SUMMER UNDERGRADUATE RESEARCH AWARD

(SURA) PROPOSAL – 2023

EXTRACTING MAXIMUM POWER

FROM

DIS_SIMILAR SOLAR PV_STRING

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INTRODUCTION

Renewable energy sources are generating a growing amount of the world's electricity. Among these, photovoltaic (PV) technology has been in the focus and has experienced an increasing number of installations. In state-of-the-art PV system installations for residential and commercial or utility-scale applications, PV panels are connected in series. However, The current generation of a PV panel is dependent on the irradiance level. In case all the PV panels in a string receive the same level of irradiance, the whole string of panels has only one **maximum power point (MPP)**, and all panels contribute to the total power of the string. In contrast, if the PV panels in a string are subject to different levels of irradiance, e.g., due to local shading of some panels, the output currents are unequal and the string shows multiple MPPs. When a mismatch between the panels occurs, the strings of photovoltaic panels have a significantly reduced power output [1].

Approach:

We identified the problem of partial shading of solar panels and found it as one of the major causes of reduced power output. Thus, we went to analyze the solar panels installed in IIT DELHI, block II rooftop (Fig1) and concluded that this problem of **mismatch** is not only caused by shading but also by other factors such as dirt or dust on panels, different orientation of PV panels, different panel manufacturers, unequal aging, etc. and thus reducing energy production and affecting the lifetime of the overall PV system.

Yet, We need to investigate new topologies capable of capturing more energy from the PV systems by using relatively low-cost interfacing systems to decrease the PV energy production cost.

In this Project, We present a novel topology based on **Differential Power Processing (DPP)**, so that maximum available power can be extracted from each panel regardless of any mismatch and the aforementioned problems can be mitigated.

Fig1 Different orientation of PV panels and partial shading on PV panel situated at the Block II roof.

MOTIVATION

A. **The Past** —The past technology, Fig. 2(a), was based on **centralized inverters** that interfaced a large number of PV modules to the grid. This centralized inverter includes some severe limitations, such as high-voltage dc cables between the PV modules and the inverter, power losses due to a centralized MPPT, mismatch losses between the PV modules, and a nonflexible design where the benefits of mass production could not be reached [2],[3].

B. **The Present—String Inverters and AC Modules**: The string inverter Fig. 2(b), is a reduced version of the centralized inverter, where a single string of PV modules is connected to the inverter. The input voltage may be high enough to avoid voltage amplification. There are no losses associated with string diodes and separate MPPTs can be applied to each string. This increases the overall efficiency compared to the centralized inverter, and reduces the price, due to mass production. The ac module depicted in Fig. 2(c) is the integration of the inverter and PV module into one electrical device. It removes the mismatch losses between PV modules since there is only one PV module, as well as supports optimal adjustment between the PV module and the inverter and, hence, the individual MPPT. It includes the possibility of an easy enlarging of the system, due to the modular structure. The opportunity to become a " plug-and-play" device. On the other hand, the necessary high voltage amplification may reduce the overall efficiency and increase the price per watt, because of more complex circuit topologies. On the other hand, the ac module is intended to be mass-produced, which leads to low manufacturing costs and low retail prices [2],[3].

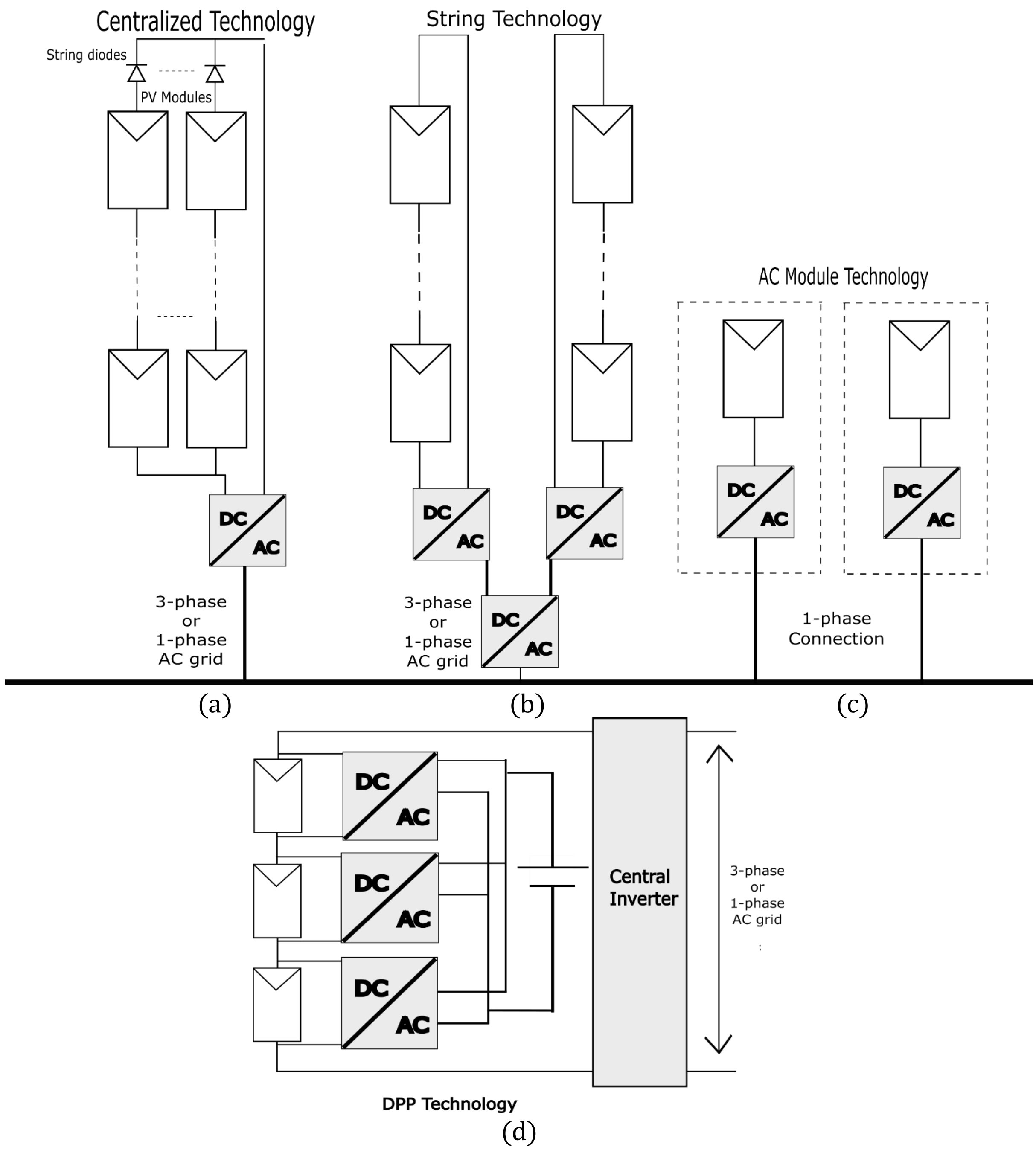


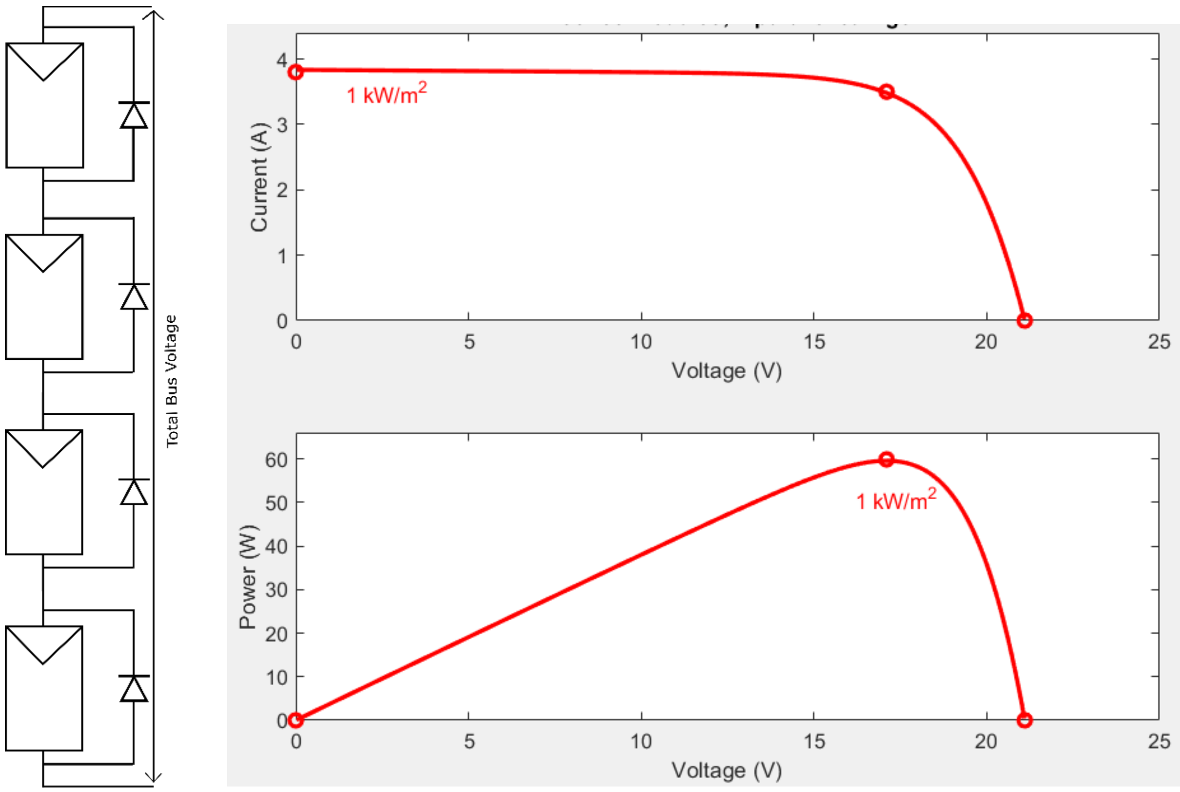
Fig2. Configurations of PV System (a) Centralized technology, (b) string technology, (c) AC module technology, and (d)Differential Power Processing (DPP) technology.

C. <u>**The Future**</u>**—DPP Converters, AC Modules, and AC Cells**: The DPP technology Fig2(c) PV modules are interfaced with their own dc–dc converter to a common dc–ac inverter. Compared with the centralized system, this is beneficial since every string can be controlled individually. Further enlargements are easily achieved since a new string with a dc–dc converter can be plugged into the existing platform. Finally, the ac cell inverter system is the case where one large PV cell is connected to a dc–ac inverter.

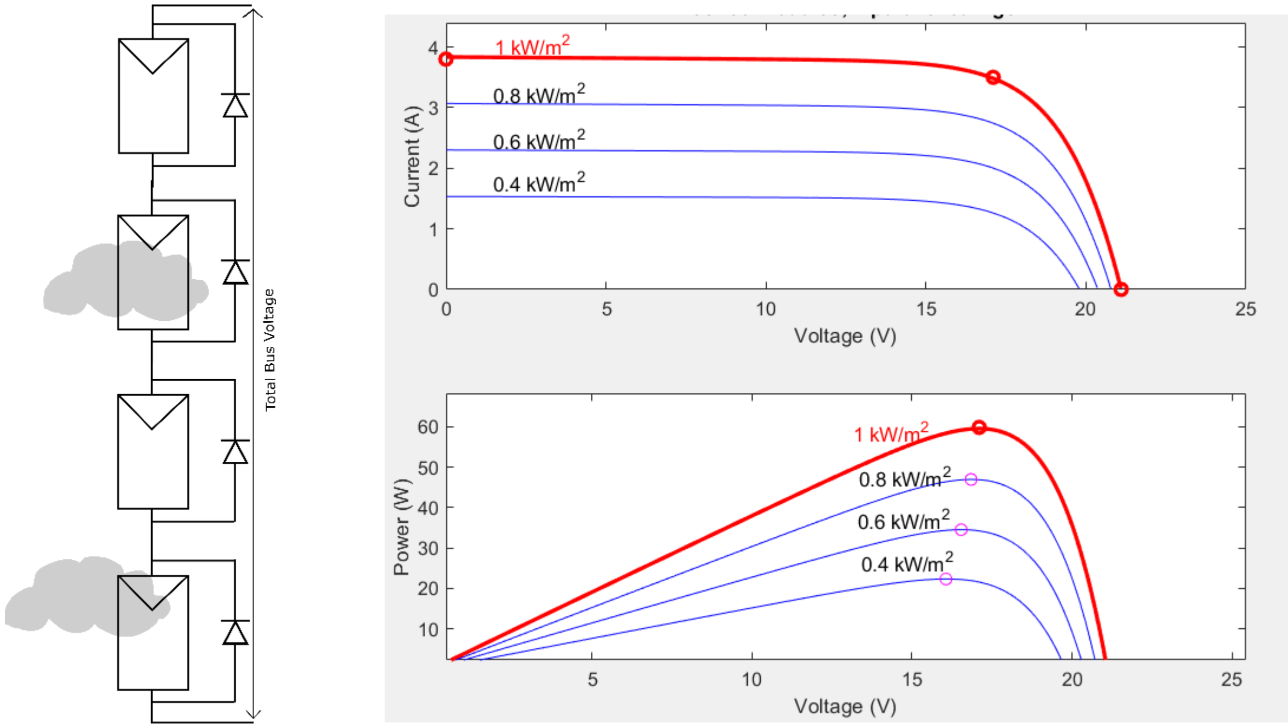
A Differential Power Processing (DPP) converter supplies mismatched power between the panels while operating each panel at its maximum power point. The proposed topology employs a bidirectional two-switch flyback converter between the isolated port and string voltage bus which regulates the voltage of the isolated port within permissible levels when it is discharged or overcharged due to a mismatch between the panels for a long duration of time. By converting only a small part of the power, the total power loss is constrained to a lower level, which means a higher overall efficiency.
Thus, DPP architectures are efficient due to their simplicity, cost-effectiveness, and scalability [2], [3].

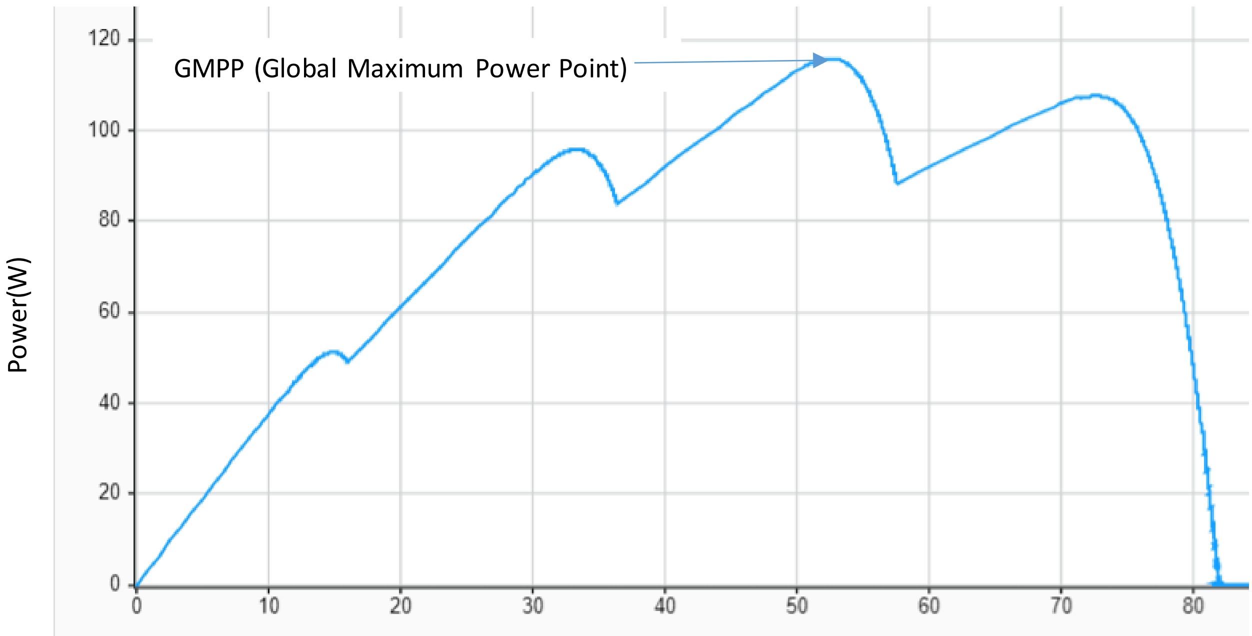
OBJECTIVES

To Make a Differential Power Processing (DPP) converter operate at Maximum Power Point (MPP).
Using the Perturb and Observe ('P & O') Algorithm for tracking the MPP of a PV array. Since The power electronic interface for PV systems has two main tasks: one is to convert the generated dc voltage into a suitable ac current for the utility; the other is to control the terminal conditions of the PV modules so as to track the Maximum Power Point (MPP) for maximizing the energy capture. This must be done at the highest possible efficiency, over a wide range, due to the morning-noon-evening and winter-summer variations. Thus, We will track the MPP using Perturb and Observe ('P & O') Algorithm. The DPP converters only process the mismatched power instead of the full power. The current processed through each converter is $\boldsymbol{I_{pv}}$ the difference between the local PV element MPP current and the local PV string current. **Thus, We will evaluate the optimal $\boldsymbol{I_{pv}}$ so that total power processed by DPP converters is minimum at a given operating condition.**



(a)



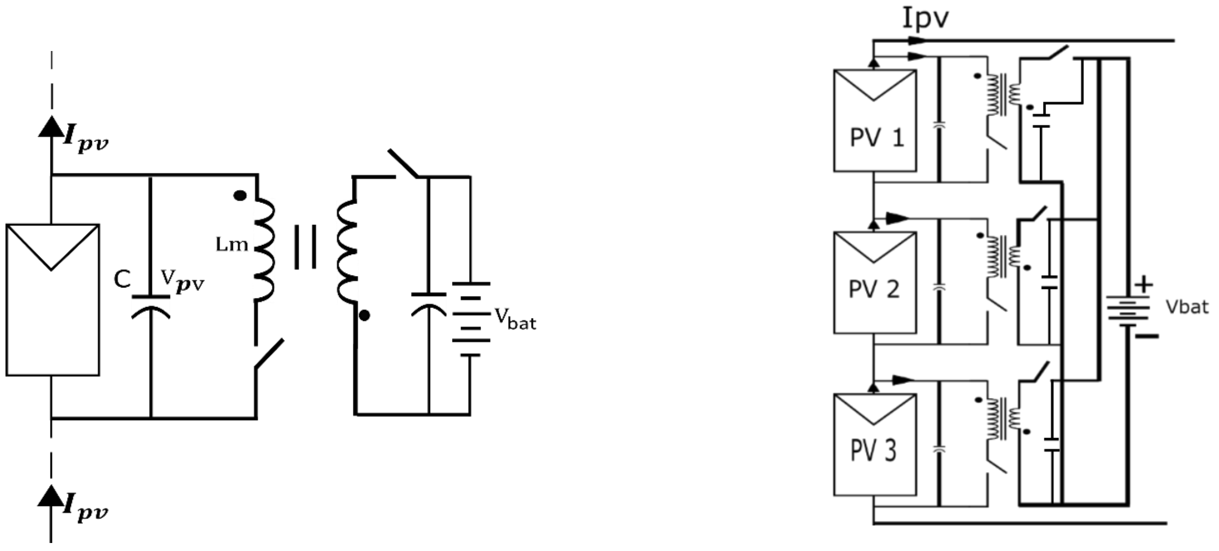


Voltage (V)
PV plot
(b)

Fig3. Impact of shading on a simplified PV string (a) output power of the PV string with only unshaded panels receiving the same irradiance and (b) with the shaded panels (plotted versus the total bus voltage).

Thus, we can see here that the unshaded panels will not be operating at their MPP. The theoretically available power $P_{total,th}$ of a PV string with N PV panels which is the sum of MPPs of all PV panels can't be harvested and is greater than the actual observed power.

$$P_{total,th} = \sum_{i=1}^{N} P_{MPP,i} = (59.85+46.96+34.53+22.33)\ \text{W}=163.67\ \text{W} > P_{exp} = 115.82\ \text{W}$$



(a) (b)

Fig4. (a) Bi-directional Flyback Converter Schematic and (b) Proposed system topology with DPP converters (flyback with battery).

METHODOLOGY

We will be developing the proposed architecture of **PV to Isolated port bus DPP topology.** DPP is different from GMPP tracking (Multiple MPPs in mismatch case Fig3(b)) and it can extract higher total power. DPP using flyback converters (Fig4(a)) is rated for a small fraction of the power produced by a panel. So, its rating is small and overall efficiency is high.

Fig. 4(b) shows the proposed system topology for a series string of PV panels. Each panel is connected in parallel to a PV-to-IP bus DPP converter (bi-directional flyback). Each DPP converter operates in input voltage mode control, thereby regulating the individual PV panel voltage. The reference voltage for each DPP converter is generated from an adaptive **perturb and observe algorithm (P&O Algorithm)** which tracks the true MPP of each panel. If there is a current mismatch between the panels, then the mismatched current flows into or out of the DPP converters. **The reference current of the boost converter is generated in such a way that the DPP converters process minimum total power (to maximize the system efficiency) while supplying the mismatched currents.**

The battery of the isolated port is connected to the string voltage bus via a bi-directional two-switch flyback converter. If the DPP converters have to supply large mismatched currents for a long period, then the battery voltage falls below its requisite value. Under such conditions, power flows from the string voltage bus into the battery in such a way that the battery is maintained at the required voltage. It may also happen that the isolated port voltage goes above the required voltage. In that case, excessive power from the isolated port flows into the string voltage bus. The two-switch flyback topology, therefore, enables the use of lower-rated switches, feeds back the energy stored in leakage inductance to the string voltage bus, and eliminates the use of snubber circuits while ensuring isolation between the battery at the isolated port and the string voltage bus. Hence **the addition of this converter has minimal effect on the overall cost and efficiency.**
The isolated port of the DPP converters can either be a capacitor with large capacitance or a battery with a high Amp-hour rating. However, the voltage across a capacitor fluctuates more than the voltage across battery terminals, thereby causing more power losses in the two-switch flyback converter. Therefore, **a battery has been chosen for the isolated port.**

WORK TIMELINE

Task	Week			
	1	2	3	4
1	Simulation of Flyback in MATLAB	Simulation of DPP with multiple flyback converters and multiple PV panels.	Component selection, learning C2000/TMS320F28379d Microcontroller programming	Ordering PCB (at the beginning of the week)
2	Design of Flyback transformer/Coupled inductors (CI)	DPP-optimal string current algorithm and P&O Algorithm	Ordering Components	Components arrival
3	Finding device ratings, CI & Capacitor rating	Running a full-scale simulation of the system	PCB Design	

Task	Week			
	5	6	7	8
1	Soldering components	Incorporation of P&O Algorithm in microcontroller	Assembling all Flyback converters	Final assembling
2	Testing of Flyback Converter	Testing single PV + Flyback Converter	Running DPP	Writing Reports

BUDGET REQUIREMENTS

The project budget requirements would be within the prescribed limit.
The project would require total funds of ₹25,000/-

- Consumable (MOSFETs, drivers, capacitors, magnetic core, resistors, sensors) - ₹16,000/-
- PCB Fabrication - ₹8000/-
- Contingency - ₹1000/-

References

[1] M. Kasper, D. Bortis and J. W. Kolar, "Classification and Comparative Evaluation of PV Panel-Integrated DC–DC Converter Concepts," in *IEEE Transactions on Power Electronics*, vol. 29, no. 5, pp. 2511-2526, May 2014.

[2] S. B. Kjaer, J. K. Pedersen and F. Blaabjerg, "A review of single-phase grid-connected inverters for photovoltaic modules," in *IEEE Transactions on Industry Applications*, vol. 41, no. 5, pp. 1292-1306, Sept.-Oct. 2005.

[3] F. Blaabjerg, Z. Chen and S. B. Kjaer, "Power electronics as efficient interface in dispersed power generation systems," in *IEEE Transactions on Power Electronics*, vol. 19, no. 5, pp. 1184-1194, Sept. 2004.

[4] P. S. Shenoy and P. T. Krein, "Differential Power Processing for DC Systems," in *IEEE Transactions on Power Electronics*, vol. 28, no. 4, pp. 1795-1806, April 2013.

[5]'Fundamentals of Power Electronics by Robert W. Erickson and Dragan Maksimović, 3rd Edition, Springer, Boston, MA.