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Analysis of Integrated DC Micro-grid System Using PI Voltage Control Strategy

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Abstract— This paper is focusing on integration of solar and wind energy in terms of DC form. AC-DC converter & DC-DC buck converter is used with Proportional Integral (PI) control strategy to control the voltage fluctuation at desired voltage level. Batteries are using as an emergency source of supply to meet the required load demand and home appliances are taken as a DC loads. MATLAB simulation models are used to implement low voltage control strategy & expected results are compared with the simulation results

Index Terms — battery, buck converter, DC micro-grid, PI controller, solar power, voltage control, wind power.

1 Introduction

Day by day population is increasing in rate; there by energy demand [1] is also increasing continuously. With the present power sources like thermal, hydro, tidal, nuclear etc are not sufficient to supply the customer demand all the times. Some source are depends on season like hydro power plant. Even lot of energies are going to loss due to transmission lines from one place to other at short, long and medium distances. Even though we are not using the energy, every month its fixed charges are going to pay to the utility.

Now a day's Renewable Energy Sources (RES) are becoming more popular due to its less complexity as compare to conventional one. But there is a conversion losses present in the system say from DC – AC or vice versa in converters. Advantages of renewable energy sources as compare to conventional are less environmental effect like pollution free, less maintenance of installed equipments etc. Initial investment is more in renewable energy sources.

The main objective of this paper is to control the voltage fluctuation of an integrated system using PI controller at 48 Vdc & 24 Vdc buses. This is the one of the major challenge in an integrated renewable energy system [4]. It deals with integration of renewable energy (solar & wind) used to supply required energy to home appliances (DC loads). AC generated from wind turbine is converted into 48 Vdc using buck converter with PI control strategy and then integrating with 48Vdc solar system. Each solar and wind can generate 5kW of power and it generates 10 kW of power after integration [3].

The additional energy after the use of DC loads (home appliances) can be supplied to other homes nearby or else exporting to grid with charges on unit basis. In case of shot fall of power or both the energy sources not available, then from the storage battery bank it can be supplied to load necessary demands [4]. Both the solar & wind energies sharing the load demand, depends on its availability of input with respect to time.

2 Proposed System

The proposed integrated DC micro-grid system is as shown in below Fig.1. DC house appliances are taken as DC loads.

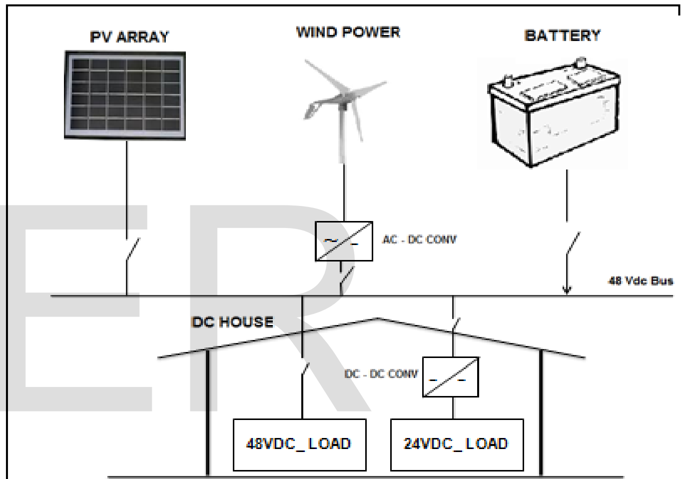

Fig.1. Integrated DC micro-grid system with DC house load

In this system, depending on the load duration used by the consumer the energy source will supply adequate amount of power. Both Wind & Solar energies are capable of providing power individually to loads in case any one source is not in operation. If none of the sources are unable to generate power due to some reason, then battery alone can handle the system operation [1].

3 Methematical Model Of Dc micro-grid system

3.1 Solar single model

I-V characteristic of diode is given by the equations.

$$I_d = I_o\,[\exp(vd/vt)-1] \quad (1)$$

$$V_T = (kT/q) \times nI \times N_{cell} \quad (2)$$

Where,
I_d = diode current (A), V_d = diode voltage (V), Io = diode satu-

ration current (A), nI = diode ideality factor ~ 1.0, k = Boltzman constant = 1.3806 x 10^{-23} JK^{-1}, T = cell temperature (K), N_{cell} = number of cells connected in series in a module & q = electron charge = 1.6022 x 10^{-19} C.

3.2 Wind turbine model

This model is based on steady state power characteristics of turbine. The turbine output power is given by

$$P_m = C_p(\lambda,\beta)(\rho A/2)V_W^3 \quad (3)$$

Where,
P_m = mechanical output power of the turbine (W)
C_p = performance coefficient of the turbine
ρ = air density (kg / m^3)
A = turbine swept area (m^2)
Vw = wind speed (m/s)
λ = tip speed ratio of the blade tip speed to wind speed
β = blade pitch angle (deg)

3.3 Load model

The generated power or consumption power (in kW) can be expressed as

$$P = V \times I \quad (4)$$

The system voltage (in volts) can be expressed as

$$V = I \times R \quad (5)$$

Where,
R = circuit resistance (ohm)
I = total circuit current (Amps)

3.4 Proportional Integral Controller

The output of PI controller is a combination of proportional & integral controllers, which is given by the equation as below

$$U(t) = K_P e(t) + K_I \int e(t)\,dt \quad (6)$$

The block diagram of PI controller is shown in blow Fig.2, which is used for stability of the control system without disturbing the steady state error in the system [7].

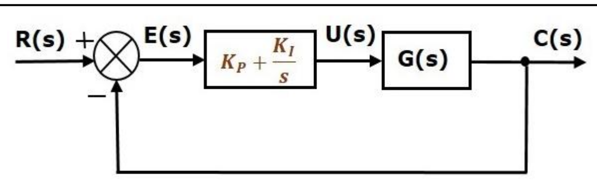

Fig.2. Basic PI controller block

3.5 Buck converter model

The below Fig.3 represents the DC –DC step down buck converter circuit diagram.

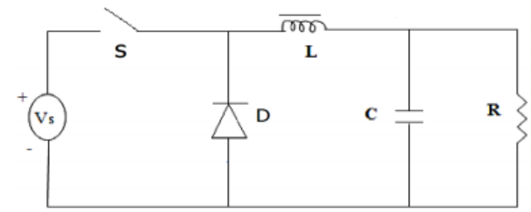

Fig.3. Buck converter circuit diagram

Where,
S = MOSFET switch with gate control, D = diode,
V_S = Source voltage and R, L & C are the circuit parameters.
V_O = output voltage

The differential equation can be described as follows

$$di/dt = (V_S - Vo)/L, \text{ S is conducting} \quad (7)$$

$$di/dt = -Vo/L, \text{ S is blocking} \quad (8)$$

3.5 Battery model

For the lead-acid battery type, the model equations are

- Discharge model (i* > 0)

$$f1(it, i^*, i, Exp) = E0 - K.[(Q/Q - it)].i^* - K.[(Q/Q - it)].it + L\text{-}1[(\exp(s)/sel(s)].0 \quad (9)$$

- Charge model (i* < 0)

$$f1(it, i^*, i, Exp) = E0 - K.[(Q/Q + it)].i^* - K.[(Q/Q - it)].it + L\text{-}1\{[(\exp(s)/sel(s)]^*(1/s)\}.0 \quad (10)$$

where,
E_0 = constant voltage (V)
Exp (s) = exponential zone dynamics (V)
Sel (s) = battery mode.
Sel (s) = 0 during discharge
Sel (s) = 1 during charging
K = polarization constant (Ah^{-1})
i* = low frequency dynamics (A)
i = battery current (A)
it = extracted capacity (Ah)
Q = maximum battery capacity (Ah)

4 MATLAB Simulation Model Of Dc micro-grid System

The simulation model of DC micro-grid is shown in below Fig.4. It consisting of Battery [6], Solar Array & Wind turbine connected to a common 48 Vdc bus inside of the sub-systems. During normal operation, solar & winds are integrated and battery is used as standby mode & DC house loads are connected to integrated RES [4].

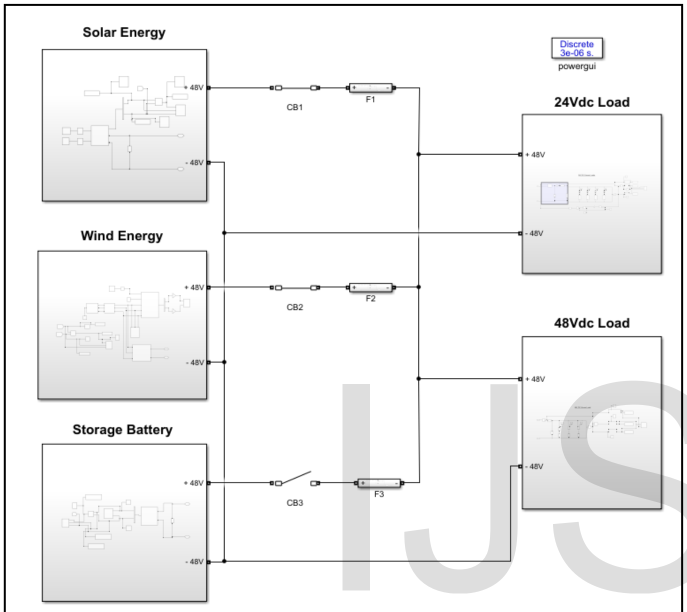

Fig.4. DC micro-grid simulation model

5 Case Study

Below Fig. 5 shows the single line diagram of integrated DC micro-grid system.

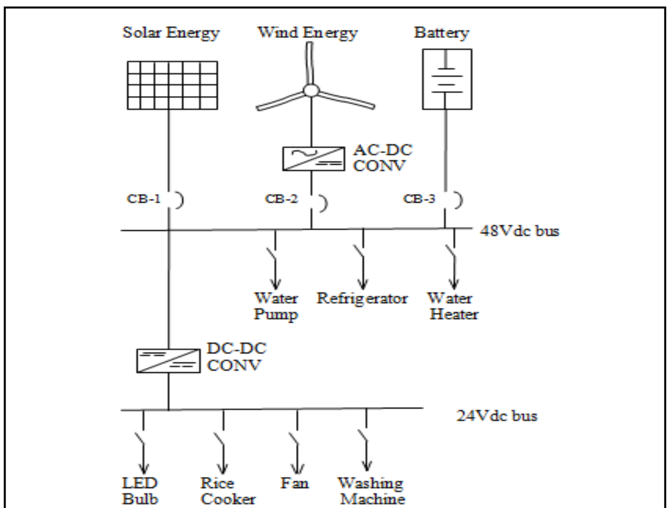

Fig.5. Single Line Diagram of DC micro-grid system

From the case study, it can be seen that loads are considered as an example to analyse the system operation in steady state. It may vary depending on the usage. Each appliance has switch and circuit breakers on source side. With the help of PI controller [7], the terminal voltage is held constant irrespective of load variation at any given time. The required results are obtained based on this case study in the following sections.

6 Dc micro-grid design parameters

To get the desired result from integrated DC micro-grid system, mainly the following component specifications are considered.

6.1 Wind Power Generation Specification

TABLE 1.1
Wind Power Generation

Sl.No.	Characteristics		Specification	
1	Wind turbine mechanical output power		5 kW	
2	Base wind speed		9 m/s	
3	Pitch angle beta		0 degree	
4	Output voltage		220 Vac	
5	Frequency		50 Hz	
6	Input wind speed	Time in second	0	0.2
		Speed in m/sec	8	11

Table 1.1 below shows the DC micro-grid system wind power generation details.

6.2 PV Array Specification

TABLE 1.2
PV Array Power Generation

Sl.No.	Characteristics	Specification
1	Open circuit voltage	49 Vdc
2	Cell per module	80
3	Voltage @ max power point	41.5 Vmpdc
4	Short circuit current	9 Amp
5	Irradiance	950 & 1000 W/m^2
6	Temperature	25^{0}C
7	Power generation	5 kW

Below Table 1.2 shows the DC micro-grid system solar power generation details

From above Table 1.1 & 1.2, total power generation = 10 kW

6.3 Battery Specification

Below Table 1.3 shows the DC micro-grid system Lead Acidbattery bank details.

TABLE 1.3
BATTERY SPECIFICATION

Sl.No.	Characteristics	Specification
1	Nominal Voltage	48 Vdc
2	Rated Capacity	100 Ah
3	Initial state of charge	100 %
4	Battery response time	30 sec
5	Internal resistance	0.0048 Ω

For crital loads battery will supply power nearly 10 Hrs. If total loads are applied as per below Table 1.4 &1.5, then it will supplies power up to 2 Hrs.

6.4 Load list of 48 Vdc bus

Table 1.4 below shows the 48 Vdc load list of home appliances.

TABLE 1.4
48 VDC LOAD LIST

Sl.No.	Description	Current in Amps	Power in Watts
1	Water Pump	1.29	62 x 1
2	Water Heater	20.83	1000 x 1
3	Refrigerator	0.729	35 x 1
Total		22.85 Amps	1.097 kW

6.5 Load list of 24 Vdc bus

Table 1.4 below shows the 24 Vdc load list of home appliances.

TABLE 1.5
24 VDC LOAD LIST

Sl.No.	Description	Current in Amps	Power in Watts
1	LED bulb	5	15 x 8
2	Washing machine	6.67	160 x 1
3	Fan	3.125	25 x 3
4	Rice Cooker	12.5	300 x 1
Total		27.3 Amps	655 W

Therefore total load consumption
= 1.097 kW + 0.655 kW = 1.752 kW (at peak load)

7 SIMULATION RESULTS

The simulation results are shown in below figures. Here peak loads are considered as per the load list mentioned in tables 1.4 & 1.5. This means at maximum loading condition, system operation is tested. Harmonics are present in the circuit due converter conversion effect.

7.1 Integrated DC micro-grid system output waveforms

7.1.1 Wind energy system

Below Fig.6 shows that, the power shared by the wind energy when combined with the solar energy source.

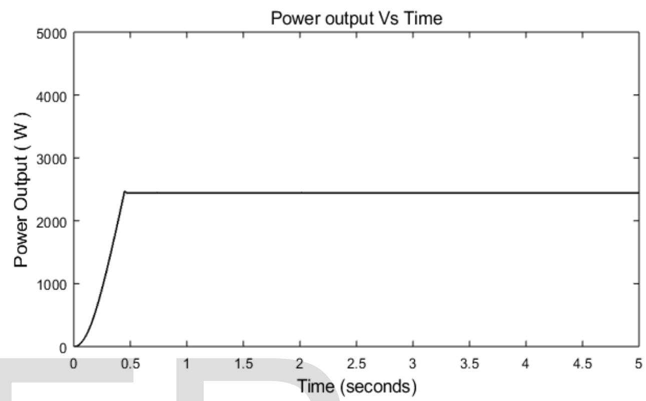

Fig.6. Contribution of DC wind power = 2.443 (kW)

The following Fig.7 shows the constant DC output voltage after conversion with PI controller strategy.

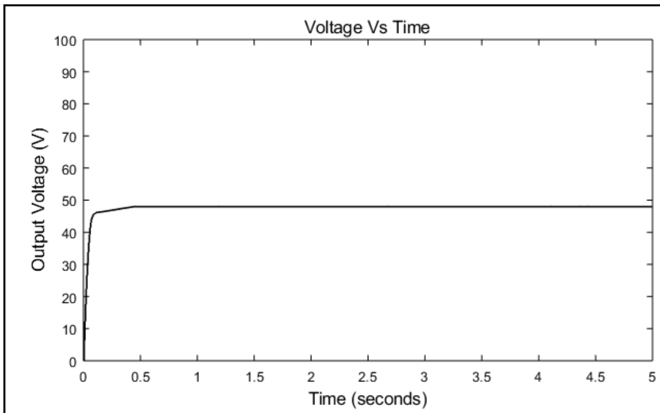

Fig.7. Controlled DC output voltage = 48 (V)

Fig.8 shows DC output current drawn by the wind energy at steady state loads.

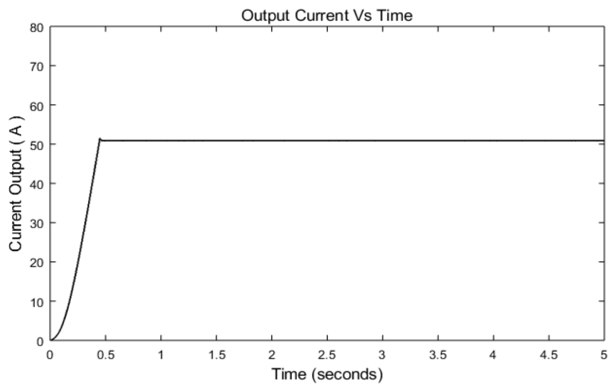

Fig.8. Output DC current = 50.89 (A)

7.1.2 Solar energy system

When solar is integrated with wind, the power shared by solar system is shown in below Fig.9.

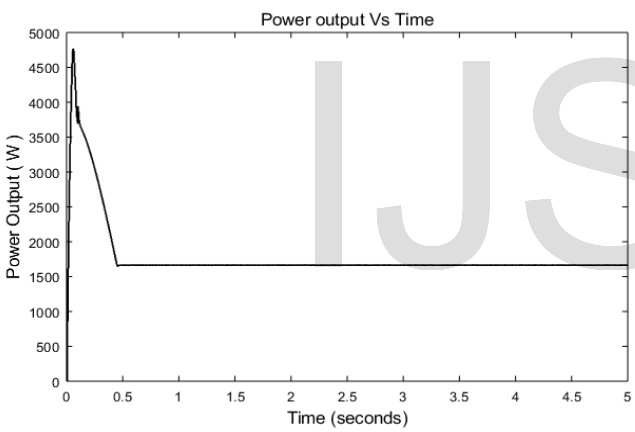

Fig.9. Contribution of DC solar power = 1.664 (kW)

Fig.10 below shows the output of DC voltage maintained constant at PV array terminal.

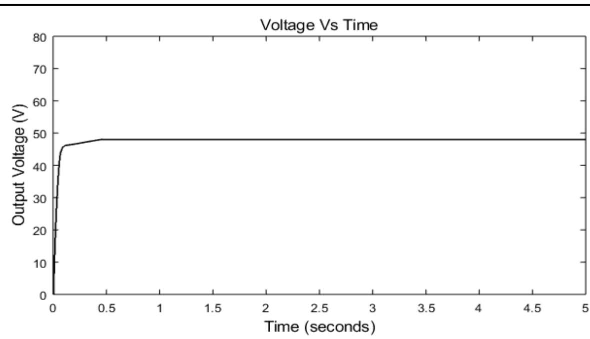

Fig.10. Controlled DC output voltage = 48 (V)

Total current drawn by solar energy during maximum applied load is obtained as below Fig.11

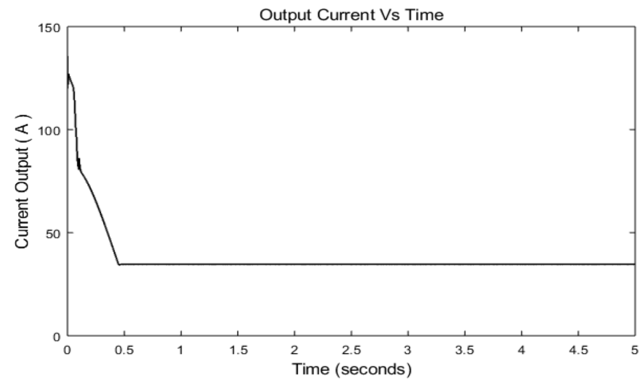

Fig.11. Output DC current = 34.67 (A)

7.1.3 At Load terminal

- At 24 Vdc load side

Below Fig.12 shows the total power absorbed by the loads when connected to 24Vdc bus system.

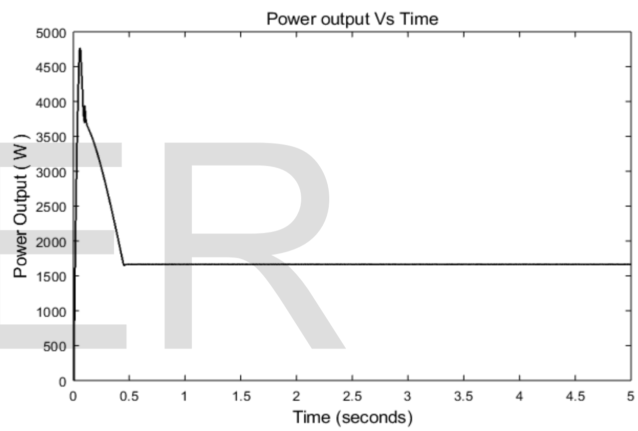

Fig.12. Power consumed by DC loads = 655 (W)

The following Fig.13 shows the constant DC output voltage after conversion with PI controller strategy.

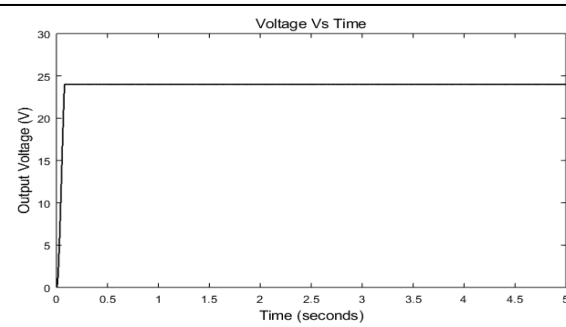

Fig.13. Controlled DC output voltage = 24 (V)

Fig.14 shows absorbed total current by the loads after conversion.

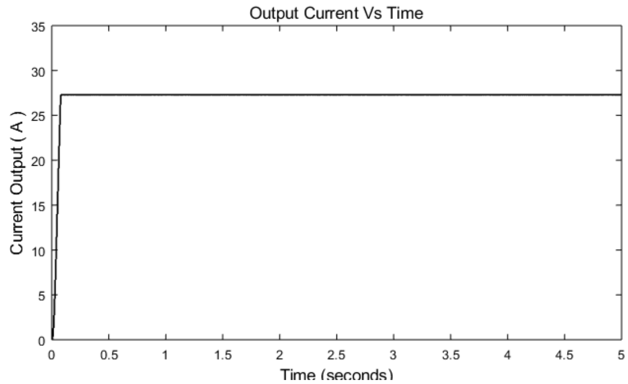

Fig.14.Load output DC current = 27.29 (A)

- At 48 Vdc load side

Fig.15 below shows the total power absorbed by loads connected to 48 Vdc bus systems.

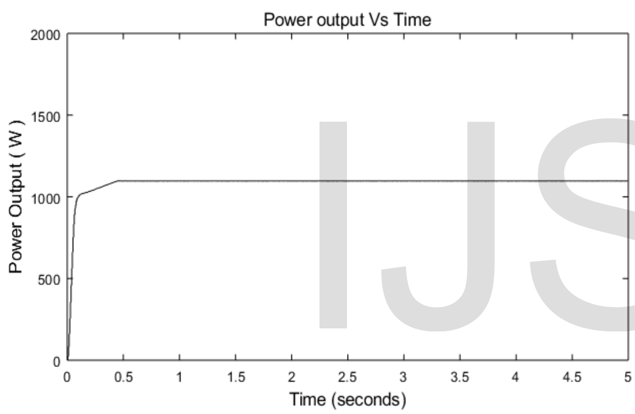

Fig.15. Power consumed by DC loads = 1.097 (kW)

Below Fig.16 shows constant DC voltage maintained at its terminals.

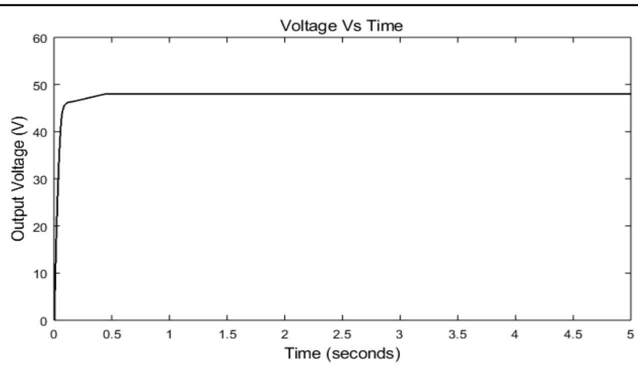

Fig.16. Controlled DC output voltage = 48 (V)

At 48 Vdc bus, total load current is shown in below Fig.17

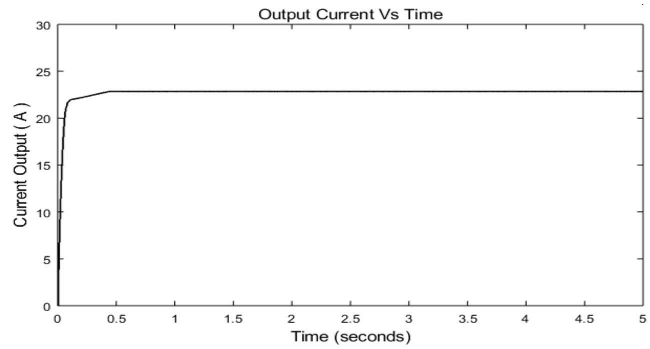

Fig.17. Load output DC current = 22.85 (A)

7.2 Battery bank system

The battery source can be used in case outages occur in RES system. At that time as an emergency source battery is going to supply the load requirement with limited periods without disturbances.

The Fig.18 shows the power delivered by the battery when peak loads are connected at different DC bus voltage level.

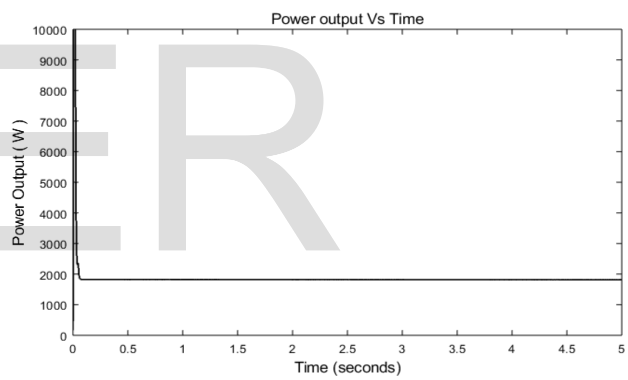

Fig.18. Power supplied by battery = 1.825 (kW)

When battery is 100% charged, the discharging voltage is shown in Fig.19 below.

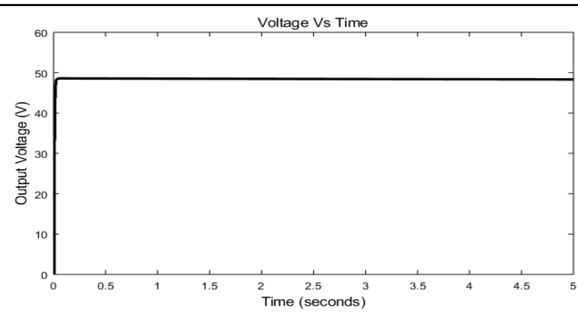

Fig.19. Battery discgarge voltage = 48 (V)

The battery current waveform is shown in Fig.20, when maximum loads are connected at its terminal.

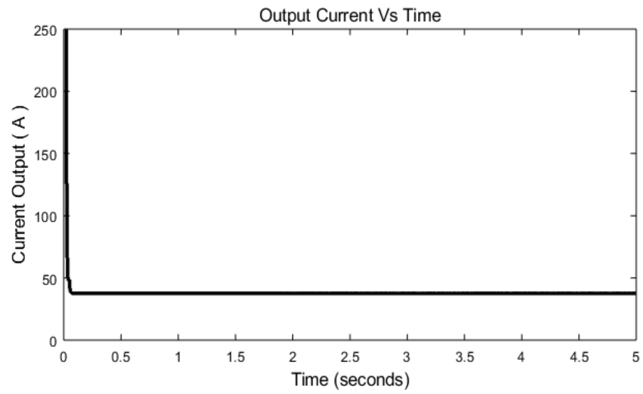

Fig.20. Battery discharge current = 37.59 (A)

lated result comparison. As load increases up to 5 kW solar systems will ready to deliver the power.

7.3.3 Integrated system

When solar & wind energy sources are integrated it will produce 10 kW of power as calculated. The simulation result of comparison is as shown in below Table 1.8.

 # Additional generated power can be exporting to grid or neighbor houses.

8. Conclusion

This paper presents the voltage control strategy using a PI controller to maintain the DC fluctuation voltage in the system at different voltage levels. The system performance is obtained by using MATLAB simulation and its output results are compared with the hand calculated results and found both are close to each other. With reference to above discussion & results, this system can be applicable to real time system as well.

TABLE 1.6
COMPARISON OF WIND POWER & CALCULATED POWER

Calculated power (in kW)		Simulated power (in kW)	
Generation	Load Consumption	Power Supplied	Load Consumption
# 5.0	1.752	4.108	1.752

TABLE 1.7
COMPARISON OF SOLAR POWER & CALCULATED POWER

Calculated power (in kW)		Simulated power (in kW)	
Generation	Load Consumption	Power Supplied	Load Consumption
# 5.0	1.752	1.799	1.752

TABLE 1.8
COMPARISON OF INTEGRATED SYSTEM POWER

Calculated power (in kW)		Simulated power (in kW)	
Generation	Load Consumption	Power Supplied	Load Consumption
Wind = 5.0 Solar = 5.0	1.752	Wind = 2.443 Solar = 1.664	1.752
# 10.0 kW		4.107 kW	

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