Black Start Feasibility Study Under Grid-Forming, Inverter-based Photovoltaic (PV) Resources

Today's black starts in the U.S. are almost exclusively carried out by synchronous machine-based conventional generators, such as gas turbines and hydropower plants. In recent years with the energy share of traditional generation assets shrinking, the penetration level of renewable energy resources (such as wind farms and PV plants) in modern transmission grids has significantly increased. Due to valuable characteristics of inverter-based resources (IBRs) in the black start process, such as flexible power output range and fast ramping rate, large-scale IBRs' black start capability has drawn a considerable amount of interest in both academia and industry.

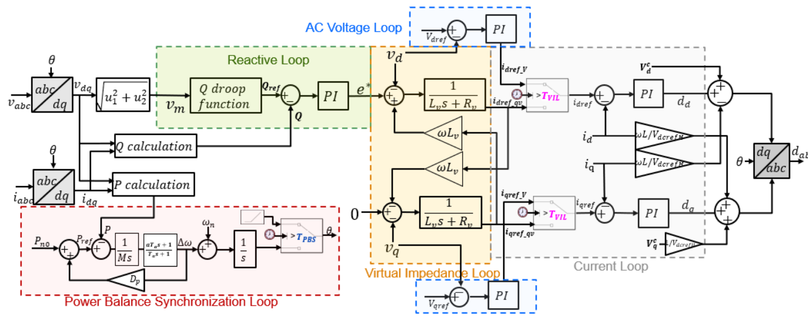

Fig. 1. Proposed grid-forming inverter control scheme

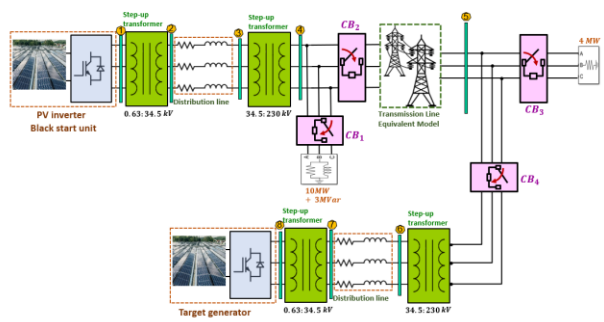

Fig.2. PV generation-interfaced 8-bus black start testbed

This paper focuses on black start studies of the transmission system interfaced PV inverter. The black start feasibility of PV inverters is investigated and compared under three IBR control schemes: the generic PV control developed by the Western Electricity Coordinating Council (WECC) renewable energy modeling task force, the inverter-mode voltage regulation control, and the grid-forming control. An IEEE 2800 compliant grid-forming inverter (GFI) control was proposed for operating inverter-based PV plants as black start units, the control diagram of which is shown in Fig. 1. Compared to the other two black start inverter control strategies mentioned above, the proposed control scheme shows eminent advantages: 1) it is applicable to handle large black start transients, such as transmission line energizations and load pick-ups; 2) it can be simulated with excellent fidelity of inverter dynamic behaviors; and 3) it features grid-side frequency and voltage regulation functionalities, which enhance the system stability in the power restoration process. The 8-bus, PV-interfaced black start testbed shown in Fig.2 is implemented in the PSCAD platform for black start case studies, and simulation results are provided for verification purposes.

A series of steady-state changes caused by black start switching actions may result in generation load imbalance, aggravating the stability of the system's frequency and voltage. Small-signal instabilities are likely to appear, especially in the initial state of the black start, where no other generators have been activated and the grid condition is very weak. The small-signal stability of GFI interconnected with passive loads was assessed using the DQ-frame impedance-based method. The critical nature of the current controller and virtual impedance loops was asserted to show how it can effect the stability of the start-up process. The use of a large virtual impedance was shown to be preferable.