Transient Response Analysis of PV based Non- Isolated Two Phase Interleaved Boost Converter for Standalone DC Microgird

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Abstract

The electrification of villages depends heavily on renewable energy sources. Village electrification works best with PV fed independent micro grids be-cause grid connected micro grids require infrastructure expansion and take about a year to reach the settlements. This study focuses on developing a Two Phase Non – Isolated Interleaved Boost Converter (TPNI-IBC) with a voltage improving module, which serves as a suitable intermediate candidate for coupling a photovoltaic green source to a DC load. Because PV is spo-radic in nature and generates small voltage, the suggested converter is con-structed to offer substantial voltage improvement with a low duty cycle. The converter under consideration is constructed to reduce the voltage stress on the switches and diodes.In turn-off operation, the clamp circuit lessens volt-age spikes of the power devices and

recycles the energy of the linked induc-tor's outflow. Additionally, PID controllers and fuzzy logic (FL) controllers are employed to stream controlled DC bus voltage at various photovoltaic ar-ray irradiance levels. The controller and FLC both produce better outcomes when the transient response parameters such as settling time and peak over-shoot are compared.

Keywords: *Interleaved, PID, Fuzzy Logic Controller, Photovoltaic, Microgrid.*

1 Introduction

Though India is booming in the development of renewable energy in various parts of the states, there are still over 31 million homes left in dark. There are over 6 million houses in different rural parts of India suffer without electricity. Therefore, for village electrification, microgrid provides a better solution. Mi-crogrid is interconnection of renewable energy sources and loads. Microgrid op-erates in islanded mode and grid connected mode. It is used both in residential and industrial sectors.

In India, AC distribution is popular as most of the loads operate in alternating current. For a microgrid application, DC fetches a vital role than AC system as it does not involve any reactance drop, no synchronization and stability problems. DC systems are more reliable. The implementation of DC microgrid is simple and less expensive.

In DC distribution, the design of DC-DC boost converter becomes the crucial part as the Photovoltaic output is variable due to its irradiation level. A family of DC-DC converter with single switch which uses diodes and coupled inductors are introduced in [1]-[2]. Though the diode recovery problem is alleviated, it pro-duces large voltage spikes and conduction losses. The converter uses large duty ratio, so that high step up voltage is achieved.

The isolated converter for non-conventional energy sources are described in[3]. This isolated configuration uses a transformer with more turns ratio to improve the voltage gain. Hence it makes the system bulky. The power loss across the switches is high because of transformer’s leakage inductance. Though it provides better step up voltage, it fails in improving its efficiency. Also, the circulating current creates higher diode voltage stress. In [4] conducted a survey on topolo-gies of transformer-less converter for applications where galvanic isolation is not a problem. These non-isolated converters improves the voltage gain, reduces the weight, size and volume compared to that of the isolated converter which in-volves the transformer. The efficiency, voltage gain, voltage stress of the switch-es and semiconductors, components of different topologies were discussed.

The switched-capacitor and switched-inductor in different DC-DC converter such as boost, zeta, cuk and sepic were implemented in [5]. This switched tech-nique helps in voltage stepping up or down. However, this method does produce high transient current.

Single stage non-isolated converter with coupled inductor is introduced in [6]. The energy from input source is stored in coupled inductor. The leakage energy from inductance is recovered through passive clamp circuit. However, the volt-age gain of such converter is less.

In [7], a interleaved transformer less quadrupler converter having 2 phase with significant voltage gain was suggested. The switching stress are ¼ times the out-put voltage. In this converter, additional diodes and capacitors are introduced.

The state feedback controller for interleaved converters were discussed in [8]. The instability of the converter leads to reduced efficiency and life time. There-fore, the instability of the interleaved converter is analyzed through static and dynamic state feedback controller which combines the interleaving and digital control techniques.

In [9] discussed a control scheme of interleaved converter using switched linear method. The current shared by interleaving techniques are considered to be the same for better performance analysis of the converter. The control scheme is verified through Lyapunov stability theory and designed through Linear Matrix Inequality (LMI) optimization. The performance of the PV fed converter for different irradiations are checked through this control technique.

In [10]-[11] discussed a current controller of a two interleaved converters which is operated bidirectional. The converging time is minimized and current path tracking is maximized by the controller. The controller gives better results during transient and steady state operations.

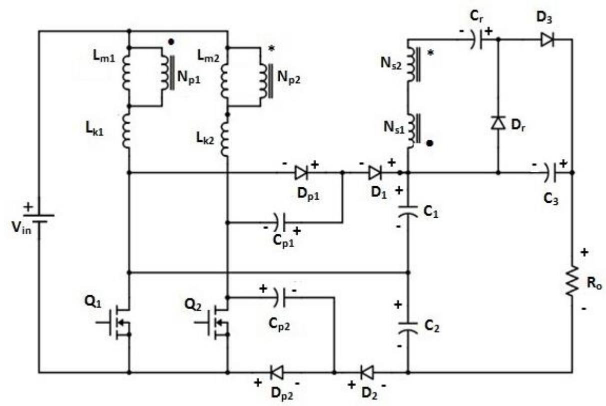
The problem identified for the work involves in searching a new way of increas-ing the intermittent PV energy source voltage which feeds a DC bus. An interme-diate DC-DC converter with minimum ripple in current and reduced switching stress has been connected in between PV source and load. By introducing proper controller, a regulated DC bus voltage should be maintained on the load side for a village electrification which has been fed by Variable PV source.

2 Two Phase Non-Isolated Interleaved Boost Converter

The converter comprises of a voltage improving circuit with a regenerative diode and capacitor, two connected inductors, two clamp circuits, two output capaci-tors, and two output capacitors. Two linked inductors and a clamp circuit make up the converter's initial segment. Equal current is shared in parallel inductance connected across supply, hence the less current stress on the switched and less rating used. As a result, the rating of both power switches are decreased. In Fig-ure 1, the coupling action is depicted as. and *.

Two clamp circuits are included. The clamp circuit circulates part of the leakage energy of the inductor to the output capacitors.

Fig .1. Two Phase Non-Isolated Interleaved Boost Converter (TPNI-IBC)



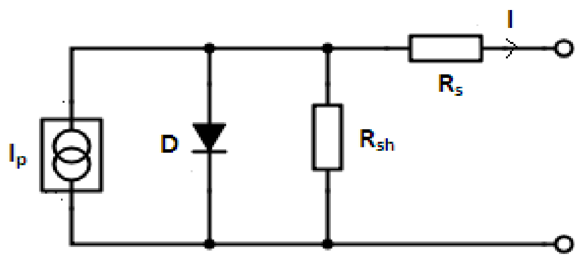
Voltage multiplier circuit is used in the converter's second section. It comprises of a secondary winding coupled inductor that is series connected, along with Dr and Cr, the regenerative elements.The overall design of the voltage multiplier circuit increases voltage gain and evenly distributes current on the parallel main side of the inductor. To lessen the voltage ripple, the output side capacitors C1 and C2 are linked in series. Continuous conduction mode is how the TPNI-IBC operates (CCM).

3 PV Modelling

Photovoltaic cell contains a current Ip source connected in shunt with diode D which is not ideal and has junction capacitance is shown in Fig.2. The constant current source implies that there is a high value of shunt resistance Rsh across the source. The series resistance Rs indicates the resistance of the metal links.

$$I_p = I_d + I_{sh} + I$$

Fig. 2. PV cell Circuit.



Where Ip is the photo current which depends on solar irradiation, Id is the current of diode and I is the current output of PV cell. Therefore, the output current of PV cell is given by,

$$I = I_p - I_d - I_{sh}$$

The PV array is formed by arranging PV cells of same characteristics in series and parallel.

Table 1. Specification of 210W Solar Panel

Electrical Parameters	Description
Maximum Power , Pm	210 W
Open circuit voltage, Voc	33 V
Short circuit current, Isc	9 A
Voltage at maximum power, Vmp	27.6 V
Current at maximum power, Imp	7.6 A

A MATLAB script file is used to detect I-V, P-V and I-P features of a PV array where 35 series and 4 compatible parallel PV cells are used to achieve 250 W power rating. The specification of PV array for power rating 210 W is given in Table 1.

4 Controllers

To further understand the NI-dynamic TPIBC's presentation, a closed loop analy-sis of the device is conducted in this section.

4.1 PID Controller

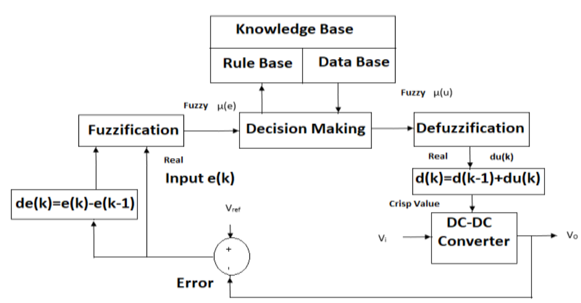
The PID controller employs closed-loop feedback control techniques to regulate any variable and achieve the desired goal level. By gradually raising the propor-tional gain Kpl , the rise time decreases and overshoot increases. Kil integral gain is inflated in order to lower the steady state error, but it also produces more oscil-latory output. In order to lessen the overshoot and shorten the response's settling time, differential gain Kdl is also used.

$$V_o(s) = (K_{pl} + sK_{dl} + \frac{K_{il}}{s})E(s)$$

4.2 FL Controller

Fig. 3 depicts the basic layout of the FL Controller utilised by a converter to regu-late the voltage. FLC handles linguistic variables and is used to control any sys-tem's non-linear behaviour.

Fig . 3. Fuzzy logic architecture



There are the four fundamental building components that make up FLC's archi-tecture. Fuzzification is the process of converting sharp or real inputs like volt-age, current, and temperature into fuzzy inputs. The rule base and data base make up the knowledge base. In rule-based systems, the language variables are con-trolled by IF... THEN rules.The fuzzy set theory's rules are kept in a database.The fuzzy set theory's rules are kept in a database. The decision making engine exam-ines the fuzzy incoming signals and the knowledge base's rules to provide legiti-mate fuzzy output subsets. The Defuzzification unit transforms the resulting fuzzy output into true output.

5 Regulation of load voltage of a PV based TPNI-IBC using PID/FLC

The PV fed standalone DC micro grid uses an intermediate non-isolated inter-leaved converter. To manage constant output voltage of the DC bus under vary-ing solar irradiation, the PID and FLC controller are used. The output of the con-verter further extended to supply a AC load via inverter.

5.1 Using PID Controller

In this section, we talk about utilising a controller to regulate the load voltage of a PV-based TPNI-IBC under various irradiances. The related load voltage varies as a result of the fluctuation in the input PV source voltage. To maintain consistent voltage at receiving side, the VL and Vref are matched. When the VL and Vref value diverge, the controller receives an error signal. The controller creates the control signal and feeds it to the PWM, which results in the gate pulsation for the TPNI-IBC switches.

The simulink model of PV module is used to produce PV voltage, current and power under different irradiation levels. The irradiation of the solar PV is varied from 1 to 1.5 using signal builder during the period of 0.1 to 0.15 sec. The PV voltage and PV power is found to be 18 V and 324 W respectively during this period and illustrated in Fig.4. This varied PV output is fed to the TPNI-IBC. A PID controller's output voltage can be adjusted to 200 V. The voltage at the re-ceiving end has a peak overshoot of 60 V and a 0.19 second settling time by ad-justing the Kpl, Kil, and Kdl gains. The PV voltage is shown in Fig. 7, along with the converter's PID-controlled output voltage. The load's output current of 1A and power of 200 W are achieved in the steady condition. . The waveforms of the load current and load power are shown in Fig. 6.

Fig. 4. PV voltage, PV current and PV power for different irradiance

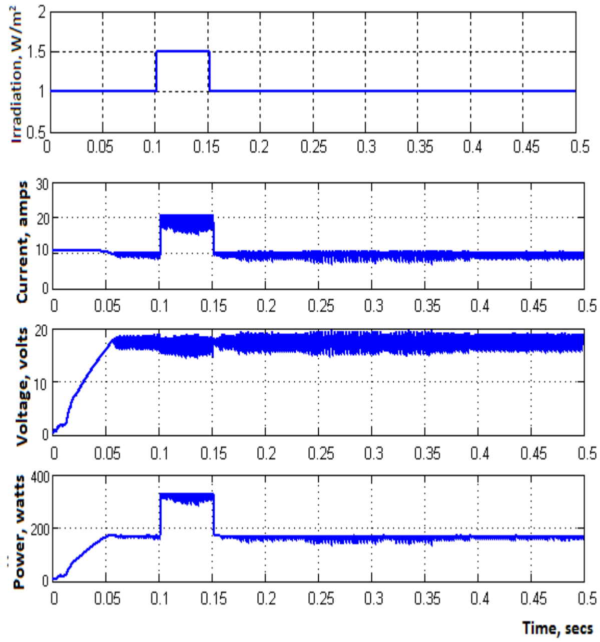


Fig. 5. Vpv and VL VL underfferent irradiation level using PID

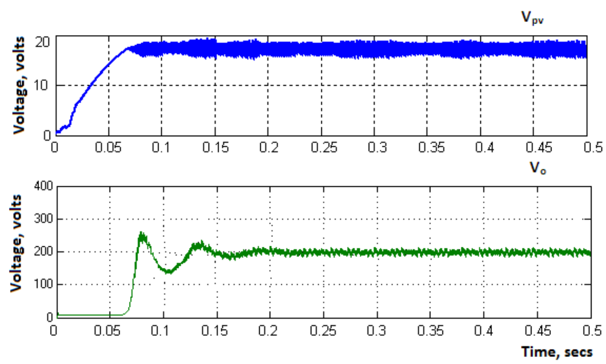
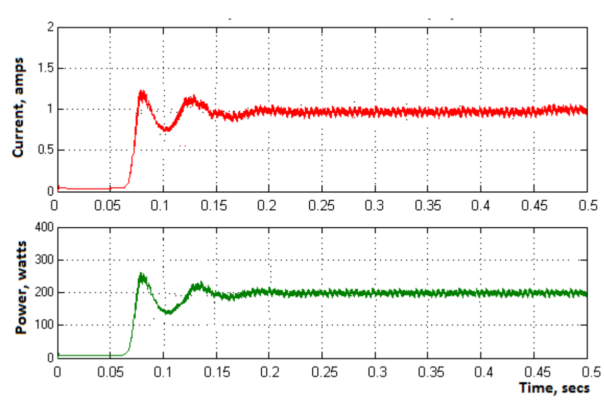


Fig. 6. VL and PLunder different irradiation level using PID



5.2 Using FLC

When there is a change in the input PV source voltage, a FL controller is em-ployed to maintain output voltage constant. As irradiance fluctuates over time, the solar voltage provided to the converter also does. To maintain consistent voltage at receiving side, the VL and Vref are matched. When the VL and Vref value diverge, the controller receives an error signal. The FLC creates the control signal and feeds it to the PWM , which results in the gate pulsation for the TPNI-IBC switches.

The converter receives the varying PV voltage, PV current, and PV power for various irradiances as shown in Fig. 4. From the waveform, it's clear that FL con-troller gives 14% less overshoot with settling time period of 0.04 sec. FLC stand-ardises 200 V at output side.

The PV voltage waveform and converter output voltage, also known as load volt-age, are shown in Fig. 7. Assuming that the output side voltage is kept constant, the load draws 1 A of current and receives 200 W of power, as illustrated in Fig. 8.

Under various irradiation conditions, the dynamic performance of the TPNI-IBC is examined by PID and fuzzy logic controllers. It was found from the Table 2, by using both the controllers, the voltage is regulated as 200 V under solar irradiance variation. But the settling time to reach the steady state is improved by using FLC and it was found 0.04 sec in case of irradiance variation which is much less when compared to PID controller

Fig. 7. VPVand VL under different irradiance levels using FL Controller

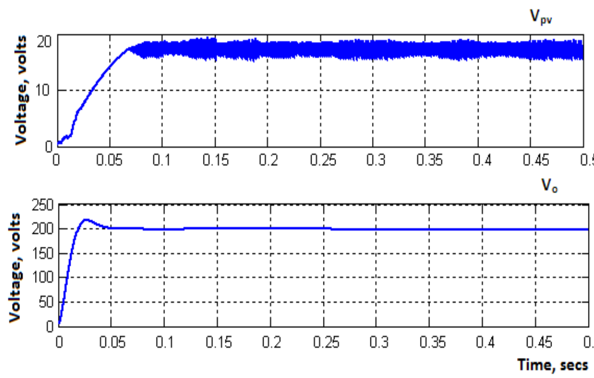


Fig. 8. IL and PL under different irradiance using FL Controller

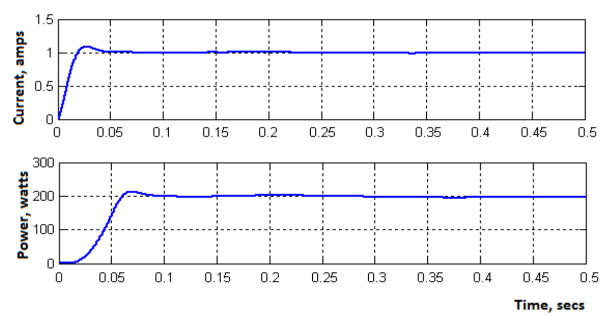


Table 2. Performance comparison of controllers

Parameter Variation	With PID Controller				With FuzzyLogic Controller			
	Peak overshoot (V)	Settling time (sec)	Output voltage (V)	Output Power (W)	Peak overshoot (V)	Settling time (sec)	Output voltage (V)	Output Power (W)
PV source voltage varied due to irradiance	60	0.19	200	200	10	0.04	200	200

5.3 TPNI-IBC extended to supply an AC load

In this section, the DC output voltage of PV based NI-TPIBC is extended to sup-ply an AC load via an inverter. Fig.9 illustrates the block diagram of standalone DC micro grid supplying an AC load. The function of inverter is to convert DC to AC.

Fig. 9. Block diagram of standalone DC microgrid supplying AC load

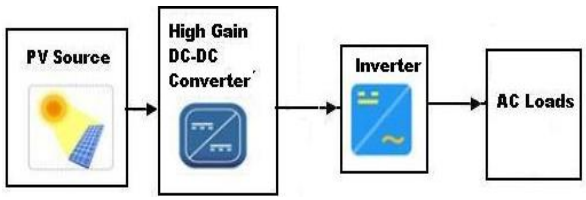


Fig.10 indicates the MATLAB/Simulink model of solar PV based inter-leaved converter feeding an AC load. So as to check the worthiness of the simula-tion model, the entire system is tested under healthy condition. Therefore, the solar PV module is considered to have constant irradiance. Thus the solar volt-age, current and power are considered as 12 V, 7 A and 84 Watts respectively as presented in Fig.11.

The voltage of solar PV is fed to the NI-TPIBC to generate DC voltage of 200 V. This 200 V DC is supplied to an inverter. The inverter consists of six IGBT switches from T1 to T6. The switches are controlled through traditional si-nusoidal pulse width scheme which is achieved by discrete PWM generator. The discrete PWM generator uses 3- arm bridge (6 pulse) mode. The constraints used in SPWM are,

- Carrier frequency=500Hz
- Sample time=50*10-6sec
- Control frequency=50Hz
- Modulation index=0.9

Fig. 10. Simulink model of PV based NI-TPIBC feeding three phase squirrel cage induction motor.

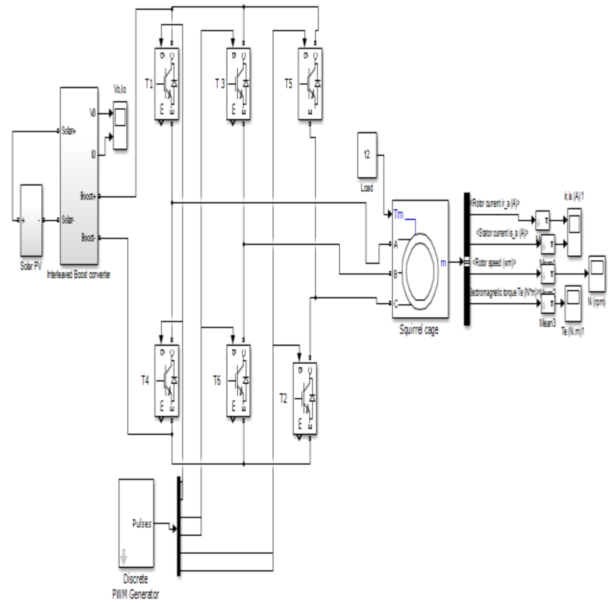


Fig.12 presents the measured inverter voltage and inverter current are 230 V AC and 20 A respectively. Thus the 200 V DC is transformed into 230 V AC through an inverter. This AC voltage is served to the standard squirrel cage in-duction motor model which is available in MATLAB/Simulink. The features of induction motor are as follows;

- Horse Power = 1 HP
- Rated Voltage=230 V
- Rated frequency =50 Hz
- Rated RPM =1745 rpm

Fig. 11. PV voltage, current and power under constant irradiance

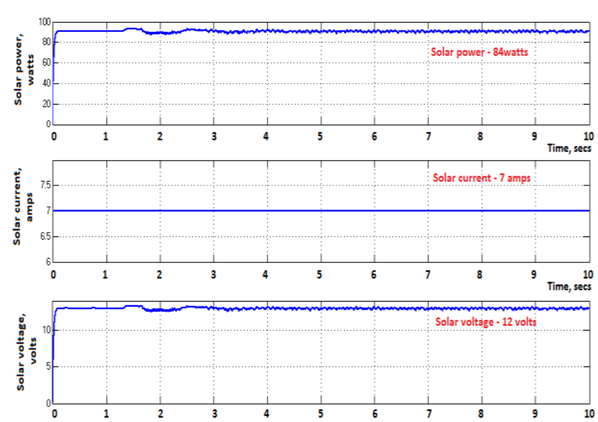


Fig. 12. Waveform of Inverter current and voltage

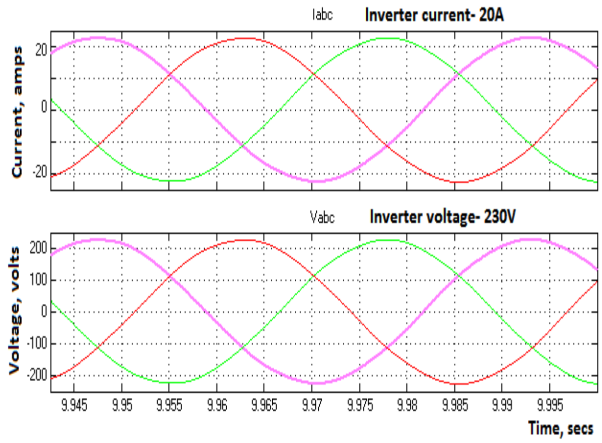


Fig. 13. Rotor and stator current of a three phase induction motor

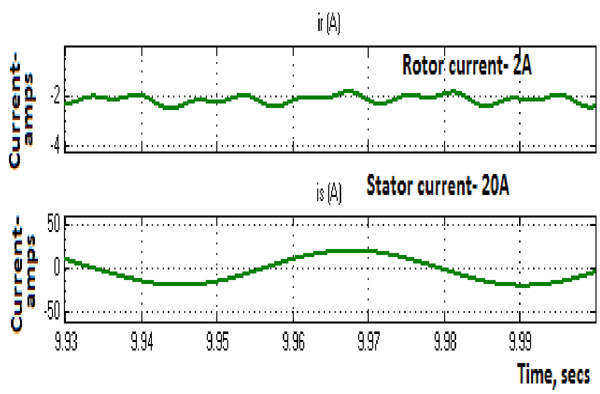
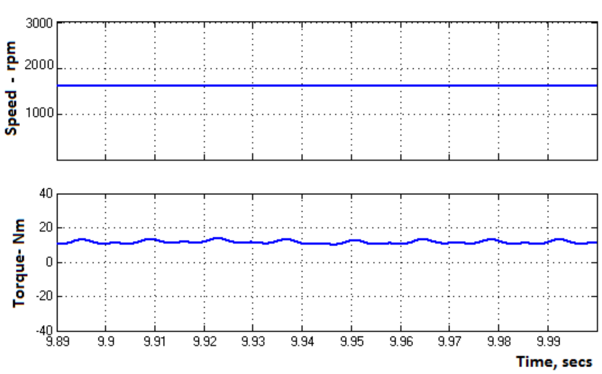


Fig. 14. Rotor speed and torque of a three phase induction motor



The rotor current and stator current are measured to be 2 A and 20 A respec-tively as indicated in Fig.13. The rotor speed and electromagnetic torque is found to be 1700 rpm and 16 Nm respectively and is illustrated in Fig.14. Thus the con-verter NI-TPIBC also works well for AC load.

6 Conclusion

The primary objective of this article is to create a TPNI-IBC for an off-grid, PV-fed DC micro grid. The implementation of DC micro grid is simple and less ex-pensive, as the DC distribution has no reactance drop, no stability difficulties and hence plays an important role in rural electrification. PV fed DC micro grid can supply power to the household in rural areas, before the government power lines reaches the village. The current development is therefore concentrated on a PV supplied freestanding DC micro grid that supplies both DC and AC loads. A DC-DC converter in between the PV energy source and the DC load is necessary since PV energy is intermittent and provides low voltage. In order to obtain high voltage gain and low output voltage ripple at the load side, a non-isolated two phase interleaved DC-DC converter is designed in this study work. A suitable controller, such as PID and FLC, are incorporated in the research work to regulate the output voltage since the TPNI-IBC should function under a variety of solar irradiation levels. This article used PID and FLC to analyse the transient response of the converter output voltage. The TPNI-IBC is also extended to supply an AC load via inverter by considering constant solar irradiation. It was found that un-der healthy condition of a standalone DC micro grid, the PV based converter DC output is converted in to an AC output with the help of an inverter. The future work can be extended by designing a Non-isolated high gain DC-DC converter without using the VMC and/or hybrid switched-capacitor technique can be de-signed. The topology may utilize two non isolated inductors that can be connect-ed in series/parallel during discharging/charging mode. It can be observed that the operation of switches with two different duty ratios is the main advantage of the converter to achieve high voltage gain without using extreme duty ratio.

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