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High Efficiency DC-DC Converters for Modular AC Nano Grids

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ABSTRACT

This project presents a dynamic modeling and control strategy for a sustainable Nanogrid primarily powered by wind and solar energy. A current-source-interface multiple-input dc-dc converter is used to integrate the renewable energy sources to the main dc bus. Potential suitable applications range from a communication site or a residential area. A direct-driven permanent magnet synchronous wind generator is used with a variable speed control method whose strategy is to capture the maximum wind energy below the rated wind speed. This analaysis considers both wind energy and solar irradiance changes in combination with load power variations. As a case study a 30-kW wind/solar hybrid power system dynamic model is explored. The examined dynamics shows that the proposed power system is a feasible option for a sustainable nanogrid application.

I. INTRODUCTION

The global population without access to electricity exceeds1.4 billion, whereas the rural electrification rate is below65%.The intermittent nature of PV and other renewable energy sources, and thus the need for energy storage and or load shedding, is a major challenge in small-scale PV-based power grids. This is despite power quality requirements. Low-power dc–dc micro convertersand ac– dc (MIV) provide high-granularity maximum power point tracking (MPPT) at the module or substring level. This leads to increased robustness to clouds, dirt, and aging effects, as well as irradiance and temperature gradients.A conventional MIV-based ac power system with the energy storage system (ESS), which is definitely required for islanded operation on the scale of one or more houses, for example, is usually based on a high power centralized bidirectional ac–dc converter, which is interfaced to a battery bank or aflywheel is shown in fig 1.1.

Existing MIV architectures satisfy the need for low capital cost and expandable ac generation, whereas there is a compelling argument to extend this technology to include small scale distributed storage. A novel topology with distributed storage is proposedfor grid stabilization while potentially improving the generator lifetime and saving fuel. MIV integrated storage helps to buffer the frequent irradiance fluctuations while also providing local backup power and reactive power support .The general architecture of a two-stage MIV with an integrated ESS. While two-stage MIVs have a slightly lower efficiency than their single-stage counterparts, the high-voltage dc-link capacitance C_{bus} can be used for ac power decoupling in single-phase systems.

This objective of this paper is to demonstrate a novel low power operating mode in dual active bridge converter, as well as dynamic dc link optimization scheme to maintain high efficiency over a broad power range and this work targets modular Nano grid for remote locations, where photovoltaic modules can be gradually introduced to grow the renewable energy at minimal cost, while reducing dc fuel consumption. Grid tide micro inverters provide a modular solution for ac power generation. The main contribution of this work is a new micro inverter platform and control scheme with bidirectional power flow between the Nano grid, the photovoltaic module and integrated short term storage, using high energy density Li-ioncapacitor technology.

II. DC-DC Converter

A DC-to-DC converter is an electronic circuit or electromechanical device which converts a source of direct current (DC) from one voltage level to another. It isa type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission).Most DC to DC converter circuits also regulate the outputvoltage. Some exceptions include high-efficiency LEDpower sources, which are a kind of DC to DC converter that regulates the current through the LEDs, and simplecharge pumps which double or triple the output voltage.DC to DC converters developed to maximize the energyharvest for photovoltaic systems and for wind turbines arecalled power optimizers.

DC to DC converters are used in portable electronic devicessuch as cellular phones and laptop computers, which are supplied with power from batteries primarily. Suchelectronic devices often contain several sub-circuits, eachwith its own voltage level requirement different from thatsupplied by the battery or an external supply (sometimeshigher or lower than the supply voltage). Additionally,the battery voltage declines as its stored energy is drained.Switched DC to DC converters offer a method to increasevoltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplishthe same thing.

Transformers used for voltage conversion at mains frequenciesof 50–60 Hz must be large and heavy for powersexceeding a few watts. This makes them expensive,and they are subject to energy losses in their windings anddue to eddy currents in their cores. DC-to-DC techniquesthat use transformers or inductors work at much higher frequencies, requiring only much smaller, lighter, andcheaper wound components. Consequently these techniquesare used even where a mains transformer could beused; for example, for domestic electronic appliances it is preferable to rectify mains voltage to DC, use switch mode techniques to convert it to high-frequency AC atthe desired voltage, then, usually, rectify to DC. The entirecomplex circuit is cheaper and more efficient than asimple mains transformer circuit of the same output.

2.1 *Types of Converters:*

Step-down A converter where output voltage is lowerthan the input voltage (such as a buck converter).

Step-up A converter that outputs a voltage higher thanthe input voltage (such as a boost converter).

2.1.2Modes of opertion:

Continuous current mode Current and thus the magneticfield in the inductive energy storage never reachzero. Discontinuous current mode Current and thus themagnetic field in the inductive energy storage mayreach or cross zero.

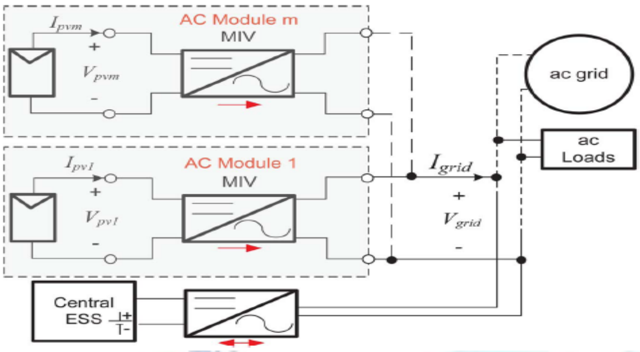
2.1.3Distrubances:

Noise Unwanted electrical and electromagnetic signalnoise, typically switching artifacts.

RF noise Switching converters inherently emit radio waves at the switching frequency and its harmonics.Switching converters that produce triangular switchingcurrent, such as the Split-Pi, forward converter, orĆuk converter in continuous current mode, produce less harmonic noise than other switchingconverters.RF noise causes electromagnetic interference (EMI). Acceptable levels depend uponrequirements, e.g. proximity to RF circuitry needsmore suppression than simply meeting regulations.

Input noise The input voltage may have non-negligiblenoise. Additionally, if the converter loads the input with sharp load edges, the converter can emit RFnoise from the supplying power lines. This shouldbe prevented with proper filtering in the input stageof the converter.

Output noise The output of an ideal DC-to-DC converterMis a flat, constant output voltage. However,real converters produce a DC output upon whichis superimposed some level of electrical noise.Switching converters produce switching noise at theswitching frequency and its harmonics. Additionally,all electronic circuits have some thermal noise.Some sensitive radio-frequency and analog circuitsrequire a power supply with so little noise that it can only be provided by a linear regulator. Some analogcircuits which require a power supply with relativelylow noise can tolerate some of the less-noisyswitching converters, e.g. using continuous triangularwaveforms rather than square waves.



2.1Conventional MIV-based PV system with a central ESS.

III. Dual Active Bridge

The objective of this paper is to demonstrate a novel lowpoweroperating mode in the dual-active-bridge (DAB) converter,as well as a dynamic dc-link optimization scheme tomaintain high efficiency over a broad power range. This iscrucial in any commercial MIV architecture; for example, theEuropean efficiency index dedicates 32% of the total evaluationweight to operation below 30% of the rated power. This paper is an extension of and includes an analysis of thequantization effects, regulation accuracy, and magnetics-relatediscuss in both operating modes.

The increased demand of an intermediate storage of electrical energy in battery systems, in particular due to the use of renewable energy, has resulted in the need of bidirectional dc/dc power converters with galvanic isolation. Uninterruptible power supplies in traction applications are examples of some fields of application of this kind of converters. A dual Active Bridge (DAB) bidirectional DC/DC converter is a topology is proposed for applications where the power density, Cost, weight, and reliability are critical factors.

3.1 Circuit Configuration

A DAB converter is made up of two controllable switching bridges and onehigh-frequency transformer. Each switching bridge is made up of four highfrequencyactive controllable switching devices (MOSFETs or IGBTs) in an H-bridgeconnection. Such connection is similar to the one used in full-bridge dc-dc converters. However, instead of using uncontrollable switching devices (such as diodes) bridge in the other side of transformer, DAB converters use twoactive bridges formed by active controllable devices. So that its called as Dual Active Bridge. Galvanic isolation is made by a solid state transformer in-betweentwo H-bridges of a DAB converter. The high-frequency transformer operationis desirable to reduce the weight and volume of the magnetic core. Compared to those converters using line-frequency transformers, DAB converters use more

Silicondevices (whose price is continuously going down) while using less copperand smaller magnetic core (whose price is continuously going up). As like normaltransformer operation, the high-frequency transformer has some amount of leakageinductance in its primary and secondary windings. The leakage inductance hastwo purposes: (1) it is used as energy storage components in DAB converters and (2) it reduces the sudden change in voltage dv/dacross switching devices during commutation transients, facilitates soft switching, and reduces switching losses. Figure2.1shows the circuit schematic of a dc-dc DAB converter. In the schematic, power IGBT can be used in place of MOSFETs. Bidirectional current flow is possible when IGBT diode pair is used in place of MOSFETs.Therefore, the circuit shown in figure 2.2is able to conduct bidirectional

current. Furthermore, DAB converters have symmetrical dual active H-bridgeconfiguration, which help achieve bidirectional power flow. On the other side, this configuration can only block positive voltage. Therefore, the topology shown in figure

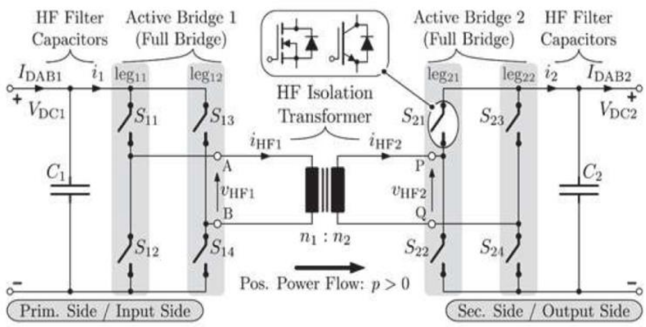
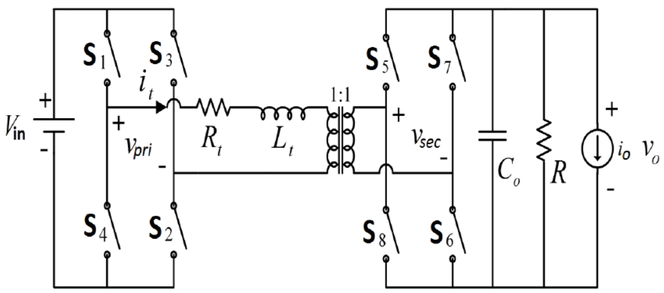


Fig::3.1 Schematic Of DAB Converter

Even an AC-AC DAB converter can be also implemented by applying sameconfiguration method. Since the input and output voltages are both dc, theswitches in an SST must block voltage in both polarities. Additionally, theymust conduct current in both directions. Therefore, each switch cell consists of two anti-serial connected switching devices. For simplicity in calculation, eachswitching device is replaced by S1, S2 etc in figure



3.2 Dual Active Bridge:

A dual active bridge (DAB) DC-DC converter is ideally suited for high – power, galvanically isolated DC-DC conversion. The DAB DC-DC converter has advantages of high- power density, Zero Voltage Switching (ZVS), bidirectional power transfer capability, amodular and symmetric structure, and simple control requirements. The DAB DC-DC converter can also be used for multiport operation,which is a feature that is useful in interfacing several DC sourcesand loads using a single converter.Not withstanding all of the advantages of conventional DAB converter, for applications requiring wide voltage variations, such as an interface for energy storage, fuel cells, or photovoltaics,the DAB converter has limited ZVS range and high circulating current at low loads results in poor efficiency when the DAB converter is under a low load condition. Thus there is a need for an improved DAB converter that provides an increased ZVS range and/or increased efficiency particularly at low load conditions.

3.2.1Zero Voltage Switching:

Switch voltage brought to zero before gate voltage is applied. Step-down (“buck”) DC-DC voltage regulator circuit design is getting harder because power density (W/m3) is rising, DC power supply voltage levels are rising, and silicon voltage demands are dropping in order to increase efficiency. The difference between the supply voltage and that required by the silicon creates a big drop across the regulator, increasing switching losses and ultimately limiting the device’s switching frequency. One solution enabling a return to faster switching frequency at higher input voltage and voltage drop is Zero Voltage Switching (ZVS). This technique, like virtually all contemporary switching voltage regulators, uses pulse width modulation (PWM)-based operation, but with an additional separate phase to the PWM timing to allow for ZVS operation. ZVS enables the voltage regulator to engage “soft switching”, avoiding the switching losses that are typically incurred during conventional PWM operation and timing.

3.2.2 *Zero Current Switching:*

A method for providing non-resonant zero-current switching in a switching power converter operating in a continuous current mode. The switching power converter converts power from input power to output power. The switching power converter includes a main switch connected to a main inductor, wherein an auxiliary inductor is connectible with the main inductor. The main current flows from an input to an output. The auxiliary inductor is connected with the main inductor thereby charging the auxiliary inductor so that an auxiliary current flows from the output to the input opposing the main current. Upon a total current including a sum of the main current and the auxiliary current. Substantially equals or approaches zero, the switch is turned on.

The proposed dc–dc architecture is shown in Fig 2.3.This converter is a modified DAB that interfaces $V_{bus}$the dc linkV_{bus}.

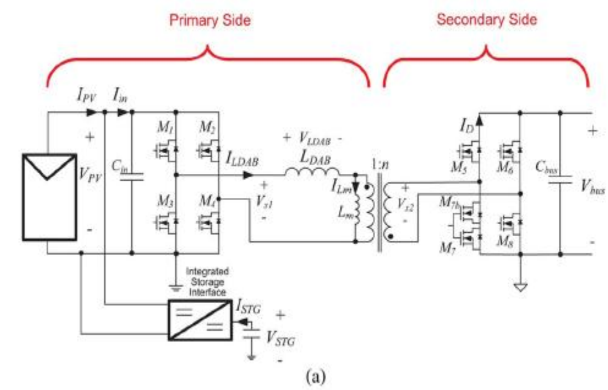


Fig 3.3 Modified DAB

IV. Modes of Operaton

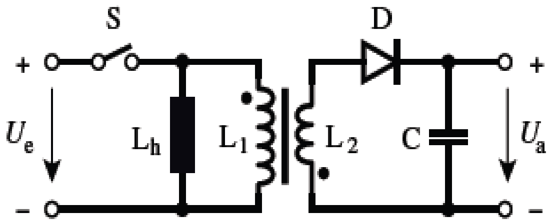
4.1 DAB MODE:

The DAB topology was selected based on

1) Galvanic isolation
2) Soft-switching operation and
3) Simple phase-shift power control.

Galvanic isolation:

Galvanic isolation is a principle of isolating functional sections of electrical systems to prevent current flow no direct conduction path is permitted, energy or information can still be exchanged between the sections by other means, such as capacitance, induction or electromagnetic waves, or by optical, acoustic or mechanical means. Galvanic isolation is used where two or more electric circuits must communicate, but their grounds may be at different potentials. It is an effective method of breaking ground loops by preventing unwanted current from flowing between two units sharing a ground conductor. Galvanic isolation is also used for safety,preventing accidental current from reaching ground through a person's body.



4.1 A transformer is the most widespread example of galvanic isolation

4.1.2Soft switching:

Switching transitions of the transistor occurring in favorable conditions such as device zero-voltage or zero-current is called as soft-switching. The benefits of soft-switching are reduced switching losses, switch stress, low electromagnetic interference and easier thermal management. These are essential features for high frequency operation of power converters. The DAB converter topology has been chosen as it features high power density, high efficiency, bidirectional power flow capability,inherent soft switching, galvanic isolation and low number of passive components. Hence the converter is a candidate for high power density aerospace applications for performance evaluation, input side of the converter is connected to the high voltage dc bus and output side of the converter is connected to the low voltageultra-capacitor. A DAB converter is modelled using SABER software. SABER simulation results under ZVS verified the soft switching performance of the DAB DC-DC converter.

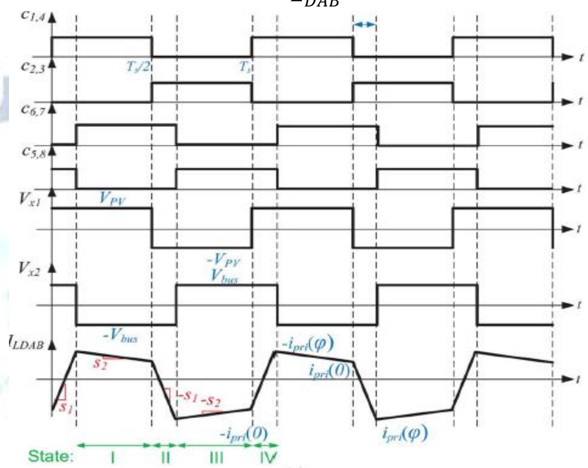
In addition, the DAB topology isbidirectional; therefore, the storage can be used to transferenergy to/from other elements in the grid. The average powerfrom $V_{PV}$to V_{bus}, i.e., P, is

$$P = \frac{V_{PV} V_{bus}}{\eta \omega_s L_{DAB}} \phi \left(1 - \frac{|\phi|}{\pi}\right)$$

where n is the transformer's turns ratio; and LDAB is the(DAB inductance, which is the sum of transformer's leakageinductance $L_{leak}$and an optional external inductance L_{ext}. φ isthe phase shift between the two bridges, and $\omega s= 2\pi fs$, where$f$sis the switching frequency.The switching waveforms of the DAB converter are shownin Fig. 4(a). The slopes of the DAB inductance current I_{LDAB}in switching states I and II are, respectively, calculated as

$$S_1 = \frac{V_{PV} + \frac{V_{bus}}{n}}{L_{DAB}}$$

$$S_2 = \frac{V_{PV} - \frac{V_{bus}}{n}}{L_{DAB}}$$



4.2 Switching waveform in DAB mode

In two-stage MIV architectures, Vbusis generally regulatedto a fixed voltage by the inverter stage. The reference voltage$V*$busis usually chosen to optimize efficiency at the nominaloperating point. It can be shown that the DAB converterachieves turn-on zero-voltage switching (ZVS) and maximumefficiency when$V_{bus}= nV_{PV}$, as the reactive circulating currentis minimized. Meeting this condition leads to $S_2= 0$,thereby resulting in full free-wheeling in I_{LDAB} during stateII

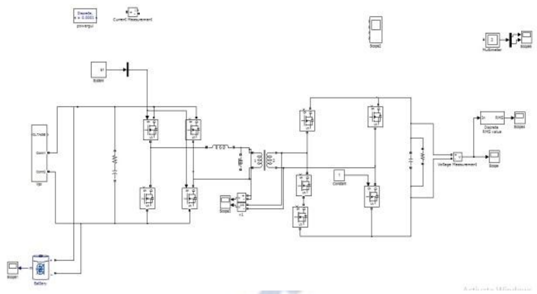
In order to minimize the losses in the DAB, the reference forthe dc-link voltage $V*$busis dynamically adjusted in the inverterstage such that $V*_{bus}= nV_{MPP}$, where $V_{MPP}$is the PV MPPvoltage. It is well known that V_{MPP}undergoes a relatively lowfluctuation of about 30% during the course of a typical day.This is in contrast to the PV current at MPP, i.e., IMPP, which isproportional to irradiance and thus has large-scale fluctuations,particularly on cloudy days

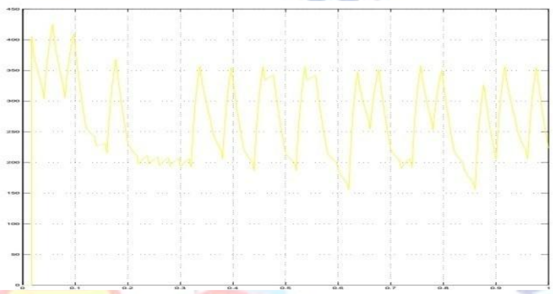
V. Simulation Results

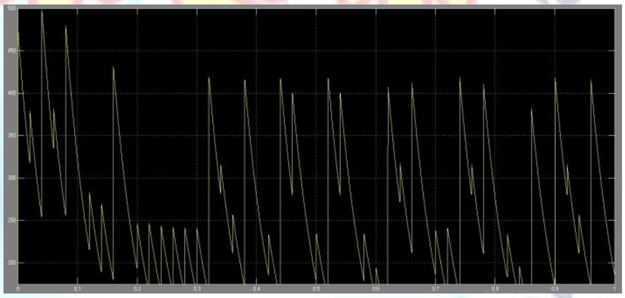
A prototype of the system was fabricatedon a custom printed circuit board, with power rating of 100W.The main specifications of the prototype are listed in Table I.A minimum frequency of 20 kHz is adopted in flyback modeto avoid interfering with the audible range, whereas a fixedfrequency of 195 kHz is adopted for DAB mode, based onoptimized efficiency. The DAB converter can be operated with lower frequencies without saturating the magnetic cores; however, reducing the switching frequency increases RMS currentsin the converter. Furthermore, the turnoff process happens athigher current values, and thus, the total switching losses donot scale down linearly with frequency. For example, reducingthe switching frequency by 50% increases the RMS current Inprimary, secondary, and active devices by about 38% at P=70W, which translates into≈90% more conduction losses,whereas the total switching losses are reduced by 22%.

The converters are digitally controlled using an onboardfield-programmable gate array. A custom planar transformer was designed to reduce the weight and profile of the prototype. The suboptimal general operation of the DABconverter without dynamicV_{bus} scaling .The steady-state waveforms in DAB mode with bus voltagescaling (V_{bus}=nV_{PV}) and flyback mode atP=70W andP=15W respectively.There are two interesting phenomena that are noticeable in flyback mode. First, the oscillations that are observed on the voltage across the DAB inductance, i.e., VLDAB, are due to the resonance of L_{DAB}With output capacitance of MOSFETson the primary side and the capacitance on the transformer's primary winding. Second,I_{LDAB}has two distinct rising slopes.The rising slope following turn-on is large, then reduces to S_3,as shown in the ideal waveforms. This happenswhenLmis not fully demagnetized by the start of the switching cycle in flyback mode. This effect whenthe flyback is operating in continuous conduction mode (CCM).

The initial rising slope of$I_{LDAB}$is equal to 1.$L_M$significantly increases at low magnetizing currents. This prevents the full demagnetization ofL_{min} one switching cycle. As a result, I_{LM}has a minimum valueof about 1 A. This effect can be mitigated by introducing an airgap in the transformer. This will reduce the reluctance of the core and linearizeLmfor the full operating range.The closed-loop dynamic response of flyback mode for a step change in P, while the dedicated integrated storage converter is off.F_{sis} increased in flyback mode bythe controller to accommodate the higher input power.The measured efficiency of the converter, i.e.,η, in bothmodes. A peak efficiency of 94% is achievedin DAB mode, whereas flyback mode has a superior efficiency up toP=40W. The power is limited in flyback mode dueto the maximum duty ratio of 50%. The design was carriedout such that the two efficiency curves intercept at a pointclose to the maximum transferable power in flyback mode. The operation is switched to DAB mode from flyback mode at thispoint for higher reference power values.







Proposed Nano Grid with Micro Inverters:

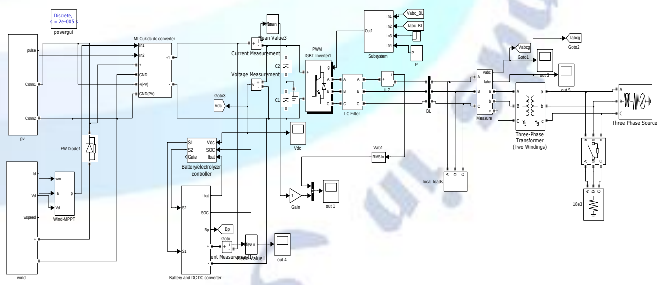


Fig: Proposed Simulation Circuit

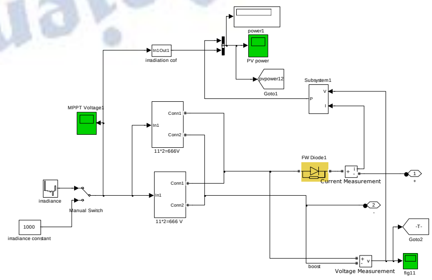


Fig: Modeling of PV

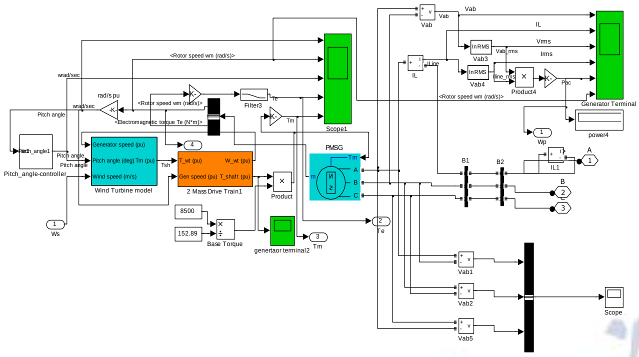


Fig:Modeling of Wind Energy Conversion System

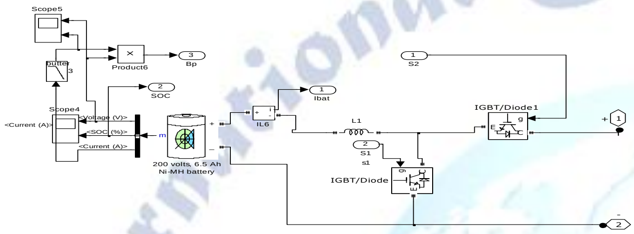


Fig: Battery with DC-DC Birectional Converter

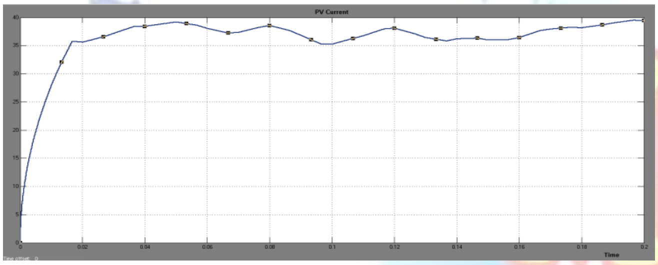


Fig: PV Current

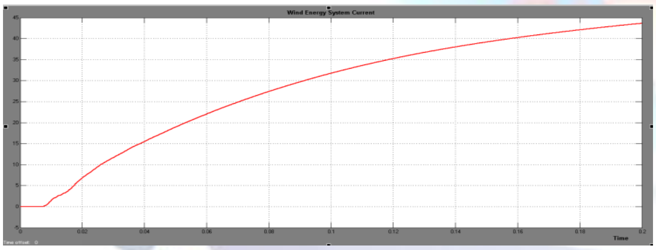


Fig:Wind Energy System Current

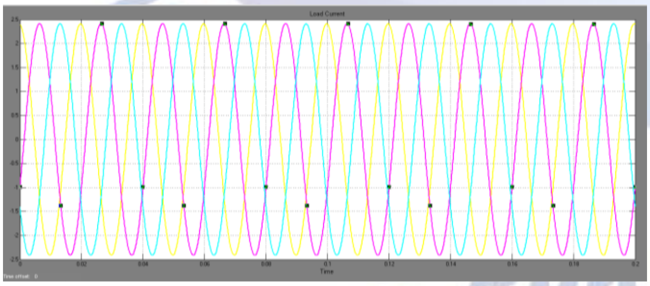
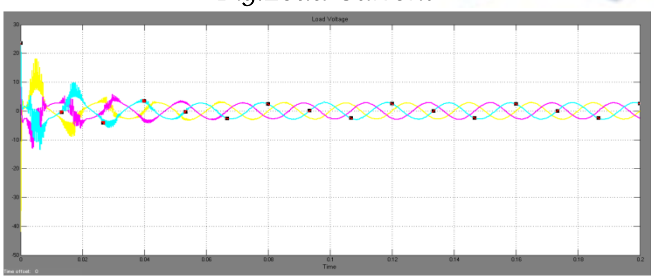


Fig:Load Current



Load Voltage

VI. CONCLUSION

A novel DAB switching scheme was introduced for the dc-dc stage of module integrated power converters for pv applications. The dual active bridge topology provides bidirectional power flow; however, it is generally suffers from poor efficiency and limited regulation accuracy at low power. The modified flyback switching scheme exhibits 8% higher efficiency than DAB mode at 10W, which comes at the cost of an additional switch. While flyback mode exhibits more core losses and conduction losses are less when compared to DAB mode, the switching losses are significantly reduced by eliminating most of the switching actions and reducing the frequency .In addition, it was shown that the flyback mode achieves higher accuracy in power regulation for low power levels compared to the DAB mode resulting in more stable operation and avoiding potential limit cycle oscillations.

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