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A New Smart Inverter For Voltage Control In Distribution Systems For Various Approaches By Using PV-Statcom

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Abstract

Flexible AC transmission system (FACTS) controllers are being increasingly considered to increase the available power transfer limits/capacity (ATC) of existing transmission lines, globally. New research has been reported on the nighttime usage of a photovoltaic (PV) solar farm (when it is normally dormant) where a PV solar farm is utilized as a STATCOM–a FACTS controller, for performing voltage control, thereby improving system performance and increasing grid connectivity of neighboring wind farms. New voltage control has also been proposed on a PV solar farm to act as a STATCOM for improving the power transmission capacity. Although, voltage-control functionality with PV systems have been proposed, none have utilized the PV system for power transfer limit improvement. A full converter-based wind turbine generator has recently been provided with FACTS capabilities for improved response during faults and fault ride through capabilities.

Keywords: Smart Inverter, Voltage Control, PV-Statcom, Controller.

1. Introduction

1.1 Preamble

In recent years there has been a growing interest in moving away from large centralized power generation toward distributed energy resources. Solar energy generation presents several benefits for use as a distributed energy resource, especially as a peaking power source.

Utilities are presently facing a major challenge of connecting renewable energy based Distributed Generators (DGs) while ensuring stability, voltage regulation and power quality. During the night time, feeder loads are usually much lower compared to daytime, while the Wind Farms (WFs) produce more power due to increased wind speeds. This potentially causes reverse power to flow from the Point of Common Coupling (PCC) toward the main grid resulting in feeder voltages to rise above allowable limits, typically ±5%. To allow further DG connections, utilities need to install expensive voltage regulating devices (e.g., Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), voltage regulators, etc.). Voltage-source inverters are essential components of PV Solar Farms (SFs), which provide solar power conversion during day time.

With the present growth rate of energy consumption the world's energy consumption is doubling every 10 years, which will lead to the depletion of the fossil fuel supply in a few hundred years. This will lead to the necessity to begin relying on other forms of energy in the near future. Recently there has been a growing interest in expanding electric generating capacities through the use of Distributed Energy Generation (DEG). DEG consists of placing small (up to tens of megawatts) generation assets around communities and industrial facilities at the distribution level. These generation assets include natural gas micro-turbines, fuel cells, wind and solar energy sources. DEG offers many advantages to the generation companies and customers alike. The generation company will benefit by not having to sink large sums of capital into a generation facility that will not produce any return on investment for several years. Another advantage to the utility company is the reduced load on the Transmission & Distribution (T&D) network. By moving the energy source closer to the end user, losses in T&D lines are reduced. All of the benefits above can be passed on to the end user in the form of lower utility costs. Another benefit to the user would be improved power quality and reliability.

PV generation provides a good solution for DEG. PV systems provide the highest power level in the middle of the day, which coincides with the peak power requirements on the utility grid, especially during the summer. Even though PV systems are intermittent resources due to their reliance on the sun shining, the times when the energy available from the sun is at its highest corresponds to the highest demands on the utility grid. This correlation makes PV generation highly suitable as a peaking source.

The motivation for the development of PV based STATCOM is to enhance the stability of the system as well as to make maximal use of available resources within power grids with increased renewable penetration. For maximal use of available resources within the grid, the existing solar farm in the grid is utilized as PV based STATCOM and it can be used for enhancing the stability of the distributed generation system in which it is connected.

The research work reported in this thesis is focused on the utilization of an existing solar farm asset both during night and day time to improve voltage stability, Fault tolerance and harmonic suppression, which would have otherwise required expensive additional equipment such as, series/shunt capacitors, or separate Flexible AC Transmission System (FACTS) devices.

2. Modeling of PV Cell

PV cell is very similar to that of the classical diode with a PN junction. In figure 3.2 when the junction absorbs light, the energy of absorbed photons is transferred to the electron–proton system of the material, creating charge carriers that are separated at the junction. The charge carriers may be electron–ion pairs in a liquid electrolyte or electron–hole pairs in a solid semiconducting material. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field and circulate as current through an external circuit. The square of the current multiplied by the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the cell and dissipates into the surroundings.

3. Voltage Stability Analysis

Voltage stability is concerned with the ability of the power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

4. Steps In Designing a PV System

Calculate the Electrical Load Analyzing the uses of energy in a home in three categories (thermal or heat energy, electrical energy, and refrigeration), conservation opportunities can then be isolated in each category that influence general electrical utilization.

Thermal energy requirement for heating living spaces, water, and cooking Non-electrical energies are solar, gas, wood, and others. Electric space heating, water heating, and cooking require an enormous amount of electricity. It is not useful to utilize photovoltaic's to make power for these reasons. Solar energy can be utilized in other forms such as passive and active solar space heating and solar water heating more efficiently. Gas can also be used for the thermal loads more economically and productively than electricity.

Electrical loads (lighting, appliance and equipment operation) Exceptionally energy efficient lighting products are readily available and the energy effectiveness of apparatuses can be effortlessly looked at for the best decisions. Best application for PVs is in this category.

Refrigeration for air conditioning and food preservation Huge measures of electrical energy consumed makes PV power very costly for these tasks. Gas powered air conditioning is accessible as an option. For food preservation, there are gas refrigerators and two manufacturers of very high efficiency electrical refrigerators and freezers. Wattage is typically recorded on the appliance. If not, multiply the voltage times the amperage to obtain wattage. See the marks for the appliance/equipment to get this information.

Steps:

1. List the appliances, lighting, and equipment that will be worked.
2. Mark the appliances that will work on DC
3. Enter the amount of appliances, evaluated hours of daily use, and their respective wattage.
4. Multiply the amount times the hours of day by day utilization times the wattage and go into the Total Daily Watt Hours Used segment for every apparatus. For every apparatus that is not DC, duplicate the Total Daily Watt Hours Used sum by 1.1 and enter that sum in the section.
5. Add the Total Daily Watt Hours Used to get an aggregate Daily Energy Use. If batteries are used to store the PV generated power, multiply the ―Daily Energy Use‖ total by 1.25 to account for battery inefficiencies. The last aggregate is the measure of force that PVs need to give to finish operation of the recorded apparatuses for one day.

5. Conclusion

This paper presents a novel autonomous smart PV inverter control as STATCOM, termed PV-STATCOM, for voltage control. The smart inverters being presently proposed in literature have the limitation of available reactive power for voltage control during high solar power output. They are unable to provide voltage control during large dips in grid voltage due to large disturbances occurring around noon hours. Moreover, their response time under volt/var control is in the range of 1-2 sec. The proposed smart inverter PV-STATCOM overcomes both these limitations. It operates as a STATCOM with full inverter capacity in nighttime as well as during any time of the day to provide critical grid support. During a large system disturbance during daytime, it discontinues its real power generation function for a short period, typically a few seconds, and releases its entire inverter capacity for STATCOM operation. It returns to normal pre-disturbance power production as soon as the need for grid support is fulfilled. The response of the proposed smart inverter (1-2 cycles) matches that of an actual STATCOM. The performance of different modes of operation of a 10 kVA PV-STATCOM, during night and day, through both EMTDC/PSCAD software based simulation studies and Laboratory implementation are demonstrated. The Low Voltage Ride Through (LVRT) performance of the proposed smart inverter PV-STATCOM is investigated through both EMTDC/PSCAD simulation and laboratory implementation studies using d SPACE control. The LVRT tests clearly demonstrate that the proposed smart inverter PV-STATCOM not only meets the LVRT requirement of the Draft IEEE P1547 Standard, but surpasses it by providing dynamic reactive power compensation as STATCOM and successfully regulating the PCC voltage to within the utility acceptable range during the LVRT period.

The LVRT tests further demonstrate that the PV-STATCOM control system continues to remain stable despite transitioning between widely different operating modes. The stability of the PV-STATCOM is ensured by appropriate design of the various PI controllers within the control system to have sufficient gain and phase margins. In addition, during the Full PV-STATCOM mode, the voltage across the solar panels is made slightly less than the open circuit voltage of the solar panels instead of exceeding it. This paper thus presents a novel concept of utilizing a PV solar farm as a STATCOM on a 24/7 basis, for supporting the grid as needed. Such applications will of course require grid code approvals and appropriate agreements amongst the different stakeholders, i.e., the solar farm owner, inverter manufacturer, the interconnecting utility and system operator. This PV-STATCOM function also opens up a potential revenue making opportunity for the PV solar farm by providing similar grid support functions at critical times as an actual STATCOM in a given application. This lab validated PV-STATCOM has been successfully installed and demonstrated in the utility network of Blue water Power Distribution Corporation, Sarnia, Ontario, Canada, in December 2016. This demonstration was performed for the first time in North America, the results of which will be described in a subsequent paper.

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