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Blackstart Studies for Future Scenarios

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SUMMARY

To avoid the costly damage from blackouts, system operators rely on restoration plans to reduce restoration time. System restoration plans include guidelines for restoring the grid from a total blackout scenario. Restoration plans are switching orders to crank the next generators and pick up critical loads. Dominion Energy faces two challenges with their restoration plan. The first challenge is due to generation retirement that affects the predefined restoration paths. The other challenge is the increasing level of penetration of renewable energy generation. To help Dominion Energy deal with these challenges, software tools are used to determine the feasibility and stability of new restoration paths such as PSS/e and RTDS. Additional restoration support tools available to Dominion Energy are being evaluated such as EPRI's System Restoration Navigator (SRN) and Optimal Blackstart Capability (OBC) software. With these tools, analysing and building new restoration paths due to generation retirement or higher penetration of renewable energy is made easier. This paper will focus on the challenges Dominion Energy faces, the algorithm of EPRI's System Restoration Navigator, and the impact of solar generation on blackstart restoration.

KEYWORDS

Blackstart, Renewable Energy, Solar, Voltage Stability, PSS/e, EPRI System Restoration Navigator.

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I. PROJECT BACKGROUND

a. Need for Restoration Plans

Society relies on electricity to move about daily life such as for transportation, entertainment, heating and cooling homes, and even cooking and storing food. Because so many livelihoods depend on a properly working grid, a blackout is costly to everyone. If the blackout is severe enough such that the entire grid has shut off, utilities must blackstart the grid. The blackstart process is non-trivial since many generation units require external sources to be started and then it becomes a tightrope walk with balancing the system frequency and voltage. When any blackout occurs, the utilities' main goal is to restore power quickly and efficiently. The longer the timeframe for a blackout, the more difficult it becomes to restore power because system load can increase to as much as double the normal loading conditions [1]. Residential motor loads such as air conditioners and refrigerators will lose their diversity during cold load pickup. With higher loading than typical, the system will be further stressed and require a longer time to restore power, thus increasing the cost of the blackout. Planning ahead for these scenarios can give additional guidance to complement an operator's experience during a restoration effort to minimize the overall time.

b. Dominion Energy System Restoration Plan

To restore the system from a partial blackout, generators can be cranked by an external source. However, during a complete blackout, help from other portions of the grid does not exist and the generator must 'crank itself'. To overcome this issue, designated small-scale generation that can be cranked without external power from the grid are used and must be able to provide enough power to crank a larger generator and some small portion of the grid. These self-cranking generating units are known as blackstart units. At the blackstart units' disposal is some type of fuel source to provide the energy required to start. Although a blackstart scenario has never occurred in the mainland United States of America, utilities are required to plan and prepare for a worst-case scenario to reduce the possible catastrophic consequences. There are different methods for restoration such as top-down and bottom-up approaches. Top-down approach involves restoring the grid with assistance from the nearby energized grid, but this is not possible during a blackstart. Bottom-up approach is the process that builds multiple islands in lower voltage level and then synchronizes the stable islands to form a larger grid.

Dominion Energy has system restoration plans that are primarily concerned with supplying power to auxiliary load at nuclear stations, servicing critical load substations, energizing the transmission system, and minimizing restoration time to the bulk power system (BPS). The System Restoration Plan (SRP) details paths that have been deemed feasible to perform a blackstart. To determine the blackstart cranking paths, several decision support tools are available for Dominion Energy such as static load flow and dynamic stability assessment with PSS/e and real time simulations with RTDS. To optimize the cranking paths, System Restoration Navigator (SRN) and Optimal Blackstart Capability (OBC) from Electric Power Research Institute (EPRI) are used [3].

c. Challenges for Future Blackstart Plans

Several generators inside of the Dominion system have been announced for retirement. These retirements pose several challenges to the current restoration plan. Many of these retired generators are located on 115 kV and 230 kV transmission line systems. Thus, generators located at even higher voltage levels (500 kV) need to be considered for future restoration plans. A weak grid with limited generation online such as during restoration, energizing 500 kV lines is very challenging due to overvoltage issues caused by the charging reactance of the transmission line. On the other hand, under voltage may occur during load pickup, especially on the 115 kV and 230 kV lines where blackstart units are located. Therefore, reactive power support using static reactors or STATCOM would be necessary to avoid overvoltage during line energization and under voltage during load pickups.

Another challenge for blackstart is related to the increasing penetration level of renewable energy, especially for solar power. Solar power is an unconventional generation type due to its uncertainty from cloud cover and lack of controllability. Communication is also a serious concern for controllability of PV and a requirement if PV is to be used during restoration. Currently, at Dominion Energy, PV and other distributed generation is kept offline during restoration and must not be allowed to reconnect to avoid accidentally tripping back off and possibly causing another collapse. However, due to ever increasing penetration of renewable energy, the grid may see drastic changes in the composition of generation types, favourable to renewables. In the U.S., many states have aggressive requirements such as Hawaii, California, New York, and New Jersey of 50% renewable energy penetration by the year 2030. Dominion Energy has set forth a plan that will enhance their solar energy fleet to a total of 4.7 GW of generation by 2033 [2]. In the future, load may be primarily serviced by renewable generation and with increased availability on the grid, renewables cannot simply be tripped off; they may even have usage in future blackstart plans.

II. SYSTEM RESTORATION NAVIGATOR

Dominion Energy is committed to continuously updating the SRP for any changes and acquiring tools to help this process. EPRI's SRN software will be a valuable resource that can be used for planning future blackstart paths as well as aiding operational duties during restoration. Previously, operators have relied on experience to make decisions for next-step restoration actions; EPRI's SRN would be able to provide additional guidance to go along with operator's experience during restoration.

Factors such as reactive power management, generator limits, voltage limits, line charging currents, and generator ramping limits are considered when determining restoration paths. The main objective during restoration is to minimize the time to restore, which is primarily affected by the time to energize lines, crank generators, and adjust generator outputs. EPRI's SRN has the capability of considering the multitude of constraints and finding an optimized path with reduced restoration time for a partial or complete blackout.

EPRI's SRN subdivides the restoration effort into two dependent processes shown in Figure 1. The primary problem determines which component can be energized nearby and the transmission path to the component [3]. The secondary problem determines generator output and the feasibility for load pickup while satisfying operational constraints [3]. After the blackstart unit has been energized, a neighbouring set of generators and critical load is created during the primary problem. Based on this set, a decision tree is constructed taking into account the secondary problem constraints. This tree is then used to identify the sequence of generating units or critical load. SRN then uses a modified Dijkstra algorithm to search for the shortest path to the component. In the secondary problem, if a generator or critical load is not feasible to pick up due to voltage limit violations or generator limits reached or if dispatchable load pickup cannot balance the system, another path is attempted. If all paths to the component are exhausted, the primary problem algorithm will choose another unit in the set and repeat the process. The Dijkstra algorithm uses line charging currents as a distance parameter to calculate the shortest path to the target. The secondary problem uses optimal power flow (OPF) algorithm whose objective function is minimizing the adjustments of generator outputs to help reduce the restoration time.

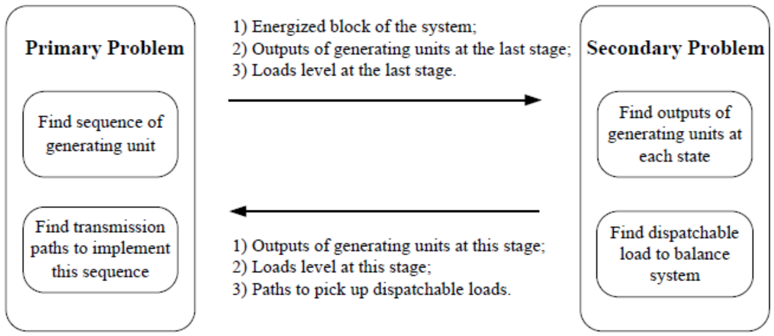


Figure 1. Overview of SRN task subdivision [3]

III. IMPACT OF PV ON RESTORATION

The main concerns with PV generation are the output variability and reduced system inertia. With higher penetrations of renewable energy, system inertia will decrease which impacts the reliability and stability of the grid. With less inertia, H, any change in power consumption or generation will cause large frequency deviations shown in equation (1).

$$\Delta f = \frac{\Delta P}{H} \tag{1}$$

These frequency fluctuations may activate relays for PV generation which could be detrimental to the restoration process. If PV were to trip offline, this could lead to restoration path collapse and forcing a restart. Moreover, blackstart units may not have enough fuel needed to perform a restart, thus leading to longer restoration times.

PSS/e provides the ability to dynamically model PV generation with varying solar irradiance. The generic, dynamic PV model provided in PSS/e documentation is used to simulate a large-scale PV plant of 50 MW capacity. The block diagram of the modules is shown in Figure 2. IRRAD, PANEL, PVGU, PVEU are the model components used for dynamic simulation. The irradiance module has ten parameter sets that specify time and irradiance level in W/m^2. Panel module linearizes the irradiance and the user specifies the available DC power of the panel based on a per unit max at 1000 W/m^2. The user has control of 5 irradiance levels and the available DC power for each level. The controller for the PV plant is shown in Figure 3 and is identical to the WT4E controller. The active power injected to the grid from the converter control depends on the power reference given by the PANEL module. The reactive power command can have several schemes to follow such as voltage reference, power factor angle reference, or reactive power reference [4].

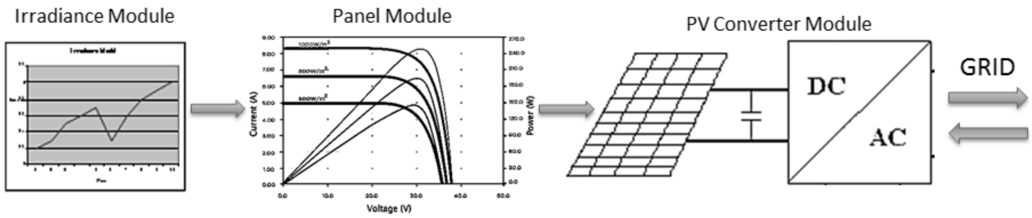


Figure 2. PSS/e generic PV model diagram

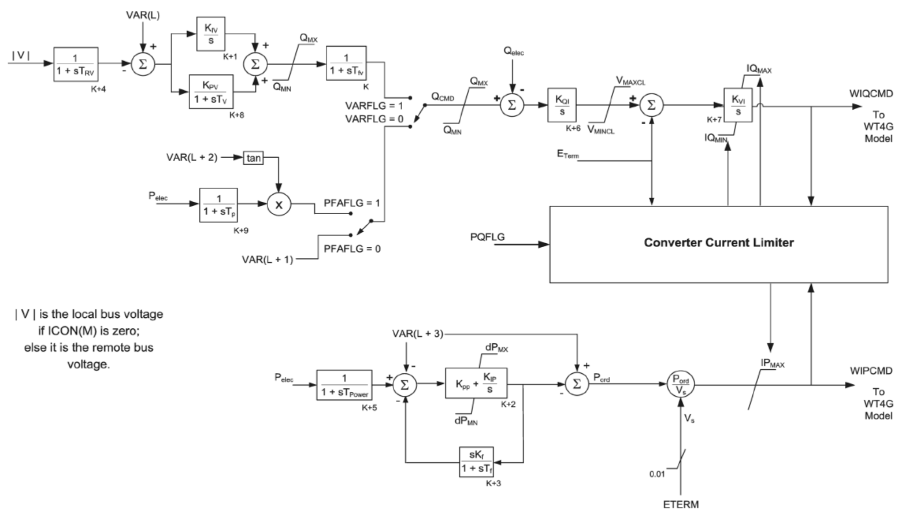
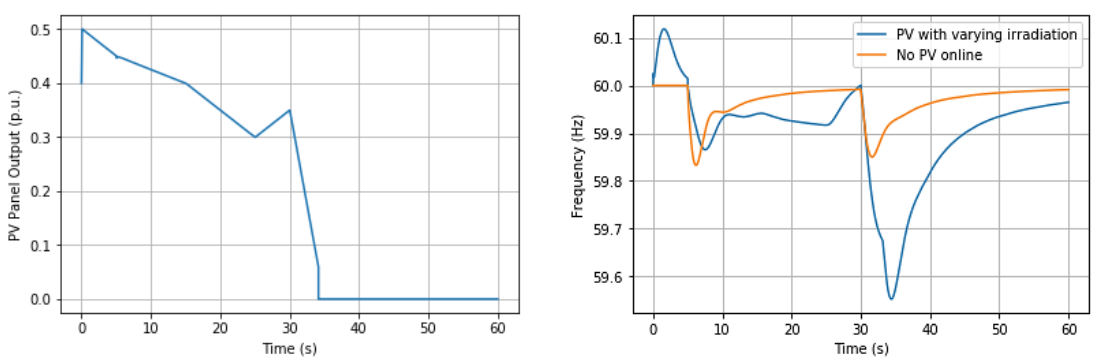


Figure 3. Electrical control diagram of PVEU

To study the impact of PV on restoration, a dynamic simulation is performed to view the stability of the system for a 10 MW load pickup and a 500 kV line energization. The detrimental effects of varying irradiation are shown below. In Figure 4(a), the active power output of the PV panel is shown as it varies with time. Figure 4(b) shows the frequency fluctuations due to energizing a line at 5 seconds and picking up load at 30 seconds; the figure also shows the frequency of the system when no PV generation is online. At 34 seconds, the system frequency gets so low that the PV generation is tripped offline and remains off throughout the simulation. Furthermore, after the PV has been disconnected, the frequency continues to decay until the blackstart unit is able to respond. If the frequency decayed this far during a restoration event, it is likely that the blackstart unit would trip off as well, causing the entire path to collapse. Without any PV online, the frequency is stable and can recover near to pre-disturbance value.



(a) PV active power generation

(b) Frequency fluctuation of load pickup and line energization

Figure 4. Impact of varying irradiance on frequency

Because of the detrimental impact of PV on a weak grid, Dominion Energy keeps all PV generation offline during any restoration events. At the distribution level, this is done through use of the transfer trip signal from substations. Transmission level PV plants are disconnected with circuit breakers controlled by the system operators.

An additional issue is the communication required for PV generation on both system levels. After PV has been disconnected, communication lines must be functional to ensure they remain offline and do not reconnect. This is an ongoing effort in Dominion for managing PV in restoration paths.

IV. DISCUSSION OF FUTURE PV FOR RESTORATION

Since renewable energy penetration is predicted to increase in the future, PV may become a prominent energy source on the grid. Thus tripping PV offline during restoration may not be feasible. Moreover, PV can be used to support the restoration process by providing grid support. For PV to provide grid support during restoration, advanced control scheme needs to be adapted.

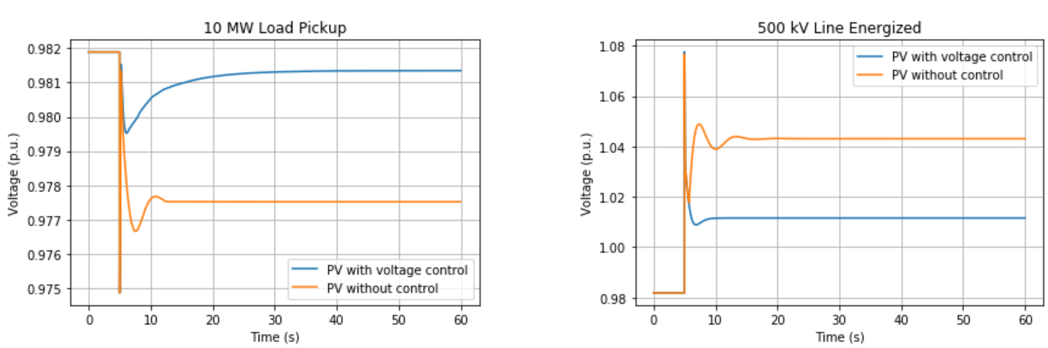
a. PV Generation to Provide Voltage Support

Studies have shed light on the capability of PV to provide reactive power support from its inverter DC/AC capacity. The amount of available reactive power a PV inverter can supply is based on equation (2).

$$Q = \sqrt{S^2 - P^2} \tag{2}$$

Where P is the dc power from the PV panel and S is the maximum power the inverter can supply. If the dc power is reduced to zero, the inverter can supply the maximum amount of reactive power. This means that PV plants can provide voltage support to the grid, even if no irradiation is present such as during night time. This control scheme is commonly referred to as ‘PV at night’ where PV acts as a static compensator [6].

In Figure 5, two events are considered and their voltage is shown. As can be seen in Figure 5(a), when PV provides voltage support through Q injection, the low voltage is mitigated during a load pickup event. Similarly in Figure 5(b), PV generation is absorbing Q to bring down the high voltage encountered during energizing of a 500 kV transmission line.



(a) PV mitigating under voltage (b) PV mitigating overvoltage

Figure 5. PV as STATCOM

b. PV to Assist Frequency Regulation

Battery storage used with PV is a popular method to provide frequency support. The battery will charge during periods of excess generation on the grid and discharge during high demand. PV panels will still operate at their maximum power but the battery will help to reduce some of the variability. However, batteries need to be sized properly and are usually very large thus making them a costly solution. Dominion Energy is currently exploring projects to install battery storage at substations to reduce the backflow from PV generation at the distribution level.

There is also a method for PV to assist with frequency regulation without the use of a battery. This method curtails the power output of the PV panel to provide some specified amount of reserve shown in Figure 6 [5]. This is achieved by adjusting the DC capacitor voltage between the PV panel and inverter. The downside is 'free' energy will be unused which is unattractive for the investment of PV. Furthermore, this method will not solve the variability issue of PV since the amount of reserve will vary with the maximum power available.

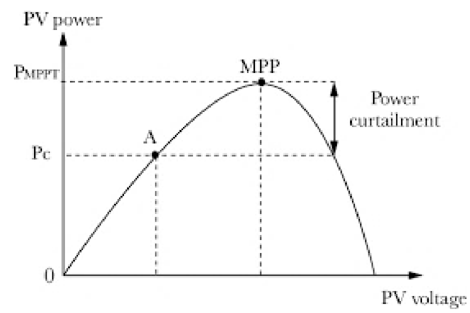


Figure 6. Active power curtailment of PV panel

Although both methods have drawbacks, a hybrid solution of both methods can help to not only reduce the cost and size of a battery, but also mitigate the variability of PV generation while providing frequency support services.

V. Conclusion

Dominion Energy recognizes the critical importance of studying the various impacts to blackstart. These studies help prepare for not only future impacts on blackstart such as higher renewable penetration, but also for current challenges such as generation retirement. Because of the difficulty with maintaining voltage stability, utilities do not consider reaching 500 kV transmission lines during early stages of restoration. However, because of the generators being retired, Dominion Energy is preparing for and studying the impacts of such a scenario. These are just a few examples of Dominion Energy's commitment to providing a safe and reliable electric grid and preparing for a worst-case scenario.

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