International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

COPY RIGHT

IJIEMR Transactions, online available on 25th June 2017. Link :
http://www.ijiemr.org/downloads.php?vol=Volume-6&issue=ISSUE-4

Title: Hybrid Fuzzy Controlled Solar Powered Srm For Water Pumping Application.

Volume 06, Issue 04,Page No: 1229 – 1238.

Paper Authors

***T. SRAVAN KUMAR , SRI. R. SATHISH KUMAR.**
* Dept of EEE, QIS College of Engineering& Technology.

USE THIS BARCODE TO ACCESS YOUR ONLINE PAPER

International Journal for Innovative Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

HYBRID FUZZY CONTROLLED SOLAR POWERED SRM FOR WATER PUMPING APPLICATION

[1]T. SRAVAN KUMAR, [2]SRI. R. SATHISH KUMAR

*PG Scholar, Dept of EEE, QIS College of Engineering& Technology, Ongole, A.P, India,

**Associate Professor, Dept of EEE, QIS College of Engineering & Technology, Ongole, A.P, India

ABSTRACT:
This project presents solar powered SRM with fuzzy controller for water pumping application. Among all special machines, the switched reluctance motor(SRM) has the simplest construction. The rotor of SRM contains no conductors or permanent magnets. Because of its high torque density, low inertia, quick response, variable losses and wide speed range capability, SRM could be a suitable candidate for water pumping powered by SPV array. The speed of SRM is controlled by varying the DC-bus voltage of the mid-point converter. A DC-DC Cuk converter operating in continuous conduction mode (CCM) is used for DC-bus voltage control. The adjustment in step size of an incremental conductance MPPT algorithm facilitates the soft starting of SRM drive. The PV array converts the received solar energy to electrical energy, which is fed to the switched reluctance motor. Further to add to its features minimal rule based hybrid fuzzy logic speed controller is introduced. The performance characteristics of the SRM drive system with fuzzy logic controller are improved and it is observed by using MATLAB/SIMULINK software.

Index Terms: Continuous conduction mode (CCM), Cuk converter, Incremental conductance (InC), Maximum power point tracking (MPPT), Switched reluctance motor(SRM), Hybrid Fuzzy Controller.

I. INTRODUCTION

The actual energy conversion efficiency of PV module is rather low and is affected by the weather conditions and output load [1-2]. So, to overcome these problems and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimized. The PV array has a highly nonlinear current-voltage characteristics varying with solar illumination and operating temperature [3-4], that substantially affects the array output power. At particular solar illumination, there is unique operating point of PV array at which its output power is maximum. Therefore, for maximum power generation and extraction efficiency, it is necessary to match the PV generator to the load such that the equilibrium operating point coincides with the maximum power point of the PV array. The Maximum Power Point Tracking (MPPT) control is therefore critical for the success of the PV systems [5]. In addition, the maximum power operating point varies with insolation level and temperature. Therefore, the tracking control of the maximum power point is a complicated problem. To mitigate these problems, many tracking control strategies have been proposed such as perturb and observe [6], incremental conductance [7], parasitic capacitance [8], constant voltage [9], reactive power control [10]. These strategies have some disadvantages such as high cost, difficulty, complexity and instability. In an effort to overcome aforementioned disadvantages, several researches have used artificial intelligence such as Fuzzy Logic Controller [11-14] and Artificial Neural Network [15]. Although these methods are effective in dealing with the nonlinear characteristics of the currentvoltage curves, they require extensive computation. Optimization algorithms like Genetic Algorithm (GA) and firefly algorithm have attracted the attention in MPPT and controller design. However, these algorithms appear to be effective for the design problem, these algorithms pain from slow convergence in refined search stage, weak local search ability and algorithms may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called Artificial Bee Colony (ABC) has been presented by and further established recently by. It is a very simple, robust, and population based stochastic optimization algorithm. In addition, it requires less control parameters to be tuned. Hence, it is suitable optimization tool for locating the maximum power point (MPP) regardless of atmospheric variations.

II. PROPOSED SYSTEM CONFIGURATION

Fig.1 shows a conventional scheme of SPV fed boostconverter based water pumping system utilizing SRM drive. Itconsists of a SPV array, a boost converter, a battery with abidirectional converter and a three phase SRM together withits drive circuit and water pump which is proposed in [23]. Thistype of scheme has its own drawbacks like reduction inefficiency and reliability due to the operating voltage of wholesystem which is fully regulated by the battery in spite of SPVarray and additional losses due to bidirectional converter. Theother limitations of this system are absence of MPPT operation,high SRM inverter losses due to PWM switching and itscomplexity.Another scheme of SPV fed water pumping using SRM driveis proposed in [26] as shown in Fig.2. It consists a storage battery connected to the SPV array through a battery voltageregulator (BVR) with the help of two switches. So apart frombattery issues, switching losses are also increased. Moreoveraddition to these losses, absence of MPPT algorithm alsodecreases the efficiency of system. The switching losses areminimized by using a concept of variable DC-link voltage forspeed control of motor drive [27].Fig.3 shows the proposed SPV array fed water pumpingsystem utilizing a Cuk converter and employing SRM drive. Itconsists of the SPV array, a Cuk converter, the mid-pointconverter feeding the SRM and a coupled water pump. TheCuk converter is so designed and its parameters are selected tooperate in CCM mode.

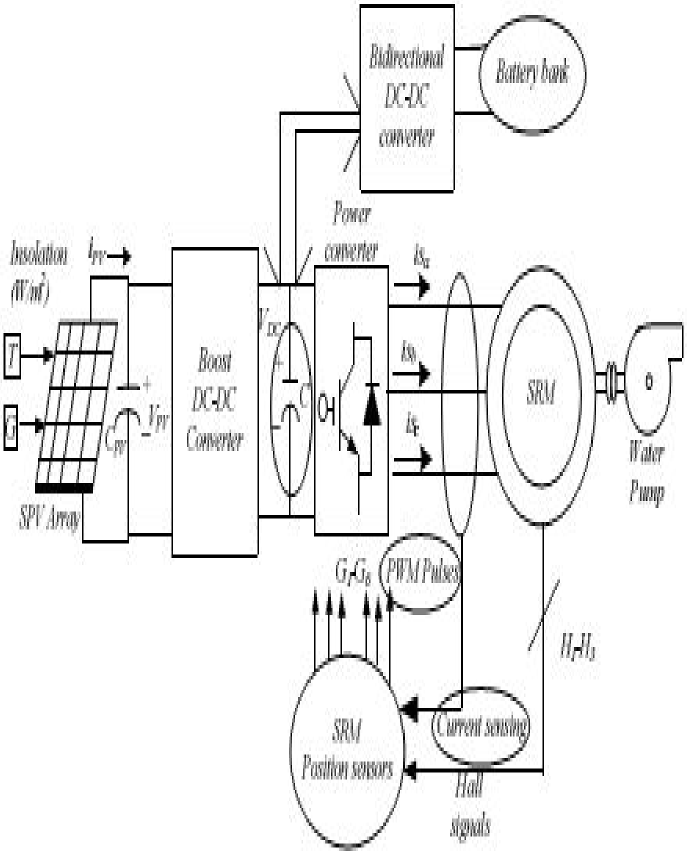


Fig.1. Conventional SPV+ battery fed SRM driven water pumping system [23].

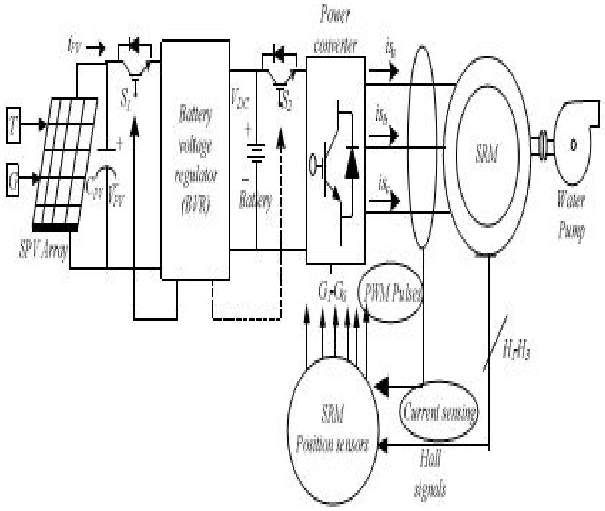


Fig.2. Conventional SPV fed SRM driven water pumping system using BVR[26].

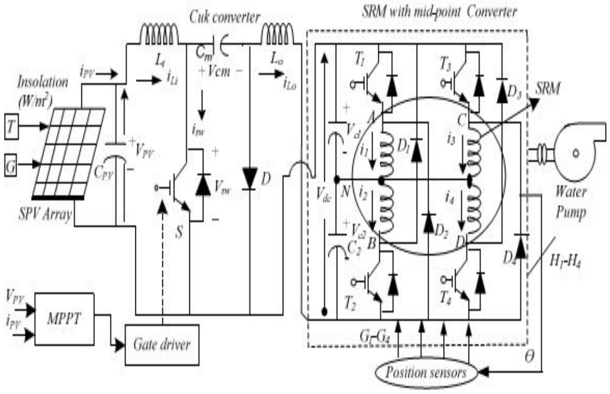


Fig.3. Proposed SPV fed SRM driven water pumping system utilizing Cuk converter

The CCM operation of Cuk converterhelps to reduce the current and voltage stresses on its devicesand to realize the DC-DC conversion ratio independent of load.The problems present in discontinuous conduction mode(DCM) like ringing phenomenon which is due to the transitionof voltage at the other end of the inductor when the currentreaches zero, cause EMI noise and increased switch voltagerating which are eliminated in CCM operation of DC-DC Cukconverter. The pulses for fundamental switching of the midpoint converter switches are generated from the Hall effectposition sensors situated on the stator part of SRM and its helpsto reduce the loss associated with switches of a mid-point converter. The SPV array output power is optimized by Inc MPPT technique.

III. DESIGN AND MODELING OF PROPOSED SYSTEM

The configuration of proposed water pumping system driven by SRM drive is shown in Fig.3. The components of proposedsystem are designed as per the requirement of SPV fed pump system. A SPV array of 900W and a four phase SRM of 750Wpower rating are selected. A four switch split capacitor midpoint converter of 320V DC link voltage is selected for proposed system. According to the power rating of the pump and a SRM drive, each stage of the proposed system is designed as follows.

A. Design and Modeling of SPV Array

A SPV array of 900W peak power capacity, somewhathigher than SRM drive rating (750W) is chosen so byconsidering some losses are always associated with convertersand the motor. All the parameters of SPV array are estimated at1000W/m^2 insolation level. A solar PV module has short circuitmodule current (I_{sc}) of 3.55A and open circuit module voltage(V_{ocn}) of 21 V. Each SPV module has a capacity of 50W. Theelectrical specifications of HB-12100 and designed SPV arrayat 1000 W/m^2. Thus, an array of 900Wpeak power capacity is designed with 1 module in parallel and17 modules in series with a PV array of 1*17 modules [28].

B. Design and Modeling of Cuk Converter

The DC-DC Cuk converter is designed in such a way that italways operates in CCM regardless of the environmentalconditions. The peak and RMS currents are substantially lowerin CCM resulting in lower losses in the conduction paths andsmaller ringing because the energy stored in inductances isproportional to the square of the current. The rated DC voltageof the SRM is as, $V_{dc} = 320$ V and the PV voltage at MPP is as,$V_{pv} = V_{mpp} = 289$ V. The relationship between the duty ratio, Dof the insulated gate bipolar transistor (IGBT) switch, outputvoltage, V_{dc} and input voltage, Vpv of the Cuk converter is givenas [27].

The duty ratio, D of the Cuk converter is estimated as [27],

$$\frac{V_{dc}}{V_{pv}} = -\frac{D}{1-D} \Rightarrow D = \frac{V_{dc}}{V_{dc}+V_{pv}} = \frac{320}{320+289} = 0.52 \quad (1)$$

The selected values for DC link capacitors are estimatedas [29],

$$C_1 = C_2 = \frac{I(30-\alpha)}{2\omega\Delta V_{dc}} \quad (2)$$

where, I=DC link current, ω =rated angular speed of SRM,α =conduction angle, ΔVdc=amount of permitted ripple in thevoltage across DC link capacitors C1& C2 i.e. 1.5% of Vdc.Considering Pin as 900 W, Vdc as 320 V, f as 50 Hz and ΔVc1=ΔVc2 as 1.5% of Vc1,2,the obtained value of 'I' is 2.34 A andthe obtained value of $C_1=C_2$ is 2441 μF; hence, C_1 and C_2 areselected as 2500 μF.

C. Design and Modeling of SRM

The equivalent circuit of SRM is modeled as a currentcontrolled voltage source as shown in Fig.4. In this equivalentcircuit, e(t) is the e.m.f. of the SRM. Due to the saliency onrotor and stator side, SRM has non-sinusoidal current and fluxacross all four windings against the pulse voltage supply. Themodeling is carried out on the supposition that the magneticcoupling between two consecutive windings of SRM isnegligible and its phase inductance profile has the non-linearshape [17]-[18]. Fig.3.5 shows the developed simulink model for750W, 8/6 pole, 1500rpm SRM.

The expression obtained after applying KVL in conductingphase of SRM is as,

$$v = Ri + \frac{d\psi}{dt} = Ri + \frac{d(Li)}{dt} \quad (3)$$

$$= Ri + L\frac{di}{dt} + i\frac{dL}{dt} \quad (4)$$

$$= Ri + L\frac{di}{dt} + i\frac{dL}{d\theta} * \frac{d\theta}{dt} = Ri + L\frac{di}{dt} + \omega_m i\frac{dL}{d\theta} \quad (5)$$

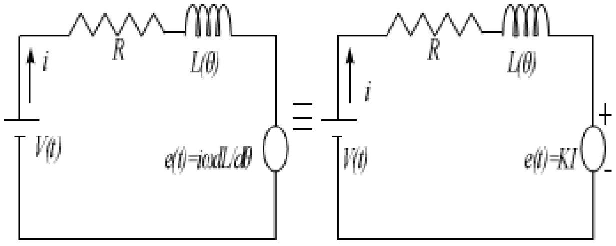


Fig.4 Equivalent circuit of SRM

where, 'V' is the terminal voltage, i is the current, ψ is the fluxlinkage in volt-seconds, R is the phase resistance, L is the phaseinductance,θ is the rotor position, and ω_m is the angularvelocity in rad/s. The last term is sometimes interpreted as a'back-EMF' as,

$$e = \omega_m i dL/d\theta \quad (6)$$

The instantaneous electrical power V*i as,

$$Vi = Ri^2 + Lidi/dt + \omega i^2 dL/d\theta \quad (7)$$

The rate of change of magnetic stored energy at any instant isgiven as,

$$\frac{d}{dt}\left(\frac{1}{2}Li^2\right) = \frac{1}{2}i^2\frac{dL}{dt} + Li\frac{di}{dt} = \frac{1}{2}i^2\omega_m\frac{dL}{d\theta} + Li\frac{di}{dt} \quad (8)$$

The mechanical power conversion is as,

$$P = T\omega_e \tag{9}$$

Thus from (7-8) & (9), the developed torque is as,

$$T = 0.5 i^2 \, dL/d\theta \tag{10}$$

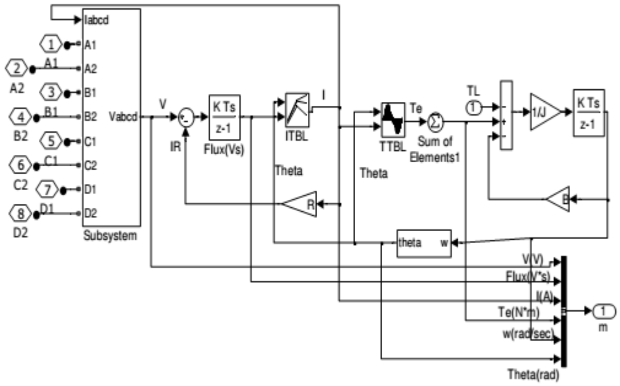


Fig.5 Developed simulink model of SRM

IV. OPERATION AND CONTROL OF PROPOSED SYSTEM

In the proposed system, maximum power of the SPV arrayis tracked using In_C MPPT technique and the mid-pointconverter feeding current pulses to the SRM is operatedthrough the electronic commutation.

A. MPPT Control

The location of MPP in the I-V characteristics of SPV arrayis not predicted in advance and always varies dynamically withinsolation levels and environmental conditions. The governingequations which explain the operating principle of In_C methodare as [7]-[8],

$$V_{pvref}(k) = V_{pvref}(k-1) + \text{step, if } \frac{\Delta I}{\Delta V} > \frac{-I_{PV}}{V_{PV}} \tag{11}$$

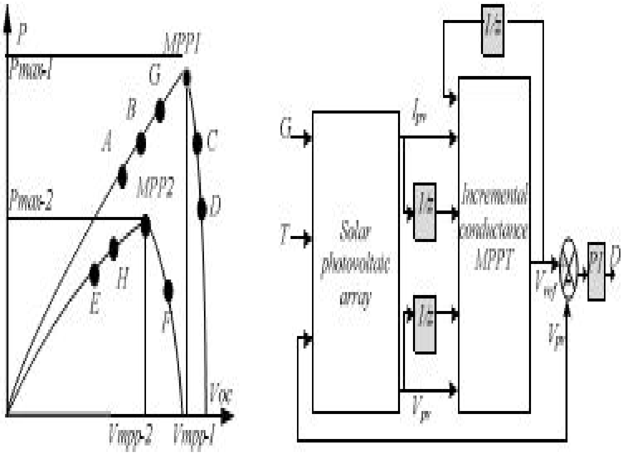
$$V_{pvref}(k) = V_{pvref}(k-1) - \text{step, } \frac{\Delta I}{\Delta V} < \frac{-I_{PV}}{V_{PV}} \tag{12}$$

Where, ΔI & ΔV =change in PV current and voltage in twoconsecutive samples.

The reference voltage of SPV array is checked for upper andlower limits which are set to 0.7Vocmax to 0.9Vocmax. In case theV_{pvref} is between the limits, it is kept as it is else the V_{pvref} issaturated to the nearest limit. The saturation block output isdesignated as new reference PV voltage (V_{pvrefn}). The $V_{pvrefn}$and sensed PV voltage are then used to estimate the duty ratiofor the Cuk converter. The governing equation for estimatingduty ratio is,

$$D(k) = 1 - \frac{v_{pv}}{v_{pv} + v_{pvref}} \tag{13}$$

This reference duty ratio is compared with saw-toothwaveform to generate switching logic for the switch of the Cukconverter.



(a) (b)

Fig.6. Explanation of In_C method and generation of duty cycle for DC- DC converter by In_C algorithm

Fig.6(a) shows a PV curve along with all possible points oncurve undergoing into execution of In_C algorithm. Fig.6(b)explains the method of duty cycle generation through MPPTmethod and it can be summarizes by all possible conditions forMPPT operations using Fig.6 (a).

B. Control of Mid-Point Converter

The complete switching scheme of a mid-point converter iscontrolled by three parameters; the advance angle (turn- onangle), θ_{on}, turn-off angle, θ_{off}, and value of the effective DClink voltage. The switching angles are defined for each phasebased on the rotor position estimation provided by a position. Hall sensors located on the stator of SRM [29]. A mid-pointconverter injects unipolar current pulses at desired rotorpositions to SRM drive. It also controls the magnitude ofcurrent for efficient operation of the motor drive and IGBTswitches [30]-[32]. The voltage equation at starting is as,

$$1/2V_{dc} = L\,(dI/dt) = L\,(dI/d\theta)\,(d\theta/dt) \quad (14)$$

$$= L\,\omega\,(dI/d\theta) \quad \text{as } \omega = (d\theta/dt) \quad (15)$$

$$\approx d\theta = 2\,L\,\omega\,dI/V_{dc}\,; \quad (16)$$

Therefore, Turn On angle:

$$\theta_{on} = 2I\,L_{min}\,\omega_{act}/V_{dc} \quad (17)$$

Turn Off angle:

$$\theta_{off} = 2k\,I\,L_{max}\,\omega_{act}/V_{dc} \quad (18)$$

Where, L_{min} and L_{max} are minimum and maximum inductancevalues. The winding excitation sequence is decided by thedirection of rotation and inductance profile. For forwardmotion, the sequence is A-B-C-D-A with excitation in therising inductance region. Fig.3.3 shows the basic circuit diagramof split capacitor mid-point converter. The excitation patternsof all four phases of SRM are symmetrical in nature.

V. HYBRID FUZZY CONTROLLER

The objective of the hybrid controller is to utilize the best attributes of the PI and fuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state or slowly varying operating conditions. However, when there is a step change in any of the operating conditions, such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations. The fuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions. Although the fuzzy controller has a slower response by itself, it reduces both the overshoot and extent of oscillations under the same operating conditions. The desire is that, by combining the two controllers, one can get the quick response of the PI controller while eliminating the overshoot possibly associated with it. Switching Control Strategy the switching between the two controllers needs a reliable basis for determining which controller would be more effective.

The answer could be derived by looking at the advantages of each controller. Both controllers yield good responses to steady-state or slowly changing conditions. To take advantage of the rapid response of the PI controller, one needs to keep the system responding under the PI controller for a majority of the time, and use the fuzzy controller only when the system behavior is oscillatory or tends to overshoot. Thus, after designing the best stand-alone PI and fuzzy controllers, one needs to develop a mechanism for switching from the PI to the fuzzy controllers, based on the following two conditions:

- Switch when oscillations are detected;
- Switch when overshoot is detected.

The switching strategy is then simply based on the following conditions: IF the system has an oscillatory behavior then fuzzy controller is activated, Otherwise PI controller is operated. IF the system has an overshoot thenfuzzy controller is activated, Otherwise PI controller is operated. The system under study is considered as having an overshoot when the error is zero and the rate of change in error is any other value than zero. The system is considered oscillatory when the sum of the absolute values of the error taken over time does not equal the absolute values of the sum of the error over the same period of time. Since the system is expected to overshoot during oscillatory behavior, the only switching criterion that needs to be considered is overshoot. However, in practice, it is more convenient to directly implement the control signal according to the control actions delivered by the controller. Consequently, the fuzzy controller can be designed so that normal behavior (no oscillations or overshoot) results in a null fuzzy action as shown in Fig.4. Accordingly, the switching between the two controllers reduces to using PI if the fuzzy has null value; otherwise, the fuzzy output is used. In particular, the fuzzy controller can be designed so that a normal behavior.

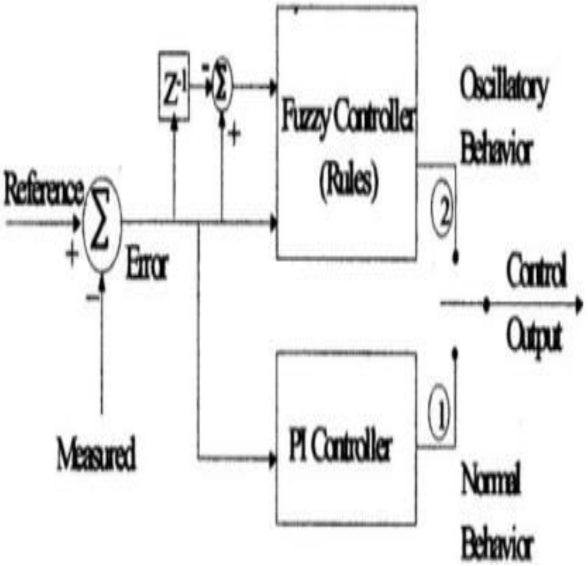


Fig.7 Structure of switching strategy results in a null fuzzy action.

VI. MATLAB/SIMULATION RESULTS

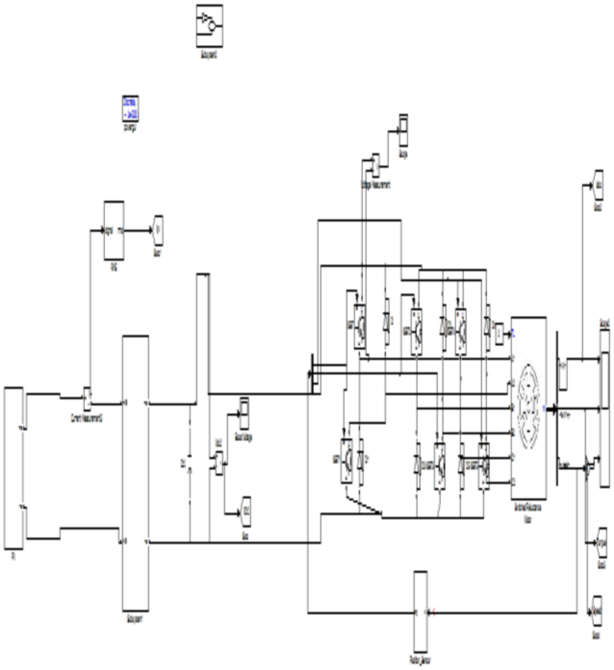


Fig.8MATLAB/SIMULINK circuit for PV fed Cuk converter with SRM drive

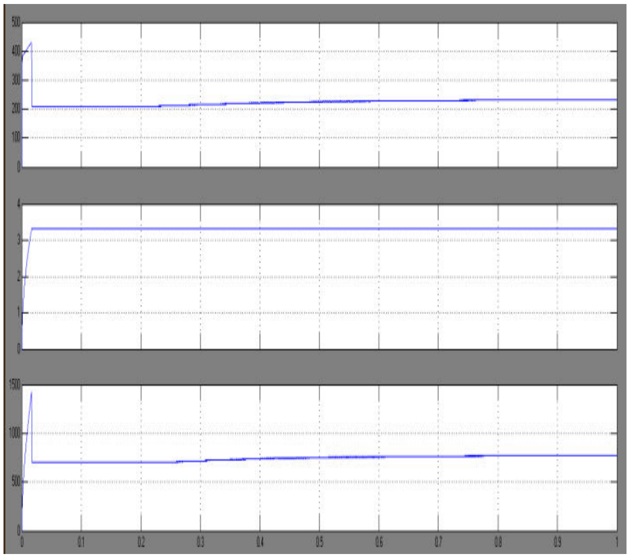


Fig.9PV voltage, Current and Power

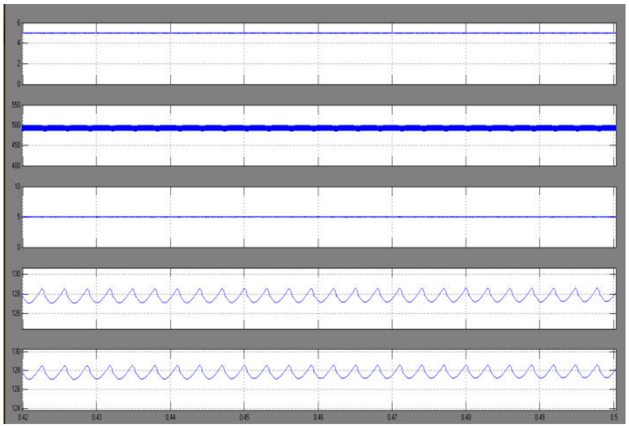


Fig.10Capacitor voltage 1, Energy transfer capacitor voltage, Capacitor voltage 1, Load current 1 and Load current 2

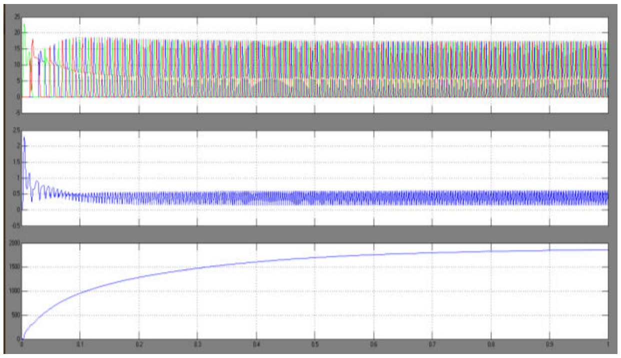


Fig.11Current, Torque and Speed

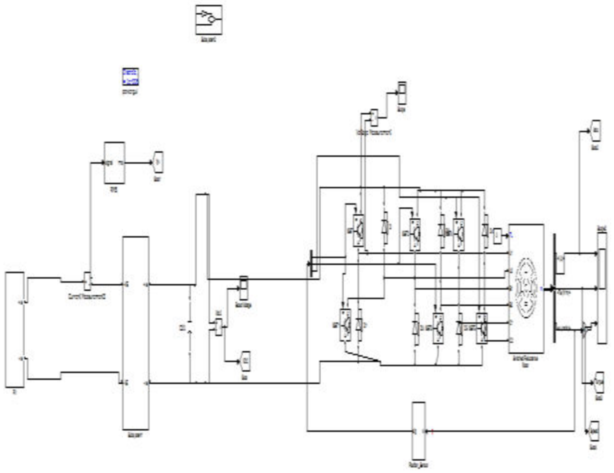


Fig.12MATLAB/SIMULINK circuit for PV fed Cuk converter with SRM drive

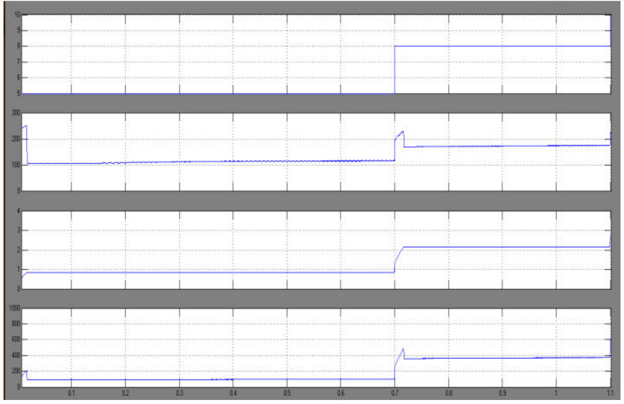


Fig.13Cuk converter duty cycle, PV voltage, PV current and Power

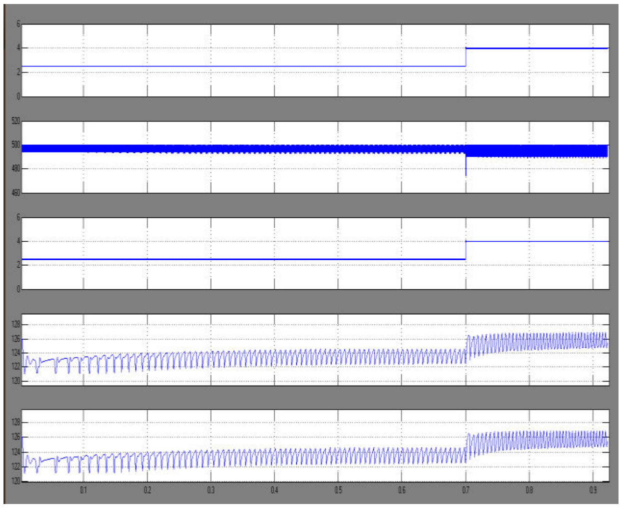


Fig.14Capacitor voltage 1, Energy transfer capacitor voltage, Capacitor voltage 1, Load current 1 and Load current 2

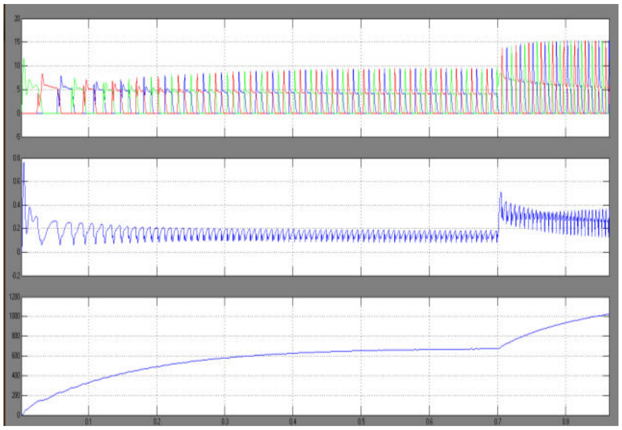


Fig.15Current, Torque and Speed

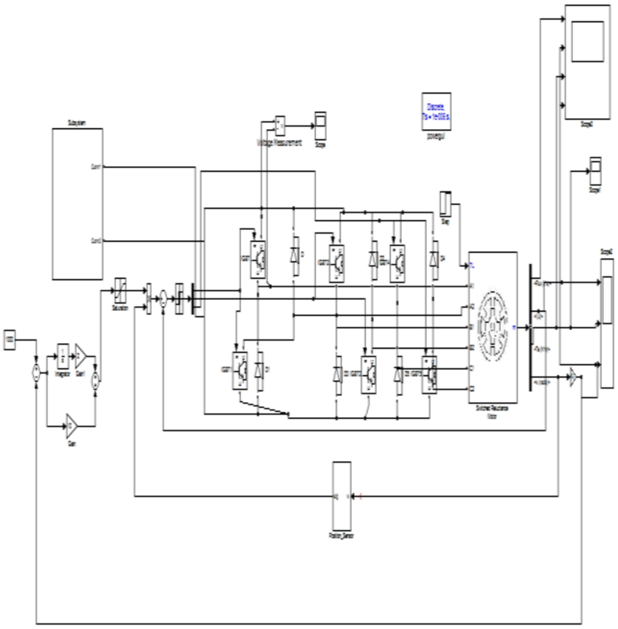


Fig.16MATLAB/SIMULINK circuit for PV fed Cuk converter with SRM drive with PI controller

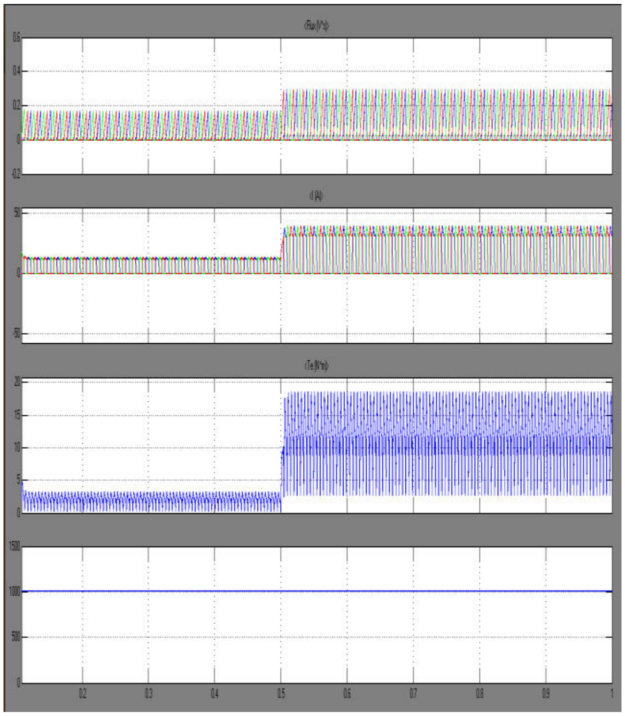


Fig.17Flux, Current, Torque and Speed

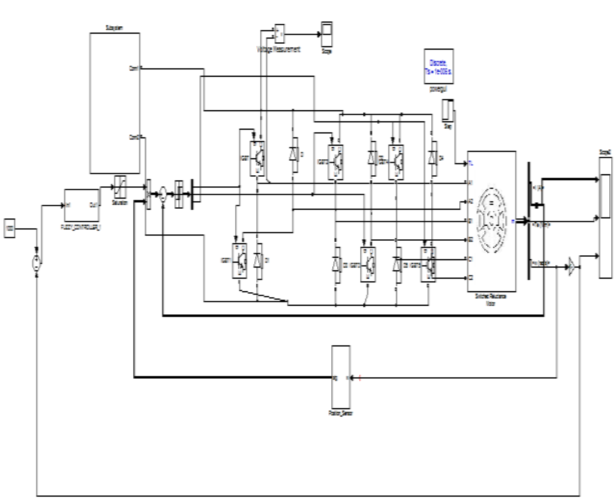


Fig.18MATLAB/SIMULINK circuit for PV fed Cuk converter with SRM drive with Hybrid Fuzzy Controller

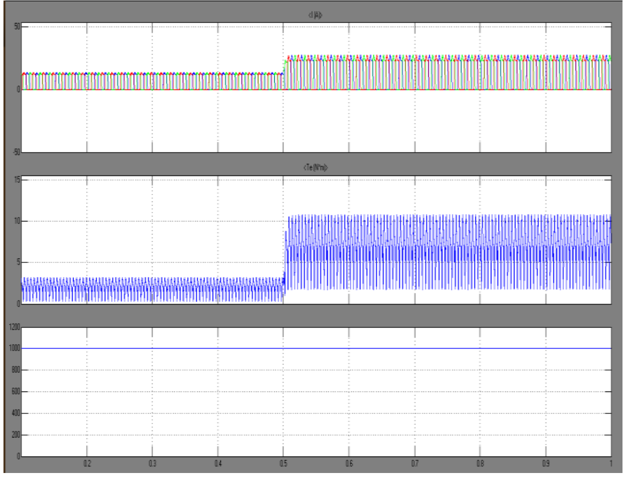


Fig.19Current, Torque and Speed

VII. CONCLUSION

The SPV array- Cuk converter fed Hybrid fuzzy controller based SRM motor-pump has been proposed and its suitability has been demonstrated through simulated results and experimental validation. The proposed system has been designed and modelled appropriately to accomplish the desired objectives and validated to examine various performances under starting, dynamic and steady state conditions. The performance evaluation has justified the combination of Cuk converter and SRM motor for SPV array based water pumping. The system under study has shown various desired functions such as MPP extraction of the SPV array, soft starting of SRM motor, fundamental frequency switching of VSI resulting in a reduced switching losses, speed control of SRM motor without any additional control and an elimination of phase current and DC link voltage sensing, resulting in the reduced cost and complexity. The proposed system has operated successfully even under minimum solar irradiance. Finally thehybrid fuzzy control system was also very stable showing a good performance and outperforming all the other classical controllers and the same system conditions.

REFERENCES

[1] Ministry of New and Renewable Energy, Government of India.

[2] (2013,May). World Solar Photovoltaic's Installations, 2000-2012 [Online].Available: https: // www.Earth-policy.Org/data_center/C23

[3] Ahmed M. Kassem, "MPPT Control Design and PerformanceImprovements of a PV Generator Powered DC Motor-Pump System Basedon Artificial Neural Networks," Int. Journal of Electrical Power & EnergySystems, vol. 43, pp. 90-98, December 2012.

[4] S. G. Malla, C. N. Bhende, and S. Mishra, "Photovoltaic based waterpumping system," Int. Conf. Energy, Automation Signal (ICEAS), 28-30Dec. 2011, pp. 1-4.

[5] S.Jain, A.K.Thopukara, R. Karampuri, and V.T. Somasekhar, "A SingleStage Photovoltaic System for a Dual-Inverter-Fed Open-End Winding Induction Motor Drive for Pumping Applications," IEEE Transactionson Power Electronics, , vol.30, no.9, pp.4809-4818, Sept. 2015.

[6] B.N. Singh, B. Singh, B. P. Singh, A. Chandra and K. Al-Haddad,"Optimized performance of solar powered variable speed induction motordrive," Proceedings of the 1996 International Conference on PowerElectronics, Drives and Energy Systems for Industrial Growth, 1996, vol.no.,1,8-11Jan1996, pp.58-66.

[7] G.J.Kish, J.J. Lee and P.W. Lehn, "Modelling and control of photovoltaicpanels utilising the incremental conductance method for maximum powerpoint tracking," IET Renewable Power Generation, vol.6, no.4, pp.259-266, July 2012.

[8] D.Sera, L. Mathe, T.Kerekes, S.V. Spataru and R.Teodorescu, "On thePerturb-and-Observe and Incremental Conductance MPPT Methods for PVSystems," IEEE Journal of Photovoltaics, vol.3, no.3, pp.1070-1078, July2013.

[9] B. Subudhi, and R. Pradhan, "A Comparative Study on Maximum PowerPoint Tracking Techniques for Photovoltaic Power Systems," IEEETransactions on Sustainable Energy, vol.4, no.1, pp.89-98, Jan. 2013.

[10] M.A.G. de Brito, L. Galotto, L.P.Sampaio, G .e Melo de Azevedo andC.A. Canesin, "Evaluation of the Main MPPT Techniques for PhotovoltaicApplications," IEEE Transactions on Industrial Electronics, vol.60, no.3,pp.1156-1167, March 2013.

[11] Mohamed M. Algazar, Hamdy AL-monier, HamdyAbd EL-halim andMohamed Ezzat El Kotb Salem, "Maximum Power Point Tracking UsingFuzzy Logic Control," International Journal of Electrical Power & EnergySystems, vol. 39, no. 1, pp. 21-28, July 2012.

[12] K. Benlarbi, L. Mokrani and M.S. Nait-Said, "A Fuzzy Global EfficiencyOptimization of a Photovoltaic Water Pumping System," Solar Energy,vol. 77, no. 2, pp.203-216, 2004.

[13] T.J.E. Miller, "Brushless Magnet and Reluctance Motor Drive", ClarendonPress, Oxford, 1989.

[14] T. Sebastian, "Temperature effects on torque production and efficiency ofPM motors using NdFeB magnets," IEEE Transactions on

IndustryApplications, vol.31, no.2, pp.353-357, Mar/Apr 1995.
[15] R. Krishnan, Switched Reluctance Motor Drives: modeling, simulation,analysis, design and applications, CRC Press, 2001.

BIOGRAPHY:

T. Sravan Kumar is pursuing M .Tech at QIS College of Engineering &Technology (Autonomous) under JNTU, Kakinada. He received his B.Tech degree from RISE Prakasam Group of Institutions JNTU, Kakinada. His current research interests are Power electronics & Power system.

Sri. R. Sathish Kumar received the B.Tech. degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, 2005 &M.Tech. degree in Electrical & Electronics Engineering from Jawaharlal Nehru Technological University, Hyderabad, India, in 2010. Currently, he is working as an Associate Professor in QIS College of Engineering and Technology, Ongole, India. He has published a number of papers in various national & international journals & conferences. His research areas are power system operation & control and economic load dispatch.