GRID CONNECTED PV SYSTEM USING CURRENT FED DUAL ACTIVE BRIDGE DC –DC CONVERTER BASED CASCADED MULTILEVEL INVERTER WITH LOW FREQUENCY RIPPLE FREE MPPT

VenkateswaRao P [*], SK Mujibur Rahman [**]

[*] Department of EEE, Amrita Sai Institute of Science & Technology, Paritala, Krishna Dt, A.P, India
[**] Department of EEE, Amrita Sai Institute of Science & Technology, Paritala, Krishna Dt, A.P, India

Abstract- A Grid tied photovoltaic system consisting of modular current-fed dual-active-bridge (CFDAB) dc–dc converter with cascaded multilevel inverter is proposed. The proposed converter allows a small dc-link capacitor in the three-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. This proposed work is carried out using MATLAB/Simulink Platform.

Index Terms- Current-fed dual active bridge (CF-DAB), optimized operation, photovoltaic (PV), root-mean-square (RMS) current, soft switching.

I. INTRODUCTION

Photovoltaic (PV) energy has become one of the most popular sustainable energy sources nowadays [1]. Due to continuous cost reduction and government incentives, the installation of grid-integrated PV system has grown rapidly in the past few years [2]. As a promising topology for grid-tied PV system, the cascaded multilevel inverter (CMI) has many advantages, such as modularity, high ac voltage application with low device rating, low harmonic spectra and low electromagnetic interference, etc. [3], [4]. In addition, distributed maximum power point tracking (MPPT) terminal for segmented PV arrays can be achieved by a CMI PV converter [5], [6]. In MW-scale high-voltage grid-tied PV systems, galvanic isolation between the PV panel and the grid is required to prevent electric shock on PV panel due to insulation damage and to suppress leakage current. Hence, compared to single-stage CMI converter, the cascaded multilevel inverter integrated with high frequency-link (HFL)-based dc–dc converters has advantage of providing galvanic isolation between the PV panel and the grid without using bulky line-frequency transformer. However, in a three-phase wye-connected CMI PV system with dc–dc stage, electrolytic capacitors are used as the dc-link energy buffers between dc–dc stage and inverter stage to provide the double-line frequency (2ω) power to the grid [7]. Though electrolytic capacitor has high capacitance density, it has been considered as a particularly unreliable component, which is on average 30 times less reliable than non electrolytic capacitor under identical conditions [8], [9]. Therefore, capacitance reduction is highly desirable in order to achieve high reliability with non electrolytic film capacitor [10]–[12], especially for the high-voltage CMI PV system. Nonetheless, the small dc-link capacitance will make the converter suffer from large 2ωvoltage ripple on the dc-link.

If this voltage ripple propagates to the PV side, it will deteriorate the MPPT performance and decrease the MPPT efficiency [13]–[15]. To solve this issue, current-fed isolated dc–dc converters have inherent advantages over the voltage-fed types because the input current of current-fed converter can be controlled directly, and thus, it is possible to eliminate the input low-frequency power ripple in the PV side by special designed current control. Several isolated current-fed dc–dc converters have been studied for various applications [16]–[22]. Jiang et al. [16] have proposed a current-fed boost-half-bridge PV micro inverter; due to the high reverse recovery loss of the diodes at transformer secondary side, the switching frequency is relatively low. To alleviate the loss on the diodes, a resonant operating mode with ZCS condition based on the same topology is proposed in [17]. Nonetheless, the dc-link capacitor is still large and the lower switch suffers from hard switching of high peak current. The current-fed full-bridge converters are suitable for high-power applications [18], however, start-up circuits are needed since the duty cycle can never be smaller than 0.5. Active clamp circuits are usually adopted to extend the duty-cycle range as well as enable ZVS operating [19], [20]. In [21], a three-phase current fed dual-active-bridge (CF-DAB3) converter is proposed for PV application on a dc distributed system. Although it has high power capability, the converter faces phase current unbalancing issues. The current-fed dual-half-bridge (CF-DHB) converter with small dc-link capacitor for fuel cell applications has been proposed by authors in [22], and the input low-frequency ripple current is successfully mitigated by applying direct feedback compensation in the phase-shift control. Unfortunately, the half-bridge topology will suffer from unbalanced capacitor voltage if the duty cycle is not 0.5. Moreover, low-frequency resonance may occur between the reduced dc-link capacitor and transformer magnetic inductor, resulting in large transformer current. This thesis proposes a grid-tied CMI PV system based on a current-fed dual-active-bridge (CF-DAB) dc–dc converter that enables using small film capacitors. A dc-link voltage synchronizing control, i.e., “d=1” control, is applied to reduce the high current stress and consequent loss in the converter resulting from unbalanced dc-link voltage between primary side and secondary side of the transformer [23]. With low-frequency power mitigation control, the 2ωripple on the input PV voltage can be greatly attenuated. Therefore, low-frequency ripple-free power can be extracted from the PV array. Furthermore, other characteristics such as the inherent zero-voltage switching (ZVS), high step-up ratio, interleaved structure, and wide input voltage capability make CF-DAB converter very suitable for PV applications. Therefore, the proposed CF-DAB-based CMI PV converter is an optimal candidate for MW-scale PV systems.

To achieve maximum solar energy harvest, the MPPT strategy should satisfy both high steady-state MPPT efficiency and fast MPPT. Among numerical MPPT methods, the variable step size incremental conductance (INC) method is attractive due to its advantages in compromising steady-state MPPT efficiency and transient tracking speed [24]–[26]. The variable step-size of INC is accurate at steady state, but the dynamic of the MPPT is not good mainly due to the degression of the iteration step size [25]. A modified variable step-size INC MPPT with an adaptive scaling factor is utilized in [26] to improve tracking speed during the transient. However, this modification increases the computational burden and still may have MPPT failure during rapid irradiation change [24]. In this paper, the variable step-size INC MPPT algorithm is improved in several aspects. First, the PV voltage is kept unchanged during rapid irradiation change to avoid possible failure of MPPT. Second, a maximum step size is adapted right after the short transient, and when approaching the new maximum power point (MPP), variable step size with an adaptive scaling factor related to PV power is adopted for fast tracking.

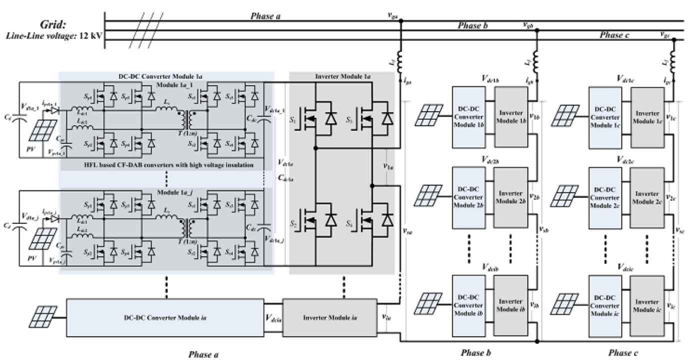

Fig. 1. Grid-tied cascaded multilevel PV inverter system based on CF-DAB dc-dc converters

II. CF – DAB DC – DC CONVERTER FOR PV APPLICATION

Fig. 1 shows Optimized Operation of Current-Fed Dual Active Bridge DC–DC Converter for PV Applications. CF-DAB converters gain growing recognition in photovoltaic(PV) and energy storage applications [26]–[30]. Comparedwith a VF-DAB converter, a CF-DAB converter has unique advantages, e.g., a wide input voltage range, a high step-up ratio, a low input current ripple, and a multiport interface, which make the topology suitable for PV applications [29]. With direct input current controllability and extra control freedom, a CF-DAB converter allows using a small dc-link capacitor instead of a large electrolytic capacitor, without affecting the input PV side, in grid-interactive PV systems, where doubleline-frequency energy oscillation exists [29], [30]. Therefore, a PV system can achieve high reliability and highly efficient
maximum power point tracking.

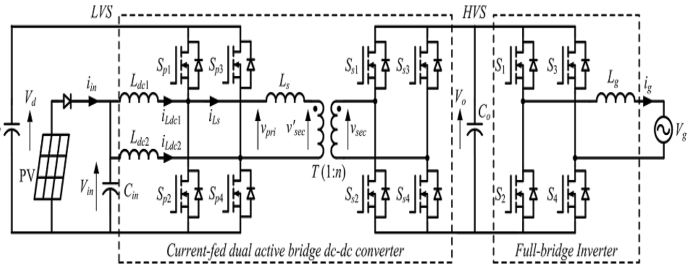

Fig. 2. CF-DAB dc–dc converter for a PV application.

To simplify the analysis, a PV system including one single dc–dc module and one inverter module, namelyi=1andj=1 for the PV system of Fig. 1, is selected for investigation. The control system for the proposed CF-DAB-converter-based PV system is described in Fig. 3, which can be divided into CFDAB converter control system and full-bridge inverter control system. The dc-link voltage vdc is controlled by the inverter module. A detailed active and reactive power compensation and optimization strategy for the inverter control has been reported in [5] and [6]; therefore, this paper only focuses on the control for dc–dc module. Duty-cycle plus phase-shift control is employed for the CF-DAB converter. The PV voltage vpv is regulated by the duty cycleD, while the low voltage side (LVS) voltage vd is controlled by the phase-shift angle φ. To minimize the peak current of the transformer,“d=1” control using PI+ Resonant (PIR) controller is applied to synchronize the LVS and high voltage side (HVS) dc-link voltage.

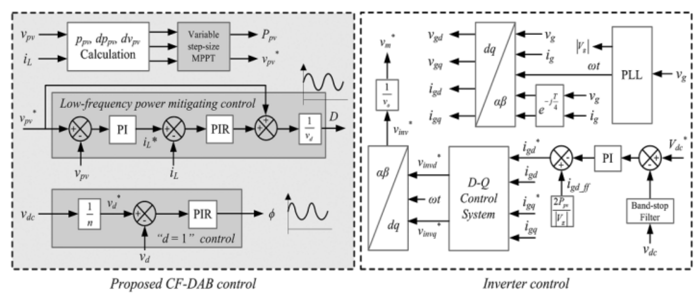

Fig. 3. Control system diagram of proposed PV converter.

III. SOLAR PV MODELLING

The equivalent circuit of a PV cell is as shown in Figure 2.2. Where Iph represents the cell photo current, I_0 represents the diode saturation current, I and V are cell output current and cell output voltage respectively. Rp is shunt resistance, Rs is series resistance. They ideal PV module for one diode circuit.

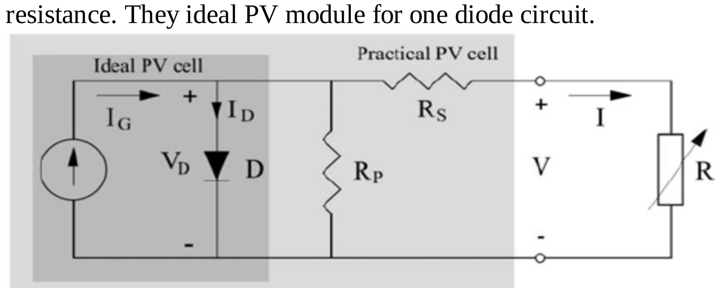

Fig 4. PV cell model

The mathematical model of PV array for single diode circuit can be represented by the following equation [1]:

A. Photo Current (Iph):

I_{ph} depends on the solar irradiation and cell's operating temperature according to the below equation.

$$I_{ph} = [I_{sc} + K_i(T_c - T_{ref})] * \frac{I_r}{1000}$$

Here, I_{ph}: photo-current (A);
I_{sc}: short circuit current (A) ;
K_i: short-circuit current of cell at 25 °C and 1000 W/m^2;
T: operating temperature (K);
Ir: solar irradiation (W/m^2).

B. Reverse Saturation Current (Irs):

Reverse saturation current of PV system can be determined by the given equation

$$I_{rs} = \frac{I_{sc}}{[\exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1]}$$

Here, q: electron charge, = 1.6 × 10^{-19}C;
V_{oc}: open circuit voltage (V);
N_s: number of cells connected in series;
A: the ideality factor of the diode;
k: Boltzmann's constant, = 1.3805 × 10^{-23} J/K.

C. Diode Saturation Current (I_0):

Saturation current of PV system varies with the cell temperature can be determined by given equation.

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{g0}}{Ak}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]$$

Here, T_r: nominal temperature = 298.15 K;
E_{g0}: band gap energy of the semiconductor, = 1.1 eV

D. output current (I):

The equation for output current of the PV system of single diode model presented in Figure 2.1 is given by,

$$I = N_P \times I_{ph} - N_P \times I_0 \times \left[exp\left(\frac{\frac{V}{N_S} + I \times \frac{R_S}{N_P}}{A \times V_t}\right) - 1\right] - I_{sh}$$

$$I_{sh} = \frac{V \times \frac{N_P}{N_S} + I \times R_S}{R_{sh}}$$

$$V_t = \frac{k \times T}{q}$$

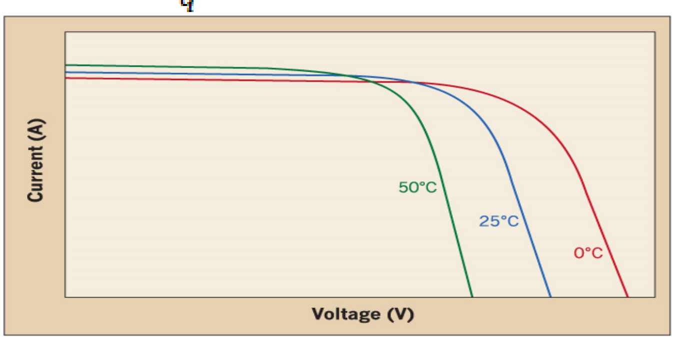

Fig 5. Current vs. Voltage curve of solar cell

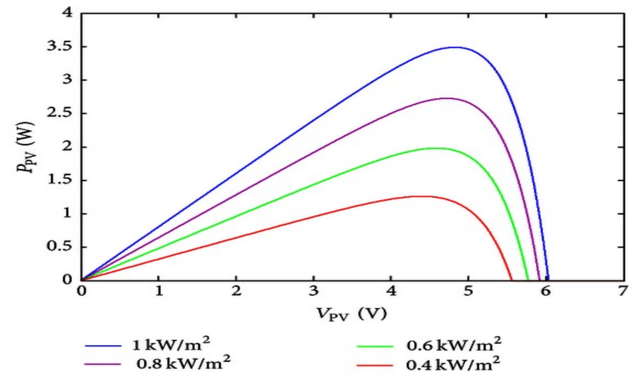

Fig 6. Power vs Voltage curve of solar cell

IV. SIMULATION RESULTS

The proposed CF DAB performance is studied in MATLAB/SIMULINK platform. The fig 7, 8 and 9 shows the simulated circuit of CF-DAB dc–dc converter for a PV application and control circuit for proposed converter. The photovoltaic system is also simulated which operates at maximum power point tracking mechanism.

A. Simulation circuit of Proposed CF DAB

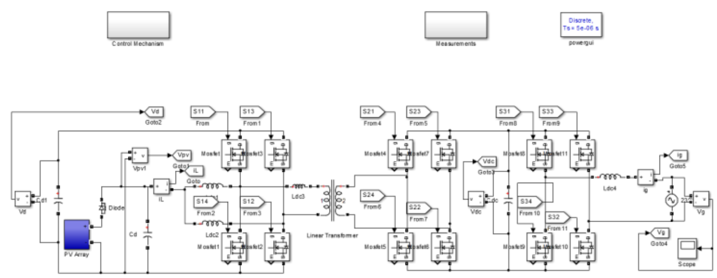

Fig 7 Propoed CF DAB

B. Simulation Circuit of Control mechanism

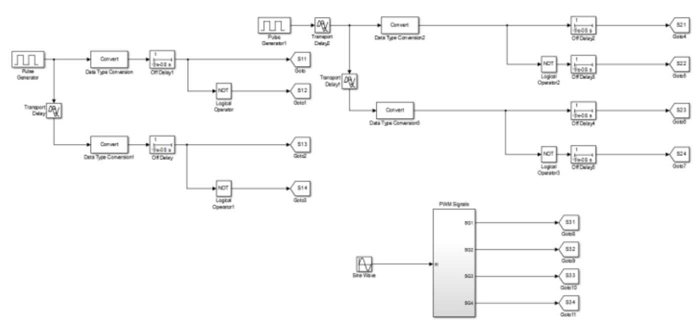

Fig 8 Simulation of control circuit of CF DAB

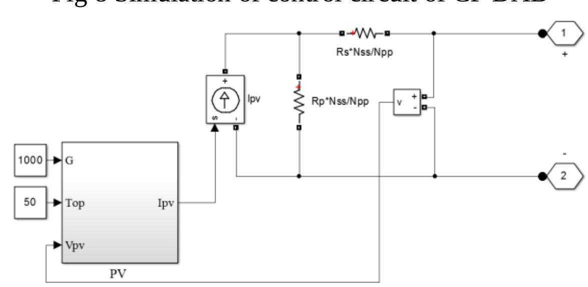

Fig 9 photo voltaic system

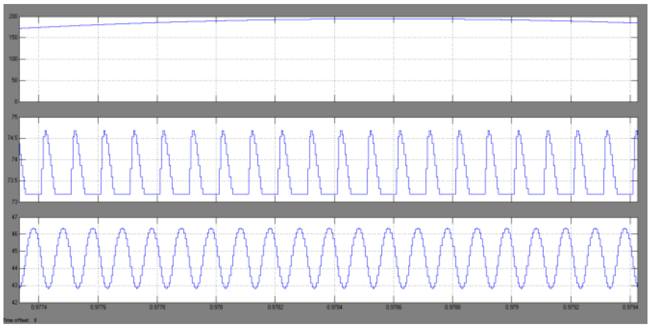

Fig 10 Modelling of PV Array

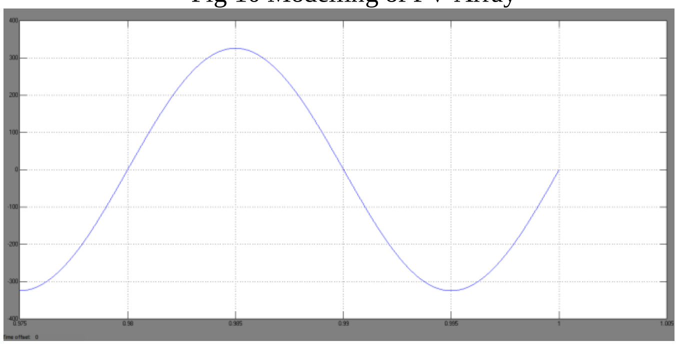

Fig 9 Inverter control

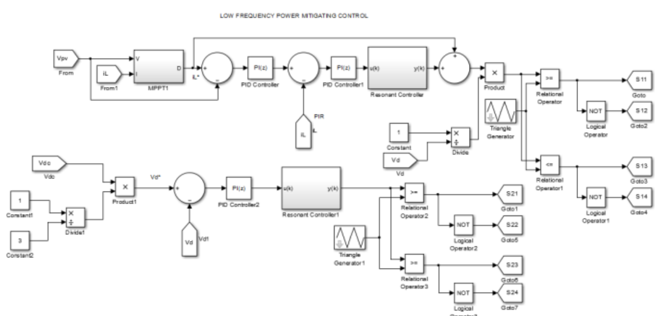

Fig 10 Proposed Control Circuit Simulation

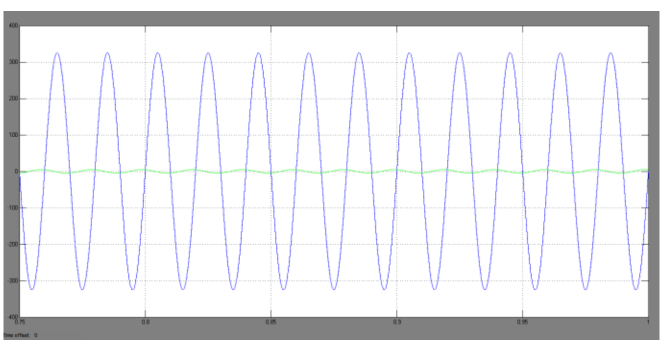

Fig 11 Grid Voltage and current

I. CONCLUSION

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 low-frequency 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.

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AUTHORS

First Author – VenkateswaraRao P, he received his B.Tech degree in Electrical and Electronics Engineering from Amrita Sai Institute of Science and Technology, Paritala, A.P, India in 2014. He is currently pursuing M.Tech Power Electronics in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronic Applications to ASDs.

Second Author – SK Mujibur Rahman**,** he received his B.Tech degree in Electrical and Electronics Engineering from Nimra Institute of Engineering and Technology, Jupudi (A.P), India, in 2001. Master of Science degree in Engineering from Chalmers University of Technology, Sweden, in 2006. He is currently working as a Associate Professor in Amrita Sai Institute of Science and Technology, Paritala, A.P, India. His interested research areas are Power Electronics & Drives and Power System.