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# Closed Loop Residential Photovoltaic Power System with Soft-Switching Push-Pull Front-End Converter

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***Abstract:***
*Renewable energy has experienced impressive growth over the past decade due to the fast depletion of fossil fuels, concern of energy security and green gas emission. Hence nowadays Photovoltaic (PV) cells play an important role in residential power system. In this paper, a novel soft-switching current-fed push-pull front-end converter with closed loop control is proposed. Push-pull converter has only two primary devices with common ground to supply and results in simple and reduced gating requirement. The device voltage is clamped naturally by secondary modulation without active clamping circuit or passive snubbers. Closed loop control is provided using PID controller which provides the gating signal to the switches. Hence provide a constant output voltage even if there is a variation in the source voltage. The proposed system is suitable for PV based power systems which provide a constant output voltage, maximum power transfer capacity and high efficiency. A 250W prototype of the converter has been built, and simulation results are provided to verify the theoretical analysis. Open loop and closed loop controlled photovoltaic power system with soft-switching push-pull front-end converter systems are modeled and simulated. The results of open loop and closed loop systems are presented and also analysed for different input voltages*

***Keywords:*** *Soft-switching, Phovoltaic cells, Push-pull converter, residential power system*

## 1. Introduction

Photovoltaics (PV) is a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. Power generation from solar PV has long been seen as a clean sustainable energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years.

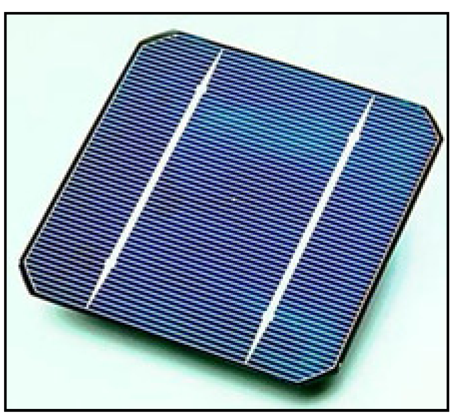

*Figure 1: Solar cells generate electricity directly from sunlight*

Solar photovoltaics power generation has long been seen as a clean energy technology, which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The technology is "inherently elegant" in that the direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialised applications, and grid-connected systems have been in use for over twenty years.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. Photovoltaics is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity.

High step-up front-end dc/dc converter is critical to design which convert wide input voltage range into regulated higher dc voltage with high efficiency. Non-isolated high step-up dc/dc converters in PV grid-connected application have been reviewed in [i]. Three level converters [ii], cascaded boost converters [iii], switched capacitor converters [iv-v], boost converters integrated with a coupled inductor [vi-vii], combination of coupled inductor and switched capacitor [viii-ix] etc. have been proposed and analyzed for solar inverter applications. Parasitic effect of devices and reverse recovery issue of diodes are the main issues and constraints for those converters with low efficiency and voltage gain [x].

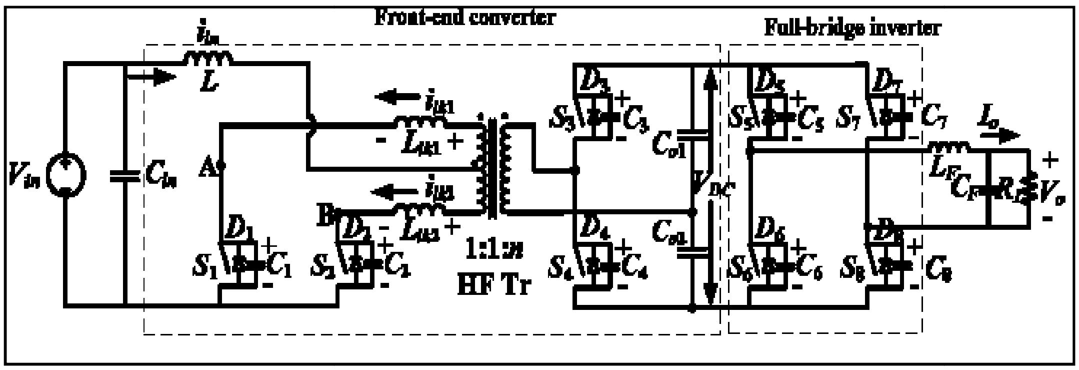


*Figure 2: Open loop current-fed push-pull dc/ac inverter*

High frequency (HF) transformer isolated dc/dc converter is preferred to obtain high step-up ratio and the galvanic isolation between the PV modules and the utility. For voltage-fed topologies, considerably large electrolytic capacitor is generally required to suppress the large input current ripple, resulting large size, high cost and shortened lifetime of PV system. Compared with voltage-fed topologies, current-fed topologies exhibit following advantages: 1) smaller input current ripple, 2) lower transformer turns-ratio, 3) capacitive output filter, 4) no flux-imbalance problem. However, it is well known that the current-fed converter suffers from high voltage spike across the switches at their turn-off. Passive RCD snubber is used to absorb the voltage spike leading to low efficiency. A non-dissipative snubber is proposed in [xi] to recycle the absorbed energy but increases the complexity. Active clamping is popularly used due to high efficiency and achieves ZVZCS of the devices at the same time [xii-xv].

A dual stage dc/ac inverter as shown in Fig.2 is composed of high step-up snubberless current-fed push-pull front-end converter and standard full-bridge inverter. No of the switches and the transformer turns ratio is reduced due to voltage doubler. Even though if the source voltage is varied, it affects the dc output voltage which in turn affects the load side input voltage. Low efficiency and power loss is high. High temperature effects in the components. The Current ripple requirement is strict. The large initial current may damage the semiconductor devices in the current path.

**2. Proposed Topology**

In this paper, a closed loop residential photovoltaic power system with soft-switching push-pull front-end converter is proposed which maintains a constant output voltage. The dc input voltage 20V is taken from the solar panel. Using MOSFET switches dc is converted into ac and given to the push-pull converter. These converters can step-up the voltage level into 200V. Finally, the inverter is used to convert dc to ac and given to the ac load. This paper presents the operational principle of the converter, a theoretical analysis and design guidelines. A 250W prototype of the converter has been built, and simulation results are provided to verify the theoretical analysis.

**3. Operating Principle**

The circuit shown in fig.3 is the open loop soft-switching push-pull front-end converter. In this Section, steady-state operation and analysis of proposed soft-switching push-pull front-end converter have been explained. To simplify the analysis, the following assumptions are made:

i. Boost inductor L is large enough to maintain constant current through it.
ii. All the components are ideal.
iii. Series inductors Llk1 and Llk2 include the leakage inductances of the transformer. The total value of Llk1 and Llk2 is represented as LlkT.
iv. Magnetizing inductance of the transformer is infinitely large.

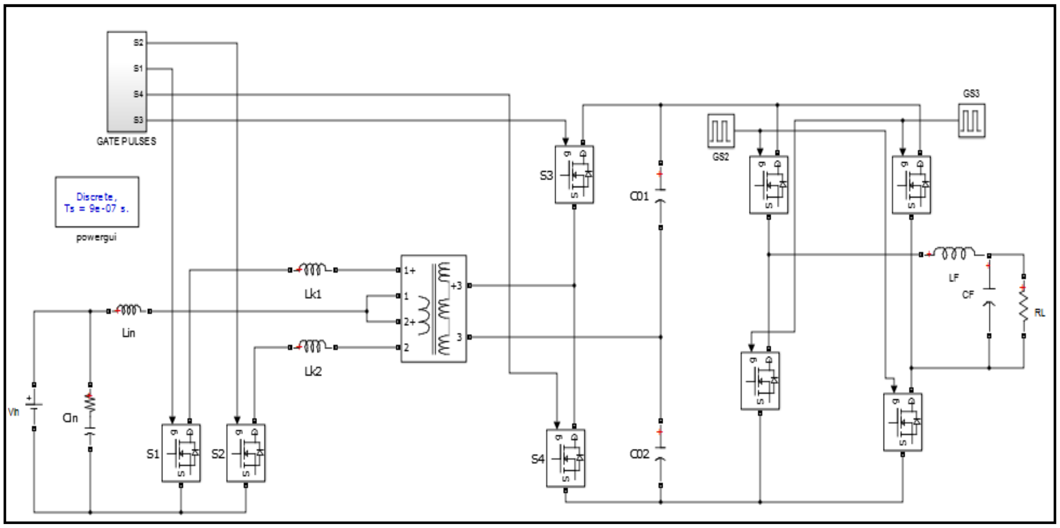


*Figure 3: Open loop soft-switching push-pull front-end converter*

The gating pulses of the primary switches $S_1$ and $S_2$ are identical with a phase shift of180°, with an overlapping. Initially the switch $S_2$ and anti-parallel body diode of the secondary side switch are conducting. High frequency transformer transfers the power to the load Then the primary switch $S_1$ starts conducting. When both the primary switches $S_1$ and $S_2$ starts conducting the output voltage is reflected across the series inductors $Llk_1$ and $Llk_2$. At the end of this interval the switch $S_3$ is turned–on with zero voltage switching. The current through all the switching devices increases or decreases with the same slope. At the end, the primary switch $S_2$ commutates naturally with zero current switching.

When the secondary device $S_3$ is turned –off, the current flows through the anti-parallel body diode switch $S_4$. Hence the transformer primary voltage polarity is reversed. The current through the switches are

$i_{S1} = i_{Llk1}$

$i_{D2} = - i_{L1k2}$

Secondary switch voltage is $V_{S2} = V_{DC} / n$

In this half cycle the current transfers from switch $S_2$ to $S_1$and hence the polarity of the transformer current is reversed.

**4. Design and Analysis of the Converter**

Soft-switching push-pull front-end converter is designed with the following specifications:

Let $V_{in}$ = 20 V; Vo= 200 V; Switching frequency = 100 KHz; Rated power =250 W

i. The average input current is given by $I_{in} = P_o / (\eta V_{in})$

For 95% efficiency $I_{in}$ = 13.15A

ii. Maximum voltage across the primary switches is given by $V = V_{DC}/n$

iii. The output voltage in terms of the duty cycle is given by $V_{DC} = n.V_{in} / (1\text{-}d)$

Where n-Turns ratio of high frequency transformer

d- Duty cycle of the gating signal

iv. Minimum duty cycle is given by $d_{min} = t_r.f = f\pi\sqrt{(L_{in}.C_{in})}$

v. Value of boost inductor is given by

$L_{in} = V_{in}.\ (d\text{- }0.5)/(\Delta I_{in}\ .\ f_s)$

Where $\Delta I_{in}$ = Boost inductor ripple current

$f_s$ = Switching frequency

vi. Percentage of the total harmonic distraction of a non sinusoidal voltage waveform:

$$THD_{\upsilon}\% = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \times 100$$

For a closed loop simulation PID controller is used in which the output is the sum of the proportional, integral, and derivative actions, weighted according to the independent gain parameters P, I, and D. The filter coefficient N sets the location of the pole in the derivative filter. For a continuous-time parallel PID controller, the transfer function is:

$$C_{par}(s) = \left[P + I\left(\frac{1}{s}\right) + D\left(\frac{Ns}{s+N}\right)\right]$$

For a discrete-time parallel PID controller, the transfer function takes the form:

$$C_{par}(z) = P + Ia(z) + D\left[\frac{N}{1+Nb(z)}\right]$$

where the Integrator method determines a(z) and the Filter method determines b(z)
Fourier series of a periodic function f (t):

$$C_o + \sum_{h=1}^{\infty} C_h \cos(h\omega t + \theta_h)$$

$$C_o = \frac{1}{T}\int_o^T f(t)dt\,,$$

$$C_h = \sqrt{A_h^2 + B_h^2}$$

$$A_h = \frac{2}{T}\int_o^T f(t)\cos(h\omega t)dt$$

$$B_h = \frac{2}{T}\int_o^T f(t)\sin(h\omega t)dt$$

### 5. Simulation Results

Simulation model of Open loop controlled soft-switching push-pull front-end converter is shown in fig. 4. The dc input voltage is 20V and the output dc voltage is 200V. The ripple magnitudes are considerably reduced. But when there is a variation in the input voltage it leads to the variation in the output voltage which in turn affects the load.

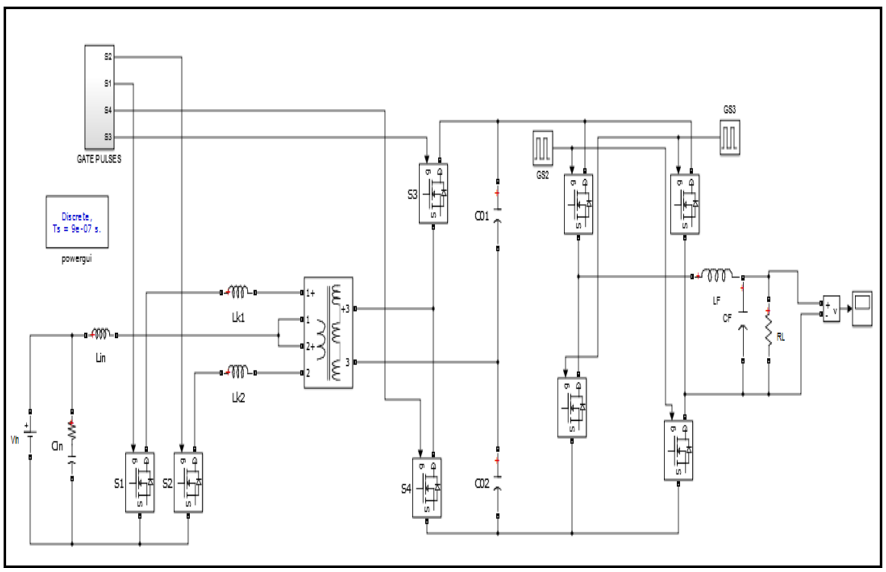


*Figure 4: Simulation model of Open loop controlled soft-switching push-pull front-end converter*

The output voltage waveforms are shown in fig.5. The 20V dc input is boosted to a voltage of 200V DC using Push-pull front-end converter. And also it is converted to 200V AC using inverter circuit.

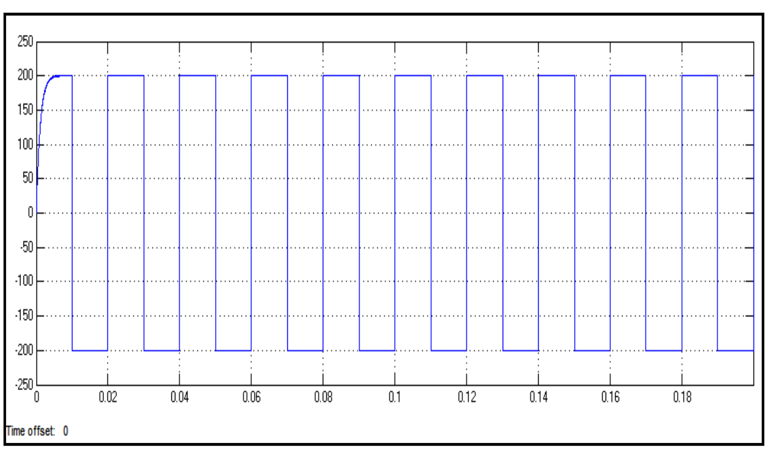


*Figure 5: Output voltage for open loop system*

*Results for a input voltage $V_{in}$ = 18V :* When the input voltage is reduced to 18 volts dc, then the input is boosted to a voltage of 164V DC using Push-pull front-end converter which is shown in fig.6

And also it is converted to 164V AC using inverter circuit. Fig. 6 shows the output waveforms when the input is 18V. In open loop controlled soft-switching push-pull front-end converter system when the input voltage varies it affects the output produced which in turn affects the load connected to it.

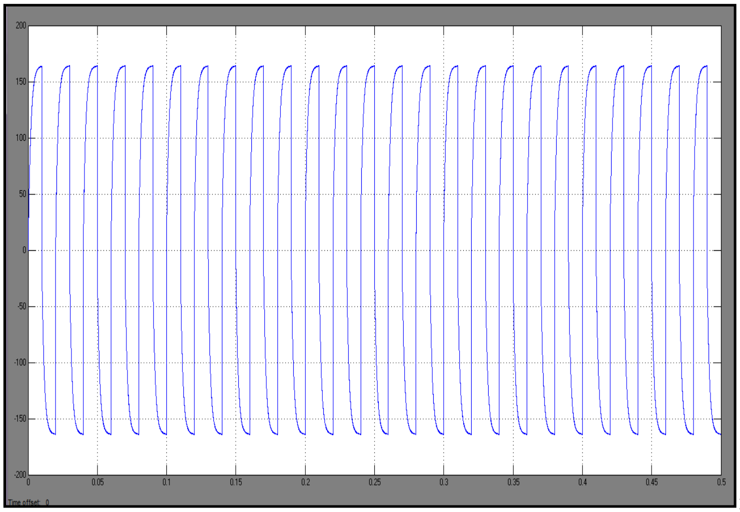

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*Figure 6: Output voltage of open loop system- 164V (AC)*

It can be overcome in the proposed closed loop controlled soft-switching push-pull front-end converter. Fig .7 shows the Simulation model of closed loop controlled soft-switching push-pull front-end converter.

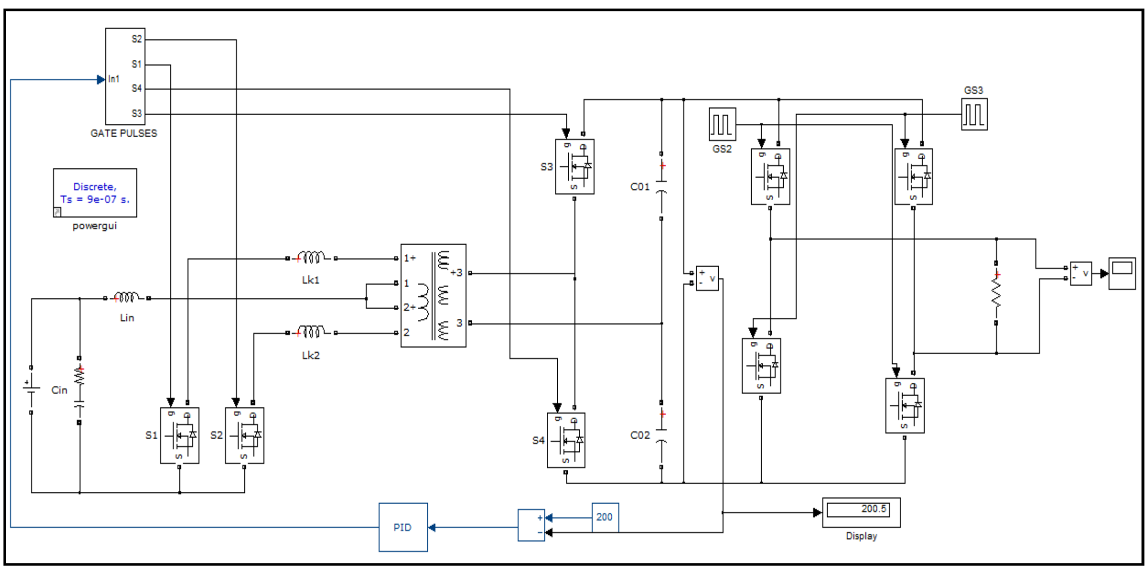


*Figure 7: Simulation model of closed loop controlled soft-switching push-pull front-end converter.*

In the closed loop control gating pulses are provided to the switches by the PID controller. The variations in the source voltage are nullified with the use of controller. The output voltage waveforms are shown in fig.8. The 20V dc input is boosted to a voltage of 200V DC using Push-pull front-end converter. And also it is converted to 200V AC using inverter circuit. In the closed loop circuit when the input voltage varies, the gating pulses of the primary switches are altered with the use of PID controller. Hence the $V_{DC}$ output can be maintained constant. Hence the ac output is also maintained constant inspite of the variations in the source voltage.

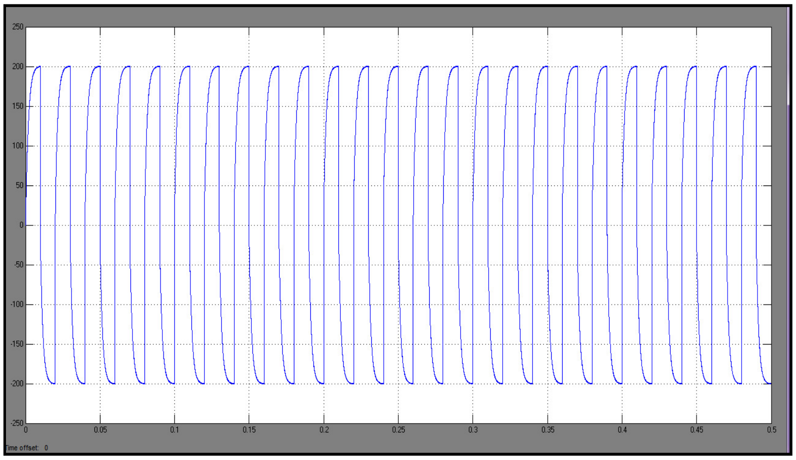

*Figure 8: closed loop circuit AC output voltage (200 Volts)*

Fig.9 shows 200V dc output voltage of the closed loop system.

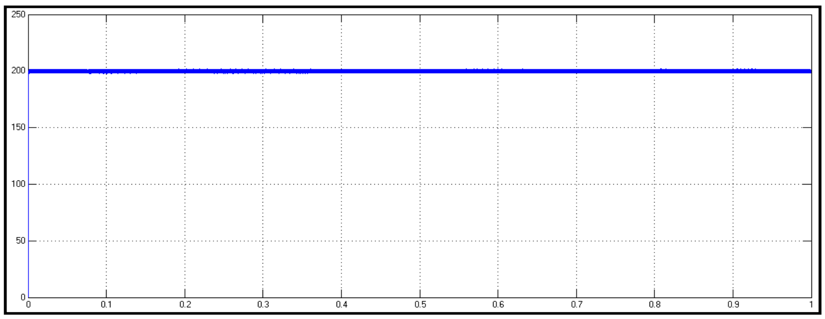


*Figure 9: closed loop circuit DC output*

In the proposed closed loop system the output voltage is maintained constant inspite of the variations in the source voltage. The THD value is also reduced to 10.79% in the proposed system. Fig.10 shows the FFT analysis of the closed loop system.

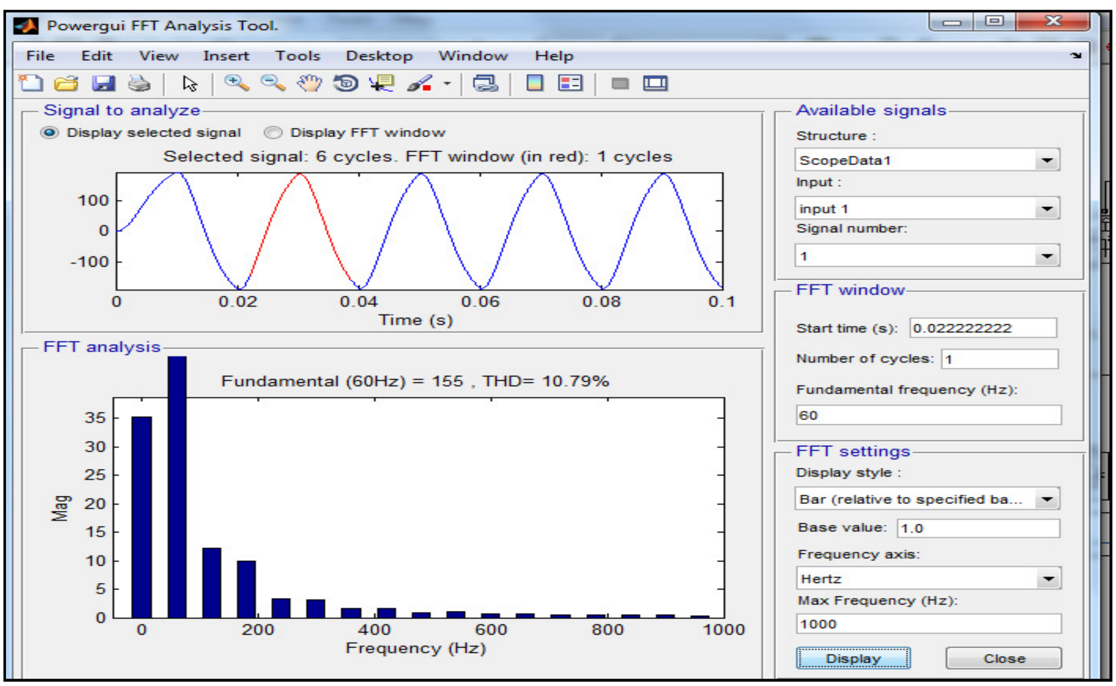


*Figure 10: FFT analysis of closed loop controlled push-pull front-end converter.*

| Loss Type | Power loss(W) at $V_{in}$ = 20V | Power loss(W) at $V_{in}$ = 40V |
|---|---|---|
| Primary switches conduction loss | 2.0 | 0.5 |
| Primary switches switching loss | 3.3 | 3.3 |
| Secondary switches conduction loss | 3.4 | 1.4 |
| Secondary switches switching loss | 0.5 | 0.5 |
| Boost inductor loss | 1.9 | 1.4 |
| Others | 2.5 | 2.8 |
| Total loss | 13.6 | 9.9 |

*Table 1: Values of Loss Component along the Components*

Loss distribution estimation of proposed front-end converter at full load condition with $V_{in}$ = 20 V and $V_{in}$ = 40 V is shown in Table I. It is easy to find that with the increase of input voltage, the conduction loss of switches and the copper loss of boost inductor and HF transformer reduce a lot. Thus the efficiency of $V_{in}$ = 40 V is much higher than that of $V_{in}$ = 20 V.

**6. Experimental Results**

Fig 11.shows the experimental set up of residential photovoltaic power system with soft-switching push-pull front-end converter. The hardware of residential photovoltaic power system with soft-switching push-pull front-end converter is fabricated. The hardware consists of power board and control board. The hardware is tested with lamp load.

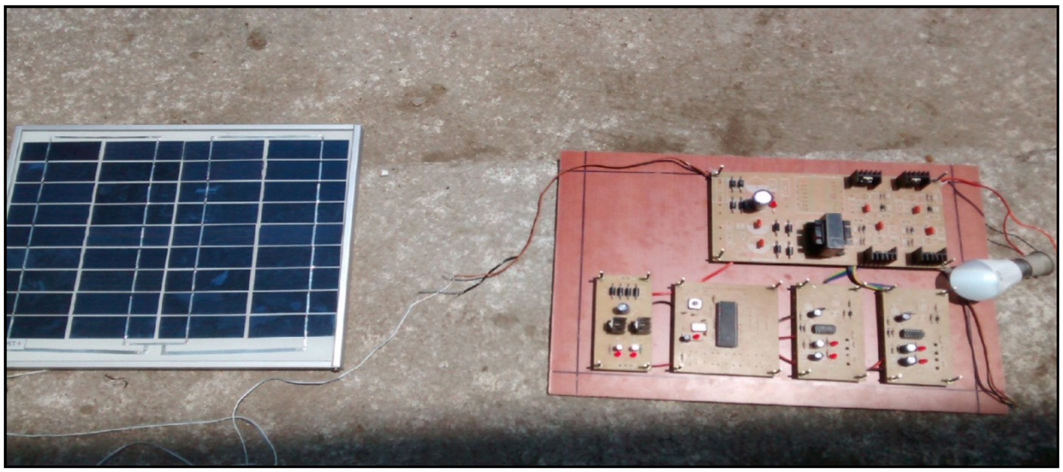

*Figure 11: Experimental setup*

**7. Conclusion**

In this paper, residential photovoltaic power system with soft-switching push-pull front-end converter is proposed. Circuit was modeled using the blocks of simulink and simulation is performed. The efficiency of the proposed drive system is improved since it uses soft switching technique. Open loop and closed loop systems are simulated and the output voltage is regulated by using closed loop system. The contribution of this work is the development of simulink model for closed loop residential photovoltaic power system with soft-switching push-pull front-end converter.

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