Analysis of T-Source Inverter with Integrated Controller using PSO Algorithm

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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 PSO 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.

Keywords : Photovoltaic(PV), DC link controller, Maximum Power Point Controller (MPPT), Space Vector Pulse Width Modulation(SVPWM), T- source inverter(TSI), PSO 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 PSO algorithms 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. 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]. 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 . 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 .

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 . 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 PSO MPPT algorithms and DC link capacitor voltage control algorithm. The PSO 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.

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 . 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.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.

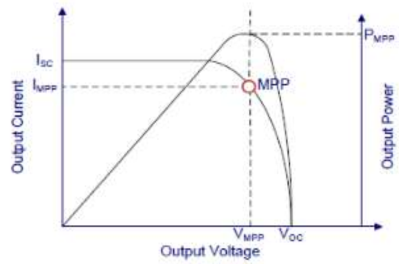

Fig.1. I-V and P-V characteristics

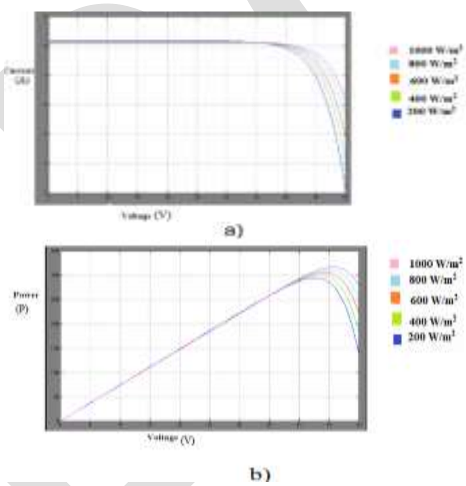

Fig.2 PV cell a) I-V characteristicsb) P-V characteristics

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 E20/327W” 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.

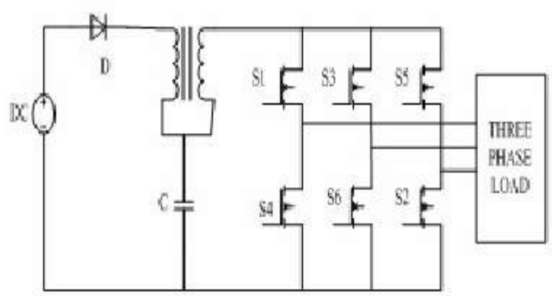

Fig.3 T-source inverter

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.

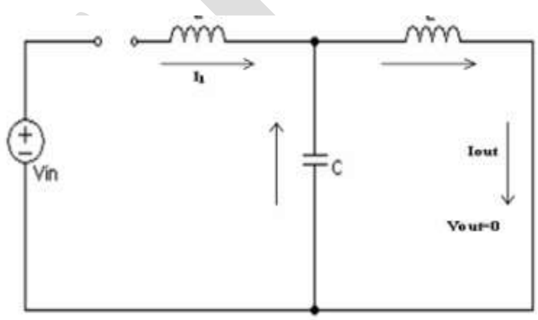

Fig.4 Shoot-through of TSI

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.

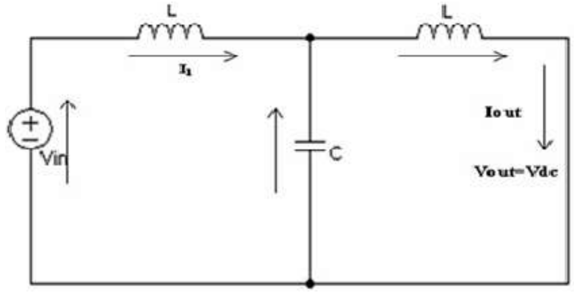

Fig.5 Non shoot-through mode of TSI

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

$$I_L = \frac{P}{V_{DC}} \qquad (1)$$

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 ΔIL, and the maximum

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

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

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

The boost factor of the input voltage is:

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

Where D_L 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 T0 - is the shoot-through period per switching Cycle Calculation of required capacitance of T source capacitors:

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

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

Table 2. 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

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 T1,T2 and T_0 of the Z source converter to produce the sinusoidal ac output voltage[16].

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

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

Tz = Ta+Tb Where Tz denotes the switching period, T is the total duration during the shoot through and non shoot through period, M represents the modulation index, K is boost factor and V 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 place the dc link voltage is boosted which depends on the total duration of T_d = 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 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.

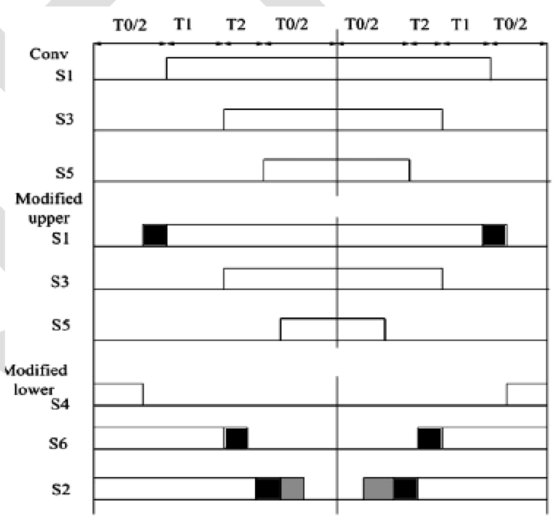

Fig 6 Modified SVPWM implementation for sector1

4. Control algorithms

4.1 PSO methodology

The general idea Control (PSO) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are update based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model.Each particle maintains its position, composed of the candidate solution and its evaluated fitness, and its velocity. Additionally, it remembers the best fitness value it has achieved thus far during the operation of the algorithm, referred to as the individual best fitness, and the candidate solution that achieved this fitness, referred to as the individual best position or individual best candidate solution. Finally, the PSO algorithm maintains the best fitness value achieved among all particles in the swarm, called the global best fitness, and the candidate solution that achieved this fitness, called the global best position or global best candidate solution.

The PSO algorithm consists of just three steps, which are repeated until some stopping condition is met:
1. Evaluate the fitness of each particle
2. Update individual and global best fitnesses and positions
3. Update velocity and position of each particle

The first two steps are fairly trivial. Fitness evaluation is conducted by supplying the candidate solution to the objective function. Individual and global best fitnesses and positions are updated by comparing the newly evaluated fitnesses against the previous individual and global best fitnesses, and replacing the best fitnesses and positions as necessary.The velocity and position update step is responsible for the optimization ability of the PSO algorithm. The velocity of each particle in the swarm is updated using the following equation:

$$v_i(t+1) = wv_i(t) + c_1r_1[\hat{x}_i(t) - x_i(t)] + c_2r_2[g(t) - x_i(t)]$$

Apart from the canonical PSO algorithm it has many variations of the PSO algorithm exist. For instance, the inertia weight coefficient was originally not a part of the PSO algorithm, but was a later modification that became generally accepted. Additionally, some variations of the PSO do not include a single global best aspect of the algorithm, and instead use multiple global best that are shared by separate subpopulations of the particles.

4.2 Maximum power point control:

Many MPPT techniques are available, (i.e.) open circuit voltage, Short circuit current, Perturb and observe method (P&O), PSO algorithm, fuzzy controller etc., An MPPT algorithm that provides high-performance tracking in steady state conditions can be easily found [12]. A very popular PSO 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.

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 In capacitor voltage control algorithm capacitor voltage of T-network. is measured and given to capacitor results reduction in response time For maximum power point tracking of PV array is done using PSO algorithm is used because it has reduced oscillation in steady state.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

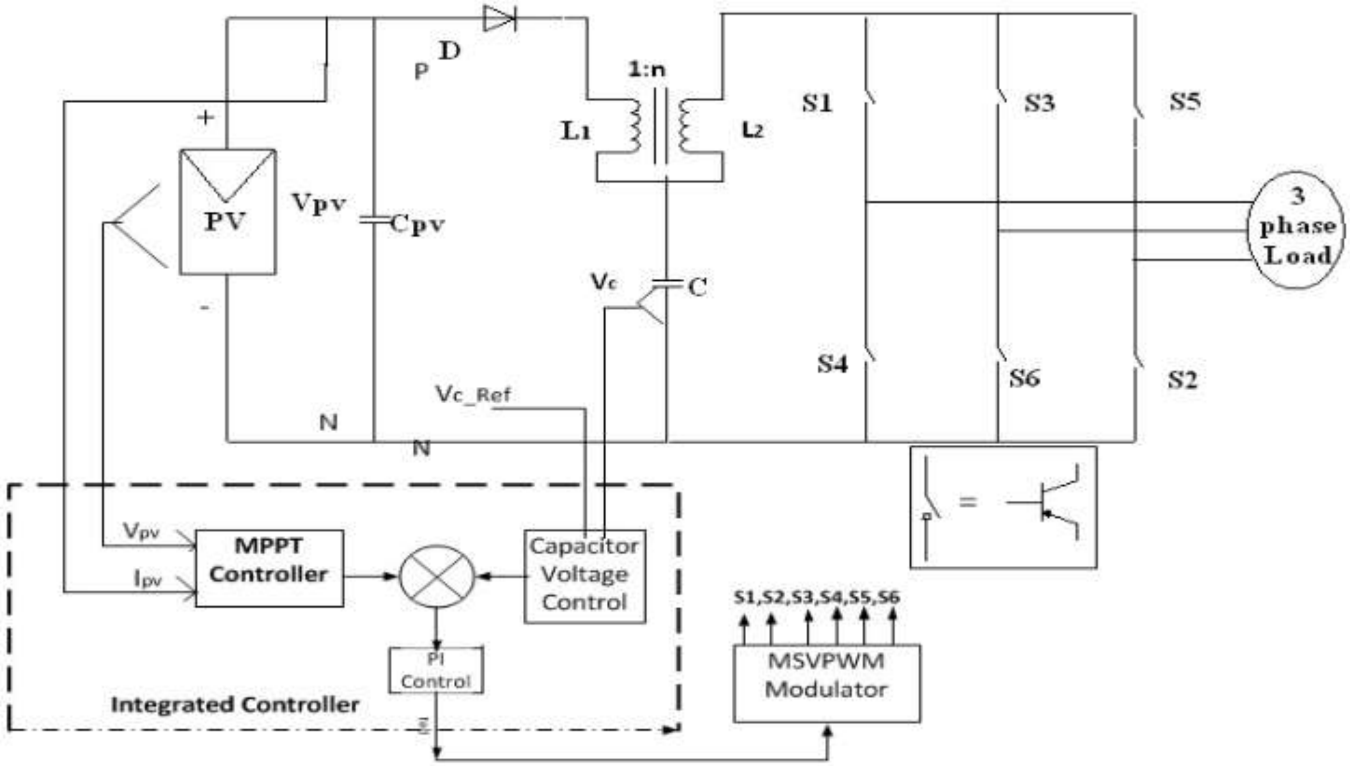

Fig.9 Proposed block diagram

6.EXPERIMENTAL RESULT

The corresponding simulation results are represented in Fig.10. 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.

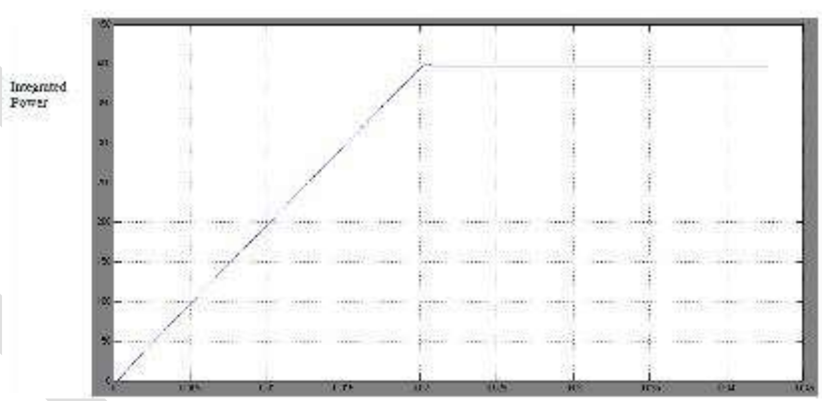

Fig. 10 Power of integrated controller

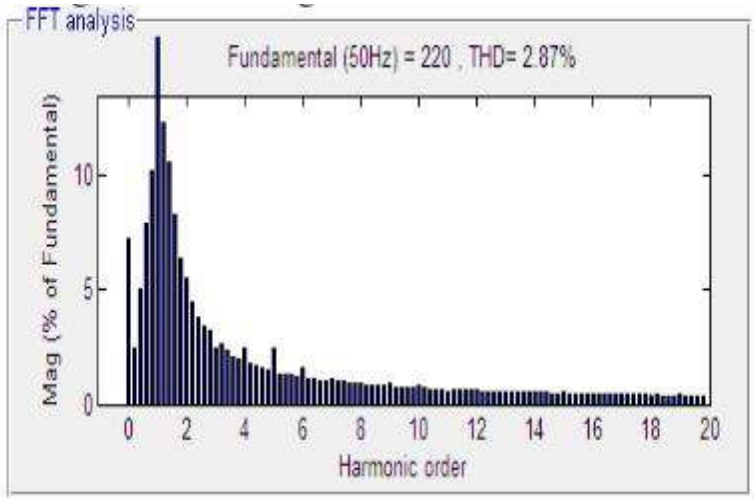

Fig.11% Total harmonic distortion

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 PSO 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.

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