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Closed Loop Zeta Converter with High Voltage Gain for Photovoltaic Application

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Abstract: ***This topology consists of an extended high voltage gain converter along with a Zeta converter. The extended high voltage gain converter is operated with a fixed conversion gain whereas the zeta converter is controlled to do the maximum power point tracking (MPPT) which is an important advantage of this structure. The input current of the topology is continuous and its voltage gain is high without using any transformer. Reduction of the number of power electronic switches and costs are other most important benefits of the structure. Input of this topology is given by photovoltaic system with pertube and observe algorithm. The objective of this paper is to maintain the constant output voltage, irrespective of change in irradiance. Change in Irradiance, causes the change of output voltage from PV panel, which causes the duty cycle (D) to vary and duty cycle depends on both output voltage from PV module and reference voltage. Change in duty cycle makes the zeta converter to operate either in buck or boost mode.***

Keywords: Photovoltaic

1. Introduction

The renewable energy resources and other enabling technologies gained quite interest due to the worry that fossil fuel resources are not perennial and will eventually dwindle, becoming too expensive or too environmentally damaging to retrieve. Among the renewable resources alternatives, one of the most notable is the photovoltaic power, which seems to become one of the greatest promises for the energy portfolio, mainly because it is a clean, emission-free, with great advantages of installation and low maintenance power source. There are some different approaches to make the arrangement of power converters for a module integrated PV system. For the DC/DC stage, the high step-up voltage ratio can be in theory achieved with the use of a simple boost or buck boost DC/DC converter. However, it has been proved that it is not possible due to their high equivalent series resistance (ESR), which is proportional to the duty-cycle and, it degrades the converter efficiency and voltage conversion ratio. Overcome the restrictions of the boost converter, various DC-DC converters such as the interleaved boost converters, soft switching boost converters, coupled inductor structures, and voltage multiplier converters have been proposed which can provide higher voltage gain than the conventional DC-DC boost converter. Each one of these structures has advantages and disadvantages. One of the most important types of high voltage gain converters is voltage multiplier topologies[1]. Typically, voltage multiplier topologies have fixed input and output voltage ratio. The most important advantages of the voltage multiplier topologies are light weight, small size, high power density, high efficiency and most of all magnetic-less structure. However, the achieved voltage gain is fixed and the output voltage cannot be regulated since it depends on the input voltage. Also, these topologies use a large number of power switches which lead to increasing costs and circuit size. It is important to note that these converters cannot be utilized for Maximum Power Point Tracking (MPPT) in PV systems. Another new voltage multiplier topology [2], the number of used switches for n capacitors is $3n$. Then, the magnitude of output voltage will be $(n+1)\ Vin$ which is a constant value. Moreover, a new voltage multiplier structure [3] has been introduced in which need n capacitors and $2n$ switches to produce $nVin$ at output. It is important to note that the input current of presented topologies in is discontinuous and it is a restriction. Also, the voltage gain of these topologies is fixed and cannot be regulated. Therefore, these topologies cannot be utilized in PV systems because of their limitation to track the maximum power point. Thus new extended zeta converter with high voltage gain for photovoltaic applications is proposed which can overcome to above mentioned restrictions of the voltage multiplier converters.

Table 1: Comparison of Proposed Topology with Other Similar Structures

Type of topology	[Multilevel dc-dc converter] [1]	[Switched capacitor high voltage gain boost converter][2]	[Switched capacitor topology with reduced number of switches][3]	High gain zeta converter
Input current	discontinuous	discontinuous	discontinuous	continuous
The number of used switches	2n	3n	2n	n+1
Capability of MPPT regulation	no	no	no	yes
cost	average	high	average	low
Output voltage	constant	constant	constant	variable
Output voltage gain	nV_{in}	$(n+1)V_{in}$	nV_{in}	$\frac{(n+1)DV_{in}}{1-D}$
The number of used capacitor	n+1	n	n+1	n

2. Photovoltaic Cell

Photovoltaic cells convert solar radiation into DC. A PV cell is the building block of a solar panel and it can be formed by the series and parallel connection of many solar cells. Single diode model of the solar cell is shown in fig1.

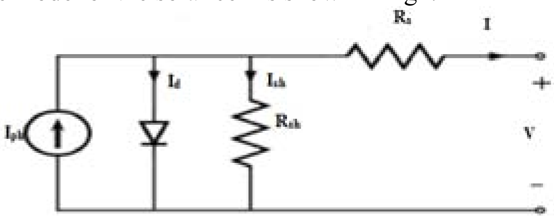

Figure 1: PV cell equivalent circuit

An ideal solar cell can be modelled by a current source in parallel with a diode, in practice no solar cell is ideal and so a shunt resistance and a series resistance component are added to the model. The characteristic equation has a common application such as nonlinear regression to extract the values of respective parameters in equivalent circuit. It is on the basis of their combined effects on solar cell behaviour. The light generated current and reverse saturation current get multiplied by the N_p.

Equation governing the voltage current characteristic of a solar cell is given as,

$$I = N_p I_{ph} - N_p I_s \{\exp q(v + IR_{sm})/N_s K T_c A) - 1\}$$

Where,

q : Electron charge = 1.6×10^{-19}C

A: Ideality Factor = 1.6

k: Boltzmann Constant = 1.3805×10^{-23}J/K

Is : Dark current/cell saturation current

I_{ph}: Photon current/light generated current

R_{sm}: Solar cell series resistance (Ω)

3. Maximum Power Point Tracking

The voltage at which PV module can produce maximum power is called „maximum power point" (or peak power voltage). Maximum power depends on several factors including environmental conditions such as solar radiation/irradiance, ambient temperature and solar cell temperature. There are several methods employed for tracking maximum power among which **Perturb and Observe** method is implemented in this paper.

1) Perturb and Observe MPPT Algorithm.

P&O algorithm is also called Hill climbing method. It is the most commonly used MPPT algorithm due to its ease of implementation. In this method the controller adjusts the voltage from the array by a small amount and measures power. If the power increases, further adjustments in that direction are tried until power no longer increases. The duty cycle is adjusted directly in the algorithm.P&O algorithm is based on the fact that, the derivative of power as function of voltage is zero at MPPT. The Fig. 2 shows the flowchart of the P&O algorithm.

The output voltage waveform of PV system with MPPT (P&O) algorithm is represented in fig 5. The adaptive P&O technique is based on duty cycle modulation for conventional pulse width modulation converters. Therefore for tracking the maximum power point, suitable MPPT algorithm is used.

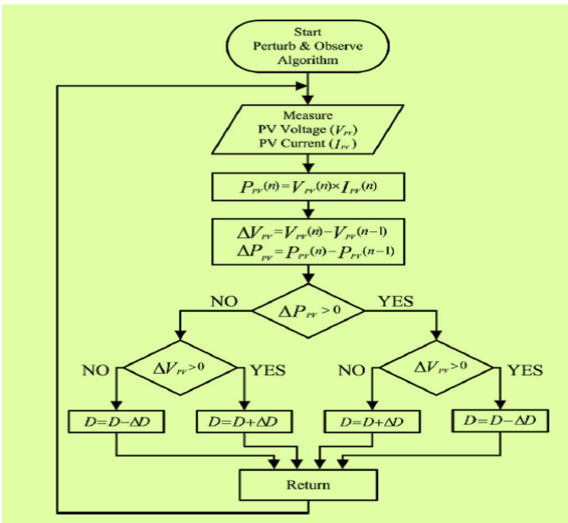

Figure 2: Flow Chart of P&O Algorithm

2) A Zeta Converter With High Voltage Gain

The extended zeta converter structure is shown in figure.1. This structure consists of two stages. The first stage is extended high voltage gain converter and the second stage is a zeta converter. The extended high voltage gain stage consists of n charging capacitors ($c_1,c_2,c_3,......c_n$), (n+1) switches ($T“_1,T_1,T_2,T_3,......T_{n+1}$), 2n, powerd iodes ($D_{a1},D_{a2},D_{a3},......D_{an},D_{b1},D_{b2},D_{b3},......D_{bn}$) and dc voltage source($V_{in}$).The elements of the zeta converter are two inductors (L_1, L_2) , two capacitors (C_{n+1},C_o) , a diode (D_{n+1}) and one switch (T_{n+1})

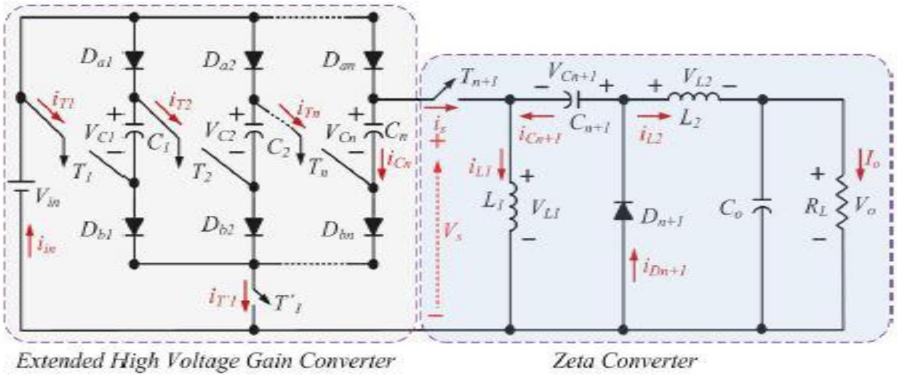

Figure 1: An extended zeta converter

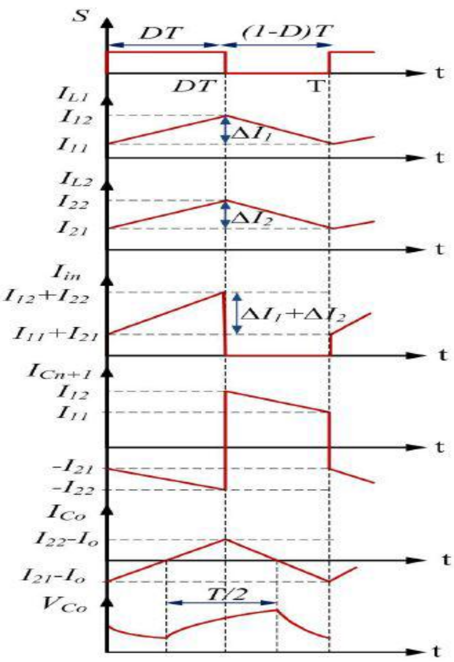

Figure 2: Waveform of extended zeta converter

4. Simulation Results

1)Simulation model of zeta converter

To show the validity of the closed loop zeta converter, the performance of structure is explained for n=4 .Table shows the utilized parameters and magnitude of the converter. Simulation results are given to verify the correctness of the analysis. The simulation parameters are: input voltage V_i = 20V; output voltage V_o = 200 V; load: resistance load R = 484 Ω; and switching frequency: f_s = 10 kHz.

Table 1: Utilized components and parameters of the converter

Parameter	*Magnitude*
Vi (input voltage)	20V
Vo(output voltage)	200V
Switching frequency	10kHz
Inductor L_2	10mH
Inductor L_2	15mH
Charging capacitor	134µF
Capacitor C_0	3.3µF
Duty cycle	0.68
C_{n+1}	9.9µF
Resistance load	484

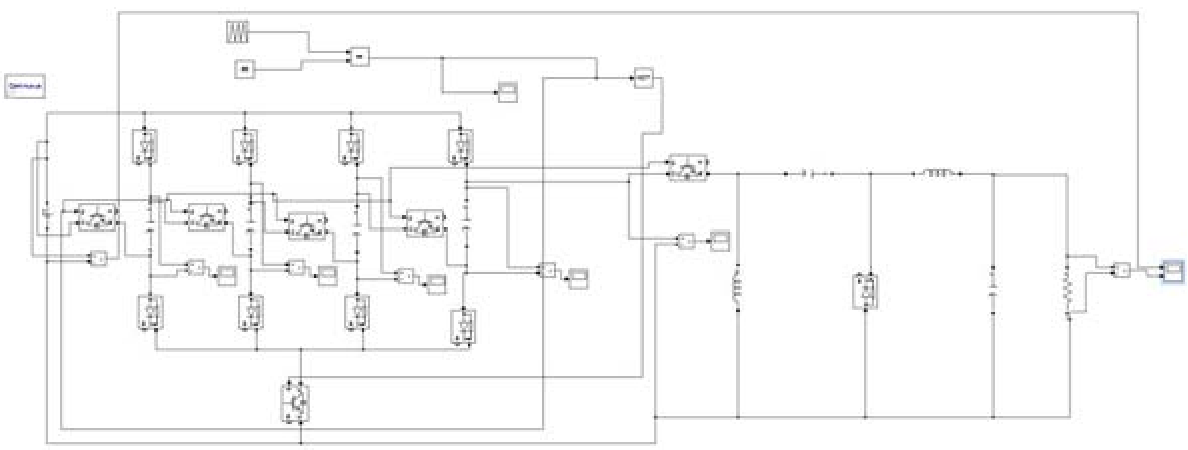

Figure 4: Simulink block of open loop zeta converter with high gain

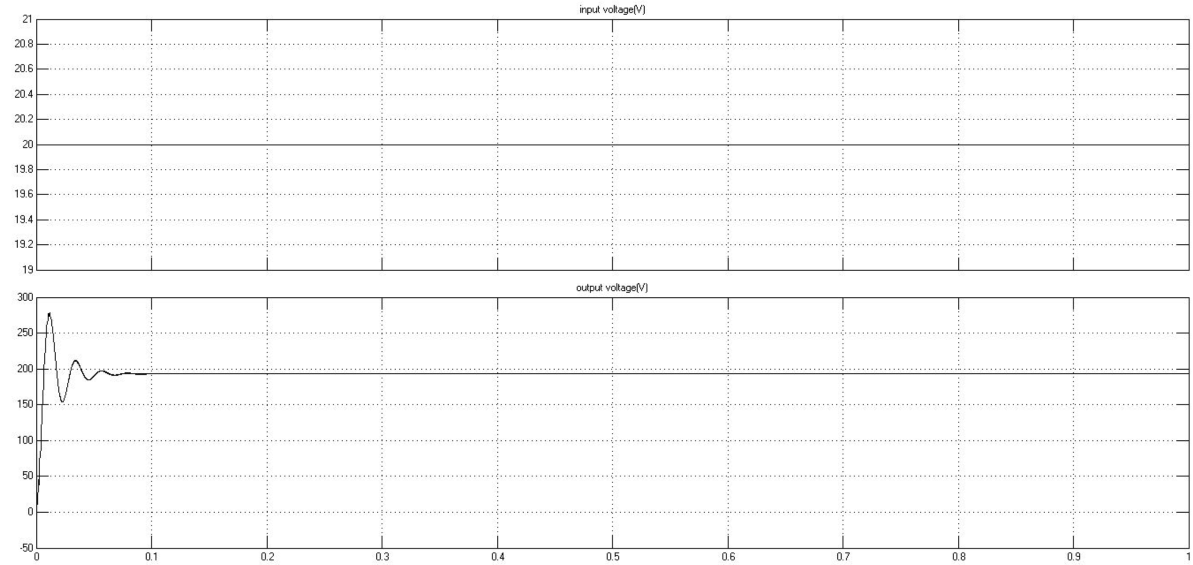

Figure 5: Simulation results of open loop zeta converter with boost mode

Zeta converter is buck-boost converter which can operate by adjusting duty cycle. Here duty cycle is set as 68 % thus 20V input has been boosted up to 198V by using high gain zeta converter with gain of 9.9

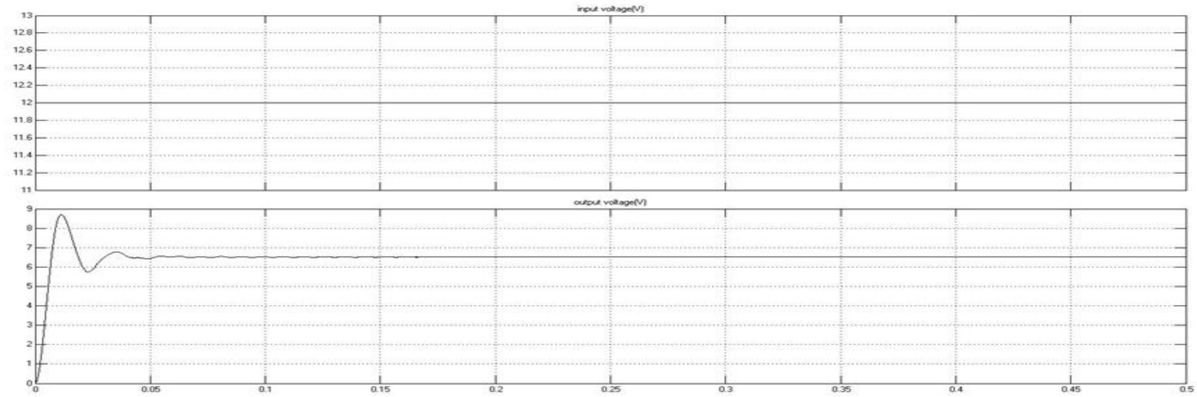

Figure 5: Simulation results of open loop zeta converter with buck mode

Zeta converter is buck-boost converter which can operate by adjusting duty cycle. Here duty cycle is set as 32 % Thus 12V input has been bucked to 6.5V.

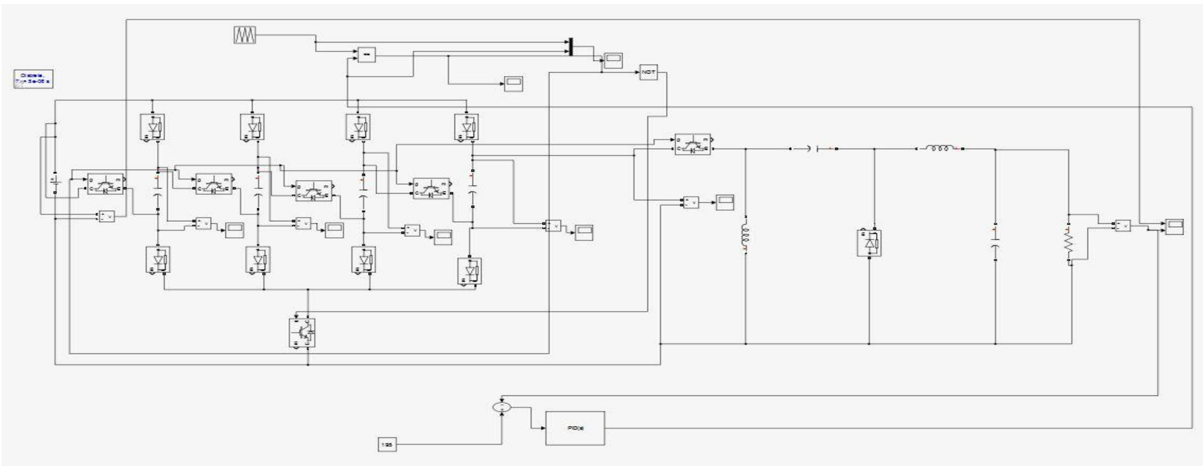

Figure 6: Simulink block of closed loop zeta converter with high gain

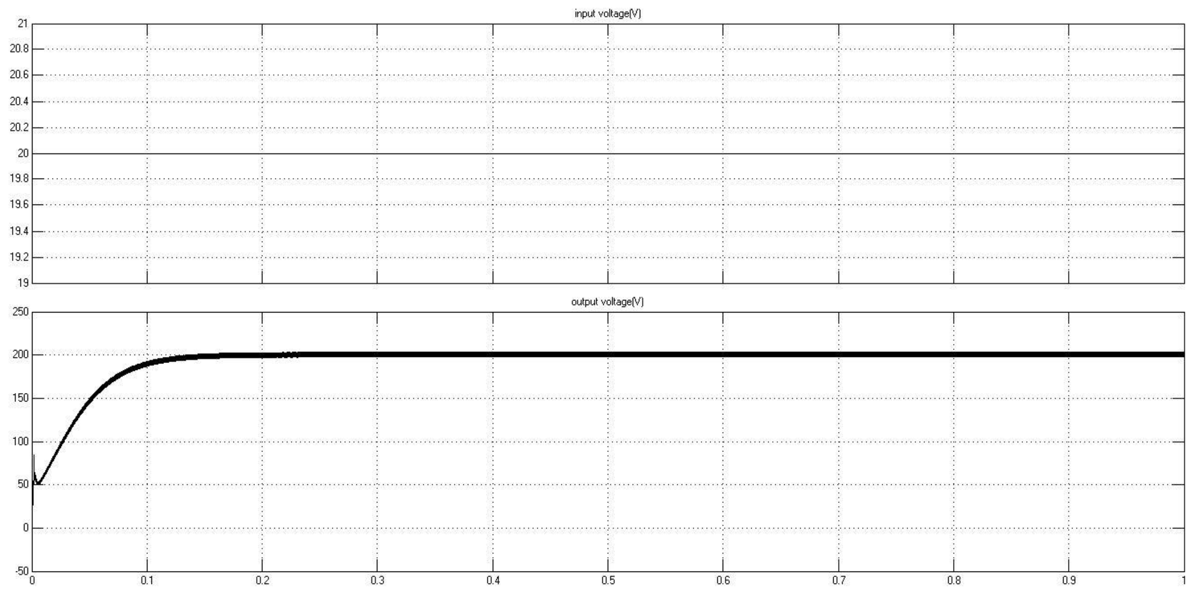

Figure 6: Simulation results of closed loop zeta converter

Closed loop zeta converter with high voltage is obtained by PI controller. After tuning output is set to 200V while input is given by 20V.Table below shows the comparison of open loop and closed loop, by variation in input voltage and load.

Table 2: Comparison of Open Loop and Closed Loop System

System	Input voltage (V)	output voltage(V)	Input voltage (V)	output voltage(V)	Input voltage (V)	Output voltage(V)
Open loop	20V	198.48	18V	188.53	25V	223.6V
Closed loop	20V	200V	18V	200V	25V	200V

System	R Load						RL Load					
	80Ω		100Ω		120Ω		80Ω,1mH		100Ω,2.5mH		120Ω,5mH	
	I_o(A)	V_o(V)	I_o(A)	V_o(V)	I_o(A)	V_o(V)	I_o(A)	V_o(V)	I_o(A)	V_o(V)	I_o(A)	V_o(V)
Open loop	.489	198.1	.478	198.4	.61	199.72	.47	198.17	.45	198.48	.43	199.72
Closed loop	.52	200	.5	200	.48	200	.53	200	.5	200	.47	200

2)Simulation model of pv system

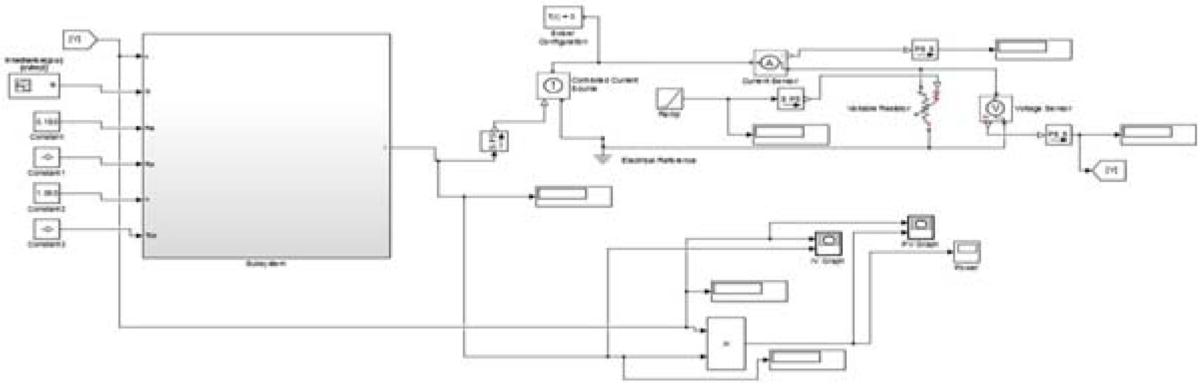

Figure 2: Simulation model of pv system

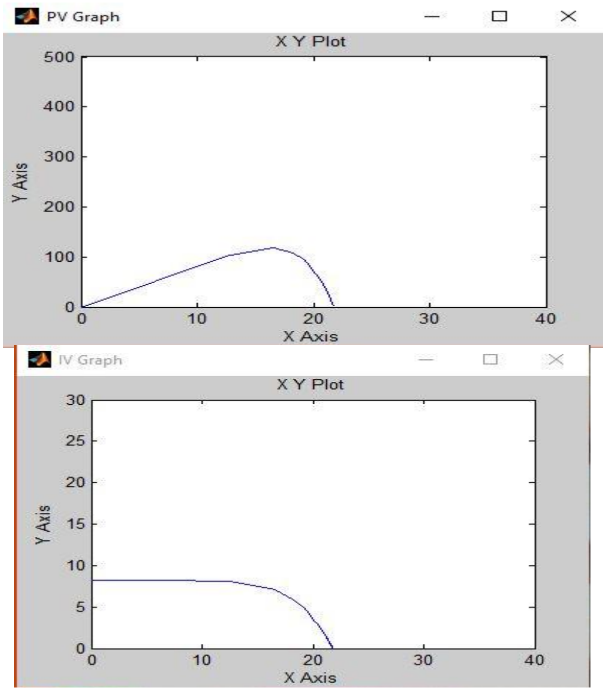

Figure 3: PV-IV curve

The model of PV panel is implemented with Matlab/Simulink. Its input is the ambient conditions like ambient temperature and solar irradiation and its output will be the panel current-voltage characteristics and panel parameters(the thermal voltage and the series resistance). This model needs the parameters from the manufacturers datasheet measured under standard test condition, such as open circuit voltage, maximum power point voltage voltage-temperature coefficient, short circuit current, maximum power point current and the current-temperature coefficient at STC.

3)Overall Simulation

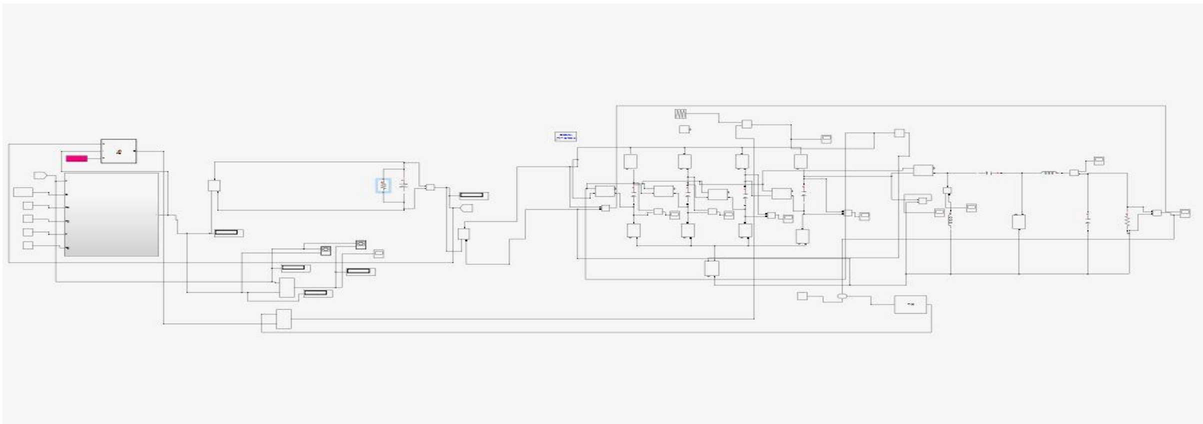

Figure 6: Zeta converter with PV input

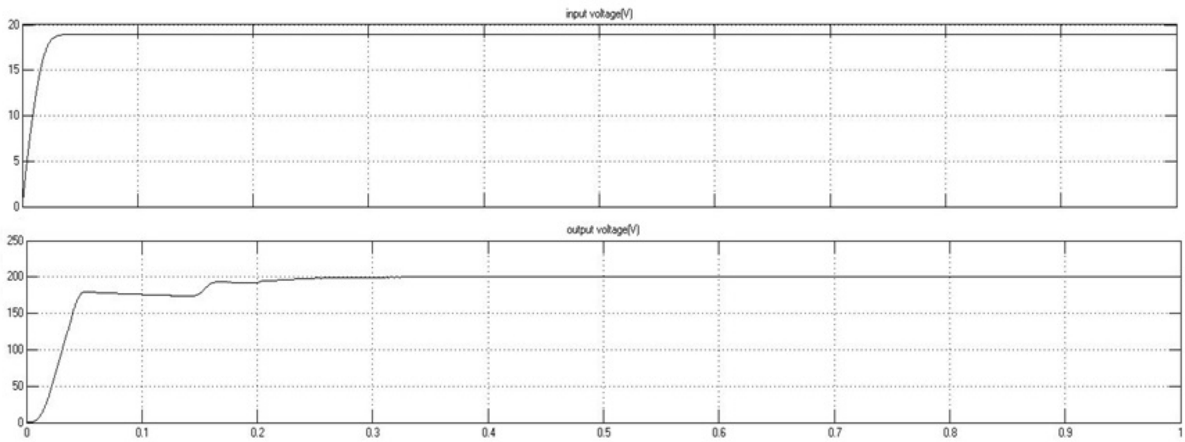

Figure 6: Simulation results of extended zeta converter with PV input

Input voltage of high gain zeta converter with PV input is 18.5V and output voltage is 200V

5. Conclusion

In this work, closed loop zeta converter was presented. The extended high voltage gain converter is operated with a fixed conversion gain whereas the zeta converter can be controlled to do the maximum power point tracking (MPPT) which is an important advantage of this structure. Using the structure, the disadvantages of voltage multiplier converters was improved. The number of the utilized switches and capacitors were reduced which lead to reduction in cost. It was shown that the topology is suitable for photovoltaic system.

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