

A COORDINATE CONTROL METHOD FOR MULTIPLE PARALLEL DC CONVERTERS USED IN STANDALONE POWER GENERATING SYSTEM

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ABSTRACT

This Paper presents analysis of current sharing issues of parallel DC converters in standalone photovoltaic (PV) system. Solar power generating system with maximum power point tracking (MPPT) technique – incremental conductance method is used for the simulation analysis. The main drawbacks of parallel converters used in system are poor power sharing and voltage drop. The paper describes about instantaneous droop calculation considering effect of cable resistance using droop index to improve the power sharing performance. The control technique is simulated using MATLAB/SIMULINK software of PV power generating system with MPPT. To analyze the effectiveness of adaptive droop control on output converter voltage is also simulated with the same ratings.

Keyword: - Droop control, PV system, MPPT, DC-DC Converter

1. Introduction

Now a days, the demand on electrical energy is increasing day by day. For our future demand the existing energy systems will not be enough. Therefore the search for alternative energy sources has become an important issue. Many researches has been done in the area of unlimited energy resources such as wind power generation and solar energy transformation. Also expensive technologies and global environmental damage techniques has led to a global scenario which point towards generating clean and eco-friendly green energy. In many ways, green energy is having a leading role in the democratized energy production and consumption in the country. Of all the renewable energy sources, solar energy have the least impact on environmental. Electricity produced from photovoltaic (PV) cells does not result in environmental pollution, deplete natural resources, or endanger living being [1].

For many years, the centralized power grid is one way of electricity flow, generated by large, remote power plants and distributed over large distance by transmission lines to homes and industries. In recent years the system's shortcomings are increasing. The traditional grid is highly depends on planet-warming fossil fuels. Due to the upcoming of negative issues there is departing from the traditional system and introduced a new model called Microgrid. A microgrid is independent systems that produce power for a specific entity. A microgrid is defined by the ability to generate power using renewable energy sources near or at the point of consumption independent of other generators. Main applications are in areas having high energy prices or remote areas (such as islands) or facilities, such as military or experimental installations that cannot risk losing power, etc. Microgrid, also named as minigrids, can be operated in islanded or grid connected mode. Compared to AC, DC microgrids are very reliable highly efficient, economic and easy to control.

The main problem faced by the DC Microgrid is that when converters are parallel connected the output voltage from converter won't be constant always. [2]- [8] Main reason for this variation is due to change in load and input power and also feedback voltage and current. Even a small mismatch of output voltage will initiate circulating current and

difference in current sharing will cause an overload to the converters and also variation in power sharing. The converter with higher output voltage will give higher power. One of most popular control technique for proper sharing is droop control method. This paper mainly focus on the voltage control and power sharing of the converters using droop index and also maximum power point tracking for better performance. The droop control method is a decentralized control technique in which each converter is controlled based on the output current [7]. This paper explains the importance of cable resistance in load sharing. In existing methods the droop used for voltage control is fixed which a major drawback [5]. An instantaneous droop is calculated to overcome this drawback which can improve the voltage control to larger extend. The droop control method is local control technique that relies on externally or internally added resistance of the parallel connected modules for maintaining relatively equal current sharing. Generally, the droop method is easy to implement, and it does not require any communication system. However, fixed droop method also achieves the equivalent current sharing accuracy but major drawback is its poor voltage regulation whereas in case of instantaneously produced droop, it can adaptively controls the reference voltage of each module.[10]-[12] This will improve the voltage regulation and the current sharing of the traditional method. The solar cell and wind turbine efficiency depends on factors such as temperature, insolation (radiation), dirt, shadow, wind speed and so on. Due to fast changing climate such as cloudy weather, storm or sunny day there will be changes in irradiance, wind speed and rise in ambient temperature can decrease the PV wind output power. PV – wind system produces energy depending to its operational and environmental conditions. Maximum power point tracking (MPPT) is a concept put forward to improve the efficiency of PV – wind system. All MPPT methods follow goal of maximizing the output power by tracking the maximum on all operating condition. Analysis study and case study of the droop control method for voltage regulation and MPPT method is explained.

2. SOLAR PV SYSTEM

2.1 solar cell

PV array's output current-voltage curve reflects PV array's dependence on environmental conditions such as ambient temperature and illumination level. Typically, the illumination level ranges from 0 to 1100Wb/m² and the temperature range is between 233 and 353 K. Normally, we select 1100 and 298 as the reference values for illumination level and temperature respectively. The relationship between PV array's output characteristics and environmental conditions could be illustrated from general simulation results of PV array. PV array's output power is increased as illumination level increases, while PV array's output power is improved with the decrease of the ambient temperature. The equivalent circuit of a typical PV-cell is given below.

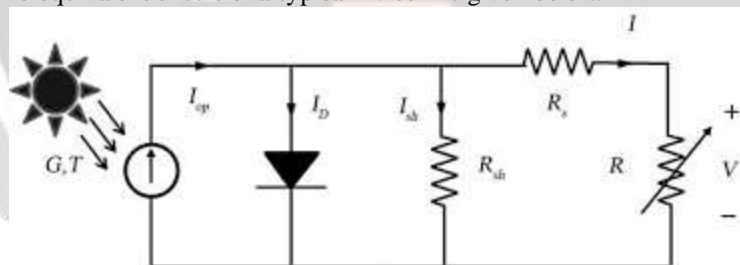


Fig-1: Equivalent circuit of photovoltaic cell

Figure reflects a simple equivalent circuit of a photovoltaic cell. The current source which is driven by sunlight is connected with a real diode in parallel. In this case, PV cell presents a p-n junction characteristic of the real diode. The forward current could flow through the diode from p-side to n-side with little loss. However, if the current flows in reverse direction, only little reverse saturation current could get through. All the equations for modelling the PV array are analysed based on this equivalent circuit.

Boost power converters have been widely used for Power Factor Correction (PFC) in AC-DC conversion and for power management in battery powered DC-DC conversions. Moving beyond low-power applications, such as cellular phones, smart phones and other portable electronic products, boost converters are being used more and more in medium-power applications. For example, in computing and consumer electronics, boost converter-based LED drivers for notebook displays, LCD TVs and monitors have been developed. In communications and industrial products, simple boost converters are used in satellite dish auxiliary power supplies and peripheral card supplies. As boost converters run to CCM (Continuous Conduction Mode), a complex pole pair and a Right-Half Plane (RHP) zero will present in the dynamic characteristic. Some applications of boost converter:

- Programmable soft turn-on for inrush current control

- Hiccup mode for over-current protection
- Complete shutdown with source-load separation
- Simple loop compensation
- Protection for power MOSFET (Q_2) failure

2.2 Incremental conductance method

The incremental conductance method of MPPT is based on the incremental and instantaneous conductance.

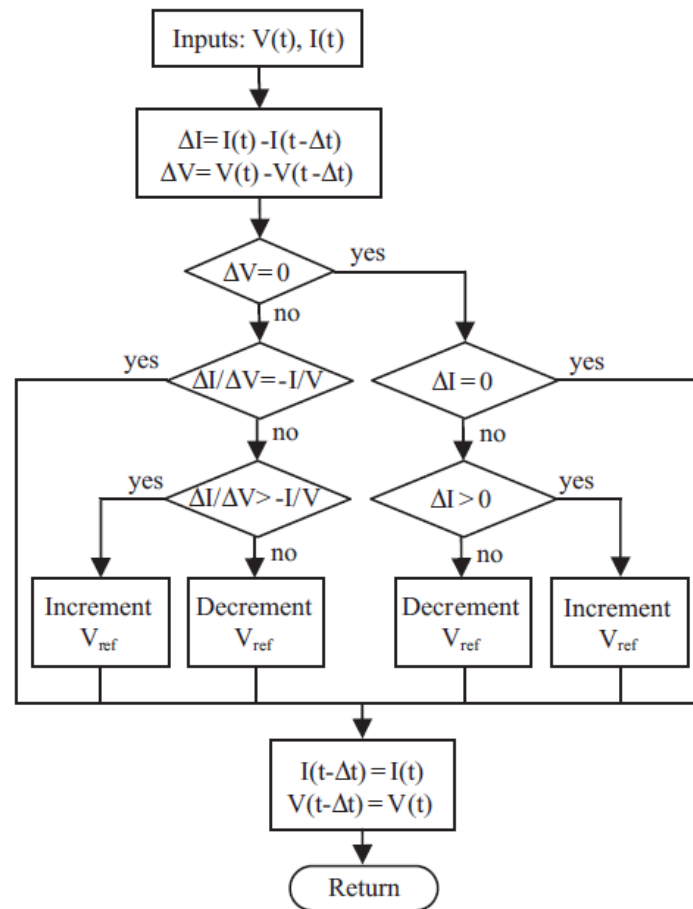


Fig:-2. Algorithm of incremental Conductance method

When MPPT has reached the maximum point by using the incremental Conductance method then it will stop perturbing at the operating point. If this condition is not satisfied, the direction in which the MPPT operating point must be perturbed can be obtained using the relationship between $\delta I \delta V$ and $-IV$. Incremental Conductance has advantages over P&O method that is it can determine when the MPPT has reached the maximum power. But in case of P&O, it oscillates around the maximum power point. Also, Incond method can track rapidly changing (increasing or decreasing) climatic conditions with higher accuracy than P & O method. The maximum output power, $PMPP = VMPPIMPP$ (2) is calculated by differentiating output power with respect to voltage and then setting the result to zero. At MPP, as $\partial P / \partial V = 0$. This equation can be written in terms of array voltage V and current I as $\delta I \delta V = -IV$

3. PARALLEL DC- DC BOOST CONVERTERS

The DC-DC boost converters are used where the output voltage needed to be higher than the source voltage. The control technique used is sliding mode control. Sliding mode controller maintains stability and consistence performance in the face of modeling imprecision. Control gains used are 0.149 and 1.35.

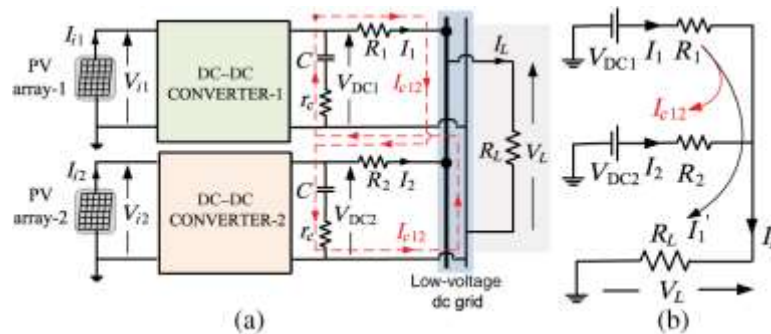


Fig-3: (a) Parallel dc–dc converters with different output voltages. (b) Steady state equivalent circuit for the dc output side.

3.1 Mathematical Analysis Of Circulating Current For Two Parallel Connected Converters

When converters are connected in parallel and if there is change in power output, then this will cause mismatch in converter output voltage which will in turn cause circulating current. Circulating current will increase the flow current through the switches which will increase the power electronic switch ratings and losses and cause overload to converters. This section explains load current sharing and circulating current issues for parallel DC-DC converters connected to a low-voltage dc microgrid. Fig. 3 shows simplified diagram of two parallel connected DC – DC converters. Output voltages, cable resistance and output currents of converter- 1 and converter-2 are represented using V_{DC1}, V_{DC2}, R_1 and R_2, I_1 and I_2 respectively. I_{c12} is the circulating current component from converter-1 to converter-2 and load current component from converter-1 is I_1' .

By applying Kirchhoff’s voltage law, the expression for output converter currents can be derived from equation and circulating current can be calculated.

$$V_{DC1} - I_1 R_1 - I_L R_L = 0 \tag{4}$$

$$V_{DC2} - I_2 R_2 - I_L R_L = 0. \tag{5}$$

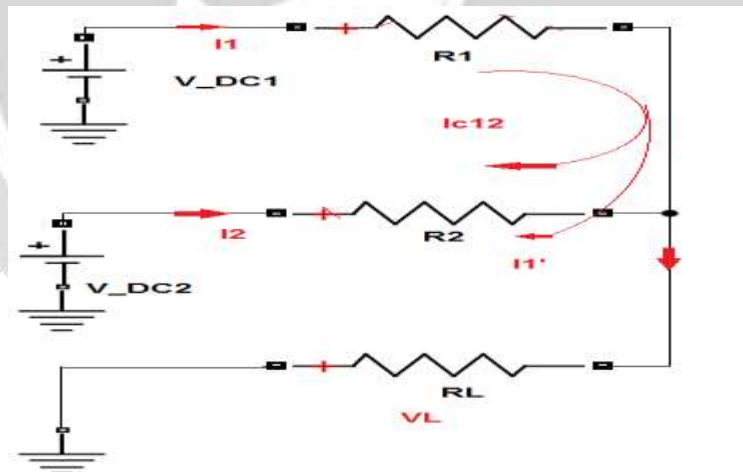


Fig-4. Equivalent circuit for DC output side

The expression for output converter currents I_1 and I_2 can be derived from equation (4) and (5) and circulating current is given as:

$$I_1 = \frac{(R_2 + R_L) * V_{DC1} - (R_L) * V_{DC2}}{(R_1 R_2 + R_1 R_L + R_2 R_L)} \tag{6}$$

$$I_2 = \frac{(R_1 + R_L) * V_{DC2} - (R_L) * V_{DC1}}{(R_1 R_2 + R_1 R_L + R_2 R_L)} \tag{7}$$

$$I_{c12} = \frac{V_{DC1} - V_{DC2}}{(R_1 + R_2)} = \frac{(I_1 R_1 - I_2 R_2)}{(R_1 + R_2)} = \frac{(I_1 - I_2)}{2} \quad (R_1 = R_2) \tag{8}$$

3.2 Voltage regulation and circulating current control by fixed droop method

This section explains converter voltage regulation and minimization of circulating current by adding a series resistor, R_{droop} to each converter output as shown in Fig.2. R_{droop} is implemented using virtual impedance method. Fig4. By adding R_{droop1} and R_{droop2} the current sharing can be controlled and thus circulating currents can be minimized to some extent. This can be done by taking output current from converters and multiplied with corresponding R_{droop} . Then the resultant signal is subtracted from the reference voltage of each corresponding converter give new voltage reference signal

$$V_{DCnew} = V_{DC} - I R_{droop} \tag{9}$$

But this method has still got drawbacks as it's a fixed value and therefore the voltage regulation will be poor.

3.3. Adaptive Droop Control Method

Instantaneous method for droop calculation for voltage regulation and circulating current minimization is explained in this section. As we have seen in above equation (8) in two parallel converters, circulating current directly proportional to the current sharing difference.

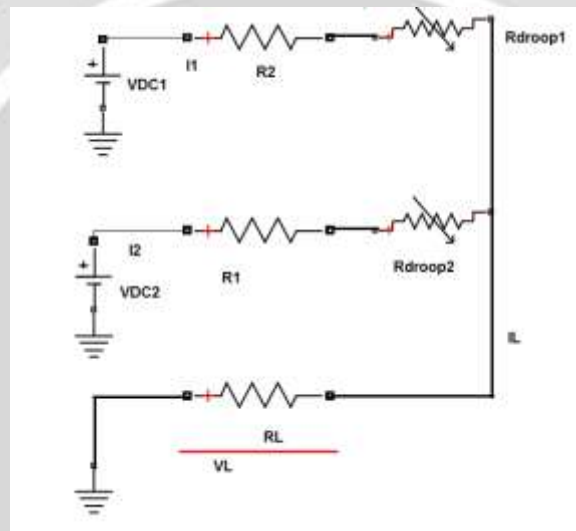


Fig-5: Equivalent circuit for DC output side with R_{droop}

If the current sharing is equal then the resultant circulating current becomes zero. There will constant output voltage from converters. But simultaneous insertion of the series resistor will cause additional power loss in the system and it will lead to drop in the load voltage. R_{droop1} and R_{droop2} are corresponding droop value of each converter. The output power loss can be expressed as,

$$P_{loss} = I_1^2(R_1 + R_{droop1}) + I_2^2(R_2 + R_{droop2}) \tag{10}$$

Calculation of droop values based on the proposed figure-of-merit called droop index. The droop index is considered function of normalized current sharing difference and output power losses based on the need of voltage regulation issues and are given as

$$\text{Droop Index} = \min [12|I_1 - I_2| N + (P_{loss})^N] \tag{11}$$

The current sharing and power loss equation can be modified in terms of parameters of second converter by introducing new variables x , y and m and given as

$$\begin{aligned} x &= V_{DC1} V_{DC2}, \\ y &= R_1 R_2, \\ m &= R_2 + R_{droop2} \\ |I_1 - I_2| &= |y R_2 + R_{droop2} + R_L V_{DC2} - 2(x-1)V_{DC2} R_L m^2 y + m R_L (y+1)| \end{aligned} \tag{12}$$

Using the modified equation of circulating current and power loss the minimum droop index is calculated. $Rdroop$ value for corresponding converter is selected in such way that $Rdroop$, it is varied from zero and corresponding droop index value is noted and $Rdroop$ value for minimum droop index is selected for further procedure. For the calculation of minimum droop index by varying $Rdroop$, the product of converter output current and $Rdroop$ should not increase the maximum allowable voltage deviation ($\pm 5\%$ nominal voltage). $Rdroop2$ Value for minimum droop index value of converter-2 is droop value. Now the droop value for converter 1 can be calculated using

$$Rdroop1 = R1R2 Rdroop2 \quad (13)$$

The calculated droop value is may not be enough for voltage regulation. Therefore fine tuning of value is required to make the output voltage same but since the value is positive further increase will cause poor load voltage. To avoid this problem $Rdroop$ shifting is done. $Rdroop$ Shifting is done bases of the converter output value. If the difference between converter output voltage is positive then ie; $VDC1 > VDC2$ then,

$$Rdroop1_{new} = Rdroop1 + (k1 * IL) \quad Rdroop2_{new} = Rdroop2 - (k2 * IL) \quad (14)$$

If the difference between converter output voltage is negative then ie;

$$VDC1 < VDC2 \text{ then , } Rdroop1_{new} = Rdroop1 - (k2 * IL) \quad Rdroop2_{new} = Rdroop2 + (k1 * IL) \quad (15)$$

And if the converter output voltage values are equal then the corresponding droop values same as before. The droop correction factor $k1$ and $k2$ (0.001 and 0.02 respectively) should be selected such that $k1 < k2$ to maintain load voltage within the limit.

4. SIMULATION RESULTS

The performance of the droop control method in different cases, two parallel DC –DC boost converters (24V-48V) with solar energy as source has been simulated using MATLAB/SIMULINK. The output cable resistance is 100mΩ for each converter. The control algorithm is verified for the following cases, (i) Step change in output voltage of any one converter with both converters with same cable resistance (a) without droop control Fig.5. (b) With $Rdroop$ control method.Fig.7. Initially up to 1.101s the simulation is done with nominal value, 48V. During time 1.101-1.3s the converter2 voltage value is increase by 1% of nominal value, 48.48V and at time 1.301s the voltage is brought back to 48V.

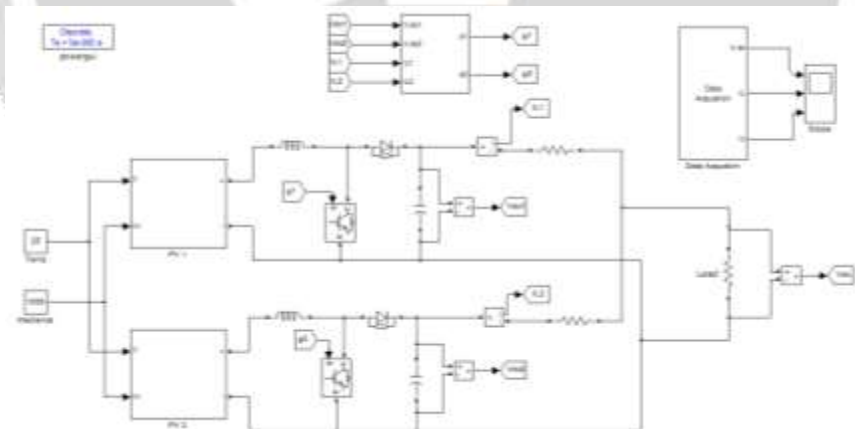


Fig :- 6 Simulink Model of Parallel converters without Droop

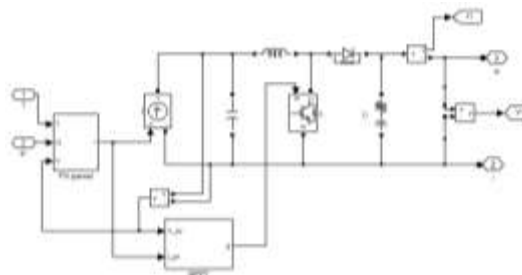


Fig :- 7 solar PV internal design

Then again during time 1.501-1.7s the value is decreased by 1 % of the nominal value, 47.52 V. Then for the rest of the simulation time the voltage of converter is again brought back to nominal voltage.

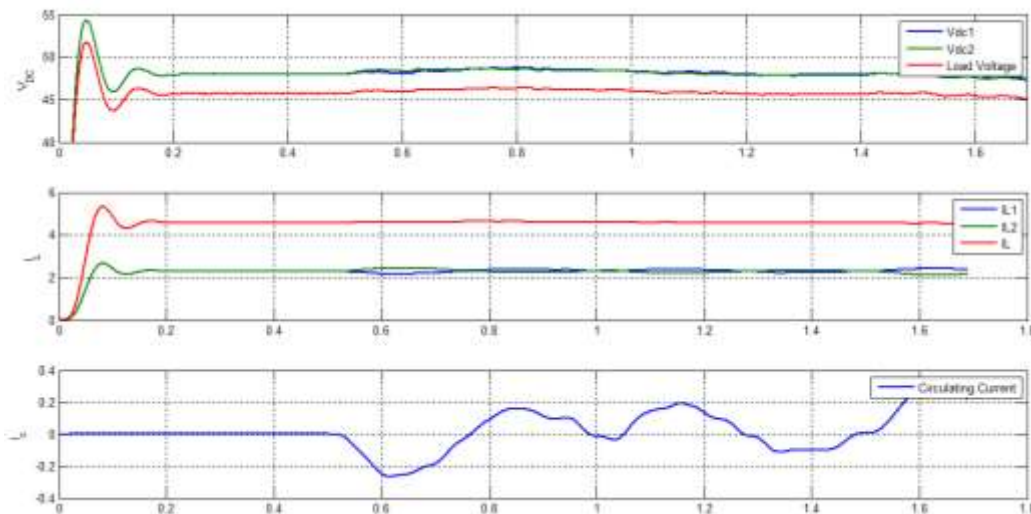


Fig :- 8. Simulation Result of without droop (a) converter output voltages and load voltage (b) converter output current and load current (c) circulating current.

From simulation result fig.8. of without droop, it can observe that the sharing is not proper and has a current sharing error of 25%. For simulation with novel droop control method, the R_{droop1} and R_{droop2} values are calculated as 0.2Ω and still there is mismatch output converter voltage. After fine tuning of R_{droop} voltage is not regulated completely. Then instantaneous value of $R_{droopnew}$ is introduced with droop shifting which can improve the current sharing and the output converter voltage to a constant. Same simulation pattern is followed for the simulation with droop case as well.

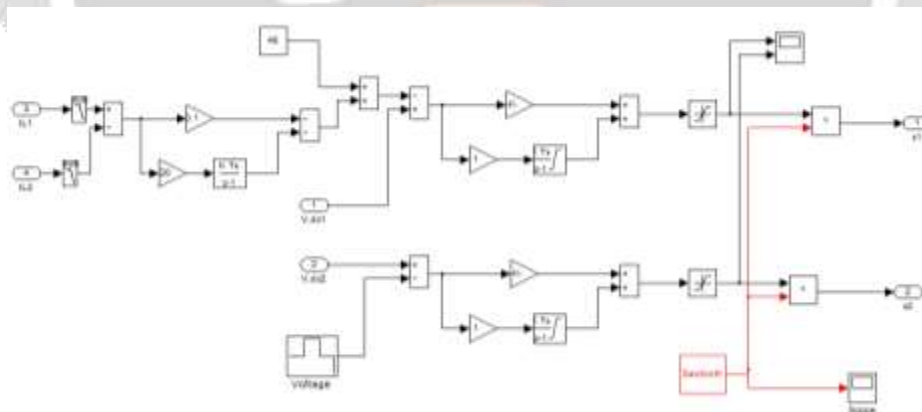


Fig :- 9 Simulink Model PV wind System with Droop Control

From the above simulation studies, fig.8. it can be seen that droop control method gives proper load sharing with minimum circulating current and improves load voltage.

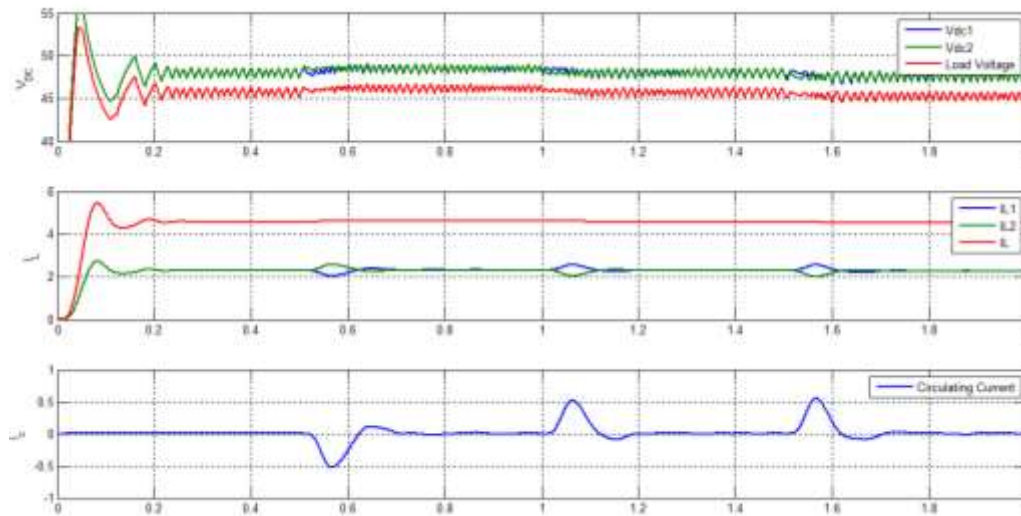


Fig-10: Simulation Result of with droop (a) converter output voltages (b) load voltage (c) converter output current and load current (d) circulating current

From the above simulation studies, it can be seen that droop control method gives proper load sharing with minimum circulating current and improves load voltage. By improving current sharing we can see that the power sharing has also been improved. Here, from the graphs it is observed that the circulating current has been reduced to 0.1 A from 1.9 A. Thus relatively equal current sharing accuracy is achieved by the parallel converters.

5. CONCLUSIONS

The performance of droop control method for parallel DC-DC converter used in standalone photovoltaic wind system is studied in different cases. The entire energy conversion system has been designed in MATLAB/SIMULINK environment. Incremental conductance method of MPPT is used to track maximum output. The parallel DC-DC boost converter with sliding mode control technique is used. The R_{droop} values are calculated considering the effect cable resistance and implemented using virtual impedance method. For different irradiation of PV array and different wind speed the droop control the system is tested and verified. Based on the instantaneous condition the new R_{droop} value is introduced into the system, which will minimize the circulating current and gives proper sharing. This droop control technique can be used with any number of parallel connected converters.

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