INTEGRATED CONTROLLER FOR T-SOURCE INVERTER BASED PHOTOVOLTAIC POWER CONVERSION SYSTEM

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Abstract: This paper deals with the design and simulation of integrated controller for T-source inverter (TSI) based photovoltaic (PV) power conversion system. The TSI has less reactive component, high voltage gain and reduced voltage stress across the switches compared to conventional inverter used in PV power conversion system. Integrated controller provides the maximum power point tracking and DC link voltage control to the PV power conditioning system. Here the Maximum Power Point Tracking (MPPT) in achieved by Incremental conductance (INC) algorithm and DC link voltage is controlled by capacitor voltage controller algorithm. T-Source inverter implemented with integrated control for PV system is simulated using MATLAB Simulink. The results are analyzed, compared with DC link controller; the same has been verified with experimental setup.

Key words: *Photovoltaic (PV), DC link controller, Maximum Power Point Controller (MPPT), Space Vector Pulse Width Modulation (SVPWM), T- source inverter (TSI), Incremental Conductance (INC) algorithm.*

1. Introduction.

The reduction of greenhouse gas emission has become a great issue among developed countries for example European Union (EU) has targeted to utilize the renewable energy source among 20% of total energy consumption by 2020 [1]. In green source effect, the photovoltaic plays an important role to generate electricity from the solar irradiation. In remote locations where there is no electricity is available the photovoltaic cells are installed on roofs and deserts [2]. The latter type of installations is known as off-grid facilities and sometimes they are the most economical alternative to provide electricity in isolated areas.

The three main factors which affect the efficiency of a PV plant are inverter efficiency, MPPT efficiency and photovoltaic plant efficiency. The PV panel is commercially lies between 8-15%, the inverter efficiency is 95-98% and MPPT efficiency is over 98%. By the growth of Perturb & Observe (P&O) and the Incremental Conductance algorithms (INC) are used to track the maximum power during different irradiation conditions. Depending upon the temperature of the panel and irradiation conditions, the MPPT is determined.

Moacyr et al (2013) have evaluated different MPPT Technique for photovoltaic applications out of which Incremental conductance (INC) algorithm gives excellent performance [20].

F.Z Peng proposed the Z-Source Inverter (ZSI) to overcome the problem of Voltage Source Inverter (VSI) and Current Source Inverter (CSI) [5, 6]. ZSI has suffered due to high input inductor ripple and more switching stress on the switches. To overcome the previously mentioned drawbacks Trans Z-Source Inverter it is also called T-source inverter (TSI) is proposed [8, 19]. This T-Source Inverter (TSI) has reduced number of passive component, high rate of input utilization, high voltage gain, total volume of system and cost is decreased [24 & 25]. In this paper, due to the above advantages the TSI with Modified Space Vector Pulse Width Modulation (MSVPWM) is used.

The Photovoltaic is an intermittent source. Output voltage of PV highly depends on environmental condition like temperature and irradiation. So it is necessary to maintain the output voltage of PV, controller is essential for PV power converter. There are lot of authors discussed the controller for PV inverters [17,18,21 & 22]. In this context MPPT and DC link controllers is play very important role in input line balancing. The DC link controller is used to sense the dc link voltage value and compares it with the reference value of capacitor voltage and changes the reference current correspondingly. Here DC link controller and MPPT controller are unified and produce a shoot through ratio and improve the response time of MPPT controller [18, 21&22]. Due to integrated controller the settling time and the oscillations are reduced. The control of T-source capacitor voltage beyond the MPP voltage of a PV array is not facilitated in the traditional MPPT algorithm.

This paper an integrated control algorithm is

proposed. The integrated control algorithm is combination of INC MPPT algorithms and DC link capacitor voltage control algorithm. The Incremental conductance (INC) algorithm is used which is used to reduce the oscillations in steady state, improve the tracking accuracy, fast response speed. DC link control is used to reduce the harmonic distortion and to prevent high voltage stress on the switching device. The proposed algorithm is investigated and compared with dc link controller is presented.

This paper is organized as follows. In section II characteristics of the PV array and the performance under different irradiation and temperature is discussed. In section III operating modes and modulation techniques used in T-Source inverter are discussed. In section IV Conventional MPPT algorithm and DC link controller is thrash out. The proposed algorithms for PV system is explained in section V.The simulation and experimental results are discussed in section VI.Finally conclusion is presented in section VII.

2. Photovoltaic cell

Photovoltaic (PV) is used in application such as PV with generators, PV with batteries, solar water pumps etc., PV has advantages such as of free pollution, low maintenance, and no noise and wear due to the absence of moving parts [23]. Because of these PV is used in power generation across the world.

The environmental factors such as illumination and temperature depends on the output power of a photovoltaic cell so we get non-linear V-I characteristics. In order to match the solar cell power to environment changes, MPPT controller is required. To track the MPP of a solar cell the P&O, fuzzy control and many algorithms have been developed. It changes frequently by the surroundings, improving the speed of tracking the PV power system could obviously improve the system performance and increase the PV cell efficiency.

The PV cell output is both limited by the cell current and the cell voltage, and it can only produce a power with any combinations of current and voltage on the *I-V* curve from fig1. It also shows that the cell current is proportional to the irradiance. Due to the open circuit voltage and short circuit current, the maximum power is produced.
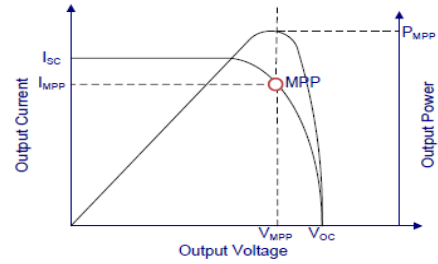

Fig.1. I-V and P-V characteristics

A single PV cell produces output voltage less than 0.6V for silicon cells. To get the desired output voltage number of photovoltaic cells is connected in series. By placing the series connected cell in a frame forms a module [8]. In series connection, the output current is same as the output current is same as the output voltage is sum of each cell voltage.Fig.2 shows the simulation of I-V and P-V characteristics of a photovoltaic cell during the different irradiation condition. By using the open circuit voltage and short circuit current, the maximum power is obtained.
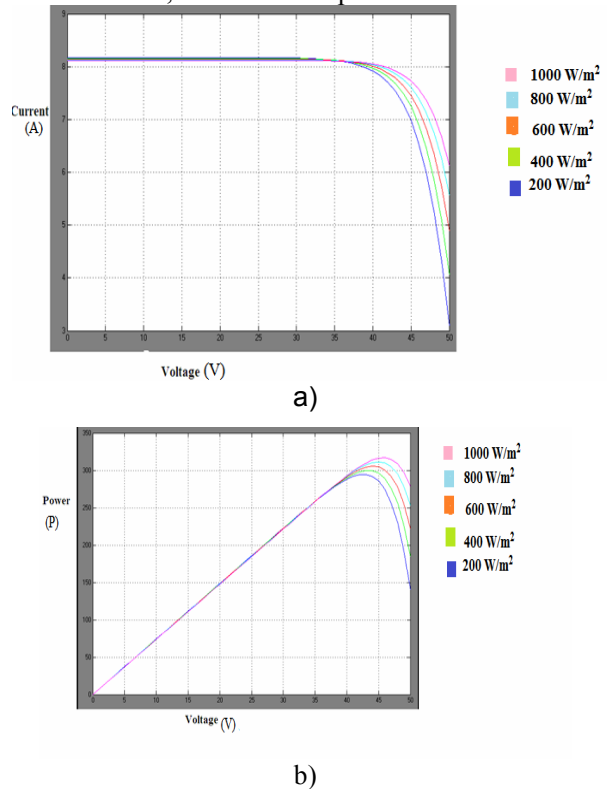

a)

b)

Fig.2 PV cell a) I-V characteristics
b) P-V characteristics

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Table 1: PV Module specification

Electrical Characteristics	Value
No of cells	96
Open circuit voltage (V_{oc})	64.9 V
Short circuit current (I_{sc})	8.2 A
Maximum power point voltage (V_{mpp})	54.7 V
Maximum power point current (I_{mpp})	7.36 A
Maximum power (P_{mpp})	327 W
Temperature coefficient of I_{sc}	3.5 mA/K
Temperature coefficient of V_{oc}	-76.6mV/K
Temperature coefficient of P_{max}	-0.38%/K

Photovoltaic Model Datasheet "Sun Power E-20/327W" is chosen for MATLAB simulation model. The module is made up of 96 mono crystalline silicon solar cells and provides 327W of nominal of maximum power [11].

3. T – Source Inverter

The New type T – source inverter (TSI) overcome the limitation of traditional voltage source inverter and current source inverter. With the use of TSI, the inversion and also the boost function are accomplished in a single stage [8]. TSI has fewer components. Due to these reasons, the efficiency appreciably increases. Unlike the traditional inverter, TSI utilizes a unique impedance network that links the inverter main circuit to the DC source. The TSI number of elements is reduced when compared to Z-source inverter; transformer and only capacitor are needed.

T-source inverter used to reduce the number of switching devices; inductor decreases the inrush current and harmonics in the inrush current. TSI works on two modes of operation shoot-through mode and non shoot-through mode.
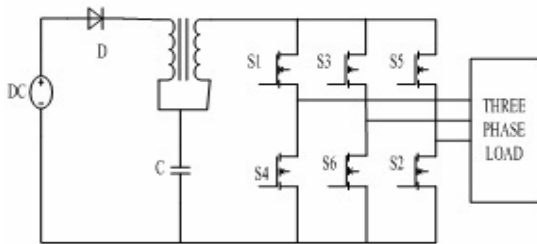

Fig.3 T-source inverter

3.1 Shoot-Through Mode

Fig.4 shows the equivalent circuit of T – source inverter in shoot through mode operation. This shoot through zero state prohibited in traditional voltage source inverter. It can be obtained in three different ways such as shoot through via any one phase leg or combination of two phase leg. During this mode, diode is reverse biased, separating DC link from the AC line.
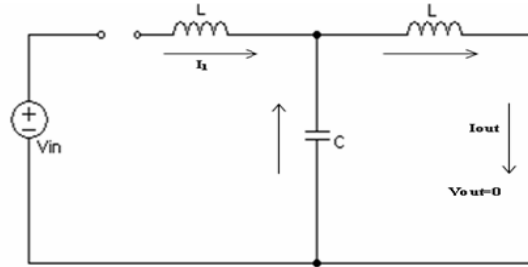

Fig.4 Shoot-through of TSI

The output of the shoot through state can be controlled by maintaining the desired voltage. Thus the T – Source inverter highly improves the reliability of the inverter since short circuit across any phase leg is allowed and it cannot destroy the switches in the inverter.

3.2 Non Shoot-Through Mode

Fig.5 shows the equivalent circuit of TSI in non – shoot through mode operation. In this mode, the inverter bridge operate in one of traditional active states, thus acting as a current source when viewed from T – source circuit. During active state, the voltage impressed across load. The diode conduct and carry current difference between the inductor current and input DC current. Note that both the inductors have an identical current because of coupled inductors.
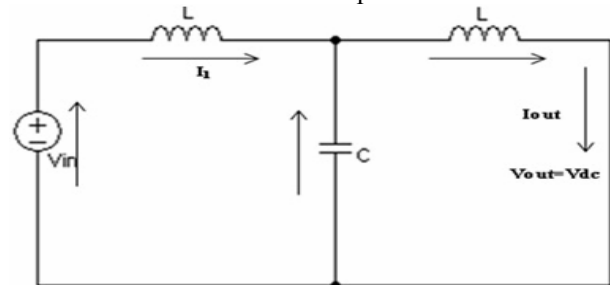

Fig.5 Non shoot-through mode of TSI

3.3 Design of T – Source Inverter

During the design of TSI the most challenging is the estimation of values of the reactive components of the impedance network. The component values should be evaluated for the minimum input voltage of the converter, where the boost factor and the current stresses of the components become maximal. Calculation of the average current of an inductor

$$I_L = \frac{P}{V_{DC}} \tag{1}$$

The maximum ripple current takes place due to the maximum shoot through states, 60% of peak to peak ripple current was selected to design the T-source inductor. The ripple current is ΔI_L, and the maximum

current through the inductor is I_{Lmin}

$$I_{L\min} = I_L - \Delta I_L$$

$$I_{L\max} = I_L + \Delta I_L$$

$$\Delta I_L = I_{L\max} - I_{L\min} \qquad (2)$$

The boost factor of the input voltage is:

$$B = \frac{1}{1 - 2D_Z} \qquad (3)$$

Where D_Z is the shoot-through duty cycle:

$$V_{a-p} = M \frac{V_{p-dc}}{2} = MK \frac{V_{in}}{2} \qquad (4)$$

Calculation of required inductance of Z-source inductors:

$$L = \frac{T_O.V_C}{\Delta I_L} \qquad (5)$$

Where T_0 - is the shoot-through period per switching cycle

Calculation of required capacitance of T-source capacitors:

$$C = \frac{I_L.T_z}{\Delta V_C} \qquad (6)$$

TABLE II. Parameters and Values of T-Source Inverter

S.No	Parameters	Values Used In Simulation
1	DC Supply Voltage	100V
2	T-Source Capacitance	360nf
3	T-Source mutual Inductance	0.2mH
4	Transformers Turns Ratio	1:1
5	Switching Frequency	7.2 KHZ

3.4 Modified Space Vector PWM

Space vector PWM (SVPWM) in three phase voltage source inverters offers improved DC link voltage and reduced harmonic distortion, and has been therefore recognized as the preferred PWM method, especially in the case of digital implementation. The output voltage control by SVPWM consists of switching between the two active and one zero voltage vector in such a way that the time average within each switching cycle corresponds to the voltage command. In order to apply this concept for Z-source inverter, a novel modified SVPWM is needed to introduce the shoot-through states into the zero vectors without compromising the active states [15] and it is represented in Fig 6.

The DC link voltage can be boosted by adding the new duration T to the switching time T_1,T_2 and T_0 of the Z-source converter to produce the sinusoidal ac output voltage[16].

$$V_{a-p} = M \frac{V_{p-dc}}{2} = MK \frac{V_{in}}{2} \qquad (7)$$

$$K = \frac{T_z}{T_b - T_a} = \frac{1}{1 - 2\frac{T_a}{T_z}} \geq 1 \qquad (8)$$

$T_z = T_a + T_b$ Where Tz denotes the switching period, T_a and T_b is the total duration during the shoot through and non shoot through period, M represents the modulation index, K is boost factor and V_P is the peak dc-link voltage. The shoot through zero vector takes place when both switches turn on in a leg, when shoot-through takes
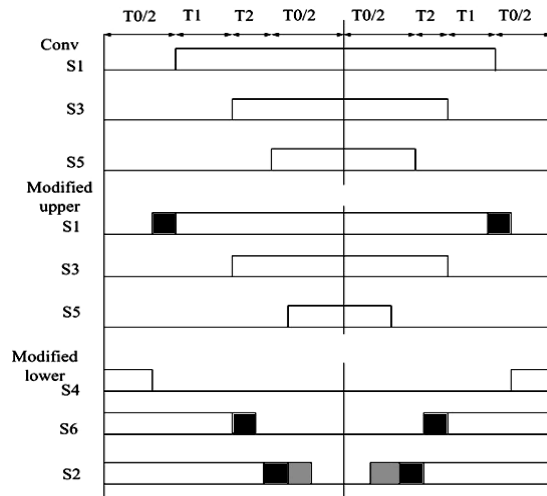

Fig 6 Modified SVPWM implementation for sector1

place the dc link voltage is boosted which depends on the total duration of $T_a = 3T$. By without changing the zero vector V_0, V_7, and T and non zero vectors V_1–V_6 , one shoot through zero state T occurs for a one period of switching cycle T_z by turning on and off switches in each phase. By adjusting the shoot through time interval, the DC link voltage and the output voltage of the inverter is controlled. The modulation index $M = a$ $(4/3)$ is determined by the zero vector duration $T_0/2$.

4. Control algorithms

4.1 Maximum power point control:

Many MPPT techniques are available, (i.e.) open circuit voltage, Short circuit current, Perturb and observe method (P&O), Incremental conductance (INC), fuzzy controller etc., An MPPT algorithm that provides high-performance tracking in steady state

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conditions can be easily found [12]. A very popular INC tracker, which has some important advantages as simplicity, applicability to almost any PV system configuration, automatically adjusts the step size to track the MPP from PV array and does not change during the environmental conditions.

4.1 .1Incremental Conductance Algorithm

In P&O and INC, the size of increment reference voltage decides the fastness of the maximum power. The drawbacks are if the irradiation changes rapidly, it can easily lose the track of MPP [13]. If the irradiation continuously changing it changes voltage and current not only due to perturbation of voltage. Due to voltage increment, the change in power is not possible to determine. If the oscillation size is increased, the rate of change of reference voltage also increased. The MPP is reached fast and is directly proportional to rate of change of voltage and inversely proportional to increment of voltage size. The MPP is reached slowly, when the oscillation is decreased and the increment size is reduced. This algorithm is only used for the changing the irradiation in step size and it follows a slope, tracking speed and steady state error is improved.

Fig.7 shows the flowchart of INC it senses the voltage and current and compares the new power with the old power and increment or decrement the reference value and the duty ratio is calculated.

4.2 Dc link control algorithm

The DC link controller senses the DC link voltage and compares it with the reference value of 250V and changes the reference current at the inverter side accordingly, which in turn regulates the PWM switches of the inverter. Here the inverter side extracts the maximum power with the use of the boost circuit, while the DC link controller maintains the dc link voltage by controlling the inverter current and reduces the dc side sensor for MPP tracking.

Fig.8 shows the capacitor voltage control algorithm senses the capacitor voltage and the previous value of the reference current. If the capacitor voltage is greater than the set value (250) is used to increment the dc line and the shoot through pulses is reduced. The value should be lie within 200 to 250 and the reference value is calculated. The reference value is calculated still it satisfy the present current value equals to the reference value.
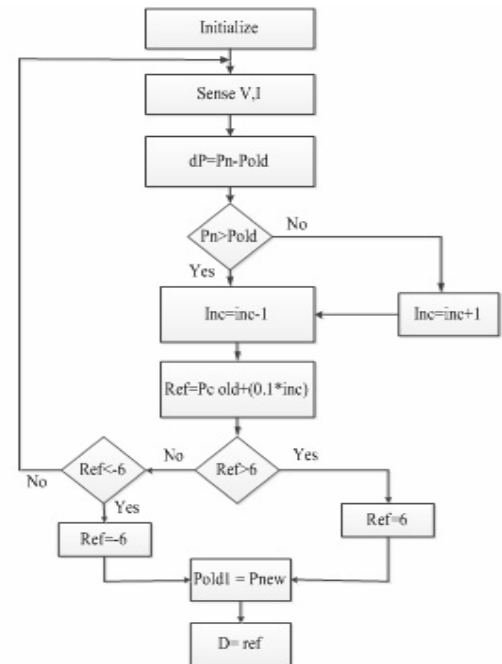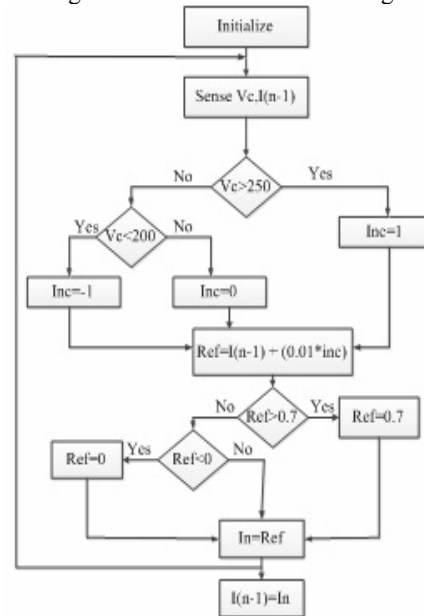

Fig.7 Incremental conductance algorithm.

Fig.8 Capacitor voltage control algorithm.

5. Proposed Controller

The proposed system is represented in Fig.9. Controller processes the maximum power point tracking algorithm and DC link control algorithm simultaneously it results reduction in response time For maximum power point tracking of PV array is done using Incremental Conductance (INC) algorithm is used because it has reduced oscillation in steady state.
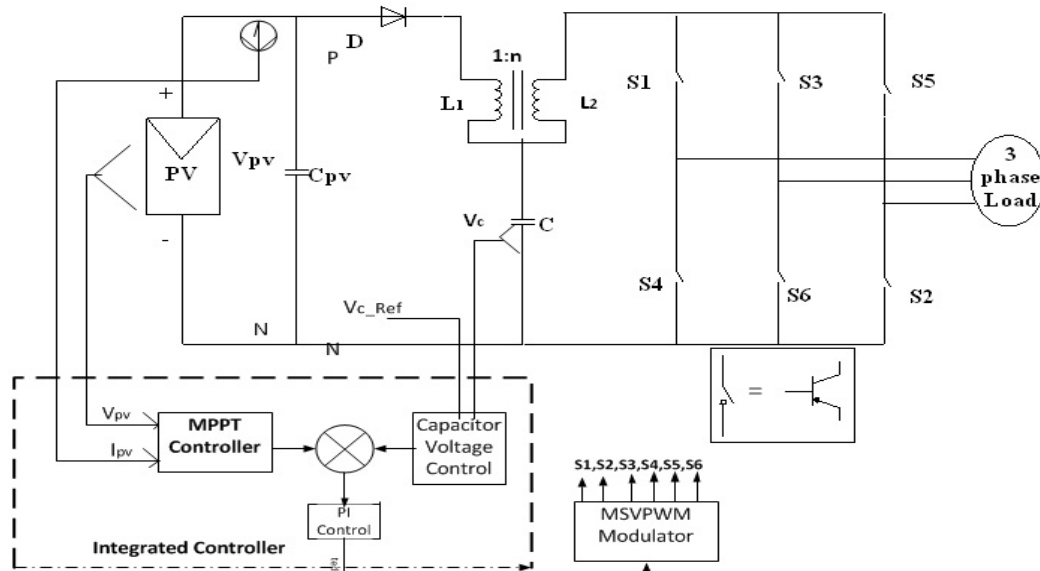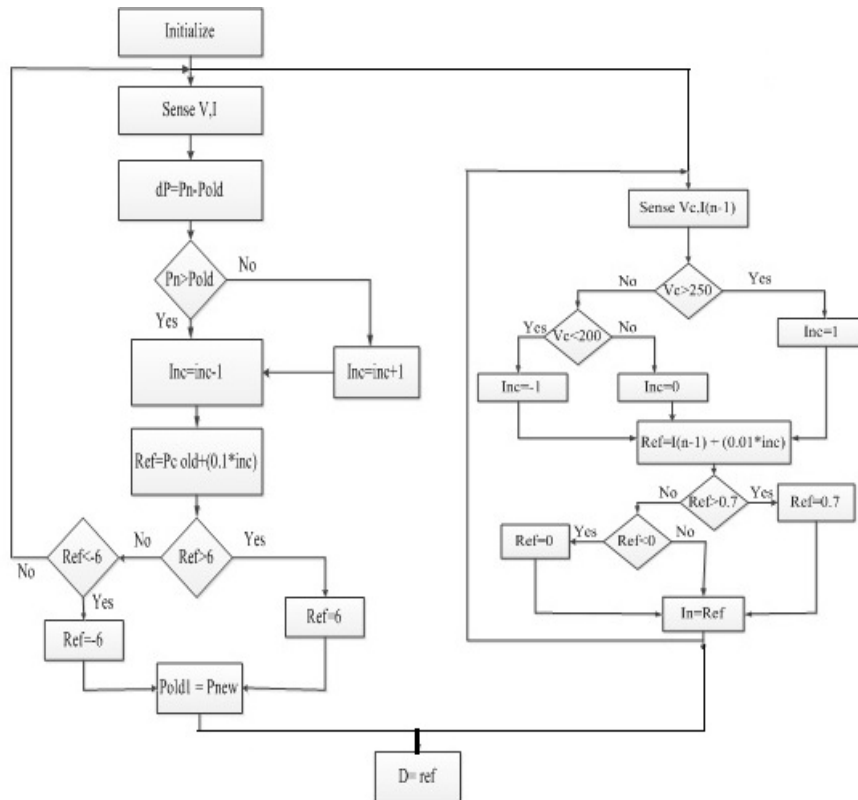
Fig.9 Proposed block diagram

Fig. 10 Proposed algorithms

In capacitor voltage control algorithm capacitor voltage of T-network. is measured and given to capacitor voltage controller. The output of capacitor voltage controller and MPPT controller is integrated using integrator and is processed then generate the reference signal. The output of integrated controller is feed to pulse width modulator to control the power switches. The algorithm of proposed work is shown in Fig.10.

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6. Result and discussion

The experimental setup of the proposed system is shown in Fig.11.The results of PV power is represented in Fig.12.The corresponding simulation results are represented in Fig.13,14 respectively. The Integrated controller gives more power output than DC link controller because the integrated controller is incorporated with MPPT algorithm and DC link control algorithm and also it gives good dynamic response. Fig.15 shows the experimental results of dynamic response comparision of integrated controller and DC link controller.
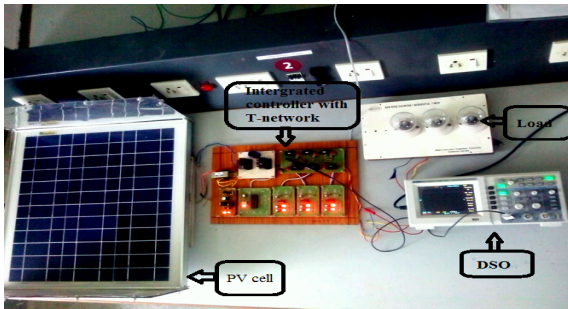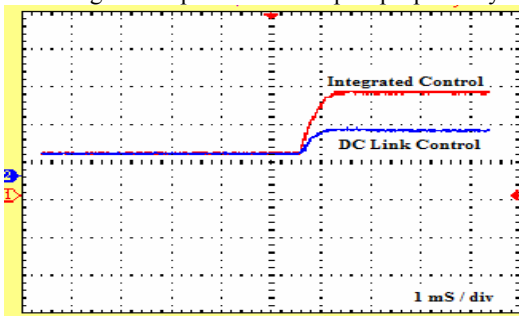

Fig.11 . Experimental setup of proposed system

Fig.12 PV output power comparison.

The output voltage and current waveform of proposed controller for T source inverter is shown in Fig.18.The total harmonic distortion of proposed system is 2.8% and is represented in Fig.19.THD value is within the limit specified by the standard IEEE 1547
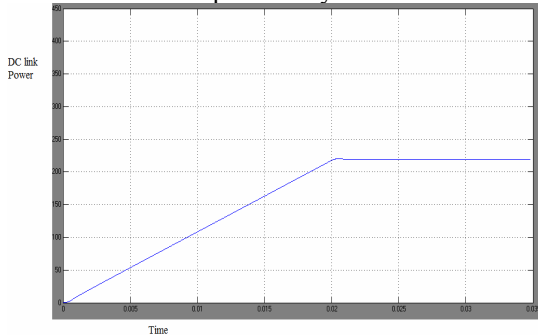

Fig. 13 Power of DC link controller

Table.IV shows the comparision of dc link controler and integrated controller with various paprameter.From the table it is observd that integrated controller gives qucik response and high power out put
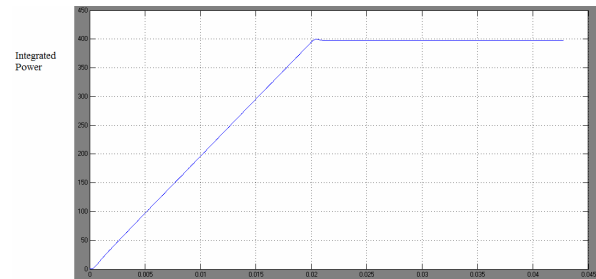
than DC link controller.

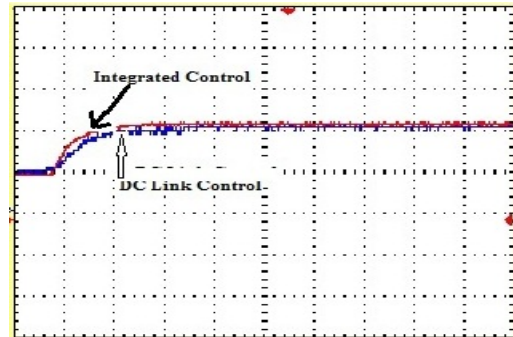Fig. 14 Power of integrated controller

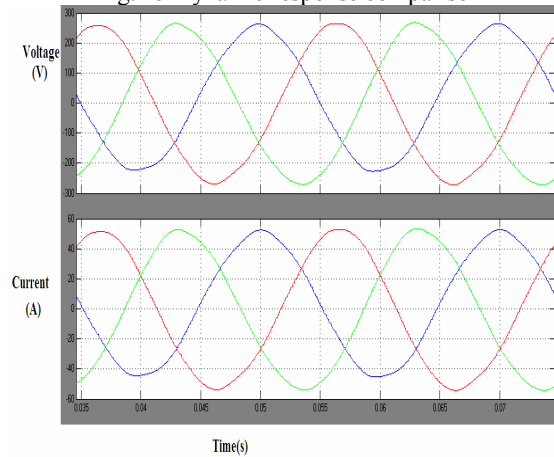Fig. 15 Dynamic response comparison

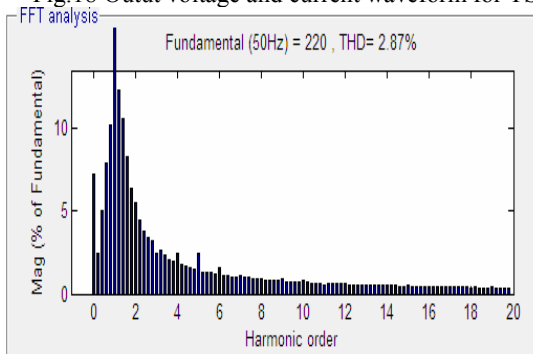Fig.18 Outut voltage and current waveform for TSI

Fig.19 % Total harmonic distortion

Table 4. Comparison of DC link and integrated controllers.

Parameter	DC link Controller	Integrated Controller
Voltage	174V	234V
Current	1.2A	1.7A
Power	232W	400W
Settling time	7.2ms	4.2ms

7. Conclusion

In this paper, integrated controller for TSI based photovoltaic power conversion system has been proposed. The incremental conductance algorithm is used to track the maximum power during different irradiations and temperature condition. The proposed method is simulated; investigated using MATLAB Simulink and the same has been implemented and verified using hardware setup. The comparison between DC link and MPPT controller are presented. The proposed algorithm improves the tracking accuracy, reduce the oscillations in steady state and the response time is reduced in the integrated controller than the DC link controller.

References

[1] The European Union climate and energy package, http://ec.europa.eu/clima/policies/eu/package_en.htm.
[2] D. JC. MacKay, "Sustainable Energy - Without the Hot Air",UITCambridge,2009.[Online].Available:http://www.inference.phy.cam.ac.uk/sustainable/book/tex/cft.pdf.
[3] J. Anderson, F.Z. Peng, *Four Quasi-Z-Source Inverters*, Proc. of IEEE PESC 2008,15-19 June 2008, pp.2743 – 2749.
[4] J.Anderson,F.Z.Peng,*AClassofQuasi-Z-Source Inverters,* in Proc. of 43rd IAS Annual Meeting, 2008, pp.1-7.
[5] F.Z.Peng, *Z-Source Inverter*, Proc. of the 37th IAS Annual Meeting**,** 2002, p.775-781.
[6] F.Z Peng, *Z-Source Inverter*, IEEE Trans. on Industry Applications, No.2, Vol.39, 2003, pp.504-510.
[7] J. Anderson, F.Z Peng, *Four Quasi-Z-Source Inverters*, Proc. of IEEE PESC 2008, 15-19 June 2008, pp . 2743 – 2749.
[8] Ryszard Strzelecki, Marek Adamowicz and Natalia Strzelecka , 'New Type T-Source Inverter' *in Proceedings on Compatibility and Power Electronics 6th International Conference-Workshop*,2009.
[9] J. Surya Kumari and Ch. Sai Babu , 'Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment' *in International Journal of Electrical and Computer Engineering (IJECE)* Vol. 2, No. 1,2012.
[10] Tarak Salmi, Mounir Bouzguenda, Adel Gastli, Ahmed Masmoudi, 'MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell' in *International Journal of Renewable Energy Research* Vol.2, No.2, 2012.
[11] Photovoltaic Model Datasheet " Sun Power E-20/327W"
[12] Seok-Il Go, Seon-Ju Ahn, Joon-Ho Choi, "*Simulation and Analysis of Existing MPPT Control Methods in a PV Generation System",* Journal of International Council on Electrical Engineering Vol. 1, No. 4, pp. 446~451, 2011.
[13] Mingwei Shan, Liying Liu, and Josep M. Guerrero, 'A Novel Improved Variable Step-Size Incremental-Resistance MPPT Method for PV Systems', in *IEEE Transactions on Industrial Electronics*, VOL. 58, NO. 6,2011.
[14] Fangrui liu, Shanxu duan, Fei liu, Bangyin liu, and Yong kang , 'A Variable Step Size INC MPPT method for PV systems' *in IEEE Transactions On Industrial Electronics,* vol. 55, no. 7,2008.
[15] S. Thangaprakash and A. Krishnan, 'Modified Space Vector Pulse Width Modulation for Z-Source Inverters'*, in International Journal of Recent Trends in Engineering*, Vol 2, No. 6, 2009.
[16] Jingbo Liu, Jiangang Hu and Longya Xu, 'A Modified Space Vector PWM for Z-Source Inverter - Modeling and Design' *in IEEE Transc. Power Electron* 2009.
[17] Jin-Woo Jung*, Member, IEEE*, and Ali Keyhani*, "*Control of a Fuel Cell Based Z-Source Converter*"*,*IEEE Transactions On Energy Conversion,* VOL. 22, NO. 2, JUNE 2007
[18] Sengodan Thangaprakash, 'Unified MPPT Control Strategy For Z-Source Inverter Based Photovoltaic Power Conversion Systems' *,in Journal Of Power Electronics,*vol.12, No.1, 2012.
[19] Wei Qian, F.Z.Peng, "Trans Z-source Inverter" , *IEEE Transactions on power electronics,* Vol.26,No.12, (2011), 3453-3463.
[20] Moacyr Aureliano, Gomes de Brito, Luigi Gallotto, Leonardo Poltronieri Sampaio, Guilhereme de Azevedo e Melo and Carlos Alberto Canesin, "Evaluation of the Main MPPT Techniques for Photovotaic Applications" *in IEEE Transactions On Industrial Electronics,* vol. 60, no.3,2013.Pp 1156-1167.
[21] Gokhan Sen and Malik E Elbuluk, "Voltage mode and current programmed Modes in control of Z-Source converter" in *IEEE Transactions on industry Applications,* Vol.46, No.2, (2010), 680-686.
[22]Yuan Li, Fang Zheng Peng, "Modeling and Control of Quasi Z-Source Inverter for Distributed Generation Applications" IEEE Transactions on industrial electronics Vol.60,No.4, April 2013,Pp. 1532-1541
[23] S.M.A.Faisal, "Model of Grid Connected Photovoltaic System Using MATLAB/SIMULINK", in *Journal of Electrical Engineering Romania*, Vol. 12,No.4, (2012).
[24] P.Sivaraman**,** Dr.A.Nirmalkumar, "Analysis and Implementation of a Novel T-Source Inverter for High Voltage Gain Application", *International Review of Modeling and Simulation,* (Vol. 5 No. 2) - April 2012,
[25] P. Sivaraman, Dr.A.Nirmalkumar, "Analysis of T-Source inverter with various PWM schemes," *European Journal of Scientific Research.*, ISSN 1450-216X Vol.71 No.2(2012),pp.203-213,Feb.2012.   ……..