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Zeta Converter Based Solar PV Array Fed Water Pumping System by BLDC Motor

Somen Dey
Department of Electrical and Electronics Engineering, Avanthi Institute of Engineering & Technology, Andhra Pradesh 531113, India.

G Prashanth
Department of Electrical and Electronics Engineering, Avanthi Institute of Engineering & Technology, Andhra Pradesh 531113, India.

ABSTRACT

A zeta converter is utilized in order to extract the maximum available power from the SPV array. The proposed control algorithm eliminates phase current sensors and adapts a fundamental frequency switching of the voltage source inverter (VSI), thus avoiding the power losses due to high frequency switching. No additional control or circuitry is used for speed control of the BLDC motor.. The proposed water pumping system is designed and modeled such that the performance is not affected under dynamic conditions.This paper proposes a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system.The speed is controlled through a variable DC link voltage of VSI. An appropriate control of zeta converter through the incremental conductance maximum power point tracking (INC-MPPT) algorithm offers soft starting of the BLDC motor.

INTRODUCTION

The water pumping, a standalone application of the SPV array generated electricity is receiving wide attention now a days for irrigation in the fields, household applications and industrial use. Although several researches have been carried out in an area of SPV array fed water pumping, combining various DC-DC converters and motor drives, the zeta converter in association with a permanent magnet brushless DC (BLDC) motor is not explored precisely so far to develop such kind of system.The drastic reduction in the cost of power electronic devices and annihilation of fossil fuels in near future invite to use the solar photovoltaic (SPV) generated electrical energy for various applications as far as possible. However, the zeta converter has been used in some other SPV based applications. Moreover, a topology of SPV array fed BLDC motor driven water pump with zeta converter has been reported and its significance has been presented more or less in. Nonetheless, an experimental validation is missing and the absence of extensive literature review and comparison with the existing topologies, have concealed the technical contribution and originality of the reported work. The merits of both BLDC motor and zeta converter can contribute to develop a SPV array fed water pumping system possessing a potential of operating satisfactorily under dynamically changing atmospheric conditions.

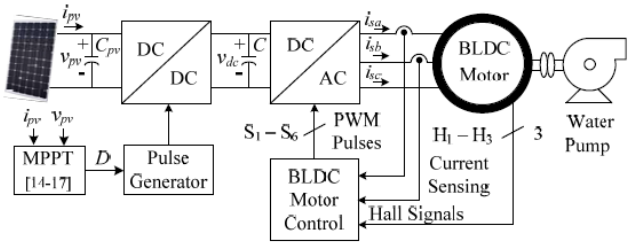

Fig. 1 Conventional SPV fed BLDC motor driven water pumping system

Fig.1.1 Conventional SPV fed BLDC motor driven water pumping system [21].

To overcome these problems and drawbacks, a simple, cost-effective and efficient water pumping system based on SPV array fed BLDC motor is proposed, by modifying the existing topology (Fig. 1) to as shown in Fig. 2. A zeta converter is utilized in order to extract the maximum power available from a SPV array, soft

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starting and speed control of BLDC motor coupled to a water pump. Due to a single switch, this converter has very good efficiency and offers boundless region for MPPT. This converter is operated in continuous conduction mode (CCM) resulting in a reduced stress of its power devices and components. Furthermore, the switching loss of VSI is reduced by adopting fundamental frequency switching resulting in an additional power saving and hence an enhanced efficiency. The phase currents as well as the DC link voltage sensors are completely eliminated, offering simple and economical system without scarifying its performance. The speed of BLDC motor is controlled, without any additional control, through a variable DC link voltage of VSI. Moreover, a soft starting of BLDC motor is achieved by proper initialization of MPPT algorithm of SPV array. These features offer an increased simplicity of proposed system.

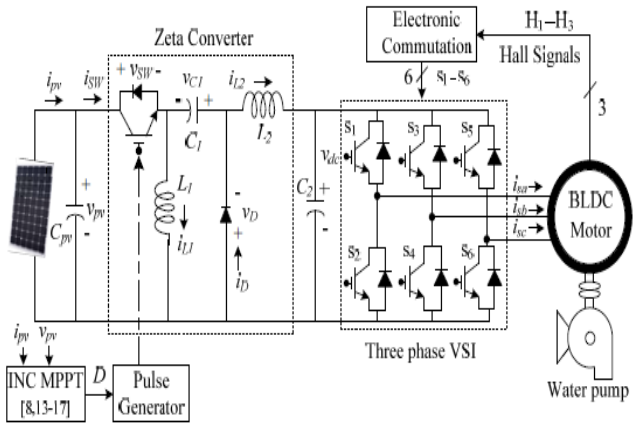

Fig. 2 Proposed SPV-Zeta converter fed BLDC motor drive for water pump.

The advantages and desirable functions of zeta converter and BLDC motor drive contribute to develop a simple, efficient, cost-effective and reliable water pumping system based on solar PV energy. Simulation results using MATLAB/Simulink and experimental performances are examined to demonstrate he starting, dynamics and steady state behavior of proposed water pumping system subjected to practical operating conditions. The SPV array and BLDC motor are designed such that proposed system always exhibits good performance regardless of solar irradiance level.

1.2. CONFIGURATION OF PROPOSED SYSTEM

The structure of proposed SPV array fed BLDC motor driven water pumping system employing a zeta converter is shown in Fig. 2. The proposed system consists of (left to right) a SPV array, a zeta converter, a VSI, a BLDC motor and a water pump. The BLDC motor has an inbuilt encoder. The pulse generator is used to operate the zeta converter. A step by step operation of proposed system is elaborated in the following section in detail.

1.3. OPERATION OF PROPOSED SYSTEM

The SPV array generates the electrical power demanded the motor-pump. This electrical power is fed to the motor-pump via a zeta converter and a VSI. The SPV array appears as a power source for the zeta converter as shown in Fig. 2. Ideally, the same amount of power is transferred at the output of zeta converter which appears as an input source for the VSI. In practice, due to the various losses associated with a DC-DC converter [23], slightly less amount of power is transferred to feed the VSI. The pulse generator generates, through INC-MPPT algorithm, switching pulses for IGBT (Insulated Gate Bipolar Transistor) switch of the zeta converter.

The INC-MPPT algorithm uses voltage and current as feedback from SPV array and generates an optimum value of duty cycle. Further, it generates actual switching pulse by comparing the duty cycle with a high frequency carrier wave. In this way, the maximum power extraction and hence the efficiency The VS, converting DC output from a zeta converter into AC, feeds the BLDC motor to drive a water pump coupled to its shaft.

The VSI is operated in fundamental frequency switching through an electronic commutation of BLDC motor assisted by its built-in encoder. The high frequency switching losses are thereby eliminated, contributing in an increased efficiency of proposed water pumping system.

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EXISTING SYSTEM:

The PV inverters dedicated to the small PV plants must be characterized by a large range for the input voltage in order to accept different configurations of the PV field. This capability is assured by adopting inverters based on a double stage architecture where the first stage, which usually is a dc/dc converter, can be used to adapt the PV array voltage in order to meet the requirements of the dc/ac second stage, which is used to supply an ac load or to inject the produced power into the grid. This configuration is effective also in terms of controllability because the first stage can be devoted to track the maximum power from the PV array, while the second stage is used to produce ac current with low Total Harmonic Distortion (THD).

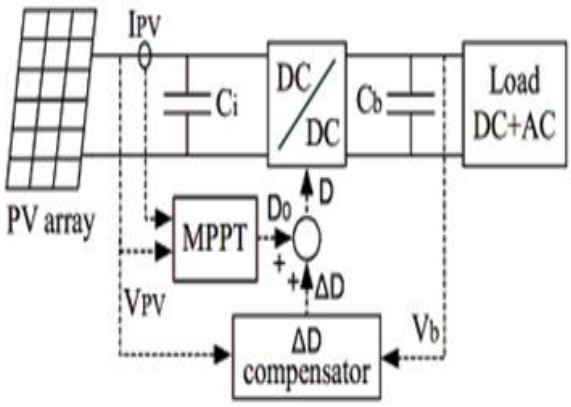

Fig 1.3 existing system of spv array fed water pumping system

DRAWBACKS:

- There is no dynamic response.
- High Total harmonic Distortion (THD).

PROPOSED SYSTEM:

Proposed SPV array fed water pumping system with an incremental conductance (INC) MPPT algorithm is used to operate the zeta converter such that the SPV array always operates at its MPP and the BLDC motor experience a reduced current at the starting. A three phase voltage source inverter (VSI) is operated by fundamental frequency switching for the electronic commutation of BLDC motor. Simulation results using MATLAB/Simulink software is examined to demonstrate the starting, dynamics and steady state behavior of the proposed water pumping system subjected to the random variation in the solar irradiance. The SPV array is designed such that the proposed system always exhibits satisfactory performance regardless of the solar irradiance level or its variation.

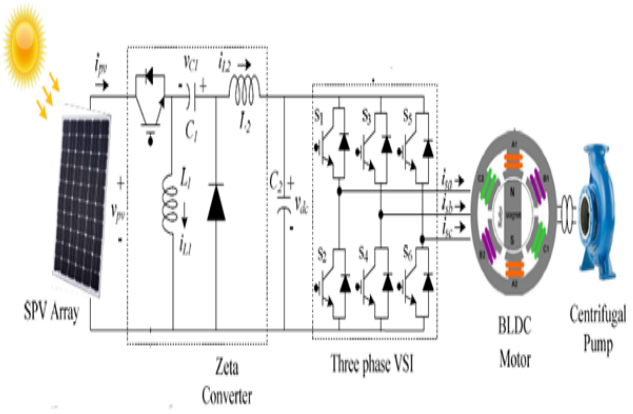

Fig 1.4 proposed system of spv array fed water pumping system

ADVANTAGES:

- Belonging to the family of buck-boost converters, the zeta converter can be operated either to increase or to decrease the output voltage.
- The aforementioned property also facilitates the soft starting of the BLDC motor unlike a boost converter which habitually step-up the voltage level at its output, not ensuring the soft starting.
- Unlike a simple buck-boost converter, the zeta converter has a continuous output current. The output inductor makes the current continuous and ripples free.
- Reduces the complexity and probability of slow down the system response

APPLICATIONS:

Household applications and industrial usage.

Solar photovoltaic (spv) generated electrical energy applications

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BLOCK DIAGRAM:

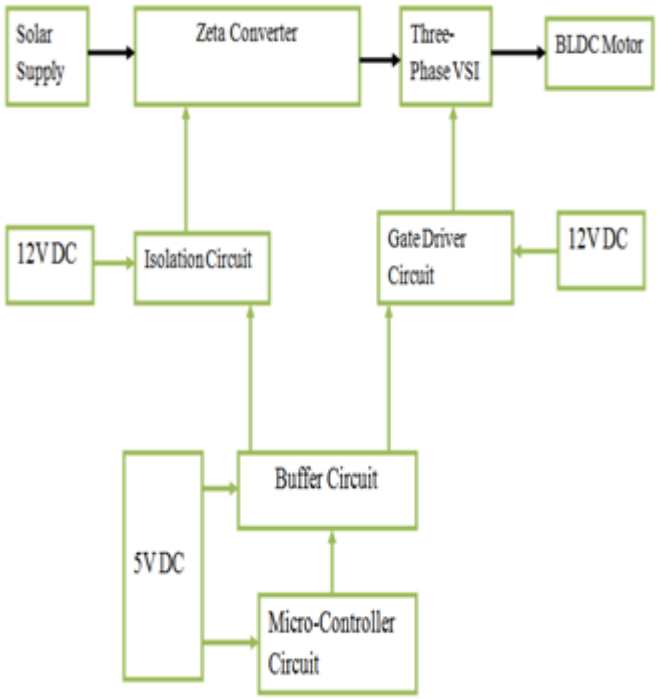

Fig 1.5block diagram of proposed system

POWERQUALITYIMPROVEMENTSINAZETACONVERTR

Thisimplemented conceptdealswithareducedsensorconfigurationofapowerfactorcorrection (PFC)basedzetaconverter for brushlessDC(BLDC)motordriveforlowpowerapplications .ThespeedoftheBLDCmotoriscontrolledbyvaryingthe dc-linkvoltageofthevoltagesourceinverter(VSI)feedingBLDCmotordrive.Alow-frequencyswitchingoftheVSIis usedforachievingtheelectroniccommutationofBLDCmotorforreducedswitchinglosses.ThePFC-basedzetaconverteris designedtooperateindiscontinuousinductorcurrentmode;thusutilisingavoltagefollowerapproachwhichrequiresasingle voltagesensorfordc-linkvoltagecontrol andPFCoperation.BrushlessDC(BLDC)motor isanidealmotorforlowand mediumpowerapplications becauseofitshighefficiency, highenergydensity,hightorque/inertia ratio,low maintenancerequirement andawiderangeofspeedcontrol. It is a three phase synchronousmotor with three phasewindingsonthestatorandpermanent magnetsonthe rotor.Itisalsoknownaselectronicallycommutatedmotor astherearenomechanical brushesandcommutator assembly,rather anelectroniccommutationbasedonrotor positionsensedbyHall-Effectpositionsensorisused.Itfindsapplications inawiderangeofhousehold appliances,industrial tools,heating,ventilation andair conditioningandmanyothers.

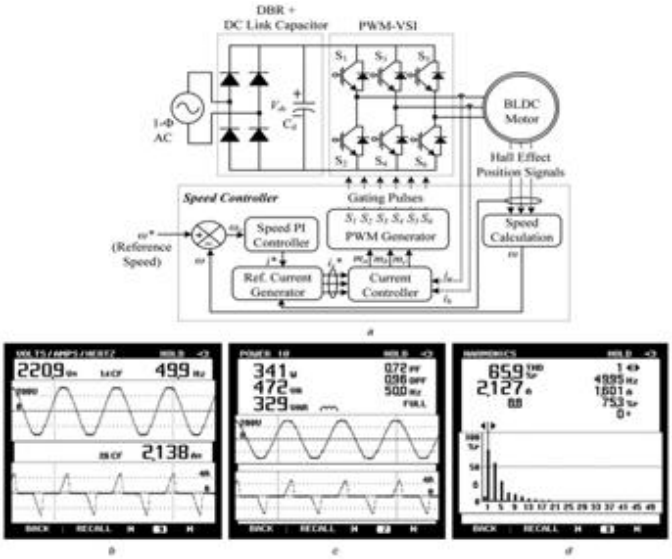

Fig. 3.1 MeasuredpowerqualityindicesforconventionalDBRfedBLDCmotordrive

Moreover, sensorreduction inaPFC-based BLDCmotor driveisrequiredforreducingthecostofcompletedrive. The PFC converter can be designed to operate in continuous inductor current mode (CICM) or discontinuous inductor current mode (DICM) operation .ThePFCconverter operatinginCICMusingacurrent multiplier approach requires sensing of dc-link voltage (V_{dc}), supply voltage (v_s) and input current (i_{in}). An inherentPFC is achieved in PFC converteroperating in DICMusingavoltagefollower approach;anditrequires sensingofdc-linkvoltage(V_{dc}), hencerequiringasingle voltagesensor.

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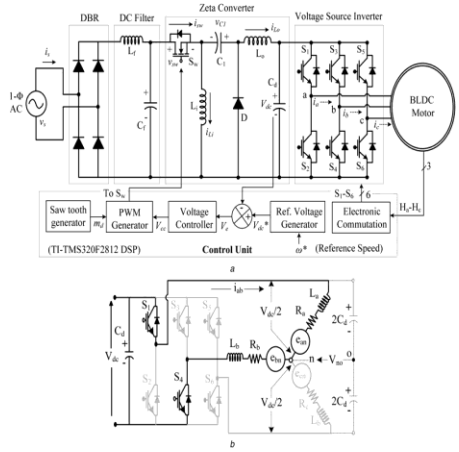
ProperselectionofaPFCconverter isrequiredfor achievingawiderangeofspeedcontrol ofBLDCmotorby varyingthedc-link voltage.AwidelyusedboostPFC converterisnotsuitableforthisapplication becauseofits limitation ofboostingthevoltagehigherthaninputvoltage. HencetheoperationofBLDCmotorcannotbeperformed atlowerspeeds.APFC-basedzetaconverterisusedforthis application because of its capability of bucking and boostingthevoltageanditsoperationasanexcellentPFcorrec tor.APFCzetaconverter andabridgeless configurationzetaconverter fedBLDCmotordrivehave beenproposedin,respectively, butitislimitedto simulation studies.Thispaperpresentsanexperimental verificationofPFCzetaconverter feedingaBLDCmotor drive.

3.2 ProposedPFCzetaconverterfed BLDC motordrive

Fig.2ashowstheproposedPFC-basedzetaconverterfeeding aBLDCmotordriveandFig.2bshowsaVSIfeeding the BLDC motor drive. The speed of BLDC motor is controlled byvaryingthedc-linkvoltageofVSI.ThePFC zetaconverterisdesignedtooperateinDICM,henceitacts as an inherent PF corrector. The complete operation of BLDCmotordriveisrealised usingasinglevoltagesensor. Anelectronic commutationofBLDCmotorisutilisedfor reducingtheswitchinglosses.Theperformance ofthe proposeddriveisvalidatedexperimentally onadeveloped prototype. An improvedpower quality is achieved for a wide range of speed control with power quality indices withinthelimits.



OperationofPFCzetaconverter

ThePFCzetaconverterisdesignedtooperateinDICM,such that the current in input side inductor (i_{Li}) becomes discontinuous,whereasthecurrentinoutputsideinductor(i_{Lo}) and the voltage across intermediate capacitor (v_{C1})remainincontinuousconductionforacompleteswitching cycle. Figs. 3a–c show the three different modes of operationofaPFCzetaconverter inacompleteswitching cycleanditsassociated waveformsareshowninFig.3d. Threedifferentmodesofoperationareasfollows.

ModeI($0<t<t_1$):AsshowninFig. 3a,whenswitch(S_w)is turned on, the input side inductor (Li) and the output side inductor (Lo) start charging. The intermediate capacitor (C1) discharges in this mode of operation and charges the dc-link capacitor as shown in Fig. 3d. Therefore, the voltage across intermediate capacitor (VC1) decreases and the dc-link voltage (Vdc) increases in this mode of operation.

Mode II (t1 < t < t2): When the switch (Sw) is turned ‘off’, the energy stored in the input and the output inductors (Li and Lo) starts discharging to intermediate capacitor (C1) and the dc-link capacitor (Cd) as shown in Fig. 3b. The diode (D) starts conducting in this mode of operation. Hence, the voltage across the intermediate capacitor (vC1) and dc-link voltage increases in this mode of operation as shown in Fig. 3d.

Mode III (t2 < t < t3): This is the discontinuous conduction mode of operation, that is, the current in input inductor (iLi) reaches zero and becomes negative as shown in Fig. 3c.Thedc-linkcapacitorsuppliestherequiredenergytothe VSIfeeding BLDCmotor;hencethedc-linkvoltage(V_{dc}) starts decreasingin this mode of operationas shown in Fig.3d. modesofPFCzetaconverterinDICMdKeywaveforms

3.5 Operation of Zeta converter in ccm mode

Vastmajorityofpowerconvertersusednowadaysemploy front-enddiodebridgerectifiers.Such rectifiers draw

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pulsating currents which leave behind agreatamountofharmonics,and considerably low power factor. For a single converter of this typeused with a single-phaseload such as in aconsumerelectronicequipment, the problemsmaynotseem serious.However,agreat numberofthoseequipmentsinparallelconnection at a point of common coupling (PCC) to draw power simultaneously introduce some serious effects concerning reactive power and harmonic. Thesituationsarequitecommon in officesand industries.

PV FED ZETA CONVERTER DESIGN

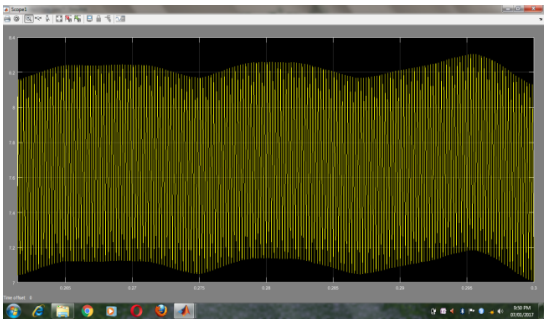
4.1. INTRODUCTION

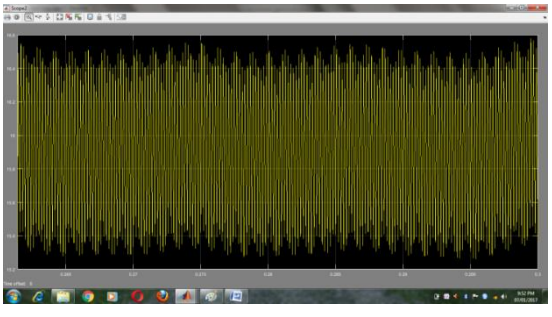
Nowadaysadc-dcconverteriswidelyusedaspowersupply inelectronic systems.Azeta converter isafourth orderdc-dcconverter capable of amplifying andreducingtheinputvoltagelevels without inverting thepolarities.

Thereasonbeing isthatitincludestwocapacitorsandtwoinductorsas dynamicstorageelements.Compared with a Cukor Sepicconverters, the Zeta converter has receivedtheleastattention.Amongtherenewable options,solarPV energyhasbeendrawing increasing interestinrecent years as an alternative and important source of energyforthefuture.Solarcellstransform energy from anessentially unlimitedsource„theSun"into useable electricity. PV systems constitute anenvironmentallyfriendlyalternativewayforenergyproduction usingtheenergyfromthesun.PVsystem, virtually zerorunningcostenergyistheinputsource ofpower. They operatequietlywithoutemissions, even iftheloadincreases. With recent developments, solar energy systems are easily available for industrialanddomesticusewith theaddedadvantage of minimum maintenance. However, the output powerinducedinthephotovoltaic modulesdepends onsolarradiation andtemperature ofthesolarcells. Photovoltaicmoduleshave a verylowconversion efficiency ofaround15%forthemanufactured ones. Besides,duetothetemperature, radiationandload variations,thisefficiency canbehighlyreduced.In fact, the efficiency of any semiconductor device drops steeply with thetemperature.

Inordertoensure thatthephotovoltaicmodulesalwaysact supplying themaximum poweraspossibleanddictatedby ambient operating conditions, a specific circuit knownasMaximum PowerPointTracker(MPPT)is employedtherefore,tomaximizetheefficiencyofthe renewableenergy system,itisnecessary totrackthe maximum powerpointofthePVarray.Inmost commonapplications, theMPPTisaDC-DC convertercontrolledthroughastrategy thatallows imposingthephotovoltaicmoduleoperation pointon theMaximumPowerPoint(MPP) orclosetoit. The proposedschemeconsists ofasolarpanel,azetadc-dcconverter, andMPPTcontroller. InthisMaximum power point tracking is achieved by using Perturbationand Observation(P&O) method, also knownashillclimbing method, ispopular andmost commonlyusedinpracticebecauseofitssimplicity inalgorithmandtheeaseofimplementation.

Results





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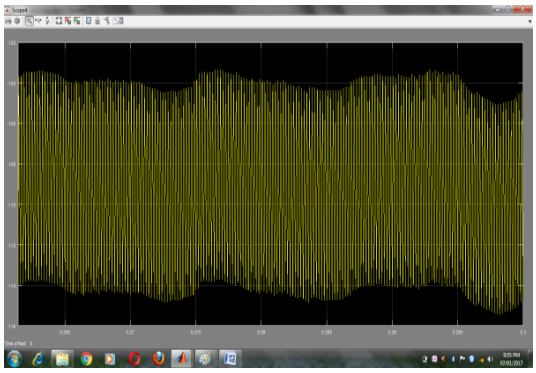

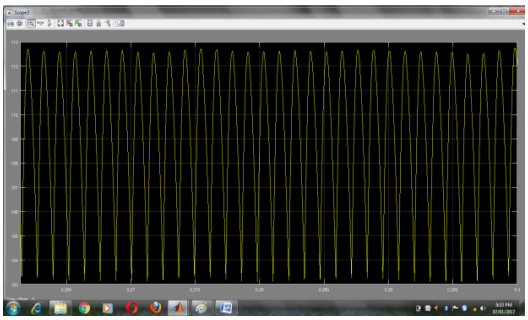

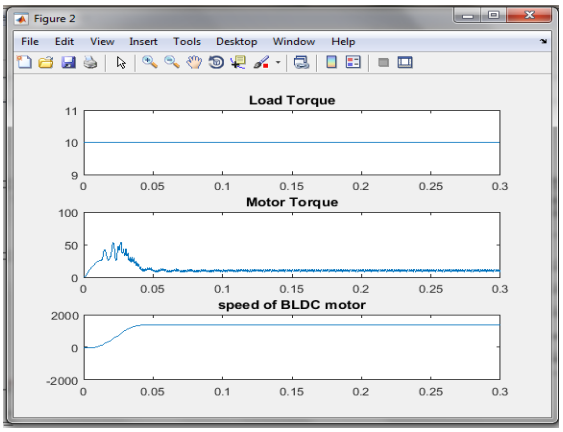

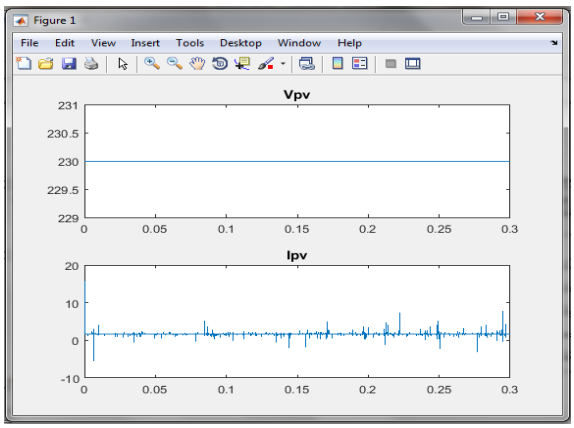

CONCLUSION

The subsystemsof overall scheme suchasPVarraymodel,ZETA converter modelhavebeenbuiltandtestedindividuallybeforeintegratin gtotheoverallsystem.Amaximumpowerpointtracking algorithmhasalsobeenincorporated. The simulation studies of the proposed scheme MPPThavebeencarriedoutandtheresults are furnished. Thevaluesofparametersusedfor simulationarelisted. Mathematicalanalysis ofZETA converter is carriedoutfordesignvaluesofthecapacitorandinductor.A simple power electroniccontrollerfor interfacingPV arraywiththeloadhasbeensimulated usingZETAconverter.

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G Prashanth
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