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Research paper

Multi-input Transformer Coupled(tied) Bidirectional DC-DC Converter For Renewable Energy Applications

M. Sunil Kumar[1]*, T. Hari Priya[2]

[1]PG-Student-VNRVJIET
[2]Assistant Professor-VNRVJIET
**E-mail:Sunilkumar.vnrvjiet@gmail.com*

Abstract

This paper gives an explanation on merging of multi renewable sources with an efficient control topology using multi-input converter of transformer tied bidirectional dc-dc converter. This multi-source converter has a desire which can fulfill the load demand, and can handle the sources even in intermittent of the nature. A bidirectional buck/boost converter is used to utilize the PV source accompanied with battery charging/discharging control; while a transformer tied current-fed boost half bridge converter is used to harness the power from fuel cell. If needed single-phase full-bridge inverter is used to feed the AC loads. This converter has less switching components, which results in lessen amount of power converting stages, make better the reliability and boost up efficiency of the system. Simulation results are carried out by using MATLAB/Simulink show the efficacy of multi input converter under various modes of operation.

Keywords:*-Renewable hybrid system; Bidirectional buck/boost converter; transformer coupled bidirectional boost dual half bridge converter; Maximum power point tracking; Battery management system.*

1. Introduction

An Ever increasing industrialization, growing population is craving for more comfort which results in energy demand. To meet these demands, we have opted for conventional energy generating stations which are drastically increased and worsening the global environment. Where these fossil fuels are exhaustible in nature and causing Green House gas effect. In the recent reviews, this GHG emissions results in damage of climatic conditions. So that people got a great concern over climate and looking forward for Renewable energy sources.
However, the intermittent nature of the Renewable sources challenges the continuous supply to the loads, which can be efficiently managed by integrating with energy storage elements. To provide high quality and reliable power to the consumers, a multi-source hybrid system and dedicated converters with an efficient control schemes need to be implemented.
Initially the Research is carried out by M. H. Nehrir.et.al [1]-[2] on integrating multiple renewable sources using a single converter one for each independent renewable source. The utilization of this each independent converter cannot carry out effectively due to their multiple power conversion stages and intermittent nature which effects in efficiency.
A huge amount of research is carried out in the area of integrating RES to grid, which mainly focused on optimization of converters, where interfacing of sources and storage elements through dedicated converters at DC-link is analyzed.
Some of the control technique for standalone PV-Wind hybrid system is explained in [3]-[4]. In [3] B.S.Borowy.et.al has analyzed the dynamic performance of standalone hybrid system along with battery storage. In order to complement the solar energy generation, a sliding mode technique is presented by F. Valenciaga et.al [4].
Further research was conducted on optimization of circuit configuration which reduces the cost and improves the reliability and efficiency. In [5] Daniel et. Al has presented a simple topology of an integrated converter for hybrid system, which suits for standalone appliances.
However, In [6] Z. Qian et. Al have proposed an integrated four-port topology for hybrid system, even though simple but control scheme offered is complex.Page layout.

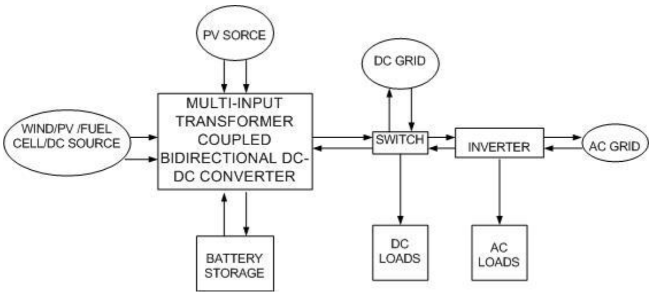


Fig.1: Grid integrated hybrid system with battery storage

Now-a-days an important research area is hybrid energy generation and its interfacing with grid. Y. M. Chen at. Al has presented a grid connected hybrid renewable generation system with multi-input DC-DC converter to improve the DC-bus voltage regulation.

2. Selection of Multi-input Converter:

Till now the integration of sources is analyzed with single input converter one for each source, but this existing converter topology may increase the component count, reduces power density and efficiency. To overcome from above disadvantages, the research people focused on a new topology that is Multi-input converter (MIC). MIC is attractive due to its advantages like improved power density, reduced component count and centralized power control.

Due to above stated advantages, there is some MIC's, and they are classified into three types,

- Non-isolated MIC
- Fully-isolated MIC
- Partially-isolated MIC

According to non-isolated topology, the power ports share a common conviction. In order to rectify the multi-inputs DC-DC converter, we have to employ a series/parallel configuration at input side and extended to output side. Some of non-isolated multiport converters for example buck, boost, buck/boost and bidirectional buck/boost units. These converters are time sharing based topology, which promises a low-cost and compactness but simultaneous power transfer from multiple sources is not possible to the loads. This topology mismatches the voltage ranges from multiple inputs. So, this made the research people to prefer the isolated multi-port topology. Fully isolated multi-port topology has increased component count, which increases conversion stages. So that partially isolated multi-port topology is attractive to address the limitations of existing system.

In [7]-[9] a tri-model half bridge converter is proposed by Al. Atrash et. Al . However it is for single input but for multiple energy interfacing, a tri-port dc-dc converter of decoupled controlled technique is proposed by Wuhua Li et. Al [8]

Above literature accommodates single source and single storage element. But present topology can interfaces both the sources and storage elements with an efficient control schemes.

The main objectives of this present system is,

- To provide un-interruptible power supply to the loads.
- Step up the voltage levels by connecting PV source and Battery in series along with step-up transformer of high frequency.

The preliminary study of present paper carries merging of multiple PV source and battery using multi-input converter, analysis of system and simulation.

3. Description of circuit topology:

3.1 Photovoltaic Module

A photovoltaic cell is a particular semiconductor diode which changes over the daylight into direct current (DC). It is an essential piece of sun based electric energy system. PV module is a bundle of crew of cells associated in series/parallel. Weather data (irradiance and temperature) is taken as input variables. P, V, I are taken as output variables. Tracing of *IV and PV* characteristics are carried out by above 3 variables. Generally each cell produce about ½ (0.5) of a volt. However to get a 40v peak output, a series connection of 80cells is employed in a module.

3.2 Source 2(PV/Fuel cell/wind):

Fuel Cell:-Basically fuel cell are an attractive power source because it is a static device that converts electrochemical chemical energy of a fuel specifically, isothermally, and constantly into electrical energy through an electrochemical reaction of hydrogen fuel with oxygen or other oxidizing agent It is essentially free of discharges and clamor, and just water and warmth are the by-products. Fuel cells produce electrical energy persistently for whatever length of time that fuel and oxygen is provided.

General reaction of process are portrayed below,

$$H_2 \rightarrow 2H^+ + 2e^- \quad \text{(a)}$$

$$2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O \quad \text{(b)}$$

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad \text{(c)}$$

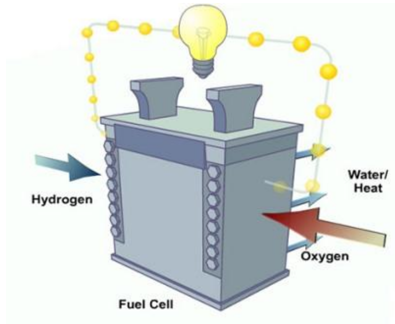


Fig.2: Fuel cell stack

Wind Source:-Wind energy is a form of solar energy, which converts the kinetic energy of a wind to the mechanical power by rotating the blades of turbine through wind gust. This mechanical power is converted to electricity by connecting a generator to turbine shaft.

An inductor is connected in series with fuel cell for continuous and smooth variation of current and to maintain the MPP current.

3.3 Battery:

Interest in energy storage is growing rapidly. Storage helps solve variability issues with renewable sources. Adding batteries to the solar provides power at critical load condition when the grid is down, instead of disconnect and refrain from generating power.

As we know, lead-acid/lithium-ion batteries are preferred storage elements for solar energy. Lithium-ion battery is the most common storage technology, which can typically deliver more cycles in their life time than Lead-acid battery. The referred configuration of battery for simulation purpose is 400Ah 36v.

3.4 Converter Configuration:

The preferred converter configuration is designed with multiple converters. A boost dual half bridge bidirectional converter is coupled with transformer along a bidirectional buck/boost converter, and a solitary stage full bridge inverter is used to feed the AC loads if needed. When compared with existing schemes, the present scheme has lessen amount of power converting stages with high proficiency and less segment check.. It requires only six switches for this simple topology.

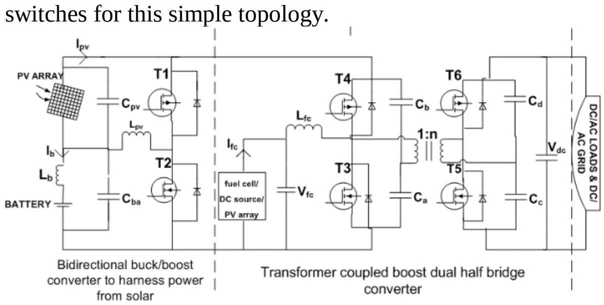


Fig.3: preferred converter configuration

4. Modes of Operation and Its Analysis:

The operation of preferred converter is carried out by switching the multi-input converters. Let PV modules of array and battery charge/discharge activity control is followed by bidirectional buck/boost converter, in which the capacitance of C_a and C_b are charged/discharged across the transformer tied half bridge boost converter depending on load demand. As well as the transformer tied current-fed boost half bridge converter pull out power from fuel cell across the capacitance bank C_a and C_b.

V_{TP}	Transformer primary voltage
V_{TS}	Transformer secondary voltage
V_{Ca}, V_{Cb}	Capacitor voltage of C_a and C_b
V_{Cc}, V_{Cd}	Capacitor voltage of C_c and C_d
V_{ba}	Battery voltage
V_{FC}	Voltage of Fuel cell
V_{PV}	Voltage of PV source
'n'	Transformer turns ratio
D, D_{FC}, D_{PV}	Duty cycle
V_{bus}	DC-bus voltage at primary side capacitor bank

Mode-1: When T1 and T3 switch is turned ON, the inductance (L, L_{FC}) of PV and fuel cell raises. The capacitor C_a can be discharged via the primary side winding of transformer and switch T3. At secondary side of transformer, a capacitor C_c is charged via anti-parallel diode of switch T5 and transformer secondary.

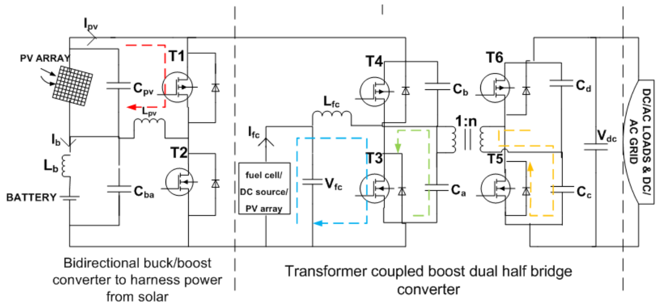


Fig.4: Converter operation at a point of turning ON the T1 & T3 switch, Capacitor C_a Discharge

During the ON-time of Switch T1 and T3, the primary voltage of transformer is
$V_{TP} = (-)V_{Ca}$,

Secondary voltage of transformer

$V_{TS} = nV_{TP} = (-)nV_{Ca} = (-)V_{Cc}$
$V_{Cc} = (+)nV_{Ca}$

Voltage over the inductor L_{FC} is V_{FC}

Mode-2: When T1 and T3 switch is turned OFF, T2 and T4 is turned ON. The current in inductor of PV is transferred to battery, but at switch T4 the inductor current I_{FC} of fuel cell is carried via anti-parallel diode of switch T4 and capacitor bank $C_a - C_b$.

At whatever point the transformer primary current equivalents the releasing current of source inductor L_{FC} the diode T4 kills.

Since switch T4 is gated ON, amid this time scale the capacitor C_b discharge via switch T4 and transformer primary.

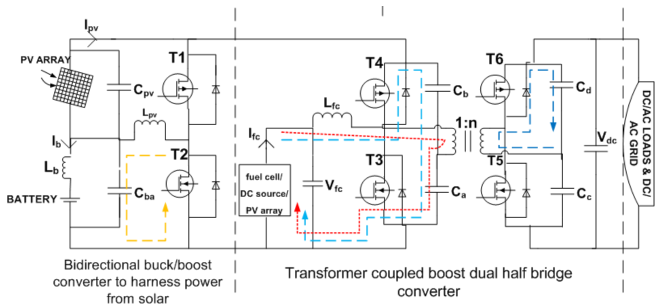


Fig.5: Converter operation where battery charges via switch T2 & switch T4 charge the capacitors $C_a - C_b$.

At secondary side during ON-time of switch T4, a diode opposite to switch T6 tends to charge the capacitor C_d. At whatever point the battery releasing current is more than PV current, the inductor current ends up negative.

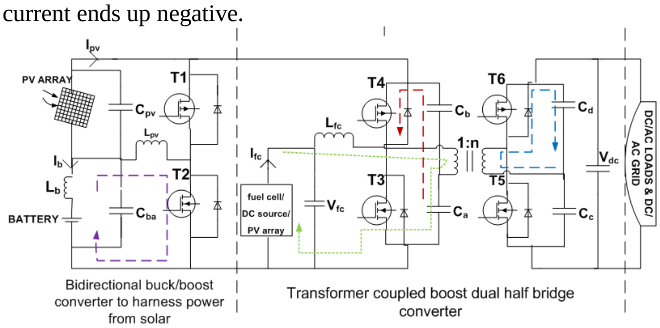


Fig.6: Converter operation at a point of conduction of switch T2 & T4, capacitor C_b discharging.

During the ON-time of switch T2 and T4, the primary voltage of transformer is
$V_{TP} = V_{Cb}$
Secondary side voltage of transformer

$V_{TS} = nV_{TP} = nV_{Cb} = V_{Cd}$

$V_{Cd} = nV_{Cb}$

Voltage over the inductor L_{FC} is
$V_{FC} - (V_{Ca} + V_{Cb})$
So that we can prove,

$$(V_{Ca} + V_{Cb}) = \frac{V_{FC}}{1-D_{FC}} \quad (1)$$

If the voltages (V_{Ca}, V_{Cb}) over the capacitor C_a and C_b are considered constant in steady state,
$V_{Cc} = nV_{Ca}$, $V_{Cd} = nV_{Cb}$

Hence the output voltage (V_{dc}) is

$$V_{dc} = n(V_{Cc} + V_{Cd}) = n\frac{V_{FC}}{(1-D_{FC})} \quad (2)$$

By above considerations, the V_{dc}(output voltage) of DC-link depends upon the converters duty cycle at primary side and transformer turns ratio 'n'.
Even the battery voltage (V_{ba}) will also depends on duty cycle of PV voltage,

$$V_{ba} = \frac{D}{1-D}V_{PV}$$

So the overall output voltage (V_{dc}) at secondary side of this converter is given by,

$$V_{dc} = n(V_{ba} + V_{PV}) = n(V_{Ca} + V_{Cb}) = \frac{nV_{FC}}{(1-D_{FC})} \quad (3)$$

The primary side voltage of a dc link can be controlled by any of these converters (half bridge boost converter, bidirectional buck/boost converter). It shows the correlation between the average value of inductor current, PV current and battery current over a switching sequence is given by

$I_l = I_{pv} + I_{ba}$,

It is proven that, I_{pv} and I_{ba} can be controlled by controlling the inductor currentI_l. For faster dynamic response I_l is used as inner loop control parameter while to ensure the MPP voltage of PV source, capacitor voltage C_{pv} is used as outer loop control parameter.

The equation for power flow balance is given by

$$V_{pv} * I_{pv} + V_{FC} * I_{FC} = V_{ba} * I_{ba} + V_{dc} * I_{dc} \quad (4)$$

Based on the less switching losses and reduced components count, this multi-input converter has a minimum efficiency of 80-85%.

5. Control Technique (MPPT):

MPPT: Maximum power point tracking is frequently referred to as MPPT. This MPPT technique delivers continuous power to the load at a high variations in the isolation and temperature occur.

As incremental conductance method is used for MPPT. In this method, Fig.7 shows the array terminal voltage is always adjusted according to the MPP voltage, which is based on incremental and instantaneous conductance of PV module.

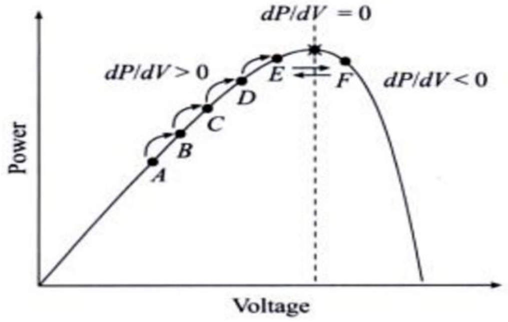


Fig.7: MPPT tracking using P-V curve (incremental conductance)

Shows the slopes of a P-V array power curve and the basic equations of this method is given by

$$\frac{dI}{dV} = -\frac{I}{V} \; for\ MPP(top)$$

$$\frac{dI}{dV} > -\frac{I}{V} \; for\ incremental\ conductance(left)$$

$$\frac{dI}{dV} < -\frac{I}{V} \; for\ instantaneous\ conductance(right)$$

The MPPT regulates the PWM control signal of the DC/DC converter until the condition $\left(\frac{dI}{dV}\right) + \left(\frac{I}{V}\right) = 0$ is satisfied. In this case, peak power of PV module lies at above 98% of its incremental conductance.

6. Simulation Results:

In MATLAB/SIMULINK platform, a detailed study of simulation is carried out and results are obtained under various operating condition. Table prescribes the parameter values used to model for simulation.

The values for source1 and source2 are set. It can be observed that V_{PV} and I_{pv} of PV and V_{FC} and I_{FC} of fuel cell is grasp set values required for MPPT operation. At constant magnitude of current the battery is charged and surplus power is fed to load/grid.

Table 1: Simulation Parameters

PARAMETER	VALUES
PV source	500W ($V_{mpp} = 34v,\ I_{mpp} = 14A$)
FUEL CELL	($V_{FC} = 37$)
Battery voltage & capacity	400Ah,36v
Inductor-buck/boost converter L_{PV}	3000e-6H
Inductor-half bridge boost converter L_{S2}	500e-6H
Transformer turns ratio	6
Switching frequency	15KHz
Capacitor banks C_a-C_b at primary	510e-6F
Capacitor banks C_c-C_d at secondary	510e-6F
Secondary side capacitor for entire DC-link	2000e-6F

The response of the converter at $V_{bus}(V_{Ca} + V_{Cb})$ when both the sources are operated in steady state along with battery charging at constant magnitude of current is shown below and the extra power is fed towards DC/AC loads.

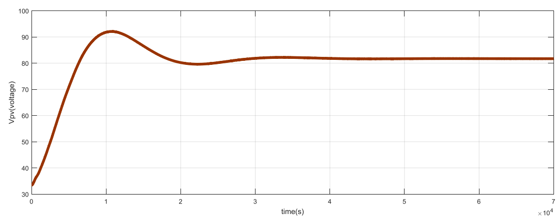
At a particular Day/night variation in climate, the PV source cannot supply continuous power while battery helps in feeding the loads.

Sometime both the sources are disconnected due to faults, while battery feed the loads as well as charge the battery from the load when required. So that we can improve the battery life cycle and balance the power flow in both directions.

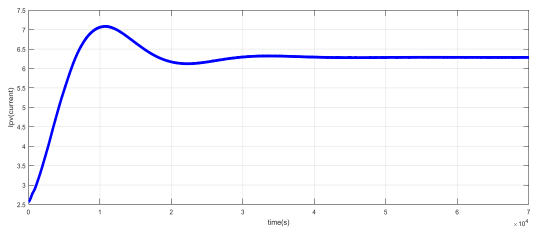
The range for source voltages (V_{PV}, V_{FC}) is 36-43V, and the range of V_{bus} at transformer primary is 60-82V. the correlation between V_{bus} and V_{dc} is given by,

$V_{dc} = nV_{bus}$

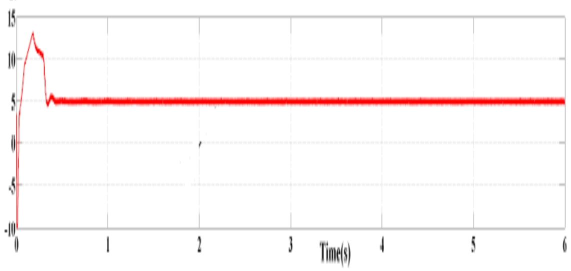
(Where $V_{bus} = V_{Ca} + V_{Cb}$)



(a) V_{bus}=81 V

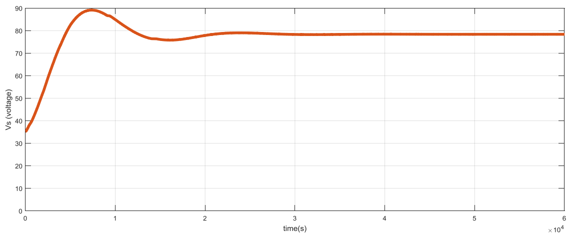


(b) I_{bus}=6.23A

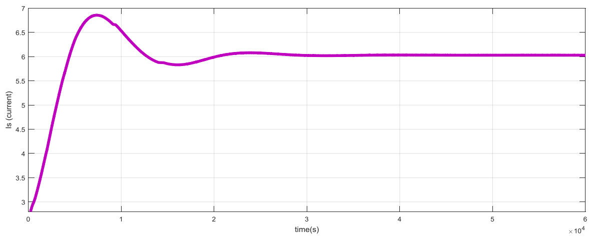


(c) I_{ba}(charging mode)

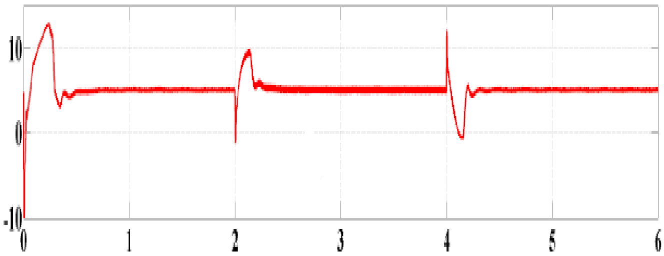
Fig.8: Response of the converter at $V_{bus}(V_{Ca} + V_{Cb})$ When PV source and fuel cell are operate at steady state.



(a) V_{bus}=76V

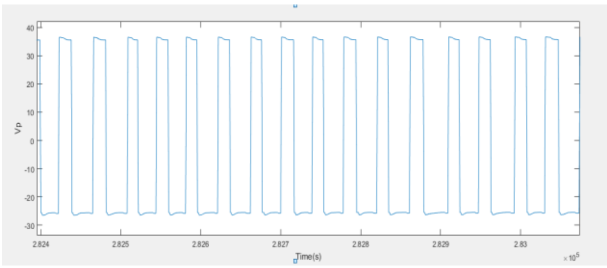


(b) I_{bus}=5.8A

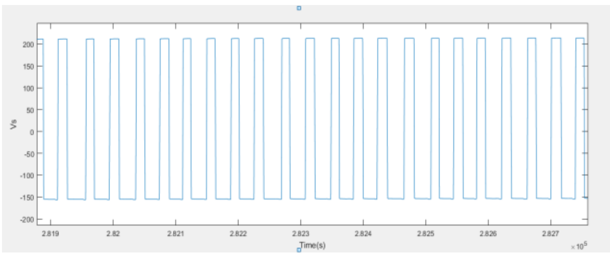


(c) I_{ba}(charging/discharging mode)

Fig.9: Response of the converter at $V_{bus}(V_{Ca} + V_{Cb})$, Where PV source is absent while the battery and fuel cell continues the operation.

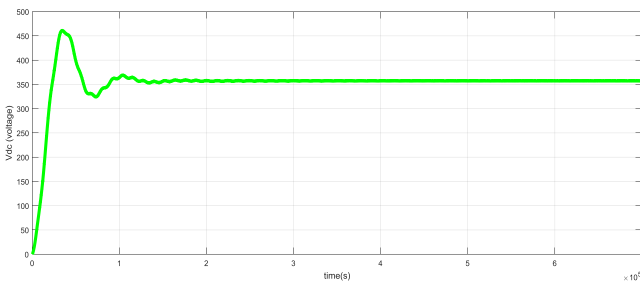


(a) Transformer primary voltage V_{TP}=38V

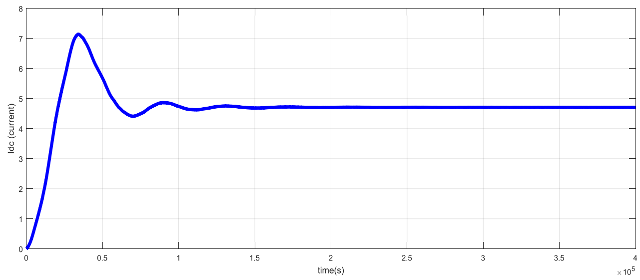


(b) Transformer secondary voltage V_{TS}=228V

Fig.10: Transformer primary and secondary voltages which is stepped up, where V_{TS} = n*V_{TP} (n=6)



(a) V_{dc}=356V



(b) I_{dc}=4.2A

Fig.11: Response of the Transformer coupled Multi-input converter at secondary side DC- link (V_{dc}) .

7. Conclusion

The interconnection of multiple sources-battery based power generation scheme for household application is presented using a multi-input converter topology. The solar and fuel cell are integrated along with high frequency step-up transformer to generate maximum energy. A transformer tied bidirectional multi-input DC-DC converter is satisfied the integration of multiple sources and interfacing between sources and storage elements is carried simultaneously. This topology achieves better usage of solar and battery without effecting the life cycle of the battery. MPPT is the better solution for extracting maximum energy from renewable sources. The installation cost of whole system is approx. 1.5 to 2lakh. This converter configuration satisfied by reducing component count, enhanced power density, supply convenient power to the DC/AC loads without interruption and we can send the extra power generated into the grid when required.

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