Implementation of DC-DC Converter for MPPT by Direct Control Method

D. D. Gaikwad
Electronics & Telecommunication Engineering
KIT COE, Kolhapur
Kolhapur, India

M. S. Chavan
Electronics & Telecommunication Engineering
KIT COE, Kolhapur
Kolhapur, India

***Abstract*— This paper presents implementation of DC/DC converter for maximum power point tracking (MPPT) based on direct control method for TL494 control circuit for solar array power generation systems. The main difference of the proposed system to present MPPT systems which eliminates second control loop i.e. proportional–integral control loop and finding of the effect of simplifying the control circuit. The TL494 is a constant frequency and variable duty cycle pulse width modulation (PWM) control IC for DC/DC converter; it has two error amplifier and dead band control pin (DTCON) which can control directly duty cycle of by DTCON pin of applying a adjustable voltage level from 0V to 3.3V maximum respectively vary duty cycle from 100% to minimum resultant that output power from input varies. By using proper algorithm method and controller the proposed system is able to track MPPs accurately, rapidly and less oscillation at MPP. The two high gain error amplifiers used for to maintain output voltage and current limit purpose.**

The proposed system was developed and tested successfully on a small dc variable power instead of using programmed MPPT microcontroller in the laboratory. Experimental results indicate the feasibility and improved functionality of the system for MPPT application.

Keywords—photovoltaic, topologies in dc/dc converter, TL494 based converter.

I. INTRODUCTION

Now days, the world is growing to developing renewable power generation system, clean and practically inexhaustible, and interdisciplinary research is continuously work in order to sustain the development of existing conversion technologies and the innovative ones [1], [2]. Photovoltaic (PV) offers an environmentally friendly source of electricity power generation, of which the fuel is sunshine, and clean pollution free. Solar panel is the fundamental energy conversion component of photovoltaic (PV) systems. It has been used in many applications, such as aerospace industries, electric vehicles, grid connected system equipment, etc. Practically the power delivered from the PV panels depends on many external factors, such as insolation (incident solar radiation) levels, temperature, and load condition.

Thus, electrical power output usually increases linearly with the insolation and decreases with the cell / ambient temperature. However, adopting a maximum power point tracking (MPPT), the photovoltaic system's power transfer efficiently and reliability can be improved significantly as it can continuously maintain the operating point of the solar panel at the MPP all the times shown in Fig.1.[3].

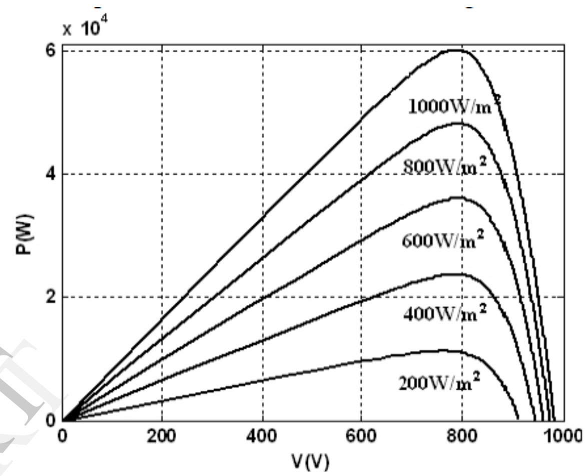

Fig.1 Power-voltage characteristics of photovoltaic module at different irradiance levels

In practice, there are two methods to extraction of generated power in medium- and large-scale PV systems. They are sun tracking and maximum power point (MPP) tracking or both. Due to economic reasons and response a uses of MPP tracking is a popular technique today and for that purpose need dc/dc converter. Generally dc/dc converter is used as a constant source of power supply, change in load and line regulation. DC/DC converter this paper used for another purpose it will operate at maximum PV voltage / power which is based on which algorithm used. TL494 based dc-dc converter is more suitable for any type of algorithm for MPPT system.

The available maximum power point trackers uses various types of control circuit or logic to search MPP point, thus to operate the converter circuit to extract available maximum power all the times. It needs to track the maximum power point (MPP) for a successful PV system. Maximum power point tracker (MPPT) uses DC/DC converter between PV and load. Various types of dc/dc converters are available based on isolated and Non-isolated converters. MPPT uses two loops one for maintaining constant switching frequency and another for maintaining tracking algorithm. For that purpose special programmed microcontroller and additional circuitry and PWM control technique require for efficient. This paper proposes a TL494 based push-pull isolated converter which requires less components and facilities provided to control duty cycle of PWM only for small change in voltage level at DTCON pin to reduce one of the loop.

II. MATERIAL AND METHODS

A. Topologies

There are various topologies are used as DC-DC converter. They are isolated or non-isolated topologies. Isolation transformer used in small-sized high-frequency electrical which provides the benefits of light weight, DC isolation, and between input and output, and we obtain step up or down of output voltage by change of transformer turns ratio. In PV applications, the grid-tied systems use these types of topologies when electrical isolation is preferred for safety reasons. Non-isolated topologies do not have isolation transformers. They are almost always used in DC motor drives. These topologies are further categorized into three types:

Step down (Buck)
Step up (Boost) and
Step up & down (Buck-Boost).

The buck topology is used where step-down requires. In PV applications, for battery charging process the buck type converter is usually used. The boost topology is used for stepping up the voltage. The grid-tied systems use a boost type converter to step up the output voltage to the utility level before the inverter stage.

B. Control Techniques

The MPPT algorithm gives information MPPT controller how to find the operating voltage by varying duty cycle. Then, job of MPPT controller to operate the PV panel voltage to a required level and maintain it. There are several methods often used for MPPT.

I. PI control

MPPT takes measurement of PV voltage and current, and then tracking algorithm calculates the reference voltage (Vref) where the PV operating voltage should move next.

II. Direct control

This control method is simpler and uses only one control loop, and it performs the directly adjustment of PWM duty cycle within the MPP tracking algorithm. The way how to adjust the duty cycle is totally based on which algorithm is preferred?

III. Output sensing control

The system usually requires another set of sensors for the output to detect the over voltage and over-current condition of load. This output sensing method measures the power change of PV at the output side of converter and uses the duty cycle as a control variable. This control method employs the P&O algorithm to locate the MPP.

C. MPPT Methods

There are a various number of algorithms that are able to track MPPs. Some of them are simple, such as those based on voltage and current feedback, and some are more complicated, such as perturbation and observation (P&O) or the incremental conductance (IncCond) method. [5][6]. On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [7] or neural network [8] methods. MPPT fuzzy logic controller shave good performance under varying atmospheric conditions and exhibit better performance than the P&O control method [8]

TABLE I. COMPARISION OF MPPT TECHNIQUES

MPPT Techniques	Speed	Complexity	Reliability	Implementation
Fractional Isc	Medium	Medium	Low	Digital / Analog
Fractional Voc	Medium	Low	Low	Digital / Analog
IncCond	Varies	Medium	Medium	Digital
P & O	Various	Low	Medium	Digital / Analog
Fuzzy Logic	Fast	High	Medium	Digital

D. Direct Method

Normally MPPT systems have two independent control loops to control the MPPT. The first control loop contains the constant switching frequency and another MPPT algorithm with proportional (P) or P–integral (PI) controller. By use of any one of the algorithm method to generate an error signal to adjust duty cycle, which is will operate at the MPP; however, it is not operate at most of the operating points. For ease of operation, and ease of design, inexpensive maintenance, and low cost made controllers very popular in most linear systems.

However, the MPPT of standalone PV system is a nonlinear control problem due to the nonlinearity nature of voltage and current characteristics and unpredictable environmental conditions, and hence, PI controllers do not generally work well [7].

In this paper, the direct control method is selected. The PI control loop, and constant frequency switching loop is eliminated, and the PWM of duty cycle is adjusted directly from algorithm controller. TL494 based converter has inbuilt two high gain error amplifier. One error amplifier used for maintain constant output voltage and another to limit output overcurrent. The objective of this paper is to eliminate the first control loop and to show that complicated MPPT methods do necessarily obtain the best results.

III. DESIGN OF PROPER CONVERTER

When proposing an MPPT tracker, the aim of work first to choose and design a highly efficient and fast response converter, MPPT is supposed to operate as the main part system. Normally high frequency switching-mode power supplies are well designed.

Among all the topologies available, buck–boost converters operates either higher or lower output voltage compared with the input voltage. This paper proposed the push pull buck-boost converter configuration is higher frequency isolated dc–dc converters used. It can also provide a better efficiency and isolation. Thus, the proper converter is employed in designing of MPPT controller.

The power circuit of this paper consists of a Push pull converter based on TL494 control circuit. The control tasks involve measuring the analog voltage and current of the PV module using current and voltage sensors, the analogue information from sensors convert them to digital using an ADC, process the present information in a programmed microcontroller with defined algorithm, and generates a valid analogue voltage for adjusting duty cycle of converter at maximum power level and the main program continues to track the MPPs.

This paper choose push-pull high frequency converter using TL494 as PWM generator. The output from programmed Mpp algorithm Microcontroller applied to Pin 4 of TL494 dead time control (DTCON), this varies duty cycle which is function of algorithm. For Design of proper converter we select the solar panel voltage of 75Wp, 1000W/m2.

Design of Push Pull Converter using TL494

A. Ferrite Core transformer Design

To design of high frequency push pull converter first step to design a ferrite core center tap transformer. The proposed converter is a ferrite core based center tap transformer the turns calculations considered during design of converter Table II shows electrical parameters considered while design of dc/dc converter.

TABLE II. ELECTRICAL PARAMETERS

Vin(min) minimum input voltage	13.5 Volts
Vin(max) maximum input voltage	20.5 Volts
Vin(nom) nominal voltage	17 Volts
Switching frequency	22000Hz
Vout Maximum output voltage	28Volts
Iout Maximum output current	4 Amp

To design a high frequency ferrite core transformer. The formula for calculating the number of required primary and secondary turns as:

$$Npri = \frac{Vin\,(nom).10.^{8}}{4.f.Bmax\,.Ac} \quad \text{---------(1)}$$

N_{pri} means number of primary turns; N_{sec} means number of secondary turns

Where,

$Vin_{(nom)}$ – Nominal Input Voltage.
f – The operating switching frequency in Hertz.
B_{max} – Maximum flux density in Gauss.
A_c – Effective Cross-Sectional Area in cm^2. A_c = 1.25 for ETD39.

Now, obtain the values of all required parameters for calculation Npri – the number of required primary turns.
From above equation Npri = 11

The output of our DC-DC converter is 28V considered. Transformer output must be 28V at all input voltages, i.e. input from 20.5V to all the way down to 13.5V. For the PWM controller, we will take maximum duty cycle to be 98%.

At minimum input voltage (when Vin = Vinmin), duty cycle will be maximum. Thus duty cycle will be 98% when Vin = 13.5 = Vinmin. At maximum duty cycle = 98%, voltage to transformer = 0.98 * 13.5V = 13.23V. So, voltage ratio (secondary: primary) = 28V:13.23V = 2.1

Hence voltage ratio (secondary: primary) = 2.1, turns ratio (secondary: primary) must also be 2.1 as turns ratio (secondary: primary) = voltage ratio (secondary: primary). Turns ratio is designated by N. So, in our case, N = 2.1.

N_{pri} = 11
N_{sec} = N * N_{pri} = 2.1 * 11
Nsec = 22

B. PWM Circuit And Feedback Control Circuit

For the generation of PWM signal and feedback control signal use TL494 control IC. TL494 control IC is Complete Pulse-Width Modulation (PWM) Power-Control Circuitry, Uncommitted Outputs for Single-Ended or Push-Pull Application. Fig. 2 show a practical push pull converter, interface between PV module and the Load used as power stage. The power circuit of the proposed system consists of a push-pull converter, TL494, and feedback components. The output of TL494 in push pull mode inverted by using NOR gate input is connected to MOSFET gate terminal. The control of the switching is done using the voltage and current feedback control circuit and also from DTCON pin which is control from MPP algorithm. Output power changes 100% to minimum for change of voltage at DTCON pin 0 to 3.3V adjust. The design of proposed push pull converter used components selected from design equations are referred from its datasheet by manufacturer Texas Instruments. Table III shows a list of used components.

TABLE III. COMPONENT LIST

Item	Quantity	Reference	Part
1	2	C1,C2	2200UF
2	1	C3	2200UF,50V
3	1	C4	100UF
4	1	C5	104
5	2	C6,C8	1UF
6	1	C7	103
7	1	C9	10U
8	1	C10	2200U
9	1	C11	22OOU
10	2	C15,C12	1000uf
11	1	C13	0.01uf
12	1	C14	CAP
13	2	D1,D8	1n4007
14	2	D3,D2	IRF3205/TO
15	4	D4,D5,D6,D7	DIODE SCHOTTKY
16	2	U1,U4	LM7808/TO
17	1	U2	4001
18	1	U3	TL494I/SO
19	1	L1 1mh	INDUCTOR
20	2	R1,R7	10
21	5	R2,R6,R11,R12,R15	10K
22	1	R3	RESISTOR
23	1	R4	51K
24	1	R5	200
25	2	R8,R9	4k7
26	1	R10	1K
27	1	R13	50K
28	2	R16,R14	O.1E,5W
29	1	T1	ETD39

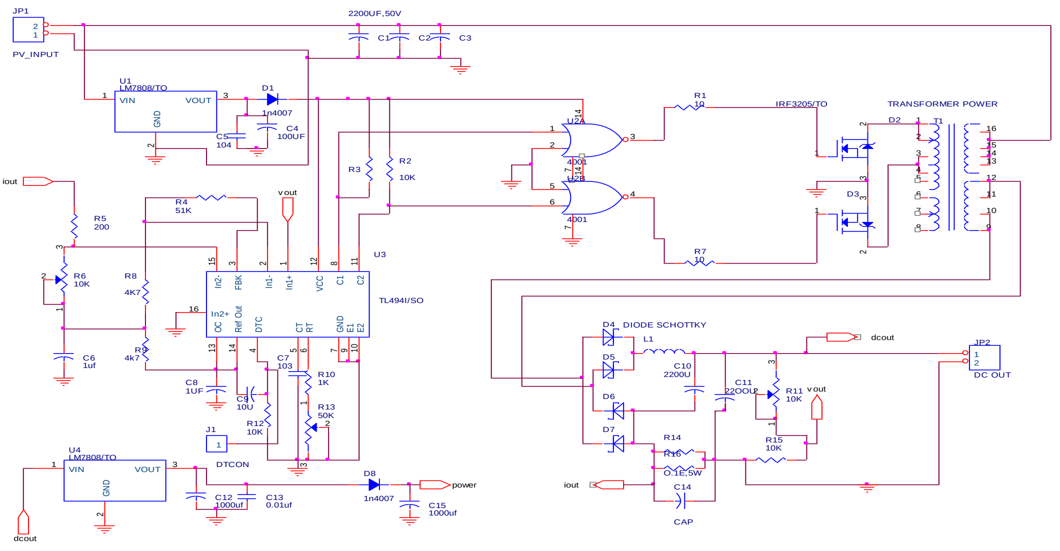

Fig 2. Experimental DC-DC Converter

IV. EXPERIMENTAL SETUP

To verify working and performance of the proposed dc/dc converter shown in Fig. 2, a prototype of the isolated push pull converter and voltage and current limit control circuit was implemented. The variable small dc source is used at place of mppt algorithm or controller, it provide the control signals for the TL494 based converter so as to control the PWM signal directly.

The Fig. 3 shows the practical closed-loop system of MPPT system, which includes the PV module, the DC-DC boost converter, and the MPPT algorithm. To test the system operation, the situation of changing voltage at pin 4 of TL494 dead time control (DTCON pin). The change of PWM duty cycle respectively converter output power varies. Voltage level is varying between 0 to 3.3V levels. Table III shows the practical values we have tested on various voltage levels at pin 4 DTCON of TL494.

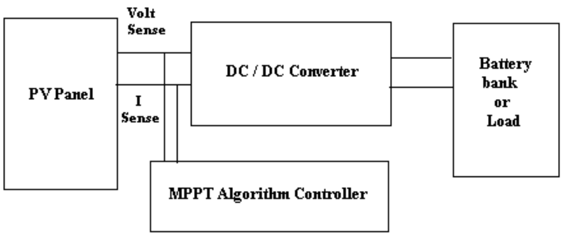

Fig. 3 shows the practical closed-loop system of MPPT

Fig 5, 6, 7 shows the duty cycle change when change in DTCON voltage. Duty cycle will vary by voltage on pin DTCON of TL494. Digital storage oscilloscope is connected to CH-1 at output of gate circuit and CH-2 at pin 4, which are absolutely the desired output power. The purpose of this paper is directly control dc-dc converter by MPPT algorithm controller.

TABLE IV.

PWM CHANGE ON DTCON VOLTAGE LEVEL

Input voltage in Volts	**Input current in Amp**	**DTCON at pin4 voltage**	**Duty cycle in %**	**Output voltage in Volts**
18.4	0.1	3.3	0	0
18.2	0.5	2.3	3.5	2.3
18	0.9	2.1	10.7	7.3
17.8	1.6	1.9	15	10.6
17.6	2.2	1.6	20	14.5
17.4	3	1.4	25	17.6
17.2	4	1.2	30	20.6
16.9	5.1	0.9	35	23.7
16.8	5.4	0.3	42	27.6

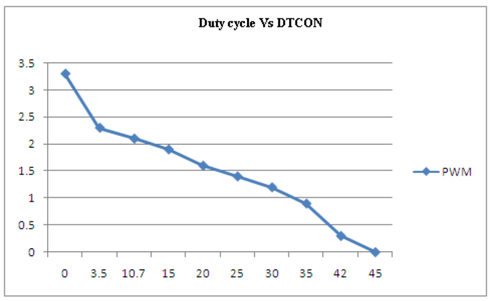

Fig. 4 Graph of duty cycle Vs DTCON reference voltage at pin 4 of TL494

TABLE V.
VARIOUS LOAD CONDITIONS INPUT OUTPUT PARAMETERS

Resistive load	Input voltage	Input current	Output voltage	Output current	% efficiency
40Ω	17.5	1.5	28	0.7	74.66
18Ω	17.3	3	28	1.55	83.6
10 Ω	17.1	4.5	28	2.15	78.23
7 Ω	15.8	9.2	27.6	4.6	87.34

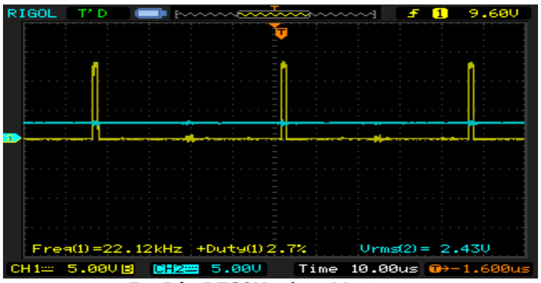

Fig. 5 for DTCON voltage Maximum

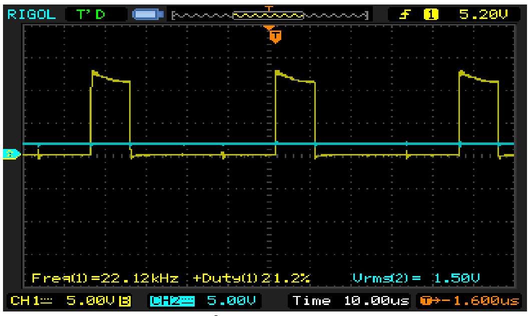

Fig. 6 for DTCON 1.50V

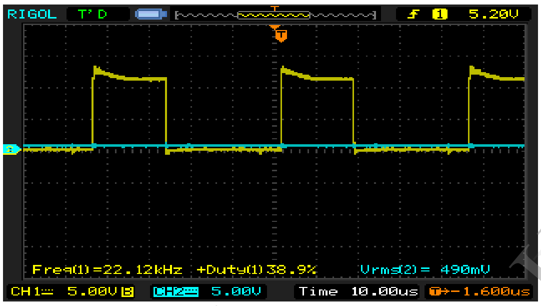

Fig. 7 for DTCON 0.490V

CONCLUSION

In this paper, a Dc to Dc Converter for MPPT for direct control method was employed, and the needed another control loop was eliminated. The proposed system was constructed, and the working of the suggested direct control concept was proven. The obtained results during the practical experiments, it was confirmed that, with a well-designed system including a proper converter and selecting an efficient, the implementation of MPPT is simple and can be easily constructed to achieve an acceptable efficiency level of the PV modules. The results shown in table IV and Fig. 4, 5, 6 and 7 demonstrates that the proposed control system is capable of tracking the PV array maximum power all the time by use of any algorithm and thus improves the efficiency of the PV system and reduces low power loss and system cost.

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