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High-Frequency-Link Based Grid-Tied PV System with Small Dc-Link Capacitor and Low-Frequency Ripple-Free Maximum Power Point Tracking

M.Suganya[1], C.N. Chinnasamy M.E.[2],

M.E. Power Systems Engineering, Department of Electrical and Electronics Engineering, Mother Terasa College of Engineering and Technology, Mettusalai, Illuppur, Pudukkottai (dt), Tamil Nadu, India.

Assistant Professor, Department of Electrical and Electronics Engineering, Mother Terasa College of Engineering and Technology, Mettusalai, Illuppur, Pudukkottai (dt), Tamil Nadu, India.

ABSTRACT: This system proposes a grid-tied photovoltaic (PV) system consisting of modular current-fed dual-active-bridge (CF-DAB) dc-dc converter with cascaded multilevel inverter (CMI). The proposed converter allows a small dc-link capacitor in 3-phase wye-connected PV system; therefore, the system reliability can be improved by replacing electrolytic capacitors with film capacitors. The low-frequency ripple-free maximum power point tracking (MPPT) is also realized in the proposed converter. First of all, to minimize the influence resulting from reduced capacitance, a dc-link voltage synchronizing control is developed. Then, a detailed design of power mitigation control based on CF-DAB dynamic model is presented to prevent the large low-frequency voltage variation propagating from the dc-link to PV side. Finally, a novel variable step-size MPPT algorithm is proposed to ensure not only high MPPT efficiency, but also fast maximum power extraction under rapid irradiation change. A downscaled 5-kW PV converter module with small dc-link capacitor was built in the laboratory with the proposed control and MPPT algorithm, and experimental results are given to validate the converter performance.

KEYWORDS: Current-fed dual-active-bridge, small dc-link capacitor, low-frequency ripple, MPPT, high-frequency-link.

I. INTRODUCTION

With the global environmental pollution and energy crisis, distributed power generation system (DPGS) based on renewable energy, such as photovoltaic (PV) and wind power generation (WPG), is playing a more and more important role in energy production. However, the output power of PV and WPG are usually strongly fluctuant due to the randomness and intermittence of solar and wind energy, which requires a large capacity of energy storage to satisfy the load demand when the system works in stand-alone mode, and results in a strong impact on the utility grid when the system works in grid-connected mode. This problem can be partially overcome by utilizing the hybrid wind-solar power system thanks to the complementary characteristics of wind and solar energy. A reasonable size of PV/WPG/battery can not only improve the power supply reliability, but also reduce the cost of the system.

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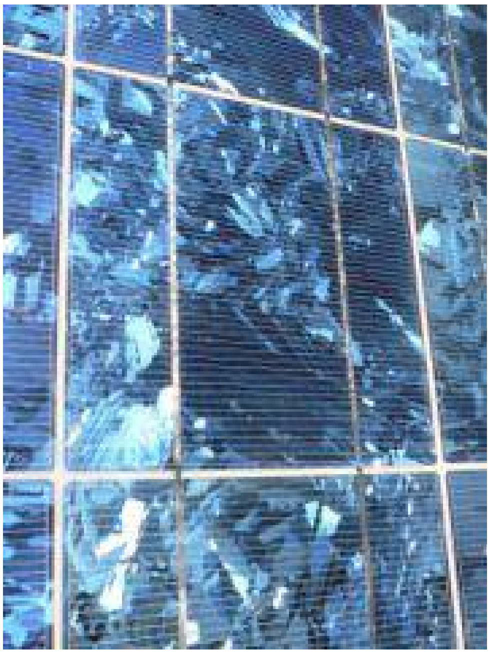

Fig.1 Polycrystalline PV cells laminated to backing material in a PV module

Renewable Energy Source – A Summary

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services. Photovoltaic (PV) technology converts one form of energy (sunlight) into another form of energy (electricity) using no moving parts, consuming no conventional fossil fuels, creating no pollution, and lasting for decades with very little maintenance. The use of a widely available and reasonably reliable fuel source-the sun-with no associated storage or transportation difficulties and no emissions makes this technology eminently practicable for powering remote scientific research platforms. Indeed, numerous examples of successfully deployed systems are already available. The completely scalable nature of the technology also lends itself well to varying power requirements–from the smallest autonomous research platforms to infrastructure-based systems.

This technology can be limited, however, by annual fluctuations in solar insulation, especially at extreme latitudes. This type of panel sees the widest use in polar applications. Thin-film technologies include amorphous silicon, cadmium telluride, copper-indium dieseline, and others. Although the cost of these panels appears attractive at first, it is important to note that the efficiencies are comparatively low. The 8% to 10% efficiencies seen in new panels quickly degrade to about 3% to 6% after several months of exposure to sunlight. Furthermore, amorphous silicon and cadmium telluride modules are sensitive to a much narrower band of colors, and the winter shift to redder sunlight results in slightly poorer performance. Newer, triple-junction thin film technologies appear to have higher efficiencies and less degradation over time, but they are still subject to the same problems mentioned above, if to a lesser degree.

PV System

A photovoltaic system, also solar PV power system, or PV system, is a power system designed to supply usable solar power by means of photovoltaic. It consists of an arrangement of several components, including solar

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panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline. Strictly speaking, a solar array only encompasses the ensemble of solar panels, the visible part of the PV system, and does not include all the other hardware, often summarized as balance of system (BOS).

Moreover, PV systems convert light directly into electricity and shouldn't be confused with other technologies, such as power or solar thermal, used for heating and cooling. PV systems range from small, roof-top mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts. Nowadays, most PV systems are grid-connected, while off-grid or stand-alone systems only account for a small portion of the market. Operating silently and without any moving parts or environmental emissions, PV systems have developed from being niche market applications into a mature technology used for mainstream electricity generation.

A roof-top system recoups the invested energy for its manufacturing and installation within 0.7 to 2 years and produces about 95 percent of net clean renewable over a 30-year service lifetime. A photovoltaic system converts the sun's radiation into usable electricity. It comprises the solar array and the balance of system components. PV systems can be categorized by various aspects, such as, grid-connected vs. standalone systems, building-integrated vs. rack-mounted systems, residential vs. utility systems, distributed vs. centralized systems, roof-top vs. ground-mounted systems, tracking vs. fixed-tilt systems, and new constructed vs. retrofitted systems. Other distinctions may include, systems with micro inverters vs central inverter, systems using crystalline silicon vs. thin-film technology, and systems with modules from Chinese vs. European and U.S.-manufacturers. The installed capacity for both, small rooftop systems and large solar power stations is growing rapidly and in equal parts, although there is a notable trend towards utility-scale systems, as the focus on new installations is shifting away from Europe to sunnier regions, such as the Sunbelt in the U.S., which are less opposed to ground-mounted solar farms and cost-effectiveness is more emphasized by investors.

Solar Array

Conventional c-Si solar cells, normally wired in series, are encapsulated in a solar module to protect them from the weather. The module consists of a tempered glass as cover, a soft and flexible encapsulate, a rear back sheet made of a weathering and fire-resistant material and an aluminum frame around the outer edge. Electrically connected and mounted on a supporting structure, solar modules build a string of modules, often called solar panel. A solar array consists of one or many such panels. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar panels are typically measured under STC (standard test conditions) or PTC (PVUSA test conditions), in watts.

Typical panel ratings range from less than 100 watts to over 400 watts. The array rating consists of a summation of the panel ratings, in watts, kilowatts, or megawatts. The first generation photovoltaic, consists of a large-area, single layer p-n junction diode, which is capable of generating usable electrical energy from light sources with the wavelengths of solar light. These cells are typically made using silicon wafer. The second generation of photovoltaic materials is based on the use of thin-film deposits of semiconductors.

These devices were initially designed to be high efficiency, multiple junction photovoltaic cells. Later, the advantage of using a thin film of material was noted, reducing the mass of material required for cell design. This contributed to a prediction of greatly reduced costs for thin film solar cells. Third generations photovoltaic are very different from the other two, broadly defined as semiconductor devices which do not rely on a traditional p-n junction to separate photo generated charge carriers.

These new devices include photo electrochemical cells, Polymer solar cells, and Nano crystal solar cells. This resulted in the production of the first practical solar cells with a sunlight energy conversion efficiency of around 6 percent. This milestone created interest in producing and launching a geostationary communications satellite by

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providing a viable power supply. Russia launched the first artificial satellite in 1957, and the United States' first artificial satellite was launched in 1958. Russian Sputnik 3 ("Satellite-3"), launched on 15 May1957, was the first satellite to use solar arrays. This was a crucial development which diverted funding from several governments into research for improved solar cells.

A. Existing System - Research Summary

In this existing system topology for single phase single level inverter is suggested. This topology uses reduced number of switches compared to conventional topologies. As the number of levels increases, the produced output waveform is staircase wave which approximates a sine wave with more number of steps. Thus the output voltage approaches the desired sinusoidal waveform. The basic idea of a single level converter is to obtain lower operating voltage using a series connection of power semiconductor switches through much lower voltage rating compared to power switches used in conventional inverter. These power switches are controlled in such a way that less number of voltage levels is generated in the output using many dc sources.

The rated voltage of the power semiconductor switches depends upon the rating of the input voltage sources to which they are connected and it is much less than the output voltage. A photovoltaic (PV) system is solid state semiconductor devices which generates electricity when it is exposed to the light. The building of a solar panel is solar cell. A photovoltaic module is formed by connecting many solar cells in series and parallel. To get maximum output voltage, PV modules are connected in series and for obtaining maximum output current they are connected in parallel. Solar PV power systems have been commercialized in many countries due to their merits such as long term benefits and maintenance-free. The major challenge which lies in using the PV power generation systems is to tackle the nonlinear characteristics of PV array. The PV characteristics depend on the level of irradiance and temperature. PV array experiences different irradiance levels due to passing clouds, neighbor buildings, or trees. The block diagram of PV generation system is shown in the following Figure.

Photovoltaic systems are mainly classified as per their functionality and operation of systems, component configurations, and the equipment connected to electrical loads. They are mainly classified as grid connected and standalone systems which are designed to provide DC and AC power service to operate with independence of the utility grid that are connected with other energy sources and storage systems.

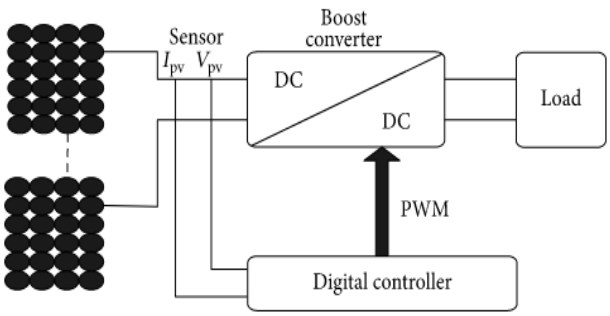

Fig.2 Block Diagram of PV Generation System

B. Proposed System Summary

MPPT techniques generally known in the literature by using a dc-dc boost converter operating in continuous conduction mode to supply a given load. If this voltage ripple propagates to the PV side, it will deteriorate the MPPT performance and decrease the MPPT efficiency. All the control, MPPT, and grid-current are implemented in the DC-AC stage (inverter) that includes of a three-phase bidirectional power flow PWM voltage source inverter (VSI).This is the principal power electronics circuit of a three-phase grid-tied photovoltaic Power System. The MPPT will not be

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carried out by a DC-DC stage; it will be implementing through the inverter, which is in addition responsible for the grid-current control.

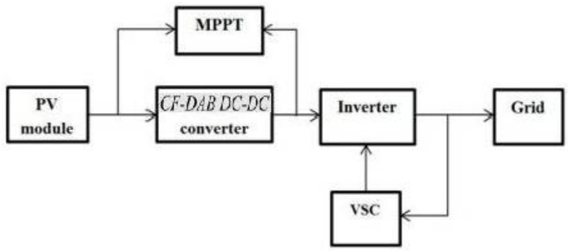

Fig.3 Block diagram OF MPPT Techniques using DC-DC Boost Converter

And the super capacitor is used to reduce the ripples. In this context, the role of energy storage/recovery system is fundamental. Stabilization of DC bus is the main task of these elements: store or recovery energy depending on system situation. Perfect bus stabilization is possible by means of coordinate operation of all energy storage/recovery modules (master-slave operation and communication between modules is required) but in LSG, with a dedicated internal DC bus, a friendly range of fluctuation of DC bus is possible and simplify design of all elements.

Using strategies of power extracted or injected to or from the DC bus voltage as a function of the voltage value (Droop Control), see figure 3, communications between modules is not required in order to assure a perfect equalization of all energy/storage modules assuring a perfect operation a high level of modularity in the whole system. This study propose the use of DAB converters as energy storage/system using a easy to implement strategy of simplified Droop Control strategies, denoted as Linear Phase Droop Control (LPDC) and Cosine Phase Droop Control (CPDC). A complete study of the DAB converter in order to make compatible LPDC/CPDC strategies with operation over optimal line (not reactive energy and zero current switching in one of the inverters) has been done.

Above figure shows the basic and well-known structure of a DAB converter used in different applications, in this case proposed as a modular energy storage/recovery system for a Lighting Smart Grid. It is a bidirectional converter and it is based in the coordinate operation of two full bridge inverters, one inductor and, optionally, one isolation transformer. Several works deals about DAB converter, reference shows a DC to DC application with output voltage stabilization, introduction of droop control can be found in, a comparison among other topologies in a study about switching optimization in, implementation in AC-to-DC applications and Home Area Network applications in. Several design strategies can be conducted in order to use this extremely flexible converter.

Duty Cycles (d1 and d2) and phase shift (d1 and d2) of both converters can be used as control signals. d2 is assumed as reference (d2=0) and d1 represents the phase of waveforms between both inverters (d1 = d). Typical waveforms and nomenclature have been included in figure 4. It is necessary to mention that d1 and d2 moves from 0 to1 and phase d moves from – 180o to +180o (Negatives values implies V1 voltage delayed with V2 voltage and positive values implies V1 voltage in advance with V2 voltage).

II. LITERATURE SURVEY

In the year of 2010, the authors "Mohammed El Alami, Mohammed Habibi, Seddik Bri", proposed a paper titled "The Modeling Of Maximum Power Point Tracking Controller For Increasing Efficiency Of Solar Power System", in that they described such as: we analyze the design and simulation of the electrical operation of a photovoltaic (PV) system adapted by a numerical intelligent controller (MPPT controller) ensuring the pursuit of the maximum power supplied by the photovoltaic generator despite the change of weather conditions. Particularly, we present the effect of meteorological conditions on the performance of a photovoltaic generator for the operation and improving the performance of a PV system adapted. The role of this command is to

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follow the maximum power point (MPP) of a photovoltaic module regardless of the system disturbances (variation of the illumination, temperature).

In the year of 2011, the authors "C. Liu, B. Wu and R. Cheung", proposed a paper titled "Advanced Algorithm For Mppt Control Of Photovoltaic Systems", in that they described such as: Photovoltaic (PV) offers an environmentally friendly source of electricity, which is however still relatively costly today. The maximum power point tracking (MPPT) of the PV output for all sunshine conditions is a key to keep the output power per unit cost low for successful PV applications. This paper proposes a new method for the MPPT control of PV systems, which uses one estimate process for every two perturb processes in search for the maximum PV output. In this estimate-perturbperturb (EPP) method, the perturb process conducts the search over the highly nonlinear PV characteristic, and the estimate process compensates the perturb process for irradiance-changing conditions. The EPP method significantly improves the tracking accuracy and speed of the MPPT control compared to available methods.

In the year of 2012, the authors "Amarnath Kurella, R Suresh", proposed a paper titled "Simulation Of Incremental Conductance Mppt With Direct Control Method Using Cuk Converter", in that they described such as: PV Module Maximum Power Point Tracker (MPPT) is a photovoltaic system that uses the photovoltaic array as a source of electrical power supply. Every photovoltaic (PV) array has an optimum operating point, called the maximum power point, which varies depending on cell temperature, the insulation level and array voltage. The function of MPPT is needed to operate the PV array at its maximum power point. The design of a Maximum Peak Power Tracking (MPPT) is proposed utilizing a cuk converter topology. Solar panel voltage and current are continuously monitored by a MPPT, and the duty cycle of the cuk converter continuously adjusted to extract maximum power. The design consists of a PV array, DC-DC cuk converter and many such algorithms have been proposed. However, one particular algorithm, the Incremental Conductance method, claimed by many in the literature to be inferior to others, continues to be by far the most widely used method in commercial PV MPPT's. The general model was implemented on Mat lab, and accepts irradiance and temperature as variable parameters and outputs the I-V characteristic and P-V characteristic.

III. EXPERIMENTAL RESULTS

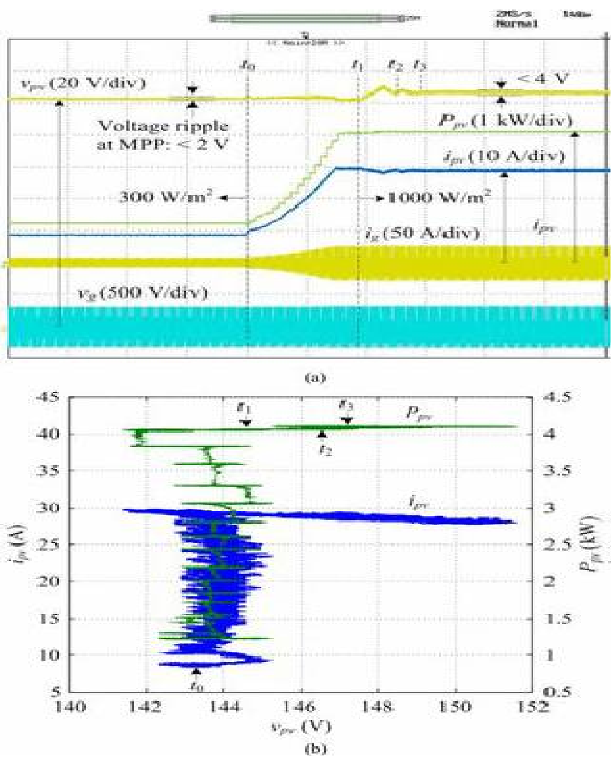

Fig.4 Output Waveform

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IV. CONCLUSION AND FUTURE SCOPE

In this paper, a grid-tied CMI PV system based on CF-DAB dc-dc converters using small dc-link capacitors has been proposed. “d = 1” control was applied to minimize the peak current stress in the converter by synchronizing the LVS dc-link voltage with HVS dc-link voltage. A detailed low-frequency power mitigation control for the CF-DAB converter was proposed based on the dynamic model of the converter. With the proposed dual loop control using PIR controller, the large lowfrequency voltage ripple on the dc-link can be blocked away from the PV side. This proposed power mitigation control can be extended to other current-fed topologies, e.g., CF-DHB and CF-DAB3. An autonomous variable step-size INC MPPT method was also proposed. Fast tracking speed under rapid irradiation change and high MPPT efficiency (>99.5%) were realized for the PV system. Experimental results of the 5-kW PV converter module were given to verify the power mitigation control and MPPT method.

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