Research Article

Fault Tolerant Discrete Control Technique for PV Fed Stepper Motor Drive

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Abstract: This paper deals with the fault tolerant discrete control technique for the Photo Voltaic (PV) fed 3-phase stepper motor (SM). The operation of stepper motor is complex under high speed applications due to dificulty in locating the step-angle and there is a chance of missing the step-angle. A robust discrete sliding mode control (DSMC) algorithm is developed to overcome this problem along with the fault tolerant topology. The drive is powered by PV array and using perturb and observe (P&O) algorithm maximum power is retrieved from the source. The closed loop control of this drive is implemented using MATLAB/SIMULINK simulation software and the speed control of stepper motor is achieved by introducing stepped reference signal. The fault tolerance is verified by introducing open circuit (OC) and short circuit (SC) faults in the driver circuit and the speed response of the same is plotted. The robustness of the discrete controller is proved by introducing changes in the irradiance of PV array, changes in reference speed and faults in the driver circuit. The oveall system is cheap, compact, robust and reliable under all test conditions and suitable for very low and very high speed applications.

Keywords: PV Array, Stepper Motor, Discrete Sliding Mode Control, MPPT, CUK Converter

1. Introduction

Stepper motors are trendy due to its commercial applications like 3D printing, Medical Imaging, Robotics as well as industrial applications such as Textile machines, printing presses, CNC machines and welding machines. The increased use of stepper motor is due to its advantages like simplicity in control, high full load torque, high precision, fast response, cheap and high reliability. Normally SM is controlled by open loop method; but the drawback of this is the chances of occurrence of resonance, missing of step-angle so that it cannot be operated in high speeds [1]. So there is a requirement of a reliable and robust closed loop controller for the stepper motor to operate it in high speeds.

A superior current control idea that selects control variables to the variation of motor components and the motor speed is projected in paper [2]. The step resolution is increased by the introduction of micro stepping techniques so that the torque ripples are reduced at low speeds [3]. The accuracy of the SM is improved by the introduction of an adaptive control technique using neural network algorithm [4]. Field oriented control (FOC) technique is implemented in paper [5] for the closed loop control of stepper motor to improve the accuracy of the position control and speed regulation.

In order to implement this FOC algorithm precise parameters from mechanical or hall sensors are required; but these sensors are sensitive to environmental conditions. To overcome this disadvantage sensor less controlling technique is projected and broadly in use with permanent magnet synchronous motors [6, 7].

The performance of the SM is improved by replacing the phase lock loop by sliding mode observer [8]; so that the system is more stable under parameter variations as well. But there is the drawback by implementing this method is introduction of phase delay. This could be overcome by the introduction of fuzzy logic with sliding mode observer technique [9]. A new sensor less speed sensing technique along with delay reduced SMO is implemented for hybrid stepper motor. So there is a lack of fault tolerant topology for 3-phase stepper motor drive with closed loop system and there is a requirement of robust controller to control it at high speed without missing its step-angle.

Since there is a demand for electrical energy there is a search of alternation for the same; renewable energy sources can satisfy this energy demand. Solar power is used in this application to make the overall system compact, environmental friendly and cheap of cost [10,11]. This paper a closed loop speed control of 3-phase stepper motor is presented with fault tolerant topology and the system is sourced from solar. The discrete sliding mode controller is used to control the speed as well as to fix and bypass the open circuit and short circuit faults.

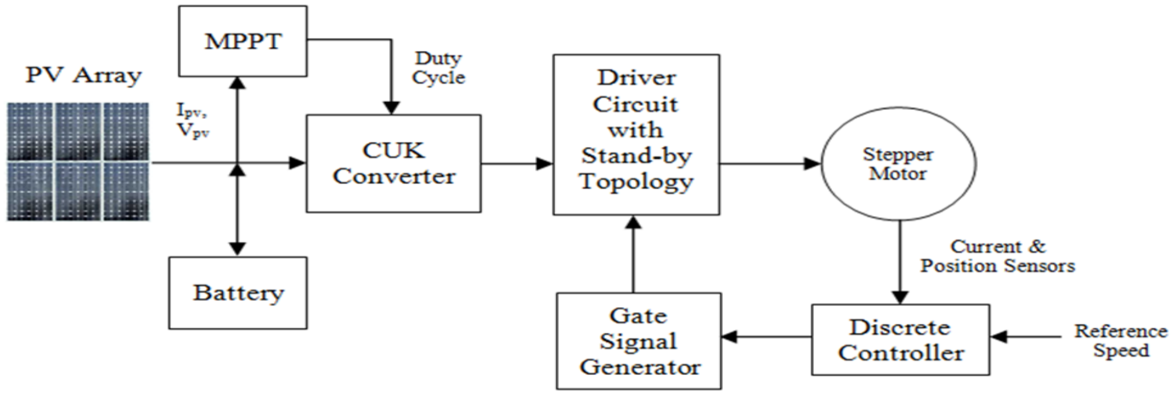

Fig. 1. Block diagram of PV fed stepper motor drive.

Fig.1 shows the block diagram of PV fed stepper motor drive with fault tolerant topology. The stepper motor used in this application is the variable reluctance stepper motor; the speed of the motor is controlled by the discrete sliding mode controller. PV array is used to provide power for the drive; the array current Ipv and array voltage Vpv are measured and duty cycle of the CUK converter is tuned using MPP technique. CUK converters can step-up or step-down the input voltage which is connected to the driver circuit with stand by fault tolerant topology. The excess power from PV array is charging the battery and the battery provides power to CUK converter whenever required.

Driver circuit is provided with stand-by topology with the help of additional two switches, two diodes and winding called spare loop. The controller checks the phase currents of the 3-phase stepper motor by means of current sensors and activates the spare loop in case of absence of any one phase current. The speed of stepper motor is controlled by comparing the reference speed with actual motor speed by sensing the speed with the help of position sensors.

2. Closed Loop Control Of Stepper Motor

The block diagram of the stand-by closed loop control system for stepper motor drive is shown in fig.1. The reference speed ωm* is compared with the actual speed ωm with the help of comparator and the error is calculated. The current controller has proportional Integral (PI) controller, threshold logic and hysteresis controller blocks. The PI controller is utilized to manage the motor acceleration, and corresponding proportional and integral gain values are 0.75 and 5 respectively [12-15].

The PI controller generates reference current i* based on error signal and it is given as input to the threshold logic. The phase currents of the driver bridge circuit are sensed and given to the threshold logic. The output of the threshold logic is given to the hysteresis controller which can limit the peak to peak values of the current. Based on the hysteresis output value gate signal is generated using gate signal generator for the driver bridge circuit.

The closed loop control has inner current loop and outer speed loop. The speed of the SM winding currents and speed are sensed; the current is given to the fault diagnosis block. If fault occurs then the driver circuit will activate the spare switch and bypasses the faulty portion. The present current controller is used to drive signals to control engine in various operating modes. Encoder is a position sensor used to sense the speed and convert it into analog or digital output. The speed calculator calculates the speed in terms of rad/sec [16-17].

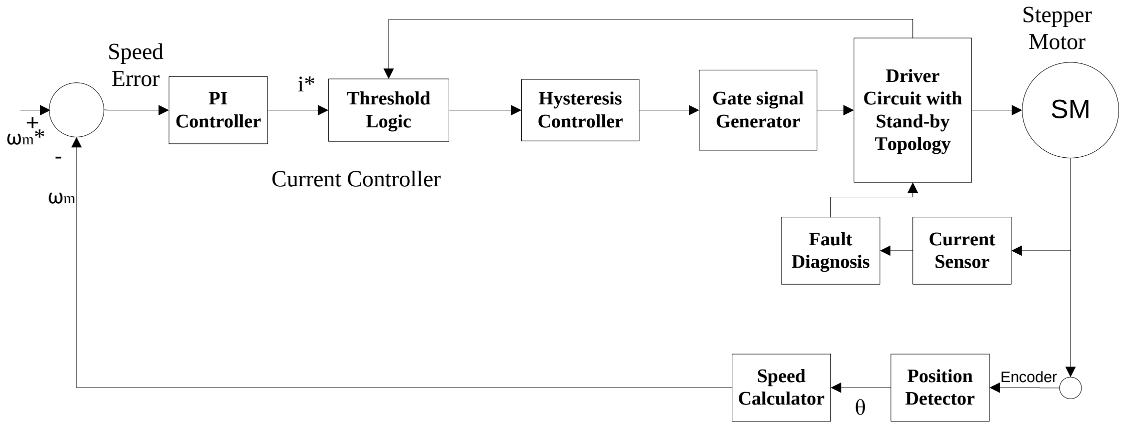

Fig. 2. Closed loop control system for stepper Motor drive.

3. Fault Tolerant Topology

The stepper motor coils are excited using driver circuit; it has six switches and six freewheeling diodes to provide current path to the coils. The fig. 3 shows the circuit diagram of stand-by topology for three phase variable reluctance stepper motor drive system. The single phase switching network MN, QR with the winding Wsp forms the stand-by network. This switching network has two MOSFETs Ss1, Ss2 and two diodes Ds1, Ds2. If fault happens in a driver circuit, the proposed single phase switching circuit switches acts as spare for the main circuit switches.

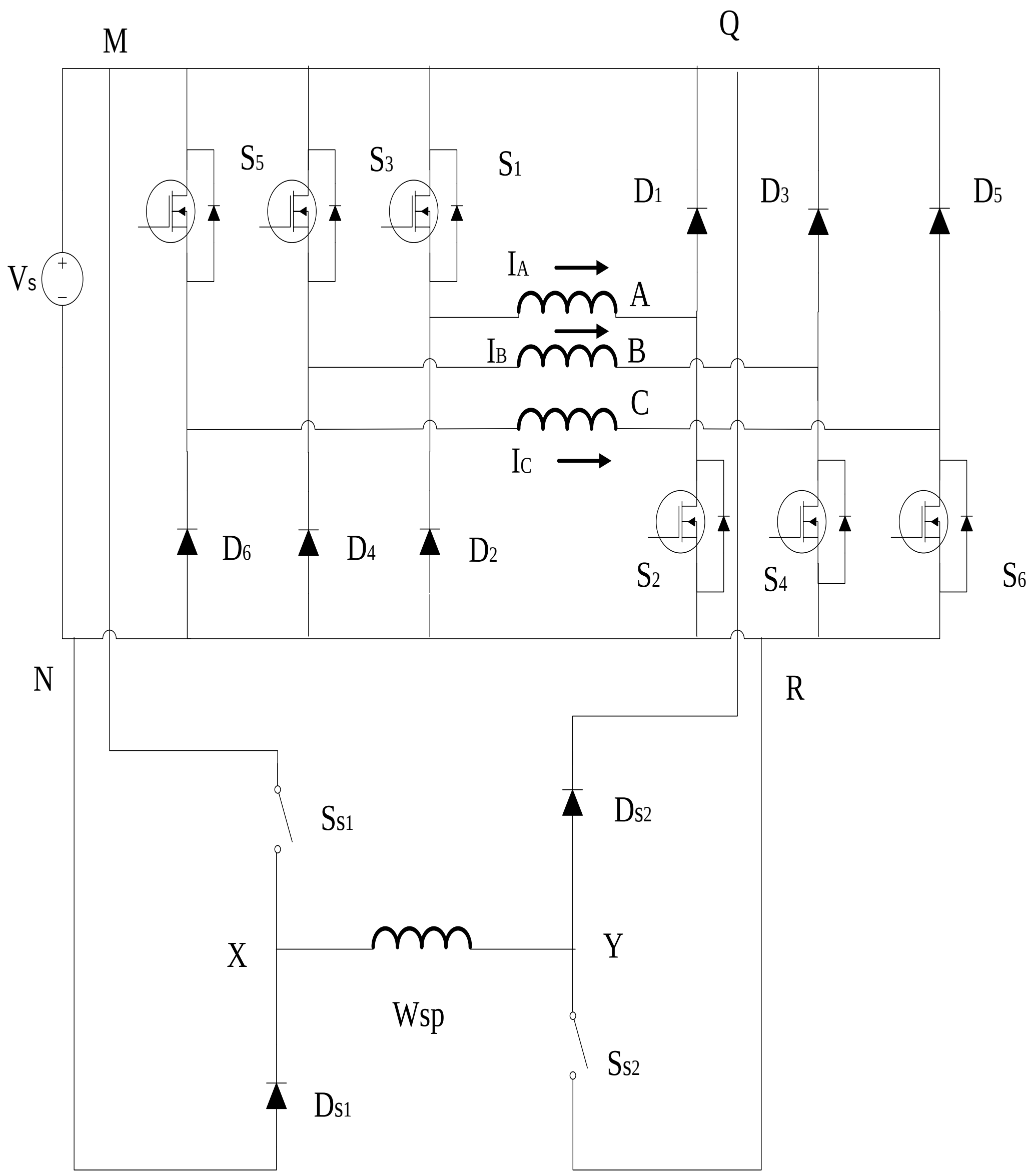

Fig. 3. Fault Tolerant topology for Stepper Motor Drive.

3.1. Open Circuit Fault Detection Topology

The controller topology is designed with the help of discrete controller, its function is to locate and bypass the fault path. Depending on the type of fault either open circuit or short circuit; the stand-by topology identifies the location and replace the fault switch with the spare switch. The performance of the SM remains stable under all types of fault conditions.

Figure 4 shows the flowchart of open circuit fault diagnosis topology. At the beginning current flowing through all the three phases are checked and the loop proceeds as the phase current is zero. If anyone phase current is zero then switches Ss1, Wsp, Ss2 are enabled. Now current through that phase is checked; in the absence of current through that winding has open circuit fault.

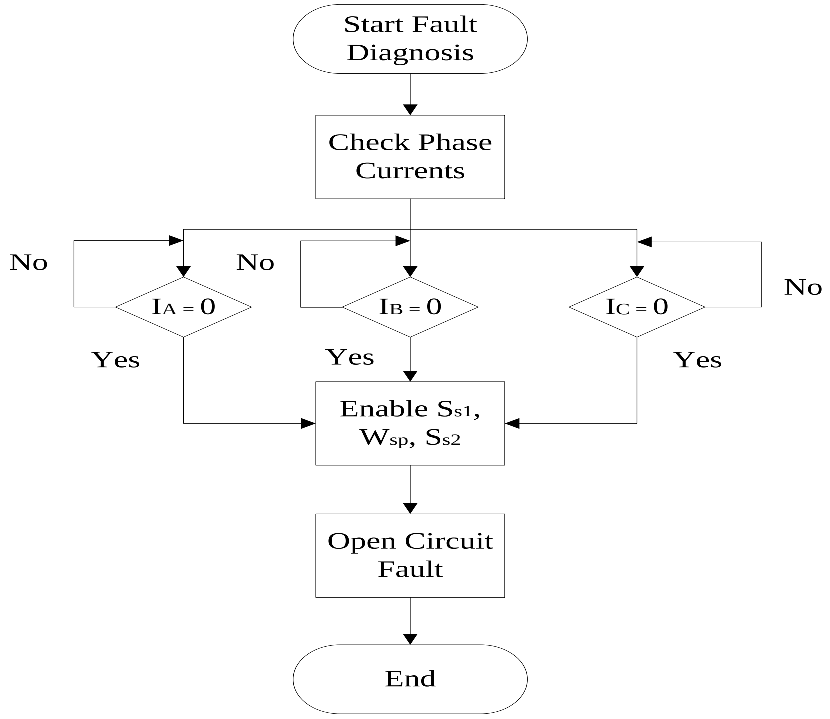

Fig. 4 Flowchart of the OC fault detection topology

3.2. Short Circuit Fault Detection Topology

Fig. 5 shows the flow chart of short circuit fault diagnosis topology. The topology is checking the current flowing through each phase and proceeds in its absence. Switches Ss1, Wsp and Ss2 are enabled and the current through the freewheeling diode is checked. Presence of freewheeling diode current identifies odd switch of that phase has SC fault; else even switch of that phase has SC fault. Mainly there are two causes to happen short circuit issues in the system, one is by the switching device short circuit and other one is the inner turn short circuit. Inner phase short circuit is nothing but when the converter is under short circuit of inner switching devices.

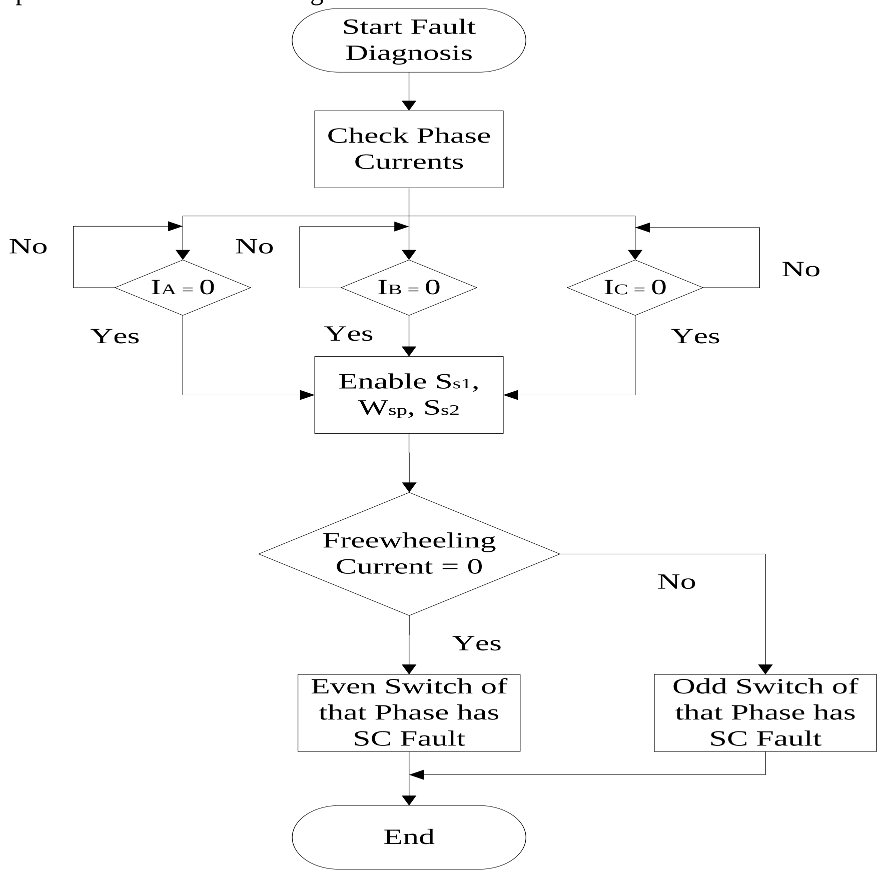

Fig. 5 Flowchart of the SC fault

4. Results And Discussion

The simulation of closed loop PV fed 3-phase stepper motor with fault tolerant topology is done using MATLAB/SIMULINK 2017 simulation software. PV Array of Model: 1Soltech 1STH-215-P is selected with 10 series and 3 parallel modules which can give maximum voltage of about 370V with the input irradiance of 1000 W/m2 at 25°C. The response of the PV array for variation in irradiance from 600 W/m2 to 1000 W/m2 is shown in fig.6. In order to retrieve maximum voltage from PV array the CUK converter gain is tuned using perturb and observe (P & O) MPP technique. The CUK converter output voltage is shown in fig.6; the output voltage is boosted to 470V even with variation in irradiance by tuning the gain.

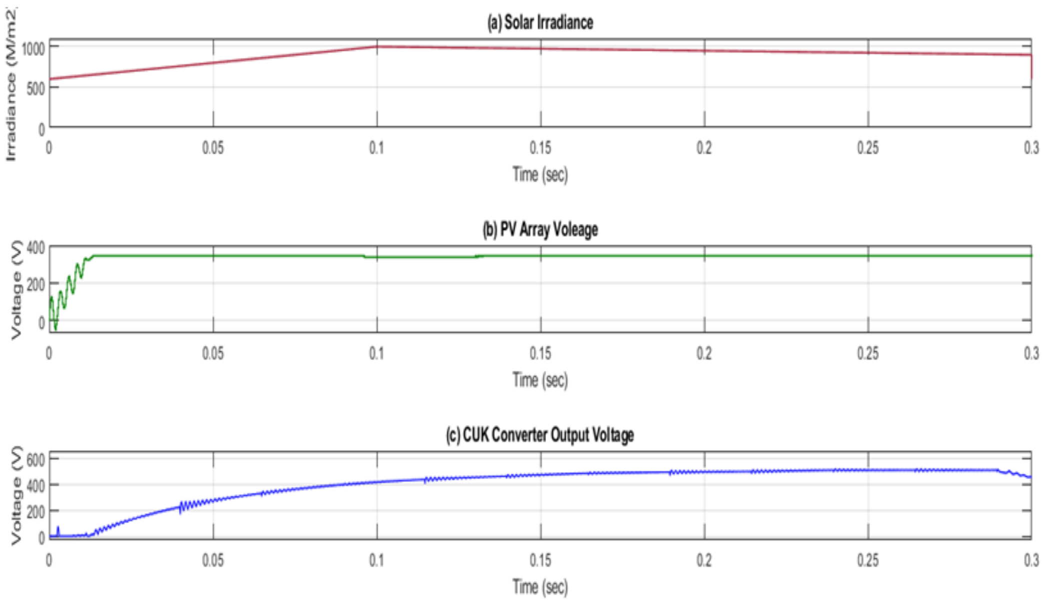

Fig. 6. PV Array Response and Converter Output Voltage

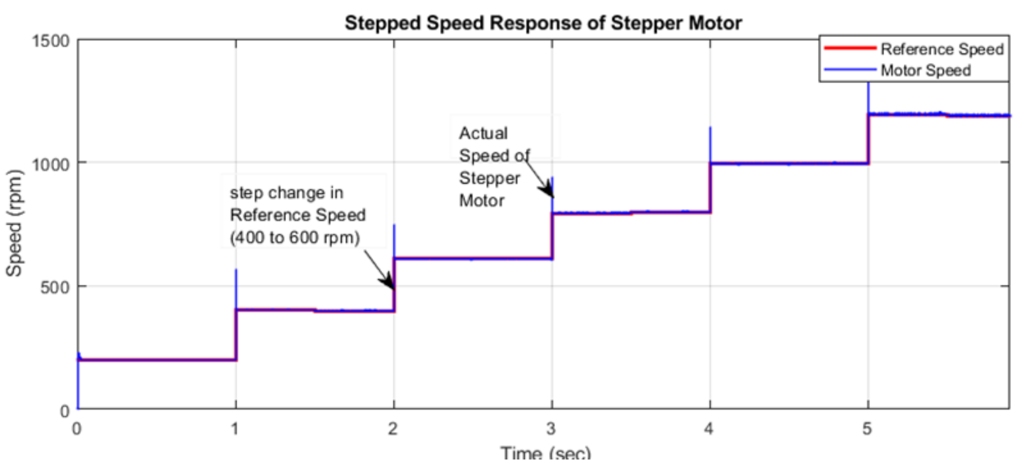

Fig. 7. Stepped speed response of stepper motor.

The reference values of stepper motor is varied in steps using signal builder circuit of MATLAB; fig. 7 shows the stepped speed response of the 3-phase stepper motor with respect to reference. The reference speed is varied from 200 rpm to 1200 rpm in step increase of 200rpm each. With the help of discrete controller the system can track the reference with zero error value, but there is the introduction of spike at every change in speed [18]. The robustness of the DSMC is proved by providing variation in irradiance and reference speed values; in both the cases the system is stable irrespective of variations.

The generated PWM signals [19-20] for the driver circuit for each phase is shown in fig. 8; to show the variation of gate pulses a step variation of reference speed is given from 200rpm to 400rpm. The response of the stepper motor is shown in fig.9 which gives the phase currents, torque, phase voltages and speed of the variable reluctance SM.

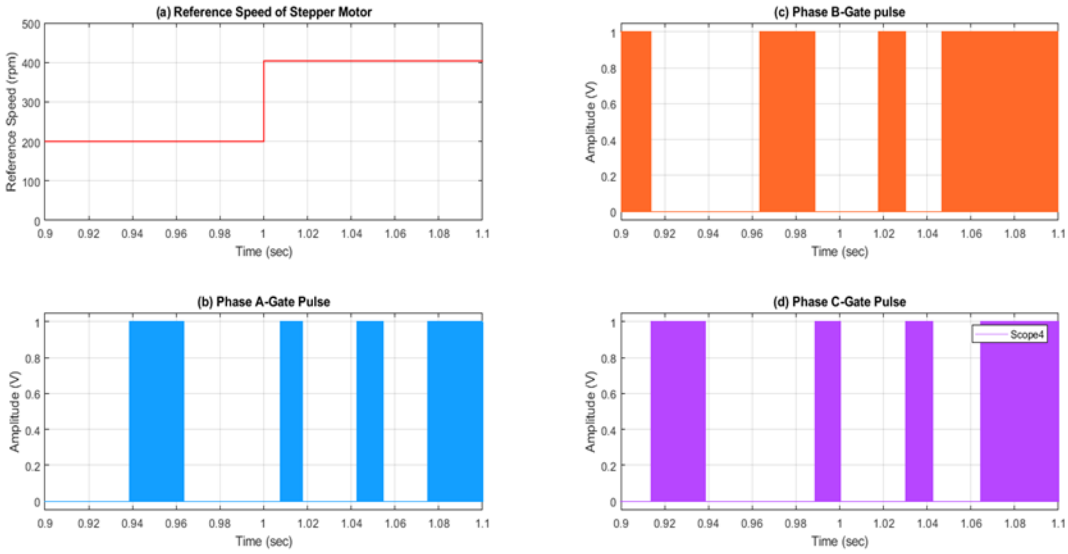

Fig. 8. Generated PWM signals for the Driver Circuit

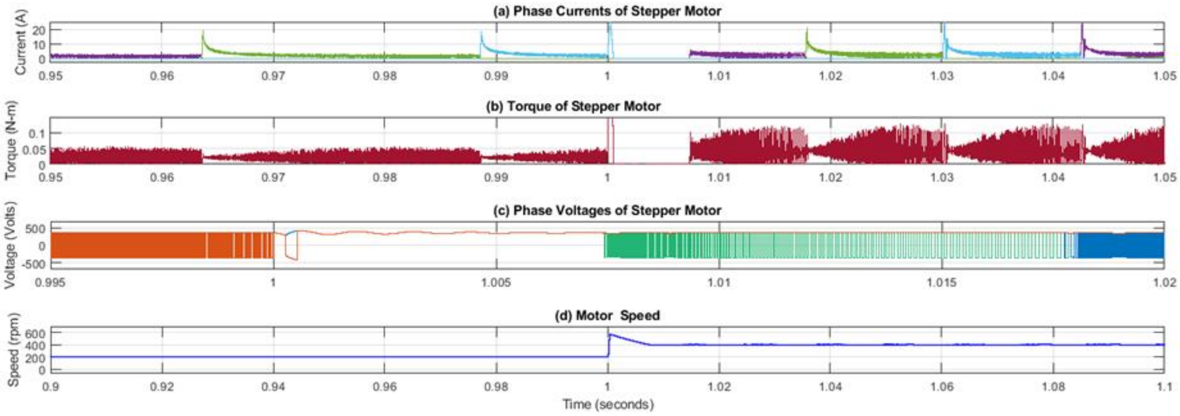

Fig. 9. Response of 3-phase stepper motor.

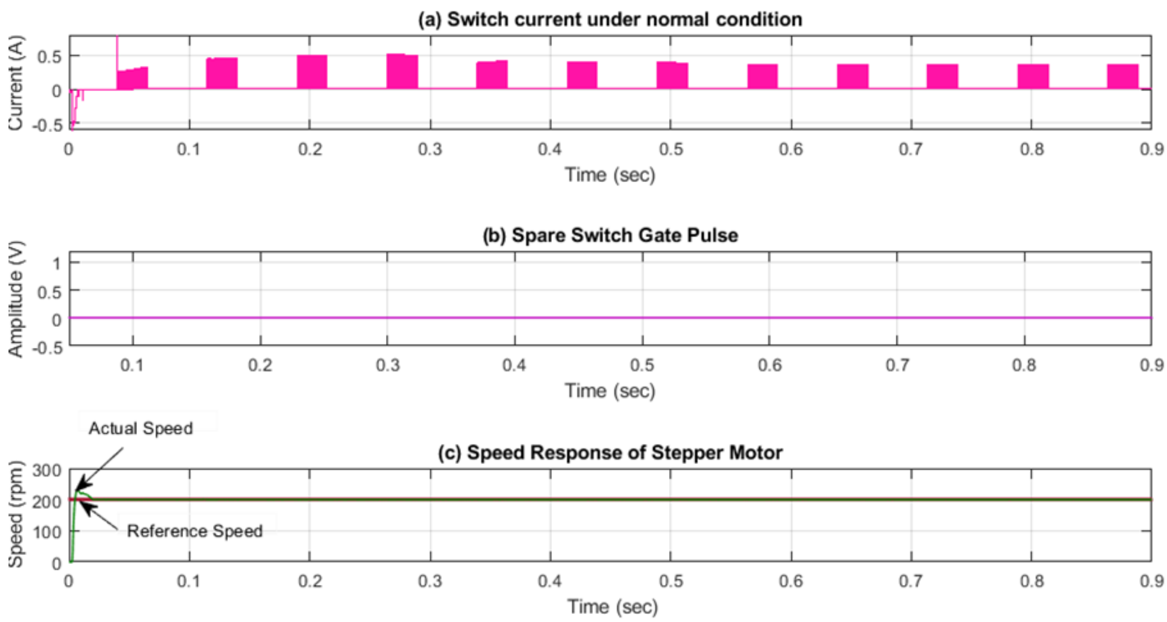

Fig. 10. Response under normal condition

The stand-by topology is having a set of spare switches, diodes and winding to form a bypass loop under fault condition. The response of the spare switch Ss1 and one of the main switch S1 along with speed response is shown in fig.10 when it is working under normal condition. Now an open circuit fault is introduced in switch S1 so that phase current IA becomes zero; now the controller activates the spare switch Ss1. The response of these switches under fault condition is shown in fig.11 along with the speed response of the stepper motor. The actual speed of the motor takes 0.02 sec to reach the reference speed under fault condition which is same as that of under normal condition. This proves that the controller takes the initiatiates imediately as the fault is detected.

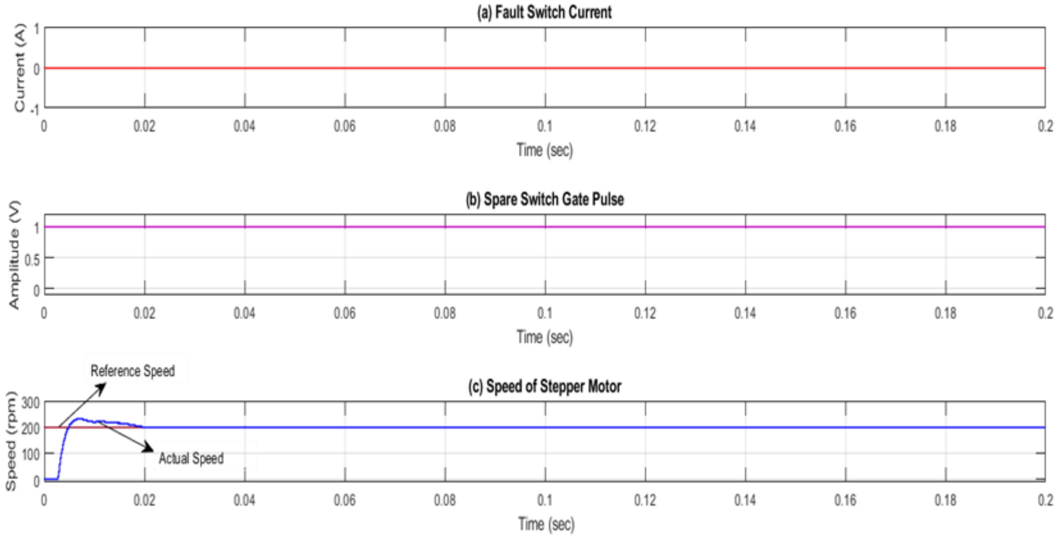

Fig. 11. Response under Fault condition

5. Conclusion

A fault tolerant discrete control technique for the Photo Voltaic (PV) fed 3-phase stepper motor is implemented using MATLAB/SIMULINK simulation software. Perturb and observe (P&O) algorithm is used to attain MPPT and the CUK converter is used to step-up the voltage according to the drive requirement. The closed loop speed control of this drive and fault tolerance is achieved by discrete controller. By implementing this controller the motor speed can track the stepped reference speed signal with zero error in 0.02sec. An OC and SC faults are introduced in the driver circuit and the fault tolerance is verified; both the cases the motor speed tracks the reference speed in 0.02sec. The robustness of the discrete controller is proved by introducing changes in the irradiance of PV array, changes in reference speed and faults in the driver circuit. The overall system is cheap, compact, robust and reliable; so can be used for very low and very high speed applications.

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