A New Adaptive Technique for Sensorless BLDC Motor Fed by Solar Powered Z-Source Inverter

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Abstract

A Z-source inverter (ZSI) is controlled to extract the maximum power from PV array and supplies to sensorless BLDC motor. To seek out the peak power from the PV array, proper inverter switching is carried out. By proper designing of control system for BLDC motor and PV array, good steady state and transient performance have been achieved in response to different operation conditions for PV array. Conventional PI speed controller are widely used in control units due to simple control structure and ease of implementation, it pose some difficulties such as load disturbances and parametric variations. In this paper difficulties are overcome by using fuzzy logic speed controller which improves the quality of the speed response. The system is tested using MATLAB/SIMULINK environment.

1. Introduction

The Application of PV system has become popular especially in remote areas, where power is not available. The solar powered water pumping system is frequently used for agriculture and house-holds. There are different methods for extracting maximum power from the PV array. Maximum Power Point (MPP) may vary time to time due to different levels of insolation. In Induction motors optimization is obtained by v-f relation of motor [1]. Different pumps are available for water pumping, among those centrifugal pumps are widely used. The optimum utilization achieved by proper load matching is the simple technique [1]-[4]. The output of PV array is dc which is converted to ac source to drive the motor pump. MPP can also track by using the duty ratio of converter in case of using a battery for charging the PV output power, which is generally placed between PV and battery. Optimization of PV pumping system can also done based on new reference voltage criterion which is the addition of open circuit voltage of PV and a segment of solar radiation so as to ensure the optimum chopping ratio of a buck boost converter [3]. It makes it possible to transfer maximum of energy from PV generator whatever are the operating conditions. Efficient usage of PV array is done by spraying water over PV panels which reduces the degradation of PV. Sensor less BLDC motor can also be used instead of IM where MPP tracked by controlling Z-source inverter [9]. Incremental Conductance algorithm for MPPT is used for good efficiency without a battery [6]. In this paper a sensor less BLDC motor has been driven by a three-phase ZSI instead of a two stage power converter. It is clear from the Fig.1 that it consists of PV array, a Z-source Inverter, a sensorless BLDC motor and the control system for both PV array and BLDC motor.

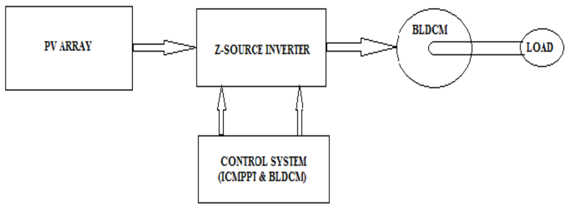

Fig.1. Block Diagram of the proposed system

Maximum power generated by the PV array is extracted by ICMPPT control method and is fed to sensorless BLDC motor. As the PV power generated varies to different environment conditions, the sensorless BLDC motor should be driven at variable reference speeds. To obtain reference speed for sensorless BLDC motor the input voltage of inverter is regulated at a constant value (V_{inref} = 300). The simulation results give the advantageous of proposed system. The other advantages of the system are less power switches, smaller capacitance and inductance value in comparison with boost converter and fast dynamic response.

2. PV array model and MPPT

The solar cell is a semiconductor device that converts the solar insolation directly to electrical energy. The PV cell is a non-linear device and can be represented by the I-V and P-V characteristics, or by an approximate electrical equivalent circuit as shown in Fig. 2. The cells are connected in series and parallel combinations in order to form an array of the desired voltage and power levels.[4]

$$V_{pv} = \frac{1}{\lambda}\ln\left(\frac{I_{sc} - I_{pv} + I_0}{I_0}\right) - R_s I_{pv} \quad (1)$$

Where Isc is the PV cell short circuit current, Io is the reverse saturation current, Rs is the series cell resistance, and λ is a constant coefficient and depends upon the cell material. These parameters for the silicon solar panel manufactured by the Iranian Optical Fiber Fabrication Co OFFC used for solving this paper are valued in Table I. equation (1) expresses a nonlinear relation between voltage-current characteristic of a PV module.

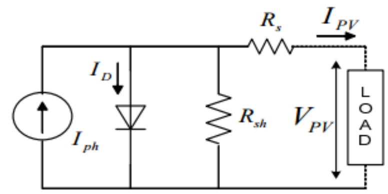

Fig.2. Equivalent circuit of PV solar cell [9]

TABLE I
OFFC SILICON SOLAR PANEL PARAMETERS [9]

Short-circuit current	$I_{sc} = 2.926$
Open circuit voltage	$V_{oc} = 19.39$
Current Temp. cofficient	$\alpha_{sc} = 2.086e^{-3} A/^{\circ}C$
Voltage Temp. cofficient	$\beta_{oc} = 0.0779 V/^{\circ}C$
Series resistance	$R_s = 0.0277\Omega$

As the voltage and current of a PV array vary in respect to insolation and temperature levels, the equation (1) has been computed for several insolation levels (G=600, 800, 1000 W/m2) for the same value of temperature level (T=25^{o}$_{C}$). The Vpv-Ipv and Ppv-Vpv characteristics of the PV array have been shown in Fig. 3. These figures illustrate the nonlinear variations of the PV maximum power point respect to irradiation levels.

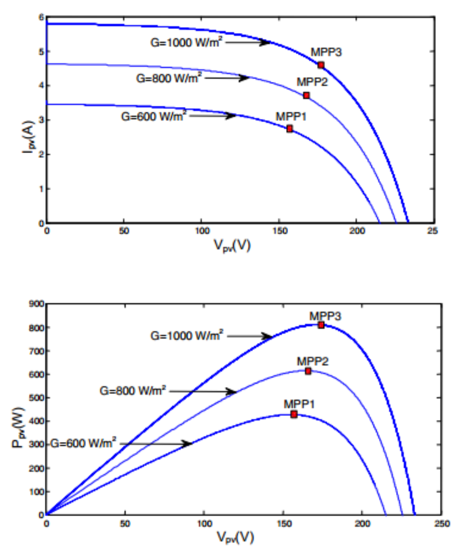

Fig.3. Output characteristics of PV module [9]

Fig. 3 shows there is only one operating point on every Ppv-Vpv characteristics that the maximum PV power can be extracted. Operating point at which maximum power is extracted is called as Maximum Power Point Tracking (MPPT) performance employed by MPPT controller. There are several methods to accomplish MPPT for PV array [3]-[5].

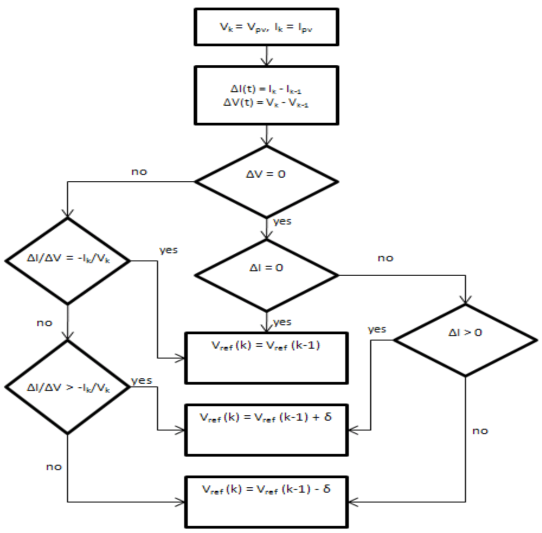

Fig.4. ICMPPT algorithm [5]

In this paper flowchart of the Incremental Conductance algorithm as shown in Fig. 4 is used as control unit for tracking the maximum power point in the PV array. In this figure the Vk and Ik are the momentary voltage and current of the PV array and Vk-land Ik-1are the previous voltage and current, respectively. The dP/dV term can be replaced by I + (ΔI/ΔV) V. The output of the MPPT algorithm is the DC voltage reference (V_{PVref}).

3. BLDC motor drive

DC motors use mechanical commutator and brushes to achieve commutation. However, BLDC motors are synchronous motors with permanent magnets on the rotor and armature windings on the stator. It adopts Hall Effect sensors in place of mechanical commutator and brushes. Magnetic fields develop by stator make the rotor to rotating. Hall Effect sensor detects the rotor position as the commutation signals.

As the rotor position is detected by incremental encoder then the Hall Effect sensors can be removed. So a motor without Hall Effect sensor is called as a sensorless BLDC motor. In this paper, a three-phase and two-pole sensorless BLDC motor is used. For the three phases BLDC motor the back EMF and phase currents waveforms with 120° conduction mode are shown in Fig. 5. [6]

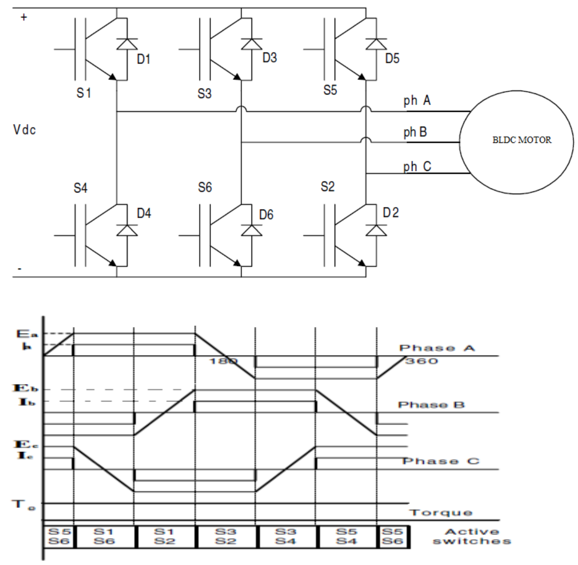

Fig. 5. Configuration of BLDC motor drive system, back EMF pattern and reference current generation

The analysis of a BLDC motor is represented in [6] as the following equations

The amplitude of the phase back-emf is proportional to the rotor speed, and is given by

$$E = k\emptyset\omega_m \quad (2)$$

Where k is a constant that depends on the number of turns in each phase, ∅ is the permanent magnet flux, and ω_m is the mechanical speed. The circuit equations of the three windings in phase variables can be written as

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (3)$$

where va, vb, vc are the phase voltages, ia, ib, ic are the phase currents, ea, eb, ec are the phase back EMF waveforms, R is the phase resistance, L is the self inductance of each phase and M is the mutual inductance between any two phases. So the electromagnetic torque can be obtained as

$$Te = \frac{eaia + ebib + ecic}{\omega r} \quad (4)$$

Where ωr the mechanical speed of the rotor. The equation of the motion is

$$\frac{d}{dt}\omega r = (Te - Tl - B\omega r)/J \quad (5)$$

Where B is the damping constant, J is the moment of inertia and T_l is the hydrodynamic load torque of the centrifugal pump which is related with the speed as following

$$T_l = k\,\omega r^2 \qquad (6)$$

Where k is the constant of the pump torque. The electrical frequency related to the mechanical speed for a motor with P number of poles is

$$\omega e = (P/2)\omega r \qquad (7)$$

4. Z-Source Converter

It employs a unique impedance network to couple the converter main circuit to the power source, load or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitors and inductors are used, respectively. The unique feature of The impedance network which is connected in an X shape LC network can boost the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of input voltage. In conventional VSI there are eight permissible switching states: six active and two zero states, while during the zero state there is no difference for the load if the upper three, the lower three or all six switches are gated on (all the states short the output terminal of the inverter and produce zero voltage to the load).

As discussed in [8] in ZSI, during the zero state all the switches are gated on shoot-through state and this state is used to achieve boosting dc input voltage. Therefore in ZSI, there are six active states and two zero states which are the same as conventional inverter and an obtain an additional zero state (it is forbidden in conventional inverters) which is utilized advantageously to boost the dc-bus voltage. Two basic operation mode of ZSI are illustrated in Fig.6

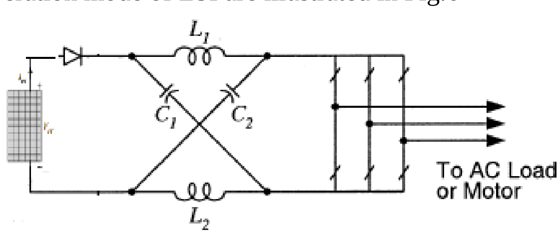

Fig.6. Equivalent circuits of ZSI [8]

As verified in detail in the basic principal, relationship for ZSI is

$$V_{c1} = V_{c2} = V_c = \frac{(1-D)}{(1-2D)} Vd \qquad (8)$$

Where

$$Vo = \frac{1}{1-2D} Vd = BV_d \quad \textit{Non soot – Through states}$$

$$Vo = 0 \qquad \textit{Shoot – Through State}$$

Where V_{C1} and V_{C2} are capacitors voltages of impedance network which are the same due to circuit symmetry. B is the boost factor of ZSI. V_d and V_O denote the input and output voltages of impedance network respectively.

5. Fuzzy logic controller

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior and performance of proposed speed controller. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of BLDC drive. The basic scheme of a fuzzy logic controller is shown in Fig 7 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action. The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model.

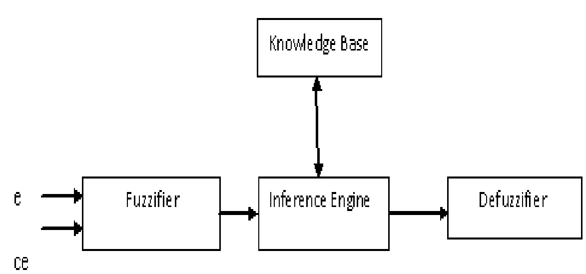

Fig.7. General Structure of the fuzzy logic controller

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model.

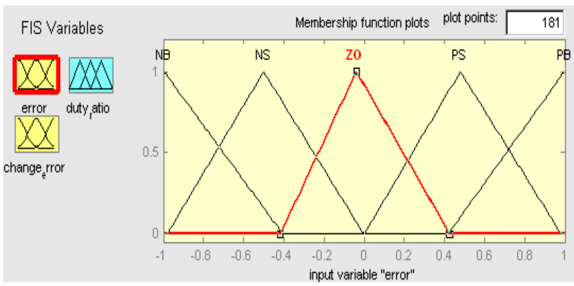

Fig.8. the Membership Function plots on error in speed

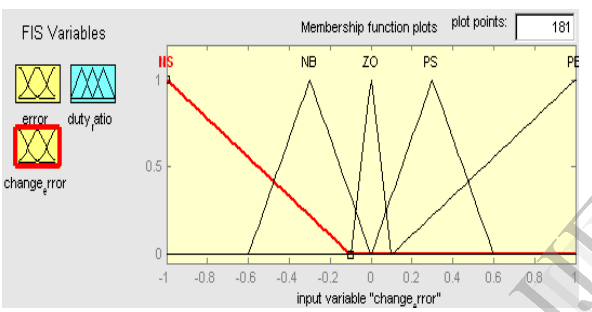

Fig.9. the Membership Function plots on change error in speed

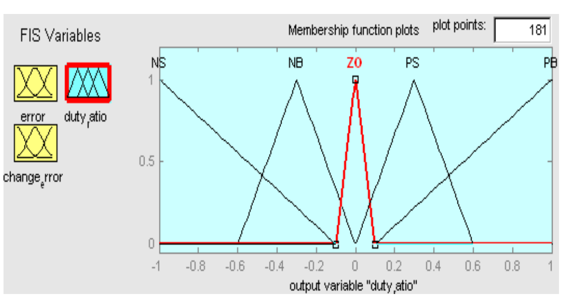

Fig.10. the Membership Function plots of duty ratio

5.1. Fuzzy Logic Rules:

The objective of this dissertation is to control the error in speed of the BLDC motor. The error and change in error of the speed will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

Table II
Table rules for error and change of error

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

6. Control system

The PV array uses MPPT control and the BLDC motor drive control system consists of fuzzy logic speed controller, reference current generator, hysteresis current controller, three phase ZSI and motor-load unit. Reference voltage of the PV array is determined by the ICMPPT controller and compared with the momentary voltage of the PV array. The error signal processed to obtain the shoot through interval time of ZSI (T_0), which regulates the input voltage of inverter (Vin). BLDC motor is made to run at different speeds. The speed obtained by motor is compared with the reference value. The error is processed by a fuzzy logic speed controller, the output of this controller is considered as the reference torque. The reference current generator block generates the three phase reference currents by utilizing reference torque and torque generated by the BLDC motor. The motor currents are compared with the reference currents and hysteresis current controller regulates the winding currents (ia, ib, ic) within the small band around the reference currents. The switching commands of ZSI and hysteresis current controller switching are ORed to drive the inverter switches.

7. Matlab/simulink modeling and Simulation results

Here simulation is carried out at three different insolation (1) first stage (0.03 < t < 0.3) (ii) second stage (0.3 < t < 0.6) (iii) third stage (0.6 < t < 0.9) in two cases 1).PV System based Z-Source Inverter with BLDC Drive Using PI speed Controller (2) PV System based Z-Source Inverter with BLDC Drive Using Fuzzy Logic Speed Controller.

Case 1: BLDC Drive Using PI Speed Controller fed by solar powered ZSI fed by solar powered ZSI

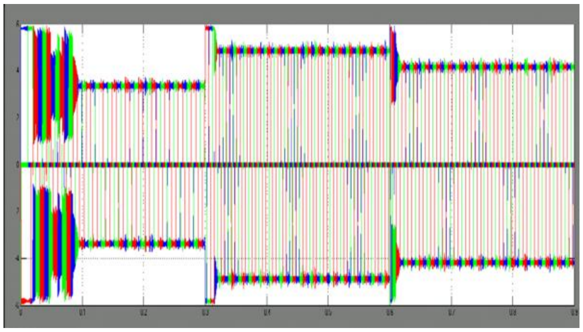

Fig.11 Stator Currents

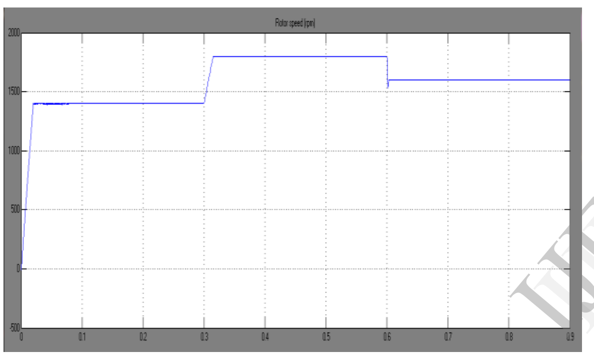

Fig.12 Speed

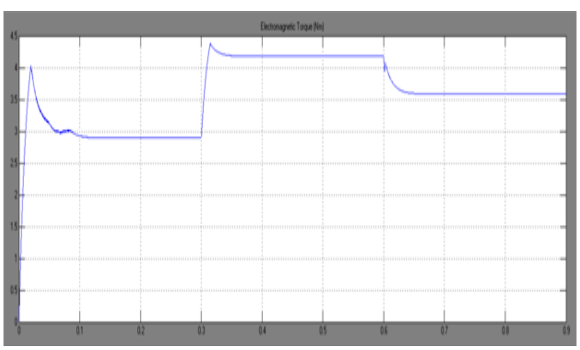

Fig.13 Electromagnetic Torque

Case 2: BLDC Drive Using Fuzzy Logic Speed Controller fed by solar powered ZSI

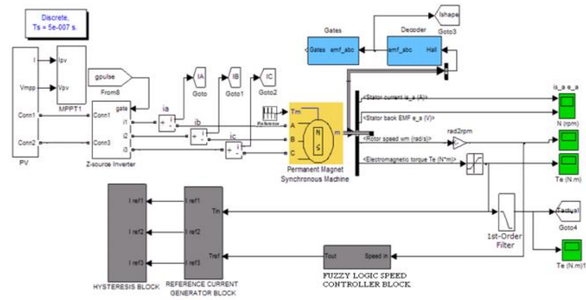

Fig. 14 Matlab/Simulink Model of Proposed PV System based Z-Source Inverter with BLDC Drive Using fuzzy logic Controller

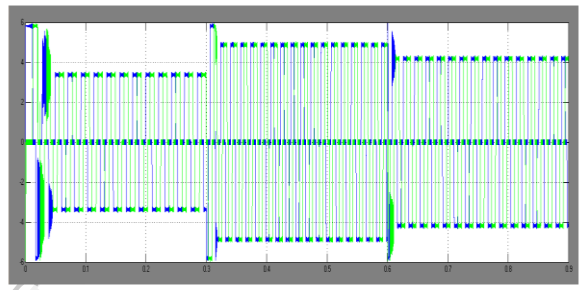

Fig.15 Stator Currents

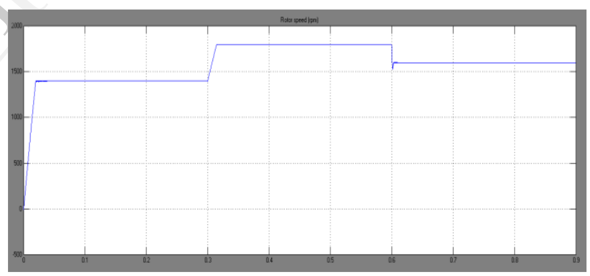

Fig.16 Speed

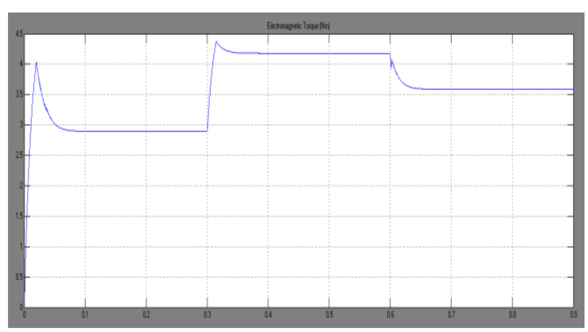

Fig.17 Electromagnetic Torque

8. Conclusion

This paper proposes a sensor less BLDC motor supplied by PV array based on ZSI. This kind of methodology implemented in this paper is using fuzzy logic speed controller with feed back by introduction of speeds respectively. The introduction of error in speed in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose. In spite of conventional PV systems needing two stages of power converters the proposed system has employed just a three phase ZSI extracting the maximum power of PV array and driving a sensor less BLDC motor simultaneously for different operation conditions. Less number of power switches associated with less switching losses is achieved. Also the good steadiness capability of system for every simulated stage can be clearly seen from the simulation results. Less power losses, rapid tracking of MPPT and low electromagnetic torque ripple, demonstrating high current control capability, have been achieved by appropriate designing an integrated controller for whole system.

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