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Brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system by using Fuzzy Logic controller

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Abstract

Objective: A buck-boost (BB)DC-DC converter is proposed for solar photovoltaic (SPV) array fed water pumping system using a permanent magnet brushless DC (BLDC) motor drive.

Statistical analysis: To design a BB converter with suitable voltage control, DC-DC boost and buck converters are cascaded such that it accomplishes the purpose of maximum power point tracking (MPPT) and soft starting of the BLDC motor**.**

Findings: The BB converter exhibits the advantages of both the boost and buck converters and interestingly emerges as a solution to problems associated with these converters in SPV applications. The good switch utilization, high efficiency, non-inverting output voltage and low stress on power devices are the features of BB converter. This paper deals with the starting, dynamic and steady state performances under varying atmospheric conditions and examines the effectiveness of the BLDC motor with the proposed BB converter for SPV based water pumping.

Application: This finding could be helpful to design the different types of converters in future and would be helpful to researcher and technology development.

Keywords: BLDC motor, SPV array, BB converter, VSI, INC-MPPT

I. INTRODUCTION:

Solar based photovoltaic (SPV) energy has developed as an elective wellspring of power era having quantities of points of interest. Also, the water pumping has turned into a cost powerful utilization of SPV energy now a days, particularly in remote areas and provincial territories[1,2]A three-phase induction (IM) is generally utilized as a part of SPV exhibit nourished water pumping for water system and local purposes because of its appropriateness for applications in tainted and disconnected zones, minimal effort, unwavering quality and low support prerequisite[3,4]. A DC motor is additionally utilized as a part of[5-7], yet attributable to a high upkeep necessity caused by the nearness of brushes and commutator, it is not favored for water pumping. Nonetheless, a confounded control of IM and high proficiency of a permanent magnet synchronous motor (PMSM) than an IM has persuaded the specialists to utilize a PMSM drive where a powerful submersible water pumping system is introduced[8-10]. A few endeavors in the zone of SPV arrayfed water pumping utilizing a synchronous reluctancemotor (SyRM) have been made in the writing.[11,12]. It has been watched that the SyRM can run satisfactorily for a constrained scope of solar oriented insolation level. Moreover, an exchanged reluctancemotor (SRM) has likewise not gotten much consideration for SPV exhibit sustained water pumping till presently, most likely because of a high torque swell and acoustic commotion issue related with this drive[13].In[14,15], the SRM is utilized in SPV exhibit based water pumping system also, satisfactorily operation even under the dynamic condition is guaranteed. On account of quantities of advantages of a permanent magnet brushless DC (BLDC) motor drive, for example, high productivity, long life, high unwavering quality, low radio frequencynoise and no upkeep[16],different analysts are concentrating on this drive for SPV exhibit based water pumping thus picked in this work. A BLDC motor is utilized to drive the water draw in light of SPV array in[17-19], which shows its reasonableness for water pumping. A DC-DC converter is regularly set between the SPV array and VSI (voltage source inverter) nourished BLDC motor pump with a specific end goal to track the ideal working purpose of the SPV array utilizing a most maximum power point tracking (MPPT) method[20-25]. Non-disconnected DC–DC buck, help, buck–boost, Cuk and SEPIC (Single Ended Primary Inductor Converter) converters utilized for MPPT in SPV applications are looked into and thought about in[26] and reasoned that a buck boost converter is most appropriate for the SPV system. On the other hand, buck-boost and Cuk converters have poor switch usage (most extreme switch use of 0.25 is acknowledged at obligation cycle = 0.5), high weight on power devices and modifying yield voltage [27]. These converters increment intricacy due to the related circuit for negative voltage criticism detecting which likewise backs off the system reaction [28]. So also, the power device of SEPIC converter likewise experiences high voltage stretch. Other than that, the Cuk and SEPIC converters have the high number of segments, which add to their fundamental disadvantage. A DC-DC support converter is utilized as a part of [19,29-30] as a middle of the road control converter to enhance energy transformation proficiency of the BLDC motor driven SPV exhibit nourished water pumping system. Having realized that the boost converter dependably expands the voltage level at its yield and consequently the delicate beginning of BLDC motor with this converter is impractical, so it is not prescribed. A DC-DC buck converter is not utilized so far in SPV array nourished water pumping be that as it may, utilizing this converter requires a vast and costly info capacitor to get a swell free information current [26]. Amassing the benefits of the boost and buck converters, for example, great switch use, high proficiency, non-modifying information and yield voltage and low weight on Power devices[27].a twofold switch buck-support converter is utilized for the front phase of the two-arrange SPV gridconnected inverter in [31-32]. A buck converter is put prior to a boost converter in this twofold switch buck-help converter. Setting the boost converter before the buck converter offers extra focal points in SPV array nourished BLDC motor driven water pump. The arrangement of the boost converter at the front end of buck converter and yield of SPV exhibit makes the information current persistent in light of the fact that the info inductor of the boost converter functions as a swell channel. Also, the situation of the buck converter at the back end of the boost converter and before the VSI adds to get the consistent yield present and delicate beginning of the BLDC motor. In this way, a boost buck (BB) DC-DC converter which takes after the previously mentioned grouping of falling the boost also, buck converters is proposed to accomplish the delicate beginning of the BLDC motor and swell free information current. The BB converter is constantly worked in consistent conduction mode (CCM) to decrease the stress on the devices and parts. The proposed BB converter, working as a non-upsetting buck-help converter likewise gives an extra element of center stage voltage control of the boost and buck converters. The itemized operation and working standard of the proposed BB converter are clarified in the accompanying segments. The beginning, dynamic and enduring state exhibitions of an electronically commutated BLDC motor combined with a water draw encouraged by SPV array BB converter are examined under the variety of environmental conditions through simulation comes out through matlab.

II. SYSTEM CONFIGURATION

BB converter nourished BLDC motor drive coupled to a water pump. A SPV exhibit goes before the BB converter which is associated to a VSI nourishing the BLDC motor pump. Utilizing a MPPT calculation, MPP of the SPV exhibit is followed by working the IGBT (Insulated Gate Bipolar Transistor) switch of the boost converter. An extra voltage control is given at the contribution of buck converter which produces the exchanging beats for the IGBT switch of the buck converter. An inbuilt encoder on the BLDC motor produces the Hall Effect signals which are additionally decoded to create the exchanging beats for the VSI by the supposed electronic compensation of

BLDC motor. The design and working rule of each phase of the design are expounded in the accompanying segments.

III. WORKING PRINCIPLE OF PROPOSED BB CONVERTER

Figure 2(a) represents the SPV array fed BB converter

Connected to the VSI fed BLDC motor pump. All the four

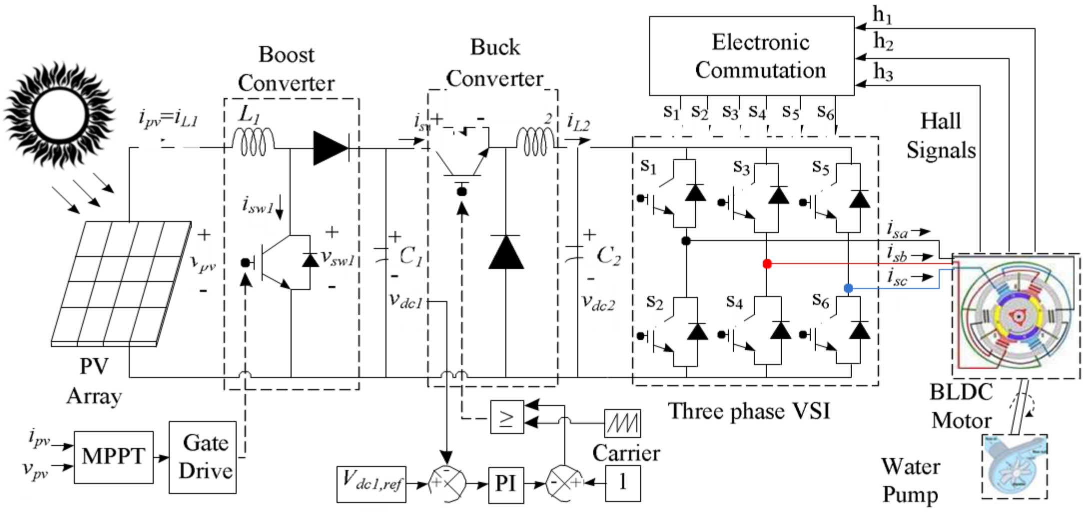


Figure 1: Configuration of the SPV array-BB converter fed BLDC motor driven water pumping system

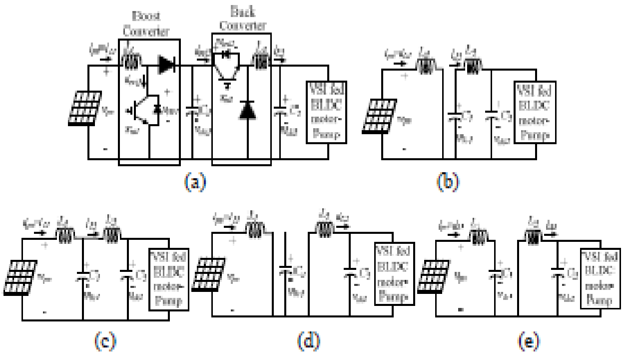


Figure 2 Two mode operation of the BB converter, (a) SPV array fed BB converter, (b) When *sw1* and *sw2* are on, (c) When *sw1* is off and *sw2* is on, (d)When *sw1* is on and *sw2* is off, (e) When *sw1* and *sw2* are of BB converter are considered for elaboration of the operation and working guideline.

As indicated by the position of switches, the operation of the converter is sorted in two modes; (i) synchronized control mode and (ii) joined control mode. (i) When the position of both the switches is same i.e. both the switches are either on or off, the converter works in the synchronized control mode. (ii) When the position of both the switches is diverse i.e. one is on and other is off, the converter works in consolidated control mode. Both the switches can be controlled autonomously. Figures 2(be) demonstrate the two mode operation of the BB converter, where, L1, L2, C1 and C2 are the information inductor, yield inductor, middle of the road capacitor and the yield capacitor of BB converter individually condition. At the point when the converter works in synchronized control mode and both the switches are on as appeared in Figure. 2(b), L1 and L2 store energy provided by the SPV exhibit and current iL1 and iL2 rise while C1 releases and shows up as a voltage hotspot for the buck converter, hence vdc1 falls. Presently, when sw1 is off however sw2 is still on as appeared in Figure 2(c), the converter works in consolidated control mode; L1 exchanges some measure of the put away energy to C1 and remaining energy to the load through the buck converter, consequently vdc1 increments extremely gradually in light of the fact that the rate of charging of C1 lessens; iL1 falls and iL2 still ascents. Next, when sw1 is on yet sw2 is off as appeared in Figure 2(d), L1 stores energy bringing about the ascent of iL1. L2 exchanges the put away energy to the load, bringing about the fall of iL2; vdc1 diminishes gradually in light of the fact that C1 is detached to the circuit and the rate of releasing of C1 diminishes. At the point when both the switches are off as appeared in Figure 2(e), the converter again enters in synchronized control mode; L1 exchanges the put away energy to C1. L2 exchanges the put away energy to the load furthermore, consequently iL1 and iL2 fall yet vdc1 rises. The variety in vdc2 is precisely comparative as in buck converter operation [27] for all the mixes of sw1 and sw2. At the point when the converter works in synchronized control mode and both the switches are off as appeared in Figure 2(e), L1 exchanges the put away energy to C1 bringing about the ascent of vdc1. Presently, when sw1 is on yet sw2 is still off as appeared in Figure 2(d), the converter works in consolidated control mode; vdc1 diminishes gradually in light of the fact that C1 is separated to the circuit and the rate of releasing of C1 diminishes. Next, when sw1 is off yet sw2 is on as appeared in Figure 2(c), L1 exchanges some measure of the put away energy to C1 and remaining energy to the load by means of the buck converter, subsequently vdc1 increments gradually in light of the fact that the rate of charging of C1 decreases. At the point when both the switches are on as appeared in Figure 2(b), the converter again enters synchronized control mode. C1 releases and shows up as a voltage hotspot for the buck converter, along these lines vdc1 falls

$$\boxed{V_{dc1} = \frac{1}{1-D_1} V_{pv}} \quad (1)$$

Similarly, when the buck converter operates in continuous conduction mode, in terms of *Vdc2*, *Vdc1* is expressed as

$$V_{dc1}=\frac{1}{D_2}V_{dc2} \tag{2}$$

where *Vdc1* and *Vdc2* are average values of output voltages of boost-buck converter. Solving (1) and (2) yields a relation between output and input voltages of this converter as,

$$\frac{V_{dc2}}{V_{pv}}=\frac{D_2}{1-D_1} \tag{3}$$

It is clear from (3) that the BB converter operates as a noninverting buck-boost converter with independent control of both the boost and buck converters.

IV. Design OF PROPOSED SYSTEM

The proposed system comprises of a SPV array, a BB converter, VSI and a BLDC motor coupled to a water pump. The parts of the SPV array, BB converter and the water pump are designed according to the necessity of the water pump regulation nourished by the SPV array. A BLDC motor of 4.4 kW control rating is chosen to drive a water pump and different segments of the proposed system are composed in like manner as explained in the accompanying areas.

A. Design of SPV Array

The SPV exhibit of 5.1 kW most extreme power rating, to some degree more than required by the motor pump system is composed in perspective of the misfortunes in the converter and the motor. The determinations of HBL Power Systems Ltd. make solar oriented PV module, comprises of 36 cells associated in series are utilized to design the SPV array of greatest power rating, Pmpp = 5.1 kW at the standard estimation of solarlight based insolation (1000 W/m2). This module has open circuit voltage and short circuit current of 21 V and 7.1 A separately. In like manner, the voltage, Vm, current, Im and power, P of this module at MPP are 17 V, 6 An and 100 W separately. Voltage of the SPV exhibit at MPP is considered as, Vmpp = 170 V according to the prerequisite of the proposed system. Presently, the current of the SPV exhibit at MPP, Impp is assessed as,

$$I_{mpp}=\frac{P_{mpp}}{V_{mpp}}=\frac{5100}{170}=30A \tag{4}$$

Number of modules connected in series are as

$$N_s=\frac{V_{mpp}}{V_{in}}=\frac{170}{17}=10 \tag{5}$$

Number of modules connected in parallel is as

$$N_p=\frac{I_{mpp}}{I_{in}}=\frac{30}{6}=5 \tag{6}$$

B. Design of BB Converter

The voltage at the input of the buck converter which is the output voltage of the boost converter is maintained at *Vdc1* = 225 V. On the other hand, *Vmpp* appears as the input voltage of boost converter as, *vpv* = *Vmpp* = 170 V. Using, *D1* is estimated as,

$$D_1=\frac{V_{dc1}-V_{pv}}{V_{dc1}}=\frac{225-170}{225}=0.24 \tag{7}$$

switching frequencies fsw1 = fsw2 = 20 kHz are chosen. Such a high benefit of exchanging recurrence is chosen to limit the measure of swells in iL1, iL2 and vdc1 even with the lower esteems of the converter components. The current of the SPV exhibit at MPP, Impp moves through L1 bringing about a normal current, IL1 = ipv = Impp = 30 A. Constraining the present swell, □IL1 in iL1 at 8%, L1 is assessed as

$$L_1=\frac{V_{pv*D_1}}{f_{sw1*\Delta I_{L1}}}=\frac{170*0.24}{20000*30*0.08}=0.85\text{mH}\approx 1\text{mH} \tag{8}$$

Neglecting the converter power loss, average current at the output of boost converter, *Idc1* = *Pmpp*/*Vdc1* = 5100/225 = 22.67A. Limiting the voltage ripple, *Vdc1* in *vdc1* at 6%, *C1* is estimated as

$$C_1=\frac{I_{dc1*D_1}}{f_{sw1*\Delta V_{dc1}}}=\frac{22.64*0.24}{20000*225*0.06}=20\mu F \tag{9}$$

The average value of the output voltage of the buck converter which is the DC voltage rating of the BLDC motor is as, *Vdc2* = 200 V. Using (2), *D2* is estimated as,

$$D_2=\frac{V_{dc2}}{V_{dc1}}=\frac{200}{225}=0.89 \tag{10}$$

Neglecting, converter power losses, average current flowing through *L2* is as, *IL2* = *Pmpp*/*Vdc2* = 5100/200 = 25.5 A. Limiting the current ripple, *IL2* in *iL2* at 5%, *L2* is estimated as

$$L_2=\frac{V_{dc1*(1-D_{2})*D_2}}{f_{sw2*\Delta I_{L2}}}=\frac{225*(1-0.89)*o.89}{20000*25.5*0.05}=0.06 \quad (11)$$

The most astounding and least frequencies of the VSI yield voltage to the motor are considered to appraise the estimation of DC interface capacitor, C2. The most astounding estimation of VSI yield voltage recurrence, h (in rad/sec.) is computed relating to the appraised speed of the motor while the most reduced estimation of VSI yield voltage recurrence, l (in rad/sec.) is ascertained comparing to the base speed of an motor required to pump the water (N = 1100 rpm) as,

$$W_h=2*\pi*f=2*\pi*\frac{N_{rated}*P}{120}$$
$$=2*\pi*\frac{2000*6}{120}=628.3 rad/sec \quad (12)$$

$$W_l=2*\pi*f=2*\pi*\frac{N*P}{120}$$
$$=2*\pi*\frac{1100*6}{120}=345.6 rad/sec \quad (13)$$

where *f* is the frequency of VSI output voltage in Hz; *Nrated* is rated speed of the BLDC motor; *P* is the numbers of poles in the BLDC motor. Neglecting a very low current flowing through *C2*, an average current flowing through the DC link of VSI, *Idc2* is equal to *IL2* i.e. *Idc2* = *IL2* = 25.5 A. Since 6th harmonic component of the

motor voltage appears on the DC link of VSI, limiting the voltage ripple, *Vdc2* in *vdc2* at 10%, *C2* is estimated

corresponding to *Wh* and *Wl* as, *C2* (corresponding to W*h*) =

$$C_2(\text{corresponding to } W_h)=\frac{I_{dc2}}{6*W_{h*\Delta V_{dc2}}}$$
$$=\frac{25.5}{6*628.3*200*0.1}=338\mu F \quad (14)$$

$$C_2(\text{corresponding to } W_l)=\frac{I_{dc2}}{6*W_{l*\Delta*V_{dc2}}}$$

$$=\frac{25.5}{6*345.6*200*0.1}=615\mu F \qquad (15)$$

To ensure the satisfactory execution of the BLDC motor pump system, the higher estimation of C2 = 615μ F 620 F is chosen out of the two evaluated esteems. The proposed BB converter is outlined according to these assessed estimations of the segments.

C. design of Water Pump

A water pump is composed and chosen on the premise of evaluated speed and energy of the BLDC motor. Since the evaluated speed, Nrated and energy of the motor, Pm are 2000 rpm and 4.4 kW

V. CONTROL OF PROPOSED SYSTEM

The control of the proposed SPV array sustained BB converter worked VSI-BLDC motor for water pumping system is grouped into three sections as takes after.

A. Most extreme Power Point Tracking

An incremental conductance (INC) MPPT calculation is utilized as a part of request to work the SPV array at its ideal working point. This strategy is less confounded by commotion and the system flow and has a decent following execution under the quickly changing natural condition.

B. Information Voltage Control of Buck Converter

As appeared in Figure 1, an extra voltage control include is given at the information phase of buck converter, so that the buck converter dependably encounters a consistent voltage at its information, notwithstanding the variety in climatic condition. The reference input voltage, Vdc1,ref is contrasted and the detected input voltage, vdc1 of the buck converter and blunder is passed through a corresponding fundamental (PI) controller. The yield of the PI controller is contrasted and 1 which is the most extreme conceivable estimation of an obligation cycle. This correlation gives the obligation cycle of buck converter, D2 which is additionally contrasted and the high recurrence transporter wave to create the exchanging beats for the switch of buck converter.

VI. EQUIPMENT VALIDATION OF PROPOSED SYSTEM

The different exhibitions of INC-MPPT, BB converter what's more, BLDC motor pump are approved on a created model of the proposed system. The system constitutes a SPV exhibit test systemtime controller (dSPACE 1104) to perform MPPT and electronic compensation, BLDC motor (Motor Power Organization make) combined with a DC generator (Benn make) furthermore, resistive load bank. A volumetric pump is acknowledged by driving the DC generator nourishing resistive load bank. Consequently, this motor generator-regulation set ends up plainly undifferentiated from a volumetric pump, having corresponding relationship amongst torque and speed. Due to the rating requirements, tests are done with a BLDC motor of 1.3 kW,

3000 rpm. Point by point particulars of SPV array, BB converter what's more, BLDC motor utilized for test are given in Appendices. A voltage sensor (LV-25P) and a present sensor (LA-55P) are utilized for MPPT control. To give the segregation between genuine time controller and door drivers, the optocouplers (6N136) are utilized. Exploratory execution and operation of the proposed system are broke down in the accompanying areas.

A. Most extreme Power Point Tracking (MPPT) of SPV Array

Test comes about for MPPT of SPV array at 1000 W/m2 and 200 W/m2. The recorded ppv - vpv and ipv - vpv attributes are shown in Figure 3(a) unmistakably express that the proposed system dependably works at MPP paying little respect to the variety in solar based insolation level. Following effectiveness for both the insolation level is 99.96%.

B. Consistent State Performance at 1000 W/m2

The recorded waveforms of different files of SPV array, BB converter and BLDC motor under consistent state at 1000W/m2 are appeared in Figure 3 and expounded in the accompanying subsections. All the records come to their evaluated esteems at the standard solar oriented insolation level i.e. 1000 W/m2.

1) Performance of SPV Array Kept up at 300 V. These records compare to the operation of the exhibit at MPP. At MPP, ipv = 6.2 An and ppv = 1.5 kW are watched. Also, vpv = 241.5 V is helped to vdc1 = 300 V.

2) Operation of BB Converter crest current anxiety, isw1 and isw2 are 9 An and 5 An individually .Bringing about a restricted weight on the gadgets. The switches sw1 furthermore, sw2 work at obligation proportion of 0.2 and 0.95 individually, legitimizing better switch use of both the switches. It might be noticed that the recorded isw1 and isw2 contain the current of decoupled capacitor specifically screwed on a similar module. Way to the IGBT and diode has not been open for current estimation. Henceforth a little ringing in isw1 and isw2 is plainly obvious.

3) Performance of BLDC Motor: demonstrates the stator current of stage "an," isa, and speed, N alongside vdc1 and vdc2. vdc1 = 300 V is decreased to evaluated DC voltage of the BLDC motor, vdc2 = 285 V, by buck operation, at the DC connection of VSI . The motor draws the evaluated current of 4.3 An and keeps running at its evaluated speed of 3000 rpm, bringing about the water pumping with full limit.

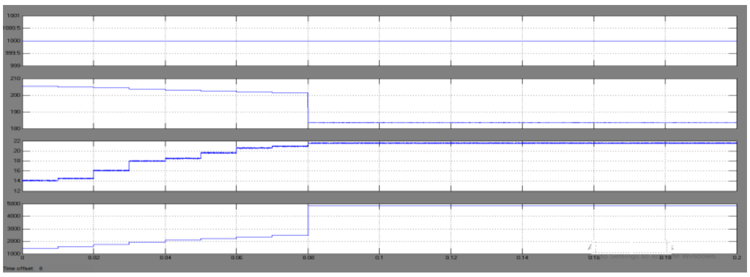
C. Beginning Performance of Proposed System

ipv, vdc1, vdc2 and isa at the beginning for 1000 W/m2 and 200 W/m2 individually. The BLDC motor draws allowable beginning current at both the standard and least solar oriented insolation level. As the MPPT calculation moves working point towards the MPP, all these records additionally come to their relentless state esteems. The PI controller conveys vdc1 to its set esteem of 300 V. In addition, the speed is not reduced underneath 1100 rpm regardless, as the motor accomplishes 1190 rpm at 200 W/m2, affirming the continuous water pumping.

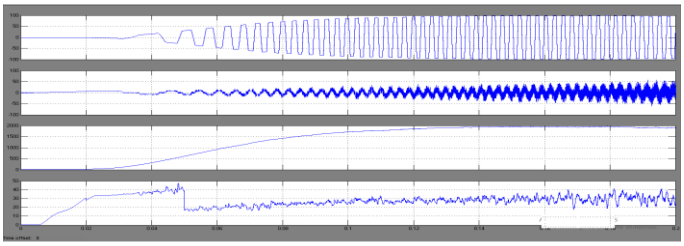
D. Dynamic Performance of Proposed System

Dynamic conduct of different execution lists, ipv, vdc1, vdc2 and isa under the powerfully differing solar based insolation level from 500 W/m2 to 1000 W/m2 are shown in Figure 3(b) and the other way around individually. This expansive variety is considered to show the adequacy of the proposed system at the very least condition. It is plainly watched that the MPP is adequately followed and the execution is not influenced by the unforeseen elements. The change in solar based irradiance from 500 W/m2 to 1000 W/m2 brings about the adjustment in ipv vdc2 from 190 V to 285 V and isa The PI controller dependably manages vdc1 to its set estimation of 300 V independent of the variety in solar based insolation level, which likewise legitimizes the best possible working of center stage voltage control circle. In this manner the water pumping is most certainly not hindered by any stretch of the imagination. The characteristics are shown in figure 3 and 4.

RESULTS:

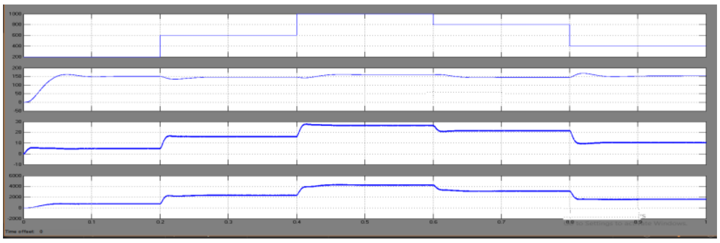


(a)

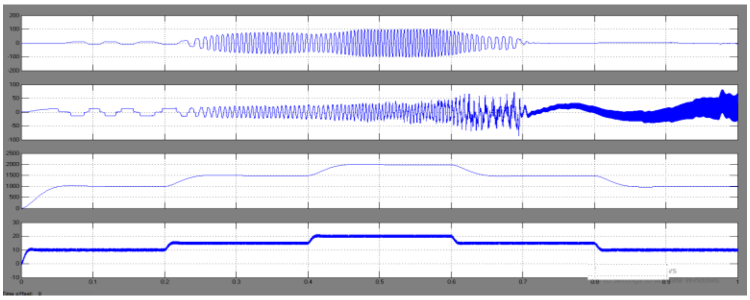


(b)

Figure3. Performance of SPV array-BB converter fed VSI BLDC motor pump system under constant irradiation solar insolation level conditions, (a)SPV array variables,(b)BLDC motor-pump variables



(a)



(b)

Figure4. Performance of SPV array-BB converter fed VSI BLDC motor pump system under Variable irradiation solar insolation level conditions, (a)SPV array variables, (b)BLDC motor-pump variables

Efficiency estimation of proposed system

By considering the experimental data, efficiency of the proposed SPV array fed BLDC motor-pump, subjected to the variation in atmospheric condition is as indicated the following table. Where P_{PV} , P_m and η are respectively the power of SPV array at MPP, mechanical power output of the BLDC motor and efficiency. The efficiency at 200 W/m^2 is 78.3% While maximum efficiency of 86.8% is obtained at 1000W/m^2.

Table. Efficiency estimation of proposed system

S(W/m^2)	P_{pv} (W)	P_m (W)		η(%)	
		PI	FUZZY	PI	FUZZY
200	275	214.5	215.4	78	78.3
300	430	347	348.6	80.6	81
450	595	486	489	81.6	82.1
500	750	620	623	82.6	83
600	880	735	738	83.5	83.8
700	1020	868	870	85.0	85.2
800	1180	1009	1014	85.5	85.9
900	1330	1145	1149	86	86.3
1000	1500	1300	1302	86.6	86.8

VIII. CONCLUSIONS

The DC-DC help buck converter for SPV array fed BLDC motor driven water pump has been proposed. The finish system has been composed, demonstrated and reproduced in MATLAB/Simulink condition and actualized on a created equipment model. Using every one of the properties of both the boost and buck converters and interfacing these two converters in a proper way, another BB converter with the low esteemed parts has been composed and worked in CCM. Functioning as a non-transforming buck-help converter, the proposed BB converter has wiped out the disadvantages of the buck, boost and topologies of buck-help converters utilized as a part of SPV based applications. The water pumping has been achieved indeed, even at the base sunlight based insolation level and the beginning current of the motor has been controlled inside the passable run. In addition, key recurrence exchanging of the VSI has stayed away from the high recurrence exchanging misfortunes. The exhibited reenactment and exploratory exhibitions of the proposed system at beginning, dynamic and consistent state have demonstrated its appropriateness for the SPV array based water pumping

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