I J C T A, 8(5), 2015, pp. 1831-1842

FLC Based Fault Tolerant Technique in Dc-Dc Converters for PV System

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Abstract: The pvtechnology is the most promising alternative technology in now a days. Dc-Dc converters play a major role in pv system. Some of the converters have an enhanced fault tolerant capacity. But oc and sc faults can cause ripples in case of over load. We have to improve the reliability of power converters. In this paper I am proposing fuzzy based fault tolerant (FT) scheme for three level boost converter. FT can achieve in two steps. Fault diagnostic and fault control method. FD is a mandatory stage in any semiconductor switches. For FT we need some additional components to the converter. To validate this we are using a resistive load circuit. The experimental results are given to verify the validity of analysis.practically it is applicable for battery charging purpose.

Keywords: PV system, Dc-Dc converter, FT, FD.

1. INTRODUCTION

Environmental concern and availability point of view are the main issues for introducing Renewable Energy Source (RES) in energy domain. Such applications are small size applications and large power applications. The main attractive features of RES are continuous availability, non-pollution energy production and naturally replenishing. Based on this features now a days it is the most promising alternative energy source. Photovoltaic (PV) technology is completely differ from all other technologies (Wind, Hydro, etc) in some aspects like stability, wide power range, withstand for all climatic conditions, modularity and low maintenance small size application are calculator,water pumps and traffic lights. Powerplants and electrification for remote areas are some of High power applications of PV technology [1]. PV modules are famous for high reliability and long life time [1]. PV systems contribute with help of power controlling and energy storage devices [2]. We know that power electronic converters are the most sensitive devices [3]. Reliability is the main obstacle for extensive applications. Main issues are technical problems as well as MPPT, islanding and also the design prospect also [4].

PV systems are mainly three types. Standalone PV systems, Grid connected system and Hybrid PV systems. DC-DCpower converters are play a vital role in all these PV systems for conditioning the power which was generated by pv panel. A failure of DC-DC converter may lead to the total system failure. The two most crucial components in power converters are Aluminum electrotype capacitors and semiconductor switches. Failure in capacitors may lead to more than 50% malfunctions and breakdown. Semiconductor failures may cause 34% in power devices.[5].Inmany power applications mostly failure components are capacitors and power switches.Because of high mechanical stress and thermal stress [7].

The main reason for failure of power switches is an excess of electrical stress and thermal stress. [8]. the most common failures in power switches are Short circuit faults, Open circuit faults, and Gating faults. These may happen based on following external or internalreasons example 1) incorrect gate voltages 2) Failure of the drives 3) Switchingrupturewhichcanbeaconsequence of an SC fault 4) Over electrical stress

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In general open circuit faults (OCF) are consequence of short circuit faults (SCF) are gating faults in this paper we are considering the both SC and OC faults. Many surveys have been presented in literature report on FD of aluminum electrotype capacitors for different applications [9]. in power converters for some critical applications to improve the reliability fault tolerant operation is mandatory step. FT can achieve in two ways. Fault diagnosis (FD), fault control method. FD method gives suitable response to the fault which occurs in power switch. FD achieve in two stages fault detection and identification.

Several methods are proposed for FT and FD for SC and OC faults [10]. For isolated phase shifted full-bridge dc-dc converters switch faults diagnosis with FT scheme was proposed in [11].In this transformer primary voltage used as diagnosis criteria. For hybrid electric vehicles an OCF detection method was presented based on comparing the duty cycle with the inductor current slope [5]. For a Unidirectional power flow boost interleaved DC-DC converter an OCF diagnosis method was presented in [13]. For H-bridge dc-dc converter an FT scheme was illustrated with help of redundancy [14] for this extra leg and a bidirectional selector switch are combined to the existing circuit. By the help of magnetic component voltage a FD method was discussed for PWM dc-dc converter. In this method we measure the inductor voltage by using an auxiliary winding in magnetic core [15]. In [16] a ED method was discussed for MOSFETfaults in (Zero Voltage Switch) ZVS dc-dc converter at the initial stage. The main drawback of this method is it does not stops the faults during DC-DC converter. It works by the help of integral and peak values of DC link current. For two cascaded buck non isolated converters an OCF method was presented in [17] in this we use the measured output voltage and current at the source and load converters. Different types of diagnostic methods for isolated converter topologies were discussed in [18]. Any one of the isolated DC-DC converter topologies can be applicable for PV system, eventhough their pulsed input current might be harmful for lifetime of PV module [19]. The above mentioned topologies are deals with only open circuit faults only. In [20] we discussed an single switch DC-DC converter with fault tolerant capability under OC and SC switch failures. For this we are using field programmable gate array (FPGA) no additional sensors are required for this method. Among all those methods three level boost converter has an advantage that it can double the voltage gain of the conventional two-level non-isolated topologies, while the power converter switch voltage stress is half [21]. Because of this noise, conduction losses and switching losses are reduce.Three level non isolated converters are used in high power rating pv systems with high voltage gain require to maintain constant dc bus voltage. Features of three level boost converters are reduced input filter size, current ripple cancellation and the switching device voltage is half of the output voltage.so the power density and effectiveness will increase. A two level version of the boost converter will be very

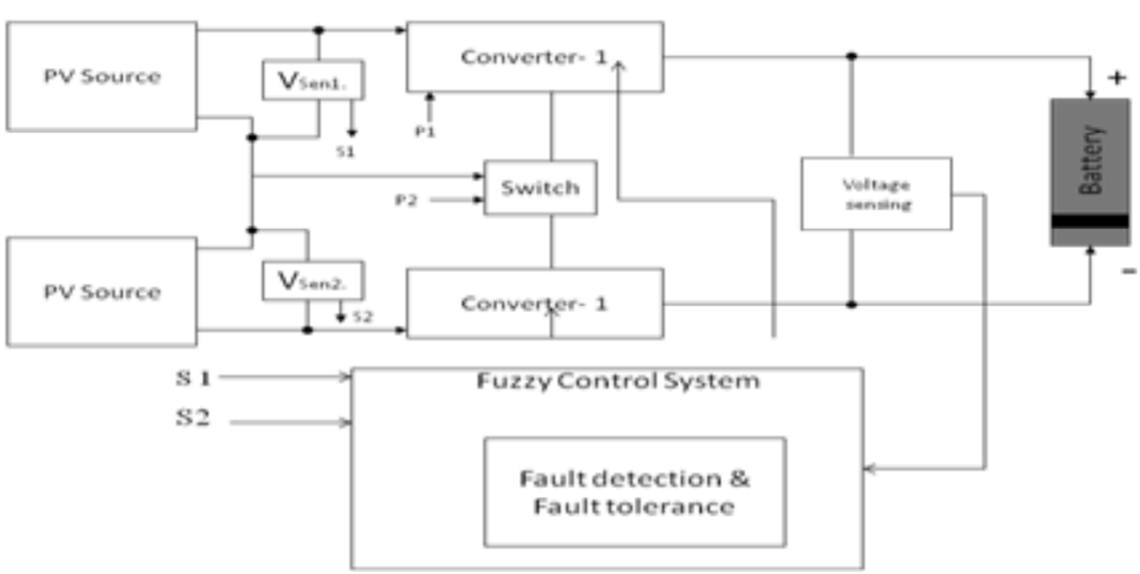

Figure 1: Three level boost converter with fuzzy control technique

simple, efficient and will have less number of components. In this the inductor loading stage is dividing into half.

This paperillustrates a new topology for three level boostconvertersto prevent faults which occur in power semiconductor switches. a fault tolerant technique also proposed with the help of fuzzy control technique. Fuzzy control is an artificial intelligent control technique. It offers a soft computation. It has faster and smoother response fuzzy control is suitable for approximation reasoning. For this technique we need some more additional components to the existing converter. A brief explanation of thepv system and operation process is given in sections[2]below. The FT and FD methods are discussed in sections[IV&V]. The validity of verified analysis is discussed with the help of experimental results in section [VIII].

2. PHOTOVOLTAIC SYSTEM

In photovoltaic system we will discuss in two parts. Overview and Configuration.

2.1. Overview

Power In photovoltaic system electricity generates directly from sun light by the help of solar cells. The process of generating electricity in solar cell based on the principle of “PHOTOELECTRIC EFFECT” it directly converts solar energy into electric.

To form a solar array numbers of solar cells are connected in series or parallel. When solar array exposed to sun dc voltage will produce. The equivalent circuit of solar cell is displayed below in general solar cell can be treated as a nonlinear current source. The factors which are effect the generating current are characteristic of material, irradiation, life time of solar cell and climatic conditions.

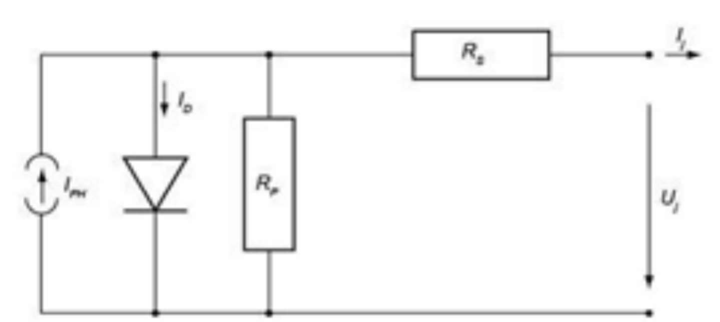

Figure 2: Equivalent circuit of solar panel

2.2. Configuration

Thepv system which shown in fig (1) is based on conventional three level boost converter. Three level converters will give efficient high voltage and high output for pvapplications [22]. When compared to conventional topology proposed scheme needs an additional extra component [1]. For application of proposed fault tolerant Dc-Dc converter topology the examples of possible combinations are1.Series-parallel2.parallel-series

Conventional topologytakes the total input current and total voltage of whole pv array. Whereas the proposed FT topology needs an extra two sensors for measure input voltage and current of each division of pv module both topologies are required voltage sensors at output capacitor for balancing dc capacitor link voltage proposed system needs an TRIAC also. In case of fault occur only TRIAC will trigger

3. NOMENCLATURE

io = Saturation current *Ipv* = Light induced current

Voc = open circuit voltage *Isc* = short circuit current

Vsc = short circuit voltage q = Electroncharge (1.60217* × 10^ – 23c)

a = diode ideality constant K = Boltzmannconstant (1.380 × $10^{-23}j/k$)

T = cell temperature (in KELVIN)

3.1. Operation Process

In normal state condition the topologies behaves as similar to conventional topology. In this power switch $S1$ used to control the current power switch $S2$ used for voltage control DC link capacitor. $S1$ maintain by MPPT [PAO] method which illustrated in [23]. It use the total array output voltage (sum of $Vpv1$, $Vpv2$), andone ofthe current ($Ipv1$, $Ipv2$).the entire process shownin fig (3).

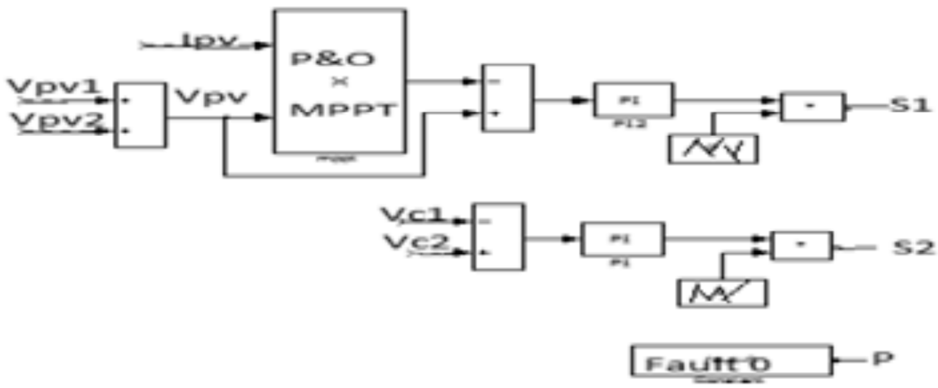

Figure 3: Fault Tolerant Control during Normal State

Total circuit analyzed in three states1.Normal State [w/o fault],Faulty State, Reconfigure State

3.2. Normal State

Normal operation is described by the help of power switch conduction modes. There are three modes of operation.1. Both switches on 2. Any one switchOn/Off 3. Both switches offthe entire process is described as three level boost converters [24].

3.3. Faulty State

Whenever the fault occurs in any one of power switches the converter will stop working. Before that a transient state will occur and then it stopped. When fault occur in one switch other will get an impulse to conduct until conductor will stop. In case of faulty state two modes are possible.1. Both switches are OFF 2. Any one switches OFF.

3.4. Both Switches Off

During this period both diodes $D1$ and $D2$ are in reverse bias and starts conduction. Then both capacitors $C1$ and $C2$ are gets charging. The analysis equations are

$$Vpv1 = L1\frac{dil}{dt} + Vc1 \tag{1}$$

$$Vpv2 = L2\frac{dil}{dt} + Vc2 \tag{2}$$

Add eqns 1 & 2

$$C1\frac{dvci}{dt}+io=iL \tag{3}$$

$$C2\frac{dvc2}{dt}+io=iL \tag{4}$$

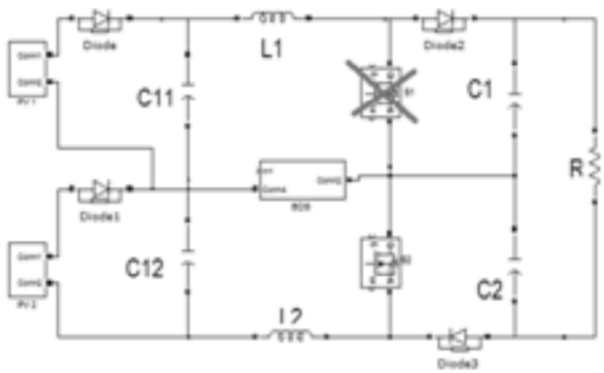

Figure 4: OC Fault in S1

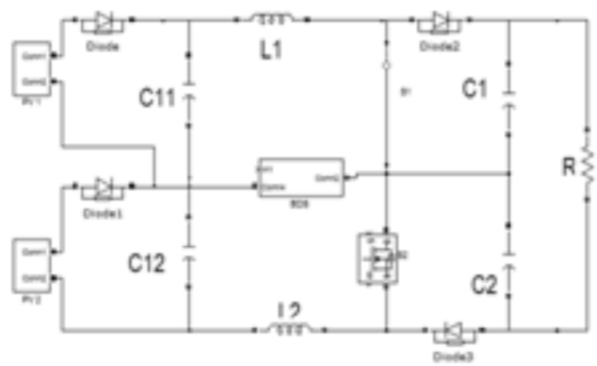

Figure 5: SC Fault in S1

3.5. One Switch Off

During this period Diode $D1$ is reverse bias and $D2$ in conduction mode capacitor $C1$ gets charging with current is [iL]& capacitor $C2$ discharge with current Io

$$Vpv1+Vpv2=\left(L1+L2\right)\frac{diL}{dt}+Vc2$$

$$C1\frac{dVci}{dt}+io=iL \tag{5}$$

$$C2\frac{dVc^2}{dt}+io=0 \tag{6}$$

When the fault occurs in switch $S2$ then $C2$ gets charge with current $C1$ gets discharge with current io.Whenshort circuit fault occur in any one of the switch converter, the voltage of that particular converter is zero $Vsc = 0$

According to the above based on the fault occur in switch cause voltage difference inDC link capacitor. Fault decides the charge and discharge of capacitors. Once the fault was identified the control circuit will reconfigure to continue the operation. The reconfiguration topology may differ based on fault location. The reconfiguration as shown below

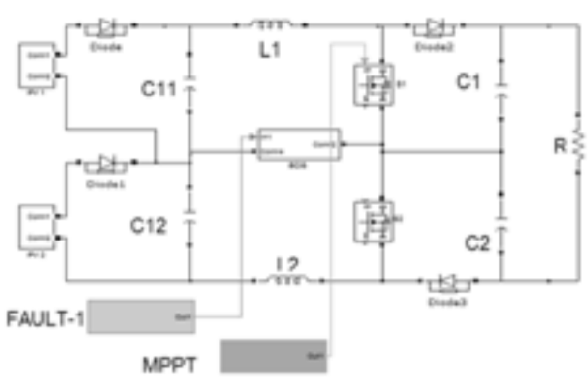

Figure 6: Fault Tolerant for S1fig

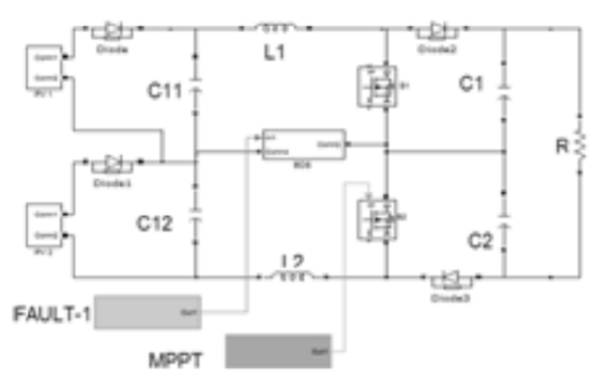

Figure 7: Fault Tolerant for S2

4. FAULT DIAGNOSTIC METHOD

Before analyzing the circuit let us made some assumptions (1). All elements are ideal 2. Voltage constant

In the convention three level boost converter control variables are input current,input voltage and output dc link capacitor voltage. Thepv array mainly affected by atmospheric conditions. Such as clouds,temperature,irradiation etc.The FD method which is used must be robust and highly reliable.Based on V-I characteristics of pv cell the effect of temperature and irradiation on pv module can be mathematically presented [25].

$$I = Ipv - Io\ \{\exp(qV|aKT) - 1\} \tag{7}$$

Series and shunt resistor losses are not influence the temperature and radiation effect on *pv* cell. So we were not taking into consideration [26].

Table 1
Effect of Radiation, Faultson PV Array Characteristics

	Current	*Voltage*	*Power*
TEMPERATURE INCREASE	increase	Decrease	Decrease
IRRADIATION INCREASE	Increase	Increase	Increase
TEMPERATURE DECREASE	Decrease	Increase	Increase
IRRADIATION DECREASE	Decrease	Decrease	Decrease
FAULTS	Decrease	Increase	Decrease

Photovoltaic cell power $P = V \times I$

$$= V\,[Ipv - Io\ \{\exp(qV|aKT) - 1 \tag{8}$$

The transcendent equations which are MPP current and voltage can be calculated based on *eqn* [9], [10] when the derivative of power is zero [15].

Voc and Isc are linearly dependent on Vmpp and Impp. It is proved by numerical methods [16]

$$Impp = Ipv - Io\left[\exp\left(\frac{qVmpp}{aKT}\right) - 1\right] - \frac{qVmpp}{aKT} Io \exp\left(\frac{qVmpp}{aKT}\right) \tag{9}$$

$$Vmpp = Voc - \frac{q}{aKT} Io\left(1 + \frac{qVmpp}{aKT}\right) \tag{10}$$

Apply short circuit conditions in eqn (7) $Vsc = 0$

$$Isc = Ipv \tag{11}$$

Ipv linearly depend on the solar irradiance and increase with temperature [25] so

$$IPV = [Ipvn + K1(T - Tn)]G/Gm \tag{12}$$

Where Ipvmis light induced current, T is Actualtemperature $K1$is temperature coefficient of the current, G is Actual solar irradiation,and Gm is nominal solar irradiation. The same properties are applicable for *Isc* and Impp.

Apply open circuit condition to eqn [7] ref [26]

$$Voc = \frac{aKT}{q}\ln\left(\frac{Ipv}{Io} + 1\right) \cong \frac{aKT}{q}\ln\left(\frac{ISC}{Io}\right) \tag{13}$$

Based on above equation we know that Voc logarithmically depends on short circuit current. To study the effect of temperature on open circuit voltage Voc, substitute Io in eqn (13)

$$Io = BTrexp\left(-\frac{EGO}{KT}\right) \tag{14}$$

Where *B* and *r* are temperature independent constants and EG0 is the band gap extrapolated to the absolute zero the temperature effect on short circuit current is very small and can be neglected.

Based on the properties of voltage and current of pv cell, the changes in maximum power will easily identified. During a fault the current and power are suddenly drop but the voltage will increase. The filter design by using a first order low pass filters with a frequency of 0.5Hz to 1Hz.

Fault detection can be applied any of DC converter for controlling purpose. Because in any power converter open circuit fault will lead to control failure and short circuit fault will lead to zero voltage.

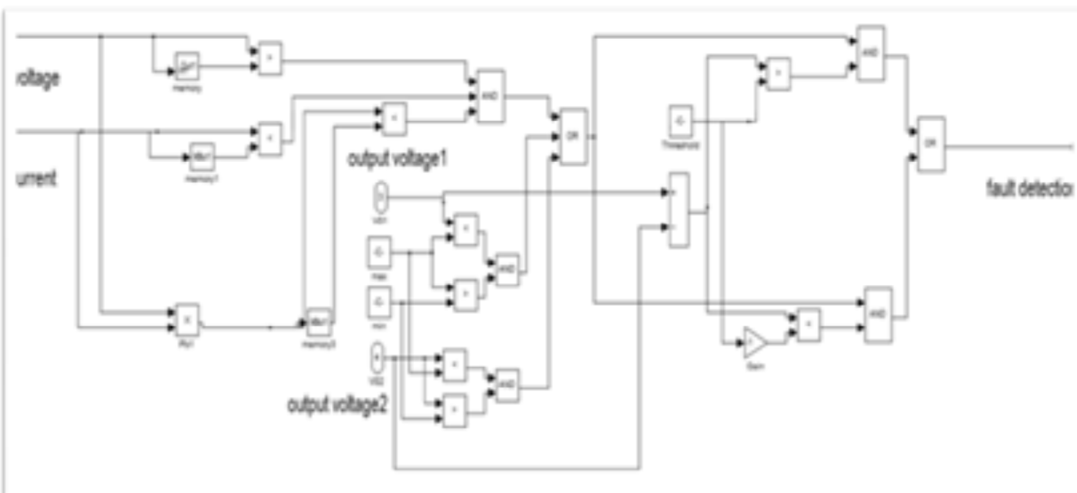

Figure 8: Fault Diagnostic Method

After detecting the fault we have to locate it. In this topology we have two power switches. To locate the fault a fault diagnostic variable can be created by comparing the two output DC link capacitor voltages.

$$F = Vc1 - Vc2 \tag{16}$$

If *F* is bigger than positive threshold *K* then the fault occurs in switch *S*1. If *F* is smaller than a negative threshold –*k* then fault occur in switch *S*2.This threshold was empirically chosen during tested. The total diagnostic method is presented in above Fig (8).

5. RECONFIGURATION METHOD

After detecting the fault and identified the faulty switch the system will reconfigure for further operations. The total control topology is discussed in below Fig. In normal state the three level boost converter uses the total output current and voltage. The output DC link capacitor voltage is used to balance it. During normal mode of operation in two switches *S*1 used to mppt control and switch *S*2 is used to balance the DC link capacitor voltage.The reconfiguration topology is as shown below Fig (9)

Once fault detection over the control system operate in different way, based on fault location occur in power switch *S*1 or power switch *S*2. When fault occur in power converter one of the switches stop working. Now the three level boost converter reconfigure into two level boost converter with mppt control. In this case mppt control the half of the module array only. So after the fault occurrence also the converter does not stop working, but it provides less power.

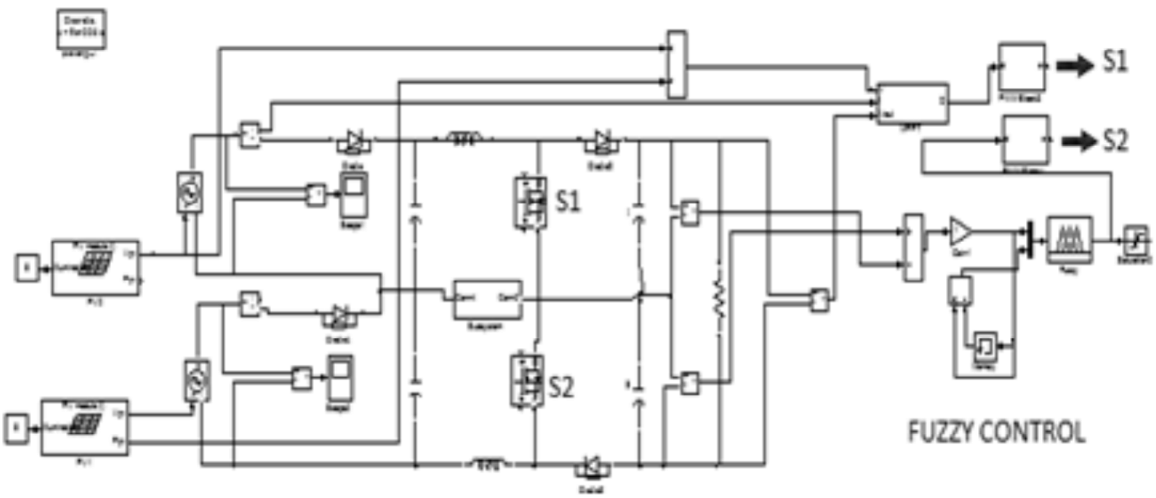

Figure 9: Reconfiguration Topology

If power switches $S1$ or $S2$ are suffers from any fault, after its identification bidirectional switch is triggered. Now the control system is rearranged according to the above circuit

6. FUZZY CONTROLLER

Error (e) and change in error (Δe) for output voltage are consider as an input of fuzzy logic controller. Pulses are given to switches by comparing the control output signal (u) with triangular waveform. The FLC design in three steps (1) Fuzzification. (2) Rule base or decision making, (3) Defuzzification

6.1. Fuzzification

In this step we define membership function for the inputs. We are using seven level triangular function. In this seven fuzzy sets or levels and set by the proper library values for the error(e) and change in error (Δe).

Error (e) and change in Error (Δe) for the output voltage are converted into Fuzzy values by Fuzzification. The input and output variables are allotted with 5 linguistic variables. NB–Negative Big, NM—Negative Medium,ZE—Zero equal, PM—positive Medium, PB—Positive Big.

The advantage of the triangular function is simplicity.

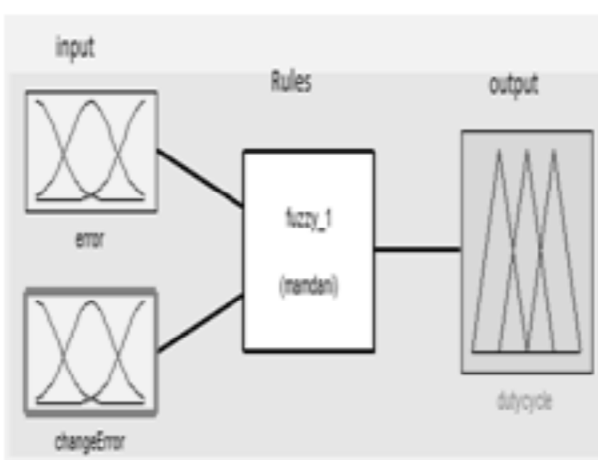

Figure 10(a): Duty Cycle Correction

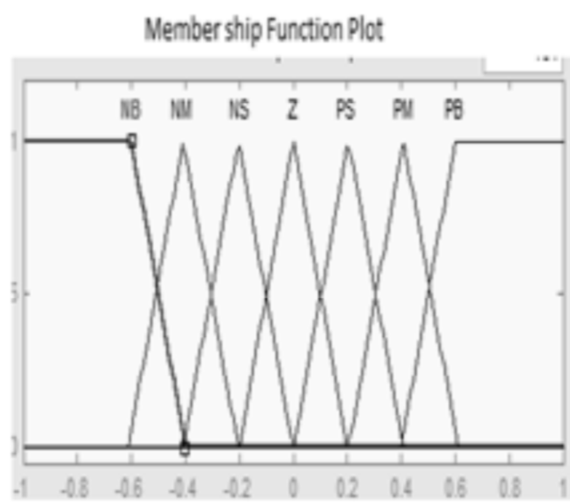

Figure 10(b): Membership Plot

6.2. Rule Base or Decision making

Fuzzy control rules are derived from thy system behavior. some of the control actions in rule table are also developed using "trial and error" from an "intuitive" feel of the process being controlled. The DC-DC converter control rules in below table (11) are derived from converter behavior.

e \ Δe	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	Z
NM	NB	NM	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PM	PB
PB	Z	PS	PS	PM	PM	PB	PB

Figure 11: Fuzzy Rule Table

6.3. Defuzzification

It is define as converting Fuzzy to Non-fuzzy or crisp. In this process a logical sum of inference results from each rule. The logical sum is fuzzy representation of the change in

7. SIMULATION RESULTS

The proposed configurations were validated through the experimental arrangement in fig 1, consisting of three level boost converter, two BP4157B pv cells and a resistive load.A DSPACE DS11103 controller

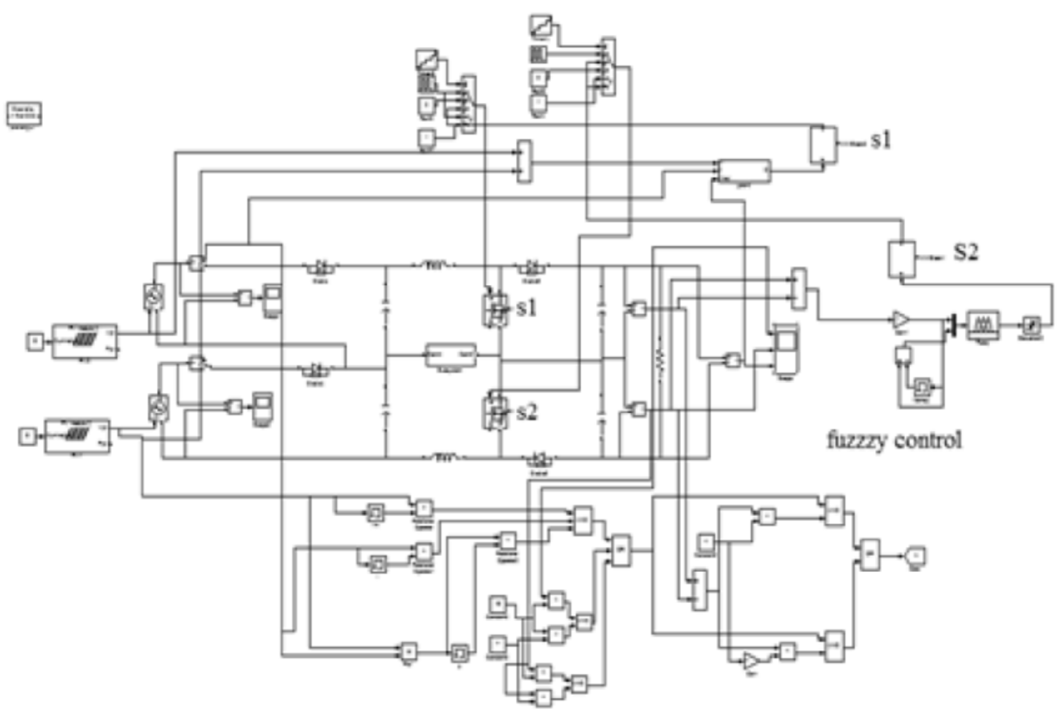

Figure 12: Simulink model of three level boost converter

board with a sampling time of 50 µs. Switches in the converter circuit are operating at a switching frequency of 20 kHz.Fig (12) shows the proposed technologies implementation. For both open circuit and short circuit faults in power semiconductorswitches. In this paper I am concentrating on the voltage only.

When oc fault occur in converter the voltage level gets decrease in it. When sc fault occur in converter the voltage gets zero. The appropriate wave forms are shown below

During the normal state, both the output voltages of two modules are add together. When oc fault occur in a switch, the pv array output voltage increase and its output current and output power are decreased

Figure 12(a): Output voltage of pv panel

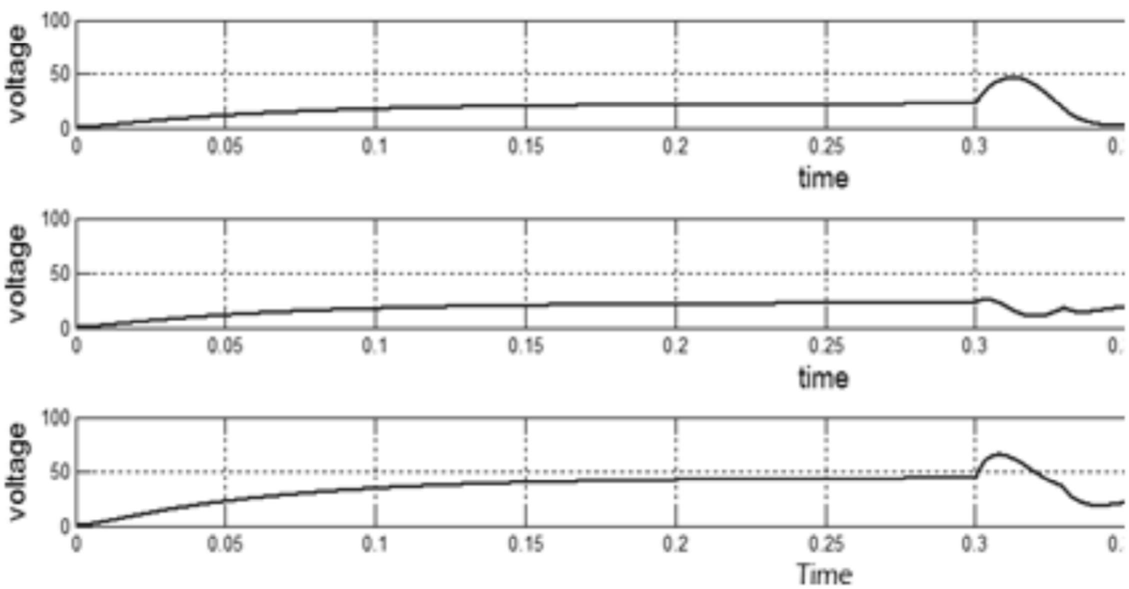

Figure 12(b): Output voltage during normal state

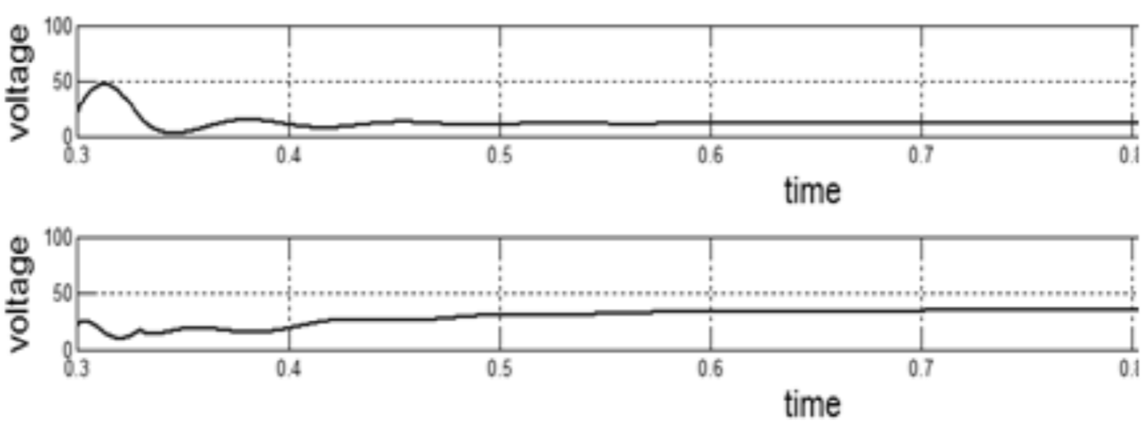

Figure 12(c): Converter 1 during open circuit fault

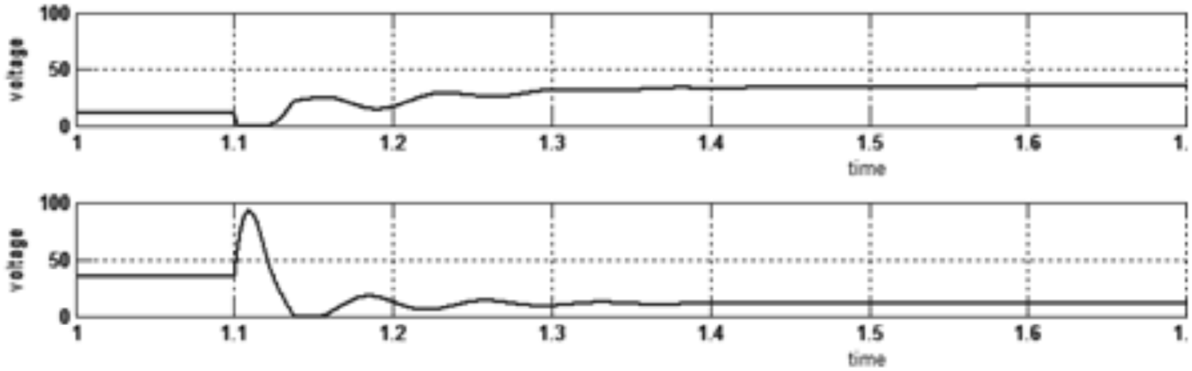

Figure 12(d):Converter2 during open circuit fault

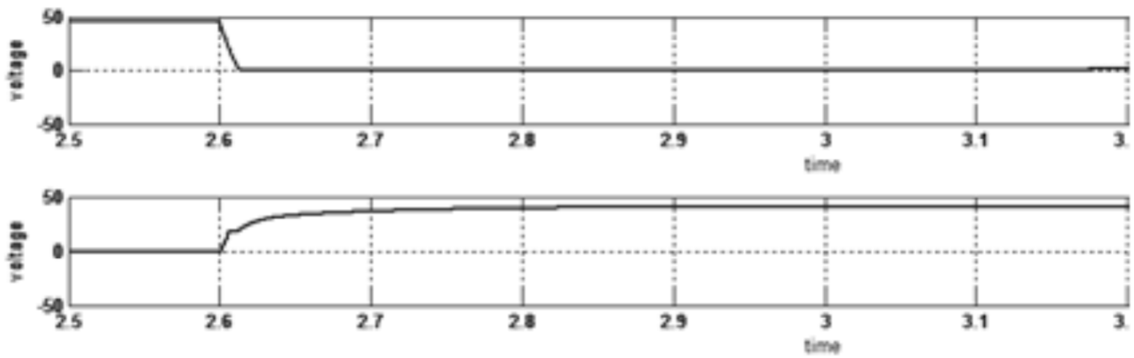

Figure 12(e): Converter1 during short circuit fault

Figure 12(f): Converter2 during short circuit fault

suddenly. When sc fault occur in switch output voltage is zero. Two level boost converters with mppt control for one module while another one will supply energy without mppt controller

The output power of the reconfigured converter produces less power compare to the original converter. The main drawback of this technique is it introduces higher stresses on healthy switches

8. CONCLUSION

A fault diagnostic method along with fault tolerant configuration based on fuzzy logic control for a three level boost converter in a power system applicable for charging batteries have been proposed. The Fault diagnostic method uses only ordinary state control variables and its implementation is not sufficient.Fuzzy Configuration help to rearrange the healthy part of three level boost converters into two level converter.This converter remains operating with MPPT control by providing only one of the pv module. Even though Fault Tolerant operation of this converter provides less output power. The converter continue its operation by rearrange itself and it proves to be an efficient and cost effective option for all those applications where there is continues power supply is crucial issue.

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