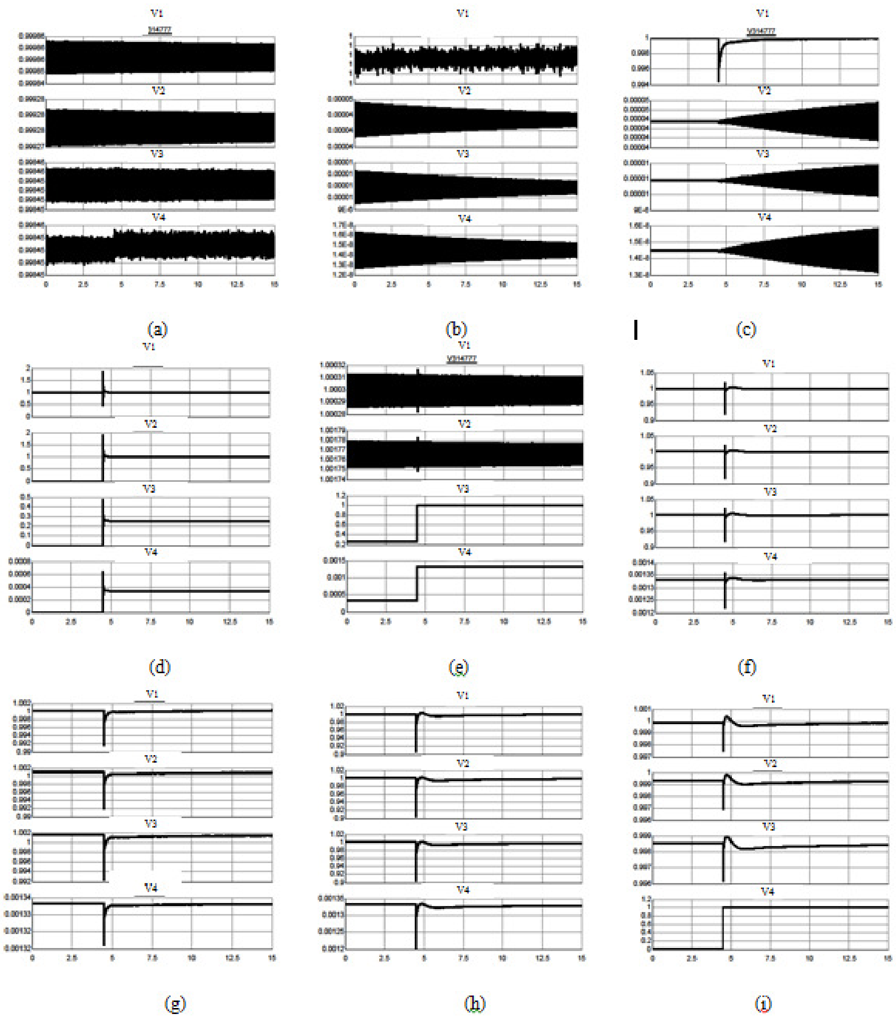

Figure 6. Voltage magnitude of all the buses at each breaker closing moment

(a)-(i) for breaker 1-9

BIBLIOGRAPHY

[1] R. Liu, R. Sun and M. Tania, “Blackstart Hardware-in-the-loop Relay Testing Platform”, CIGRE US National Committee, 2016 Grid of the Future Symposium.

[2] M. M. Adibi and N. Martins, "Power system restoration dynamics issues," 2008 IEEE Power and Energy Society General Meeting, Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh, PA, 2008, pp. 1-8.

[3] C. Noce, S. Riva, G. Sapienza and M. Brenna, "Electrical energy storage in Smart Grid: Black-start study using a real-time digital simulator," 2012 3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aalborg, 2012, pp. 216-220.

[4] M. Henderson, E. Rappold, J. Feltes, C. Grande-Moran, D. Durbak and O. Bileya, “Addressing restoration issues for the ISO New England system,” 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, 2012, pp. 1-5.