CHAPTER 3

NON INVERTING FOUR SWITCH BUCK BOOST CONVERTER FED SENSOR LESS BLDC MOTOR USING HYSTERESIS CONTROLLER

In General solar power generated is utilized either for grid interface or for standalone applications like variable frequency drives, electrical vehicle, lighting and water pumping applications and used for serving other industrial domains like automotive, appliances. MPPT technique along with a dc-dc converter is added for utilizing energy generated from solar cells to maximum level. BLDC motors are recently preferred for various applications other than electrical motors due to its advantages A. G. de Castro et al., 2016. Sensor less control of BLDC motor is been in research over the years because of maintenance free operation and it is also a cost effective during both manufacturing and also while in operation. Control techniques including position or speed sensors increase computational complexity and additional electronic circuits to the control module. The major fact to be considered for sensor less control technique is to find a starting method when the motor is at stand still condition and controlling the motor in low speed regions.

3.1 Autonomous PV Module

Ananda Kumar et al., 2011 is introduced the autonomous photovoltaic module using a non inverting four switch buck boost converter with perturb & observe algorithm is designed for driving three phase inverter fed BLDC motor. The proposed PV module is simulated in MATLAB/Simulink environment by modeling using its equivalent circuit based on single diode model. Structure of sensor less control of BLDC motor with proposed control technique powered from an Autonomous PV module including intermediate non inverting four switch buck boost converter with P & O MPPT algorithm is shown in Figure3.1. The main objective of this PV module with NFSBB converter is to improve dc-link performance of inverter without using any controller is presented by Caracas et al., 2012.

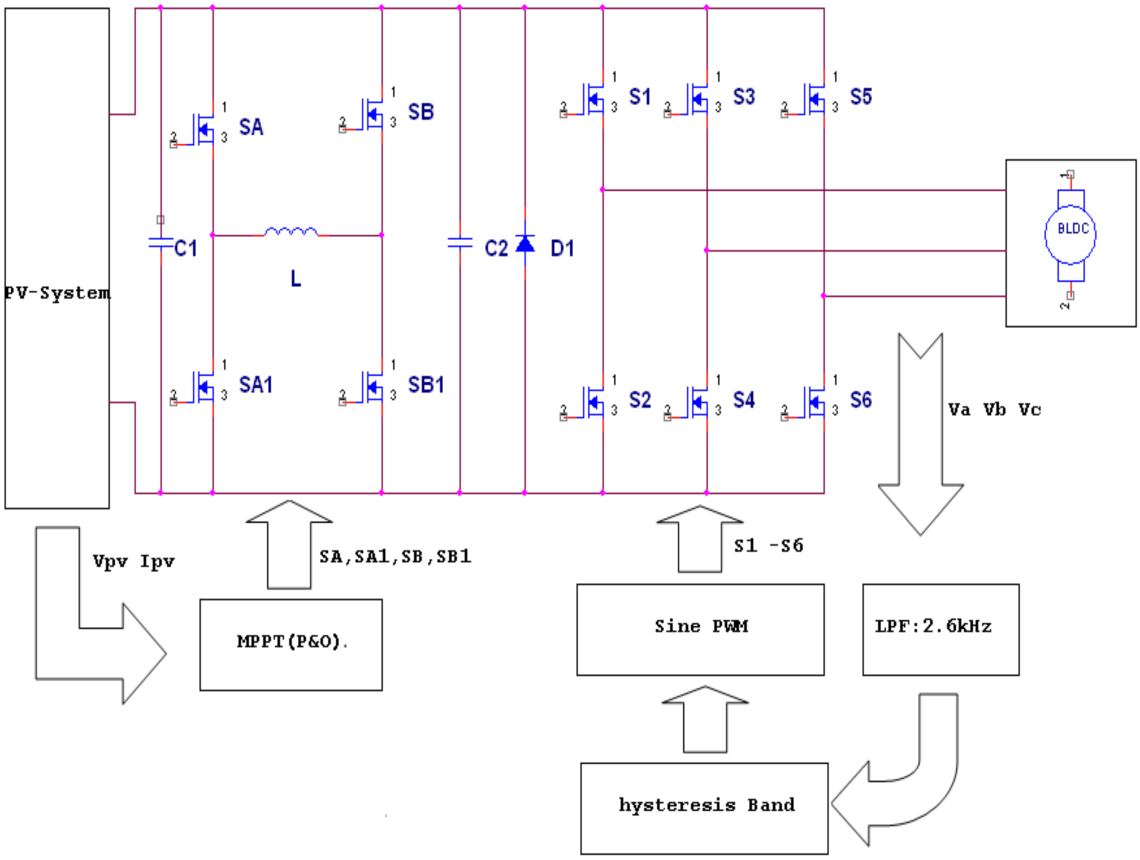

Figure 3.1 Overall structure of Autonomous PV module

Equivalent circuit diagram of autonomous photovoltaic module is shown in Figure 3.2. In the equivalent circuit both load and source side voltages are shown by ideal voltage source converters. The transfer function G_{oi} of the equivalent circuit shown above gives the voltage gain of the NFSBB converter is introduced by Chiu et al., 2013. Transfer function is calculated based on voltage of the converter, ratio between load or output voltage and source or input voltage is obtained as transfer function and is given by

$$G_{oi}(s) = \frac{\hat{v}_{PV}}{\hat{v}_o}\bigg|_{\substack{\hat{d}_1=0 \\ \hat{d}_2=0}} = \frac{1-D_2}{D_1}\frac{\left(1+\frac{s}{w_{z1}}\right)}{\left(1+\frac{s}{qw_0}\left(\frac{s}{w_0}\right)^2\right)} \tag{3.1}$$

The maximum voltage that can be obtained using NFSBB converter with P & O MPPT algorithm is given by

$$\frac{\partial i_{PV}}{\partial V_{PV}}\bigg|_{MPP\ (PV)} = \frac{1}{R_{MPP\ (PV)}} \tag{3.2}$$

Where

w_0 is the resonant frequency,

D_1, D_2 is duty cycle,

q Electron charge ($1.6*10^{-19}$C),

R_{MPP} is MPPT resistance

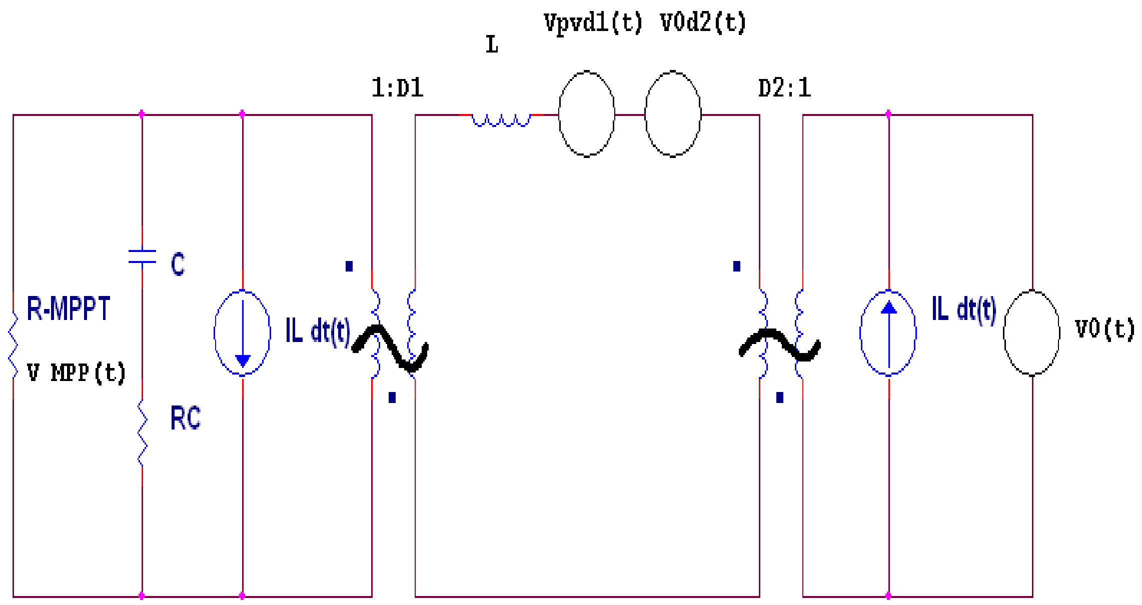

Figure 3.2 Equivalent circuit diagram of autonomous photovoltaic module

3.2 Non Inverting Four Switch Buck Boost Converter

This converter works with more number of power switches and lesser number of passive components when compared with traditional buck-boost converter topologies like SEPIC, Cuk and zeta. It produces a voltage with positive polarity that is non inverting with respect to input voltage polarity unlike special dc-dc converters. This converter has high reliability; high step up output of given input voltage and can act as an excellent buck converter. Photo voltaic source is fed as input to NFSBB converter which will boost the PV generated voltage to the required DC-link voltage for BLDC motor operation. For improving the power rating of the converter pulse generation scheme takes duty cycle command from perturb and observe MPPT algorithm. Pulse generation methodology including high frequency ramp based carrier wave and MPPT for three different operations like buck, buck-boost, boost using NFSBB converter is shown in Figure 3.3. For buck operation of the converter only first leg switches are turned at a certain frequency and it acts as an excellent voltage regulated power supply for low voltage DC applications. Similarly for buck boost operation first leg switches are operated at higher duty cycle and second leg switches are operated at lower duty cycle over a single conduction period time. The switching frequency of the converter also determines the voltage step up ratio of the converter. The output voltage gain of the NFSBB converter is given by

$$G_V = \frac{V_{out}}{V_{PV}} = \frac{D_1}{1-D_2} \tag{3.3}$$

Where D_1 *and* D_2 are duty cycle obtained from perturb & observe MPPT algorithm for switches in top of the both legs. The NFSBB converter can operate in discontinuous conduction mode while stepping down input voltage where inductor current comes to zero during every conduction period. While stepping up input voltage the inductor operates in continuous conduction mode where the current flow through inductor never comes to zero ensures constant dc current flow through load.

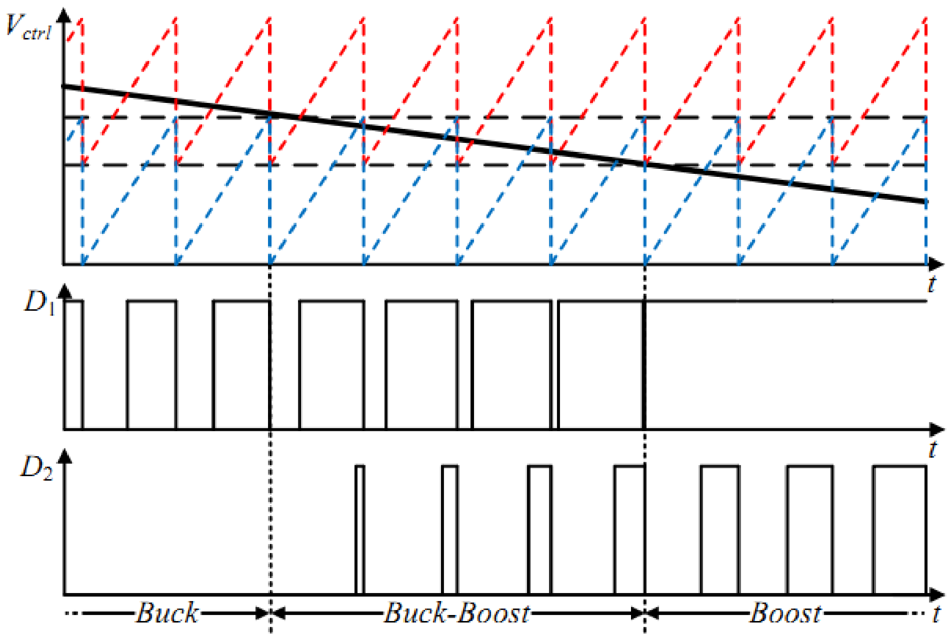

Figure 3.3 Pulse Pattern of NFSBB converter

3.3 Perturb & Observe Algorithm

This is one of the MPPT techniques which are commonly suited to most of the applications. It continuously senses the voltage and current of a PV cell and it calculates the power developed by solar panel that depends on the current value of temperature and irradiance.

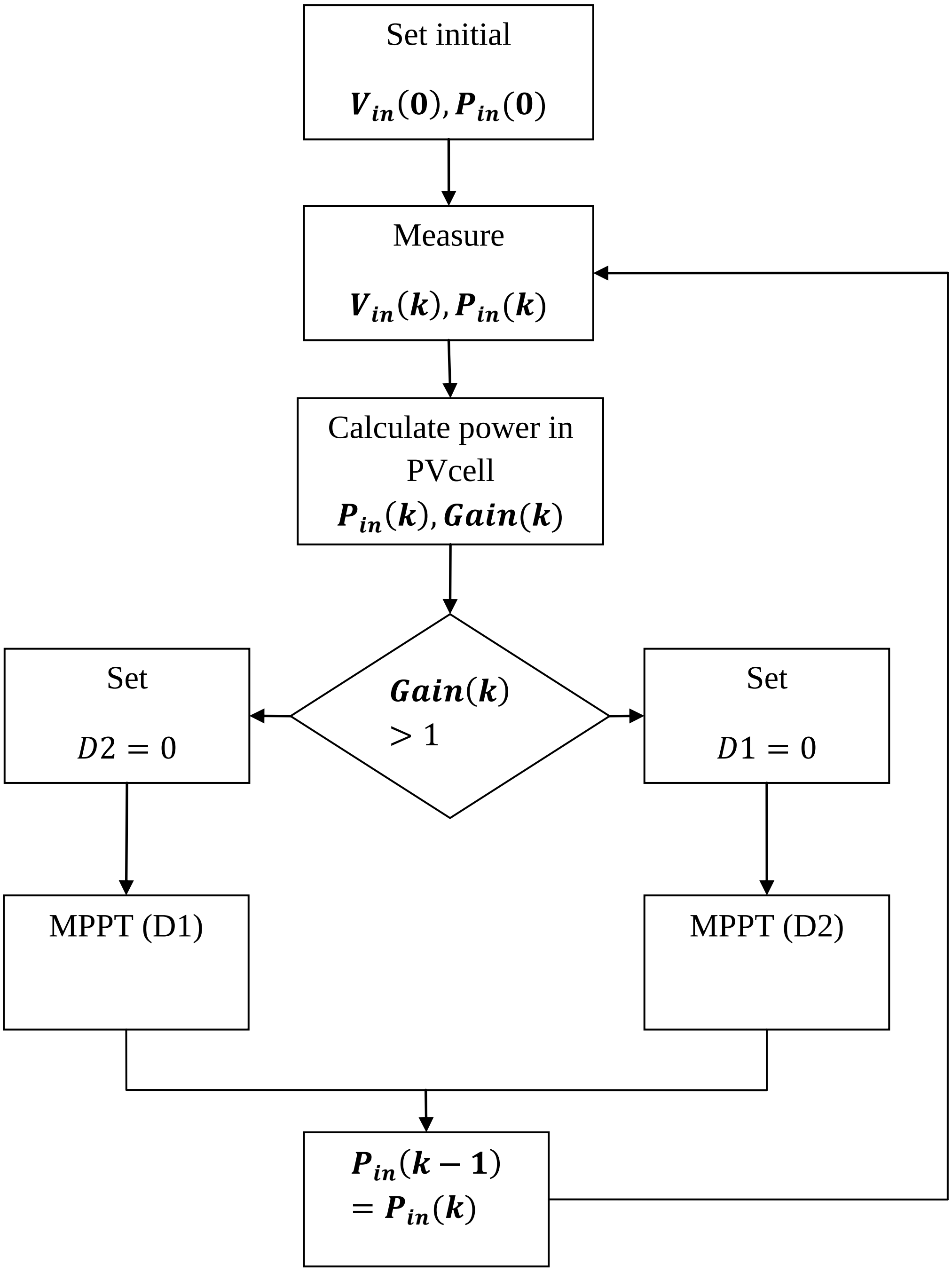

Figure 3.4 Flow chart of P & O algorithm applied for NFSBB converter

Then it finds a maximum power point of the particular PV source within short period of time based on conditions. It converges to MPP within a short settling time and MPP deviates around original MPP of the panel. Here conventional P & O algorithm is modified for application to the use of non inverting four switch buck boost converter and the flow chart of the implemented P & O algorithm is shown in Figure 3.4.

3.4 Inverter

Conventional three phase inverter employing three leg and six switches drives the BLDC motor. The inverter always operates in 120^0 degree conduction mode where output voltage of inverter is always a stepped square other than pure square wave. The other reason for working in the above mentioned conduction mode is back-EMF of BLDC motor is trapezoidal and one phase potential of BLDC motor winding is kept at open circuit or in floating condition to achieve trapezoidal back-EMF. Conduction period of every switch of inverter for a single fundamental cycle is shown in Figure 3.5.

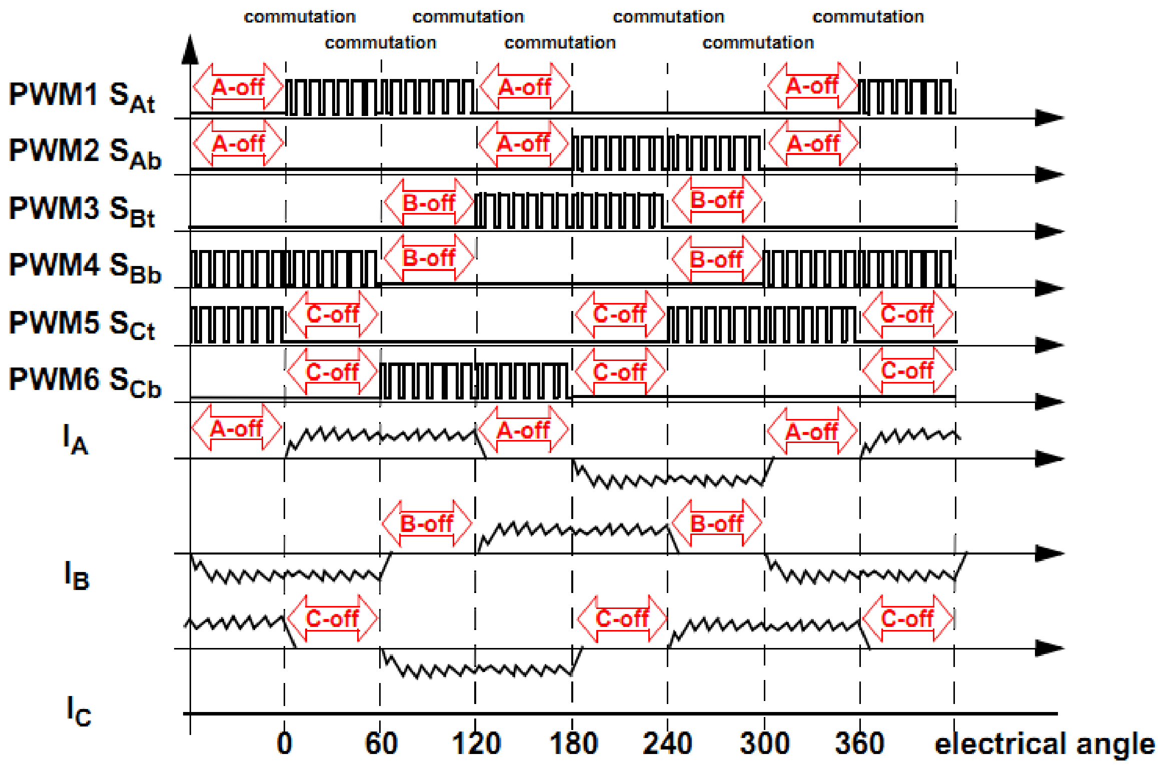

Figure 3.5 Switching pattern of three phase inverter fed BLDC drive

From the pulse diagram given one can observe that every switch conducts for 120^0 and at every 60^0 interval two powers switches one top switch and bottom switch from different leg conducts is discussed by Dadashnialehi et al., 2017. BLDC motor commutation is not performed mechanically due to the absence of brushes and electronic commutation instant of BLDC motor. Commutation in power electronics meant to turn off any particular conducting device which is previously in on state; here commutation helps to achieve trapezoidal shape of back-EMF. Current drawn by BLDC motor of all three phase is also shown in the Figure for single conduction cycle. From current waveforms we can infer that at every 60 interval any one phase of current is zero which shows that current shape of BLDC motor is rectangular and not sinusoidal is explained by Rai et al., 2016.

3.5 Sensor less Control technique using Hysteresis Controller

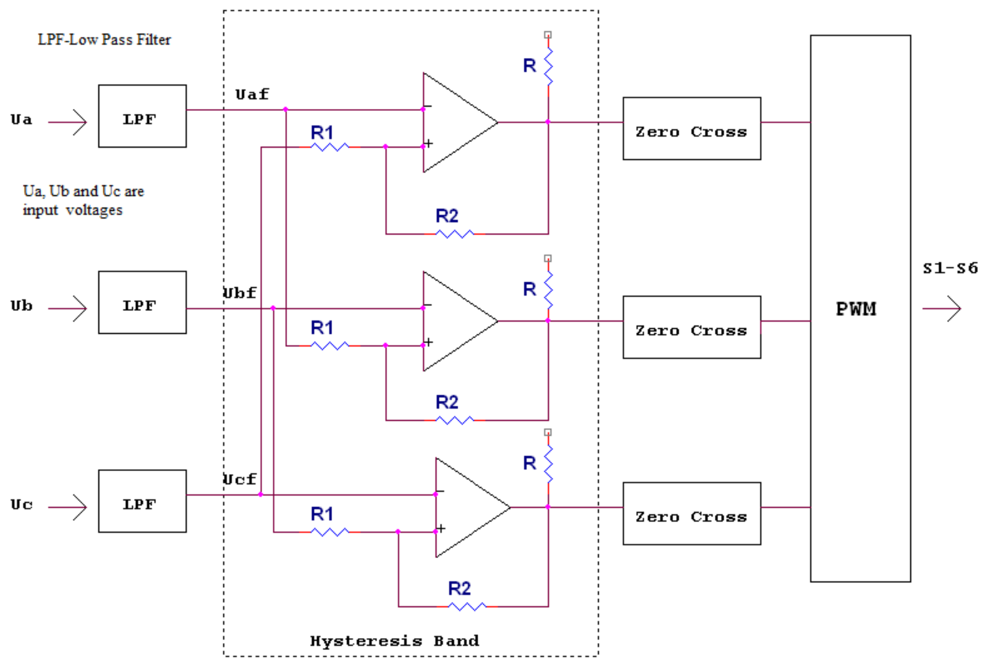

Figure 3.6 Block Diagram Sensor less control using Hysteresis Controller

The sensor less control scheme including reference voltage signal generation for hysteresis sinusoidal PWM generation and closed loop controller is shown in Figure 3.6. The current process of sensor less control technique in any motor control applications is sensing three phase voltage, current and back-EMF of motor and then deriving required speed or position signal from machine mathematical model.

Performance of sensor less control method is done by adding a low pass filter to reduce harmonics and higher frequency components from sensed three phase voltage.

Measured voltage from voltage sensor is given as input to low pass filter and it provides the actual voltage signal (U_{reff}) and the reference voltage signal $U_{reff}*$ is compared with actual voltage signal without noises through an hysteresis comparator Ali A and Ramesh, 2017. The purpose of this comparator is it compensates lag in phase angle of voltage occurred due to low pass filter. Reference voltage is chosen such that it closely resembles the back EMF of the motor so that commutation sequence of BLDC motor for any 60^0 interval can be obtained easily. A single hysteresis band comparator compensates for the phase angle and provides three phase reference voltage signal for sine carrier pulse width modulation. The other importance of hysteresis band comparator is for obtaining proper current commutation through three phase inverter by generating appropriate triggering pulses for switches used in the inverter is discussed in B. Singh and V. Bist, 2012.

Low pass filter used a cut off frequency in the range of 2.6 kHz because if frequencies higher than this specified cut off frequency present in reference voltage signal it can affect electromagnetic torque and speed performance of BLDC motor. Harmonics content of higher frequencies including noise will appear in the speed and torque signal.

3.6 Simulation Results and Discussion

The sensor less control of brushless DC motor using hysteresis controller scheme with sinusoidal pulse width modulation and autonomous PV module is simulated in MATLAB/Simulink environment and the implemented circuit topology is shown in Figure 3.7. Table 3.1 shows the circuit parameters of proposed topology applied in MATLAB simulation. Dc-link performance shown contains three modes of operation including buck, buck-boost and boost.

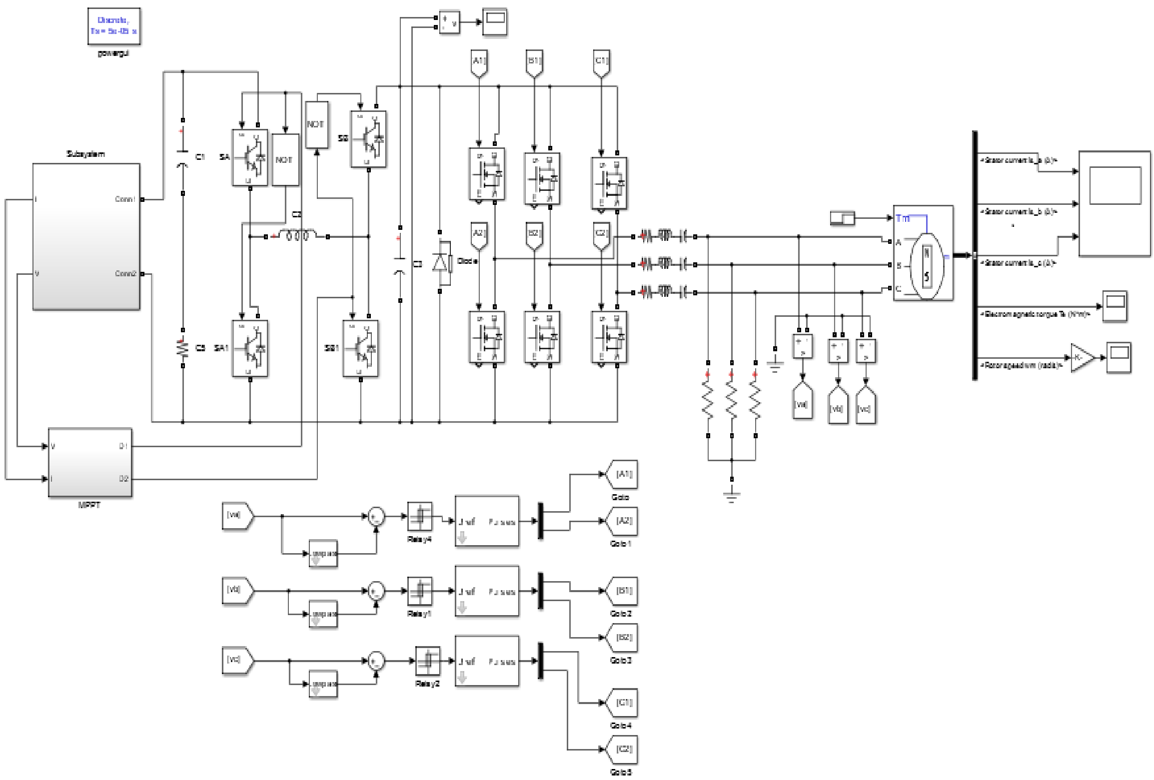

Figure 3.7 Simulation implementation circuit of Autonomous PV module for sensor less control of BLDC motor

Table 3.1 Parameters of Overall Circuit

NFSBB Converter Parameters	
Name	Value
$V_{PV}(V)$	25
$I_{PV}(A)$	2.5
$P_{PV}(W)$	62
$V_{out}\ (V)$	60
$L(\mu H)$	800
$C1(\mu F)$	200
$C2(\mu F)$	200
$R(m\Omega)$	50
$L(mH)$grid side	1
$C1(nF)grid\ side$	1

BLDC Motor Parameters	
Rated voltage(V)	60
Rated Current(A)	3A
Nominal speed (rpm)	3000
Stator Resistance(Ω)	0.19
Stator Inductance(mH)	0.835
Rotor moment of inertia J(kg.m^2)	1.9959µ

Autonomous PV module has an intermediate dc-dc conversion stage employing a NFSBB with perturb and observe MPPT technique whose DC-link performance is shown in Figure 3.8.

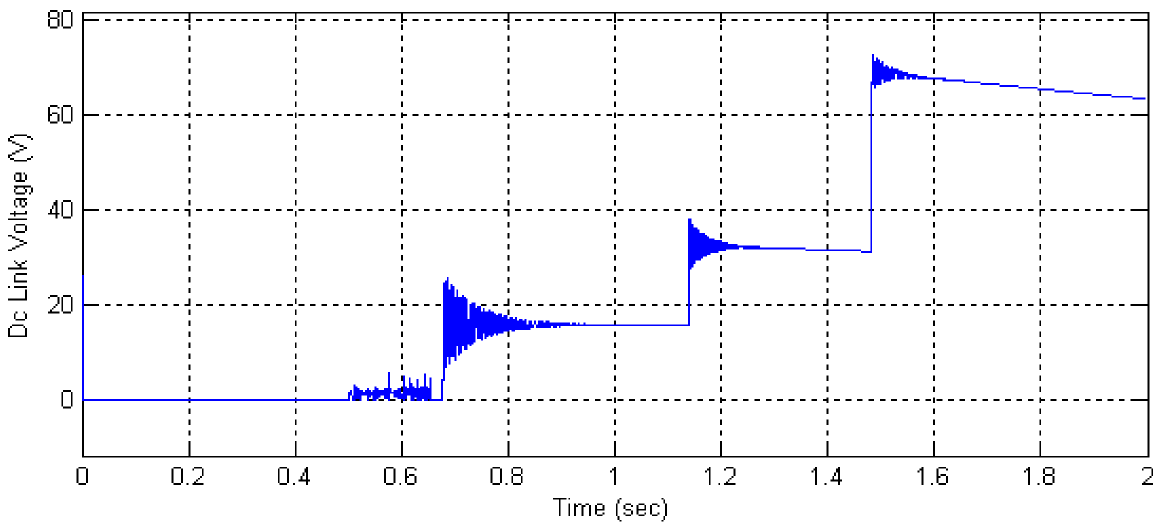

Figure 3.8 DC Link response of three phase inverter driven BLDC motor

Figure 3.9 shows R phase stator current of BLDC motor. The proposed hysteresis control technique is implemented for generating less harmonics is shown in Figure 3.10.

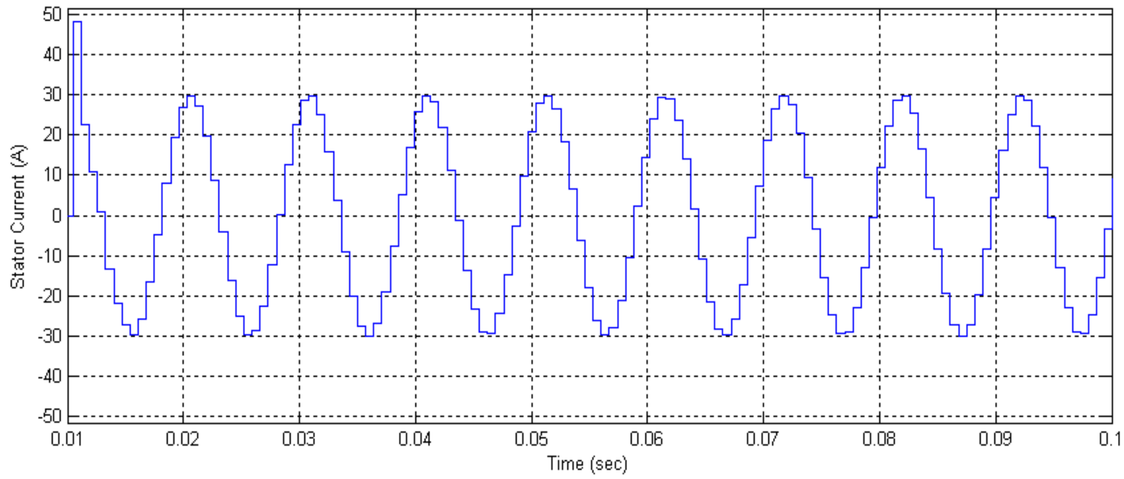

Figure 3.9 Stator current response of BLDC motor per phase stator current

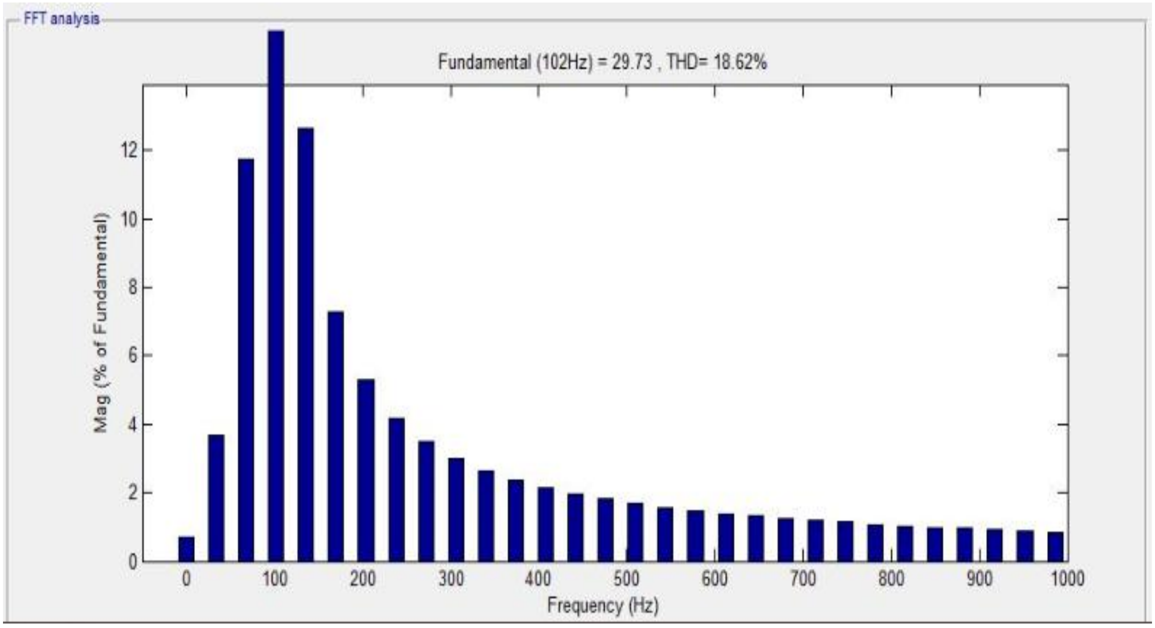

Figure 3.10 FFT Analysis on Stator Current using hysteresis Comparator based Sine PWM

The speed response and smooth torque as shown in the Figure 3.11 & 3.12 has contains less harmonic content which shows the performance of BLDC motor under sensor less control. The torque settling time is 0.02 sec is shown in Figure 3.12.

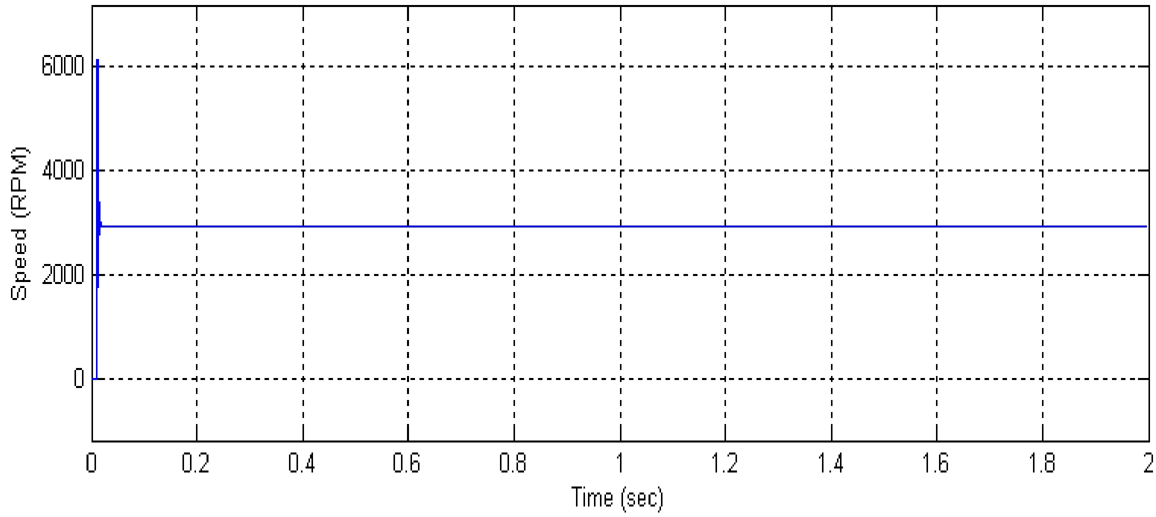

Figure 3.11 Speed response of BLDC motor in RPM

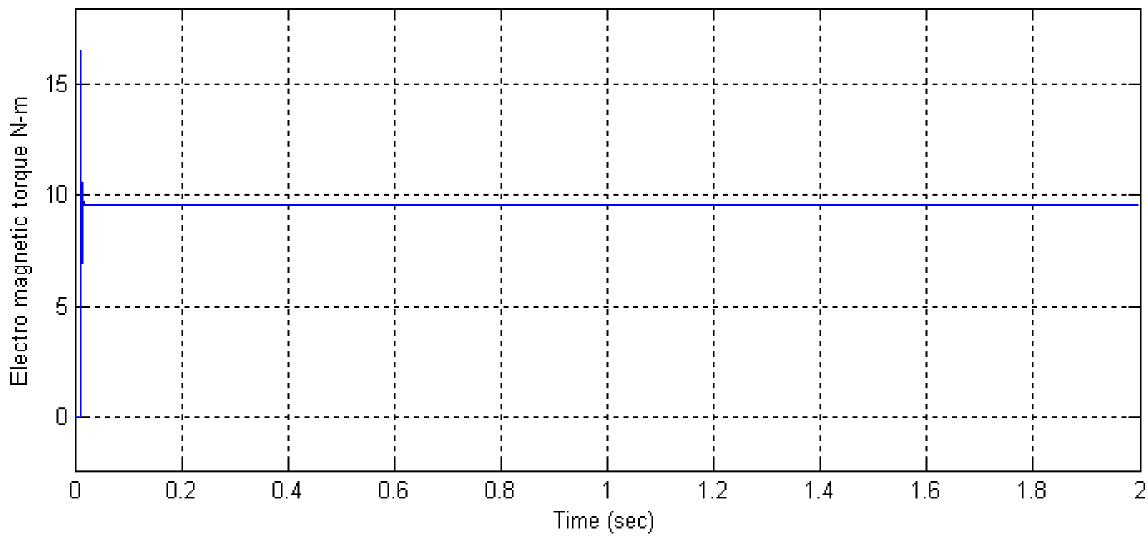

Figure 3.12 Electromagnetic Torque Responses

3.7 Summary

An autonomous PV module including non inverting four switch buck boost converter extracts maximum possible power from solar panel using perturb and observe algorithm. NFSBBC converter supplies continuous DC-link power to three phase inverter driven BLDC motor, it uses only lesser number of passive elements and shows high efficiency in power conversion. It operates either in buck or boost mode based on solar parameters and its generation capacity which depends on atmospheric conditions. Hysteresis band PWM control is applied in sensor less control which is effective in terms of control of BLDC motor. The inverters voltage phase angle can be controlled and any delay in phase angle can be compensated using hysteresis comparator. The phase lag compensation provided by hysteresis comparator obtained excellent speed and electromagnetic response of brushless DC motor. The overall performance of NFSBB converter based on sensor less BLDC motor with advanced hysteresis controller system is implemented in MATLAB/Simulink environment.