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Power Management of Hybrid AC-DC Microgrid with Li-ion Battery for Pulse Loads along with Feasibility Report for INDIAN Villages

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Abstract: In vast countries like INDIA, the electrical power is generated with the help of traditional power plants (i.e, Thermal & Large Hydro). But it is very difficult to deliver this power to remote areas which are far away from load centres. These areas mostly depend on diesel generators for daily needs, and releases enormous pollutants into environment causing Global Warming. Because of all these reasons it is advisable to integrate Renewable sources into the present system to form a Hybrid Power System.

This paper aims to design a hybrid Off-Grid AC-DC Microgrid with Solar & a DG supplying both buses. and works autonomous mode. BESS is also used for backup purpose. A feasibility report is made for the proposed HPS and the present system.
Keywords: Hybrid Microgrid, Renewables, BESS, PV system, Feasibility report.

I. INTRODUCTION

Andaman & Nicobar Islands has a total number of 372 small islands which spreads over 750km in the east Bay of Bengal and is about 1200KM away from the landmass of Chennai and Kolkata. Of these 372 islands, there are 37 inhabited islands but only 19 inhabited islands are electrified with diesel generators and the rest of the islands are remain are not electrified. Most of the domestic customers are located in the middle and north islands, non-domestic customers are located on the south islands. The total load demand of these islands is about 58MW as per the data from the Electricity department of A&N[2]. Most of the power is generated by diesel generators only. But these conventional fossil fuelled power plants causes a severe environmental issues such as Greenhouse effects, also these conventional sources are shrinking day-by-day. In order to overcome these issues, researches are looking towards the alternate form of energy sources i.e., renewable sources which are readily available in natures and causes less effect to the environment such as solar thermal technology, photo voltaic technology, wind energy etc., Also the technologies for integrating these renewable sources into distribution systems are improving day-by-day.

Increasing in the recent trends of technology in renewable sources integration and utilization, hybrid power system gain more importance than an ordinary traditional power system. These hybrid power system uses distributed generators which are connected to distribution system and are implemented as Microgrid, where the practicing of primary grids is not economical [3]-[4]. So a hybrid micro grid essentially consists of both AC & DC bus. Furthermore with the increase in the semiconductor technologies DC grids gain more importance. There also been an increase in the DC loads such as Light Emitting Diodes (LED) & plug in electric vehicles (PEV's) which are connected to the grid to save energy & decrease the emission of greenhouse gases [5]-[6]. These DC microgrids are supplied by the sustainable DC power sources such as solar cells, on the other hand the AC micro grids are supplied by renewable such as wind and other conventional sources.

Islanding mode and Grid connected mode are the two different operating modes of a microgrid. In the grid connected mode, total power supply to the micro grid is less than the demand the excess load is supplied by the primary grid. Where as in islanding mode of operation the entire load is supplied by the distribution generators attached locally to the microgrid is disconnected from main grid [7]-[8]. Hybrid power system faces more challenges when it is operated in island mode than that it works in grid connected mode [9]. Interconnections of both AC & DC grids and their coordinate controlling are the major technical issues faced in microgrids [10]. Researches proposed several ideas and models of hybrid AC-DC micro grid which works in both modes. They also proposed several methods for coordinate control of the system[11]-[13]. System stability and the control modes under the influence of the pulse load is an open issue. In this paper a hybrid AC-DC Microgrid, operated in islanding mode is modeled and simulated. The PV farm is used to feed the DC grid and a Diesel (Synchronous) generator is used to feed the AC grid. The DC and AC loads are connected to the DC and AC buses respectively, under normal loading condition the system is stable, but when the pulse load influence is considered the voltage and current of the buses are adversely affected. Then the system frequency changes rapidly and system will collapses. In order to bring the system back to the stable state a backup system such as storage devices are used. In this paper Li-Battery are used as storage source when support the variation in AC load and also supply the DC load when the solar output is less under sunny weather conditions [14]. A DC converter is used to connect PV farm to DC bus and a bidirectional DC-DC converter is used to connect the battery bank to the DC bus. The AC and DC buses are connected through a bidirectional AC-DC converter. By properly controlling these converters the system stability and robustness in increased.

A feasibility report is also done in this paper, in this report five parameters are calculated by dynamic economic evaluation method. These parameters are then compared among the PV, Diesel and Hybrid system.

II. SYSTEM MODELLING AND CONFIGURATION

A. The Electrical Load Demand

Most of the loads in India are domestic and Agricultural loads only. The load demand of household purpose on an average for a medium class house is of 3-4 units per day. Assuming a total of ten houses the total load demand is 40KWHr per day.

B. Pv Farm Modelling

The PV cell is the basic element of a PV array. This PV cell is made up of high purified Silicon which is readily and abundantly available. This silicon is converted in silicon wafers and cut into thin slices. These are then doped with boron and phosphorous materials which possess excess number of electron hole pairs. So whenever this cell gets exposed to solar radiation, these electron hole pair breaks its bond and converted into freely movable particles, and when the load is connected across the cell it produces direct current. This phenomenon is called photovoltaic effect. PV cells produced by different technologies such as poly crystalline, mono crystalline and amorphous silicon. So a PV cell is a device which converts the solar radiation directly to the DC supply.

Depending upon the rating, no of cells are arranged in series and parallel connection. Equations (1)-(3) show the mathematical model of a PV panel.

$$I_{pv} = n_p I_{ph} - n_p I_{sat}\left[\exp\left(\left(\frac{q}{AKT}\right)\left(\frac{Vpv}{ns} + I_{pv}R_s\right)\right) - 1\right] \tag{1}$$

$$I_{ph} = \left(I_{sso} + k_i(T - T_r)\right).\frac{S}{1000} \tag{2}$$

$$I_{sat} = I_{rr}\left(\frac{T}{Tr}\right)^3 \exp\left(\left(\frac{qE_{gap}}{KA}\right)\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \tag{3}$$

C. Sizing of PV System

For proper designing of the system one must has to know the size of the PV system that has to be installed in order to supply the total load demand.

So the peak power of a PV system (P_{pv}) is given by (4)

$$P_{pv} = \frac{E_L}{\eta_v \eta_R PSH} S_f \tag{4}$$

Where E_L(daily load consumption)=40KWHr, Inverter Efficiency η_v=0.92, Charge Regulator Efficiency η_R= 0.9, Peak Sun Hours PSH=5.5, Safety factor to compensate system losses S_f=1.15. So the peak power required to be generated by the PV system is:

$$P_{pv} = 10.10KWp$$

A polycrystalline type Luminous Solar panel of ratings 24VDC and a peak power of 150Wp is selected. Therefore the number of panels required are

$$N_{pv} = \frac{P_{pv}}{P_{mpp}} = 79 \tag{5}$$

So by considering a total of 81 panels of which 9 panels are connected in series to form a 9 parallel strings. The open circuit voltage (Voc=22V) and short circuit current (Isc=7.0A) for the solar panel at standard test conditions. So we obtain a open circuit voltage and short circuit current for the 9x9 array is:

$$V_{oc} = 22V \times 9 = 198V$$
$$I_{sc} = 8.9A \times 9 = 80.1A$$

D. Modelling of LIB Bank

In islanding mode the DC bus voltage is regulated with the help of an accurate battery cells. In the proposed model a lithium-ion battery or LIB which is a rechargeable type of battery is used. This battery stores energy when there is excess of supply, low load and discharges when the supply is less load is high.

E. Sizing of Battery Bank

The sizing of the battery bank must be properly selected such that they must have long life time(>10 years), capability of standing very deep discharge and high cycling rate. In order to supply the load for a period of 2 days without sun, the ampere hour capacity C_{Ah} and watt hour capacity C_{Wh} of the battery bank is obtained as bellow:

$$C_{Ah} = \frac{2 \times E_L}{V_B \times DOD \times \eta_v \times \eta_B} = 633.7Ah \quad (6)$$

Where V_B=220V and η_B= 0.85 are the voltage and efficiency of the battery bank, DOD=0.75 is the allowed Depth of Discharge of the bank.

$$C_{wh} = C_{Ah} V_B = 104.575KWh \quad (7)$$

To install this capacity, each cell rated 2V/600Ah of 110 numbers are connected in series

F. The Diesel Generator

A huge number of high rating Diesel Generators are mostly used in Andaman & Nicobar islands for electrical power. But as the proposed system is a HPS the number of Diesel Generators and its rating is also reduced such that the carbon emissions are also reduced.

For the proposed system the ratings of the diesel generator is selected such that it has to deliver a load of 4-10KW. Hence we select a 15KVA (Kirloskar) with 3 phase AC output.

G. The Charge Regulator and Inverter

The control system has three major elements which are Boost converter with MPPT, Bidirectional DC-DC converter, and Bidirectional AC-DC converter. These three control schemes are properly designed for coordinate control of the hybrid Microgrid system with high degree of reliability and stability.

Here the boost converter and bidirectional AC-DC converter is used as charge regulators CR. The boost converter with MPPT tracks the maximum power from PV system and regulates the system voltage, and the AC-DC converter is used to regulate the voltage of the battery bank during the charging and discharging period.

III. STRUCTURE OF HYBRID MICROGRID

The complete structure of the proposed hybrid micro grid is as shown in fig.1. The AC bus consists of synchronous generator and AC load, whereas DC bus consists of distribution generators, backup devices and DC load. The DC loads may be LED's or DC motors. In present days with the increase in the battery vehicles, PEV's are also treated as DC loads. The Distribution Generators are connected to DC bus through DC-DC converter and both the DC bus and AC bus are connected through a bidirectional AC-DC-AC converter.

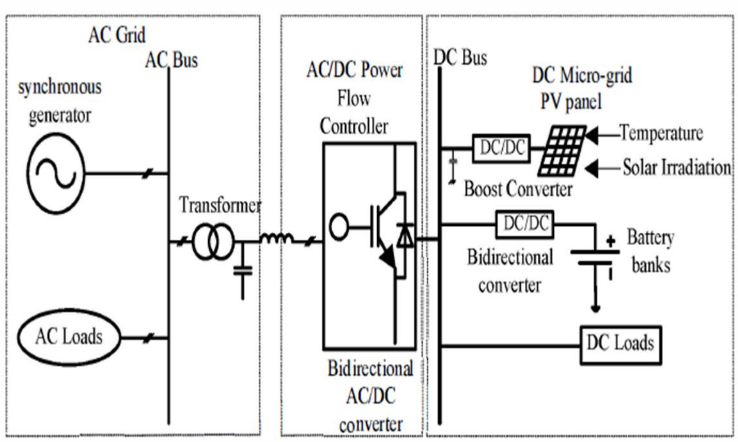

Fig.1 Hybrid AC-DC Microgrid system

The proposed hybrid microgrid uses 10Kwp PV farm and 10KW DC load connected to the DC grid. The DC bus voltage is maintained at 300 Vdc and the AC grid is supplied by a diesel generator of rating 13.8KW and a constant load of 4KW, pulsating load of 10Kw is also connected to the AC bus, the AC bus voltage is maintained at 208 Vrms (P-P).

IV. ECONOMIC EVALUATION

The main purpose of economic evaluation is to make decision regarding the alternative uses of scarce resources. A project economic value is determined mostly based on this economic evaluation techniques or feasibility reports.

A project can be evaluated based on either static procedure or dynamic procedures[15]. In this paper we make use of dynamic procedure to evaluate the project because a project value is changed based on the time value. This dynamic method provides better results than static method because of time component involved in evaluating the project.

A. Net Present Value (NPV)

The NPV is used to calculate the total of all cash flows that can be directly linked to the project. It means it is the algebraic sum of the todays value of an amount of money in the future.

$$NPV = -I_o + \sum_{t=0}^{T} (R_t - I_t)\, q^{-t} + L_T q^{-T} \tag{8}$$

$$q^{-t} = \left(1 + \frac{i}{100}\right)^{-t} \tag{9}$$

Where $I_o$is the investment cost at t=0, T is life time of the project, R_t is the returns in time t, $I_t$is the investment in time t, q^{-T} is the discounting factor, $L_T$is the salvage value.

A project is most acceptable in NPV is positive, otherwise you might reconsider the investment.

B. Internal Rate of Returns (IRR)

IRR is the interest rate at which the NPV of all cash flows from a project or investment equals to zero.

$$0 = -I_o + \sum_{t=1}^{T} R_t \left(1 + \frac{IRR}{100}\right)^{-t} + L_T \left(1 + \frac{IRR}{100}\right)^{-T} \tag{10}$$

If the IRR of a new project exceeds a company's required rate of returns, the project is desirable.

C. Annuity (A)

It is a fixed sum of money paid to someone each year, typically for the rest of the period. An annuity is a series of payments made at equal intervals.

$$A = NPV \times RF(i, T) \tag{11}$$

$$RF = \frac{q^t (q-1)}{q^t - 1} \tag{12}$$

D. Cost Annuity (A_k)

Cost annuity is the another form of annuity method without the inclusion of income in the calculation. This A_k is used in calculating the per unit production cost .

$$A_k = \left[\left(\sum_{t=1}^{T} k_o q^{-t}\right) RF(i, T)\right] + (I_t - L_T) RF(i, T) + L_T i \tag{13}$$

So a project with lowest A_k or per unit cost should be preferable.

E. Dynamic pay back period (DPB)

The need for calculating the DPB is to know at what time point during the life time of the project, the capital investment will be recovered by annual returns. The DPB must be lesser than the project life time.

$$\text{DPB} = \frac{I_o}{\left[\left(\sum_{t=0}^{T} (R_t - I_t)\right)/T\right]} \tag{14}$$

V. SIMULATION RESULTS AND FESABILITY REPORT

A. Simulation Results

The PV farm is subjected to Standard Test Conditions (STC) i.e., the PV farm is tested at 25°C and a solar irradiation varies from 0-1000W/m^2. A boost converter is used for PV farm to boost the output voltage to a desired value. This boost converter is controlled by Maximum Power Point Technique in order to track the maximum power from the PV cell. This MPPT is designed by using P&O method and enables the boost converter at 0.4s. Fig.2 shows the output power, output voltage, duty cycle and solar irradiation. Before the MPPT is enable at 0.4s the duty cycle is fixed at 50% and the output voltage of PV panel is at 149V and output power is tracked at 10Kw, as soon as the MPPT is enable the duty cycle is decreased to 45% and the terminal voltage of PV panel is increased to 165V and output power also increases to its peak value of 10.15Kw. Simulation results show that the P&O MPPT tracks the maximum power very efficiently and in very less time.

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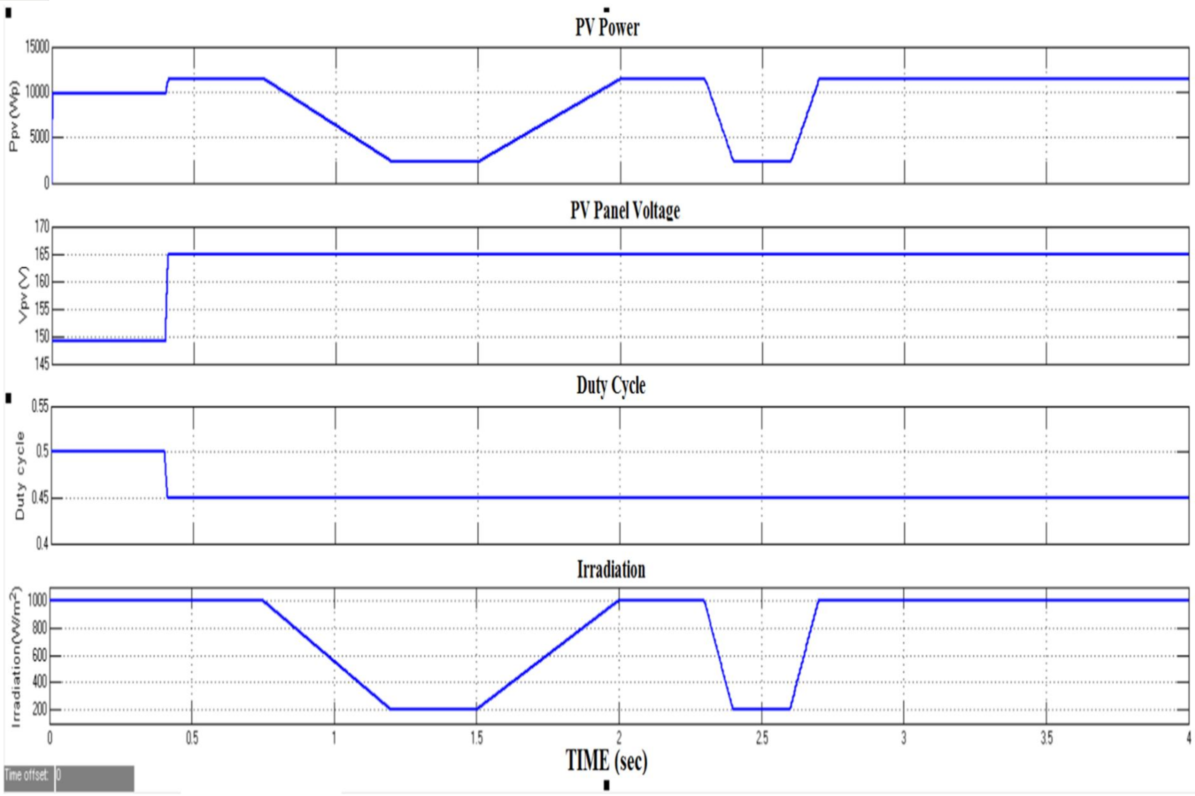

Fig.2 PV farm output with MPPT

Fig.3 shows the DC bus voltage. The MPPT tracks the PV panel voltage to 165V; this voltage is then boosted to a value of 300V. The DC bus voltage enters the steady state value within 0.3s.The solar irradiation variations did not influence the DC bus voltage as the battery banks have sufficient energy to balance the power flow with in short duration of time.

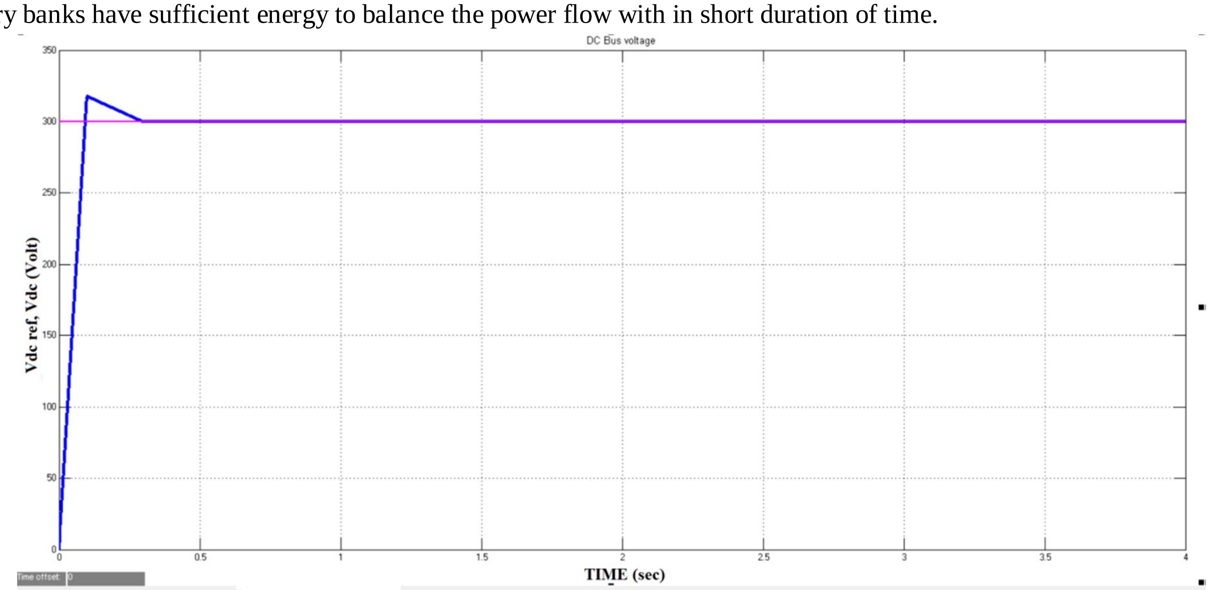

Fig.3 DC bus Voltage

Fig.4 (a),(b),(c) shows the Microgrid AC side pulse load response without any DC support. A constant load of 4Kw is maintained until 1.6s and a pulse load of 10Kw is applied at 1.6s. So the total load on the AC side rises to 14Kw which is more than the generation. At 2.2s the grid fails and the system collapse. It could not recover even the 10Kw load is removed at 3s. Fig4 (a) shows the generator active and reactive power, fig4 (b) & (c) shows the AC voltage & AC current under the pulse load influence. After 2s the AC bus voltage and current changes rapidly and settles at new steady state after the 10Kw load is removed at 3s.

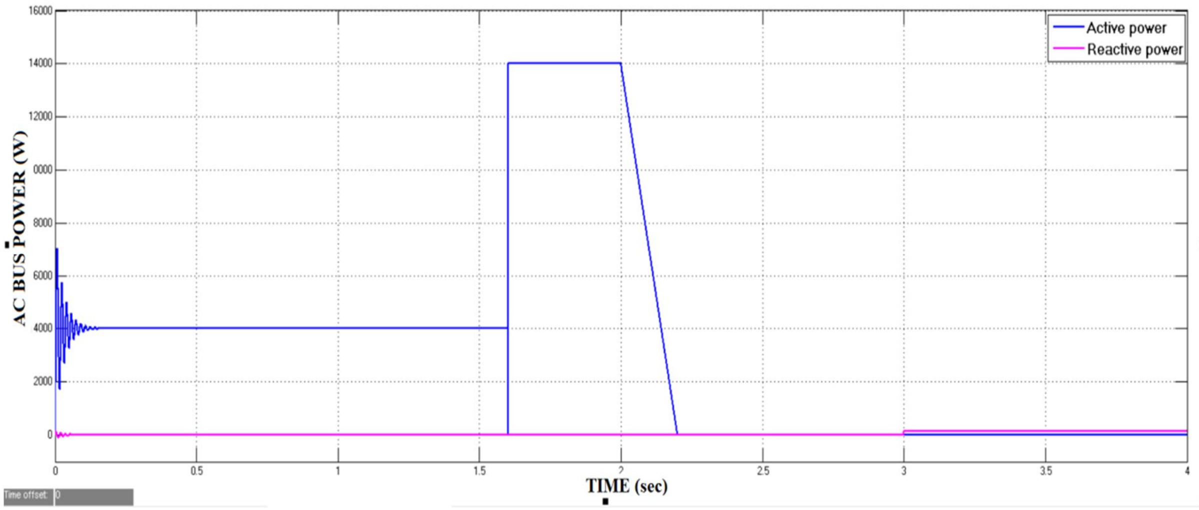

Fig 4(a) Generator output active and reactive power

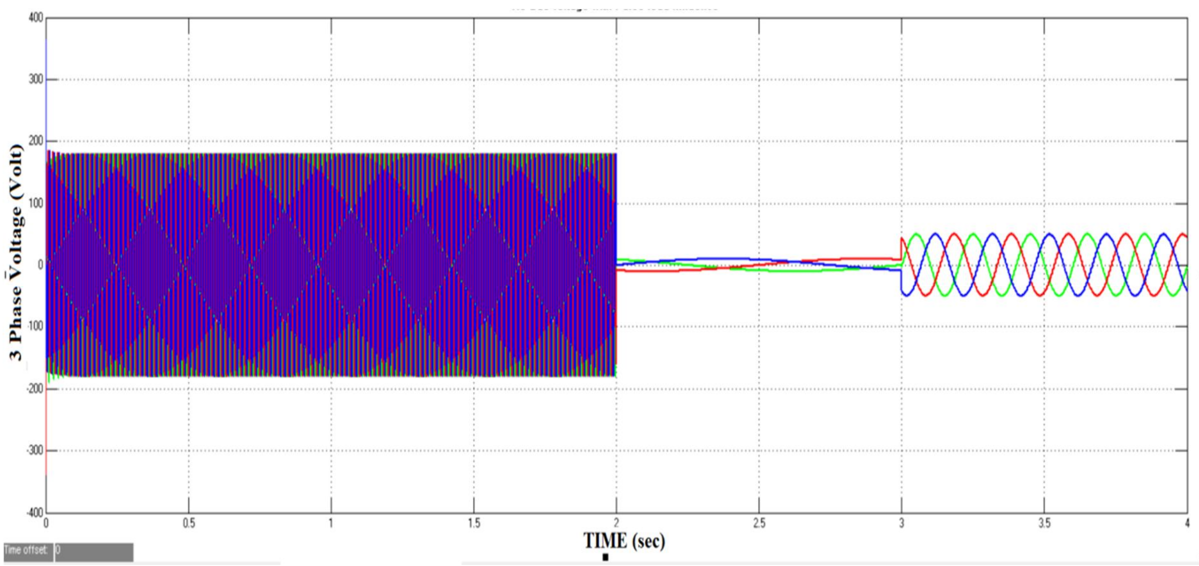

Fig 4(b) AC voltage with pulse load influence

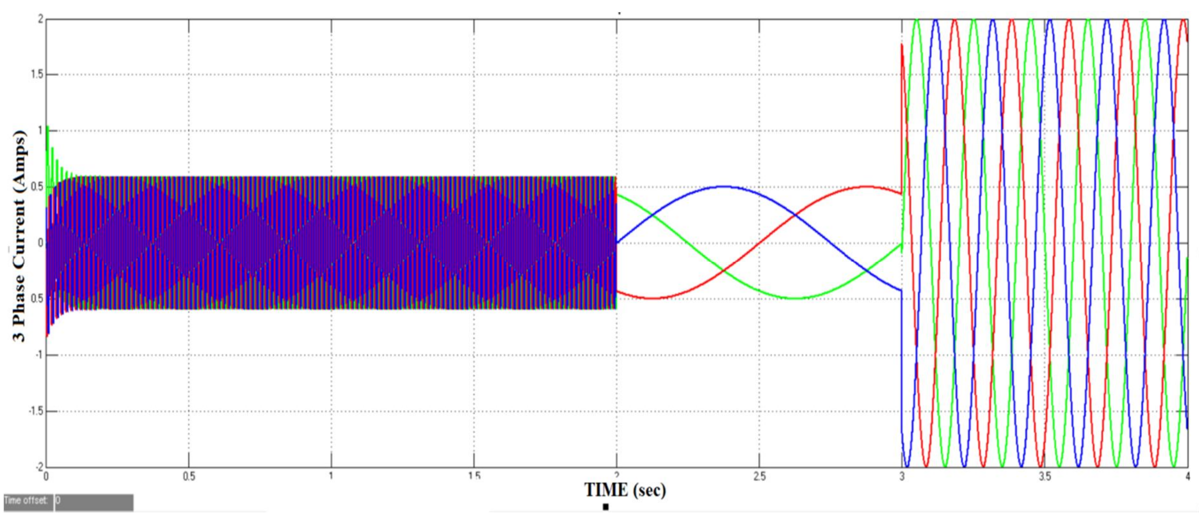

Fig 4(c) AC current with pulse load influence

Fig.4 Microgrid AC side response with pulse load & without DC support

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As the proposed system makes use of Li-ion battery bank, these storage devices are able to supply the excess load on the AC side. Fig.5 (a), (b) shows the AC bus voltage and current waveforms under the influence of pulse loads and with the DC support. So the bus voltages come back to stable state.

When the load is increased suddenly the current flow increases suddenly from DC to AC side and when the load decreases the current flow also decreases.

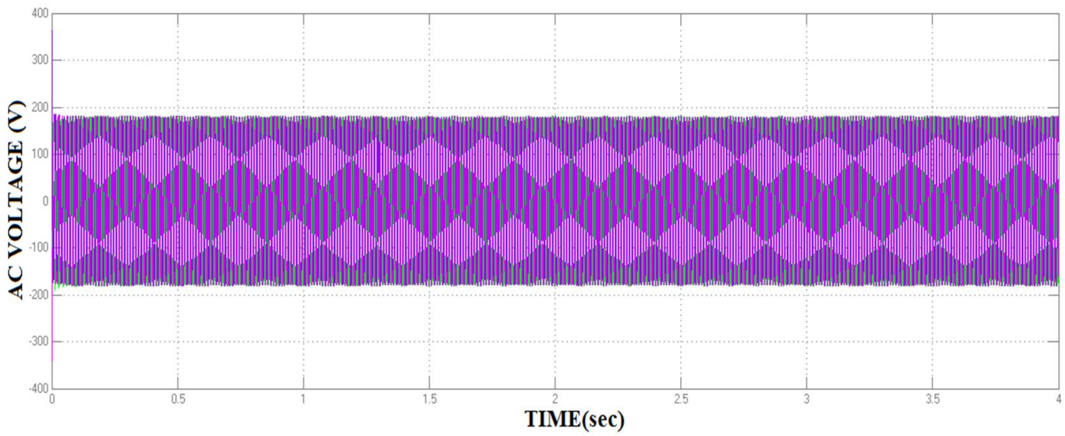

Fig 5(a) AC side voltage with pulse load influence

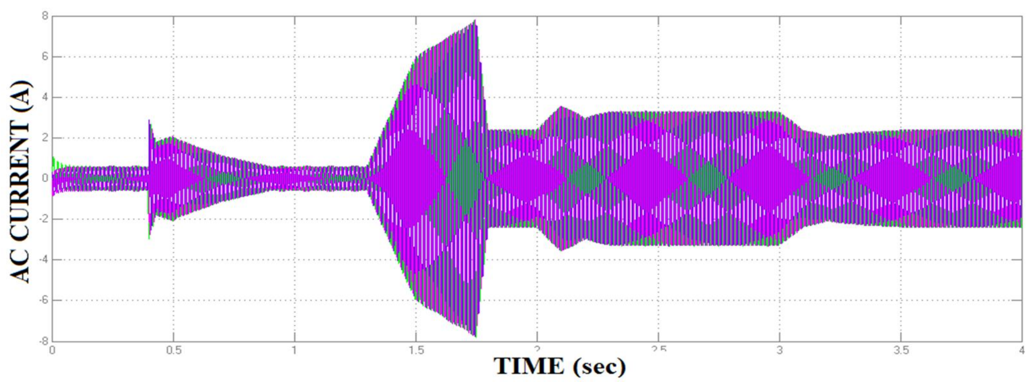

Fig 5(b) AC side current with pulse load influence

Fig.5 Microgrid AC side voltage & current with DC support

Fig 6 shows the AC bus frequency, as load increases at 1.3s the grid frequency falls to a value of 57Hz and gains back with DC support in less than 1s. Again at 3s when the 10kw load is removed so the frequency increases suddenly to a value of 62Hz and then settles to 60Hz at 3.5s.

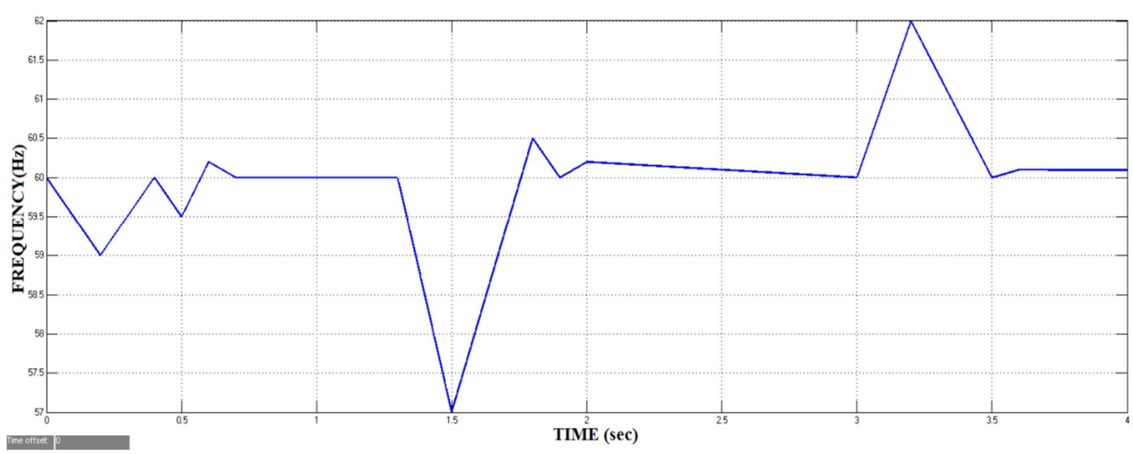

Fig.6 Microgrid AC side Frequency response

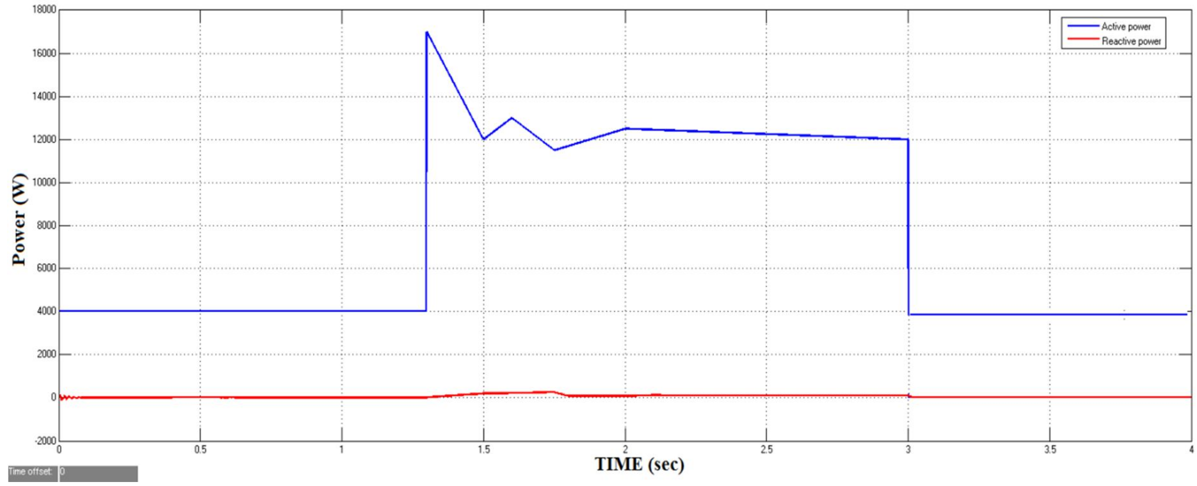

Fig 7(a) Generator active and reactive power output

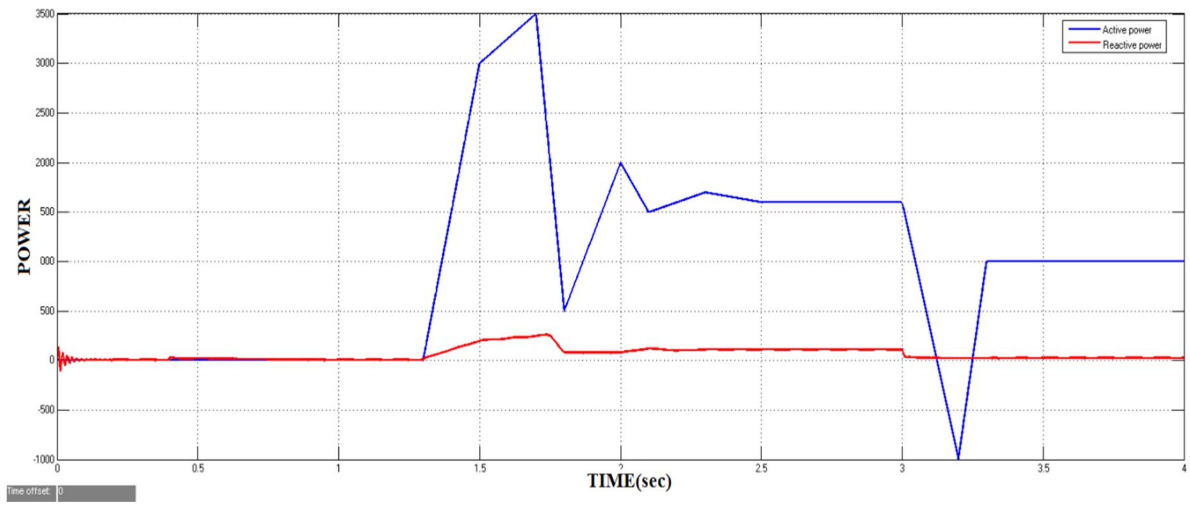

Fig 7(b) Ac bus active and reactive power output

Fig.7 Microgrid AC side active & reactive power with DC support

Fig.7 shows the active and reactive power flow from both generator bus and AC bus to compensate the load variations. Fig.7 (a) shows the active power and reactive power output from generator, up to 1.3s the load of 4kw is supplied by generator itself without DC support but after 1.3s the total load on the AC bus rises to 14Kw which is higher than the generation. So it takes the DC support and supplies the load. Fig7 (b) shows the AC bus Active power and reactive power flow from dc side to ac side. Some of the load on ac side is now feed from the DC support by using bi-directional inverter.

B. Economic Calculations

1) For PV Powered System

Initial cost I_o= 21,82,135/-

Annual Expenditure I_t =*10,000/*-

Annual Returns R_t = 2,11,200/-

Salvage value L_T 10% of initial cost = 2,18,213/-

Interest value i=10%

Substituting the assumed values in the dynamic indicators we obtain

Net Present Value (NPV) =3,10,43,830.19/-

Annuity (A) =34,14,821.32/-

Cost Annuity (A_k) =1,96,307.27/-
Dynamic Pay Back Period =10.84Yrs
Cost in Rs/KWh = 11.44/-

2) For Diesel generator powered System

Initial cost I_o= 2,61,110/-
Annual Expenditure I_t =*2,63,821/-*
Annual Returns R_t = 3,15,360/-
Salvage value L_T 10% of initial cost = 26,111/-
Interest value i=10%
Substituting the assumed values in the dynamic indicators we obtain
Net Present Value (NPV) =1,00,86,864.49/-
Annuity (A) = 11,09,555.204/-
Cost Annuity (A_k) = 3,41,444.80/-
Dynamic Pay Back Period =6.65Yrs
Cost in Rs/KWh =15.39/-

3) For Hybrid(PV+DG)source powered System

Initial cost I_o= 24,43,245/-
Annual Expenditure I_t =*2,73,821/-*
Annual Returns R_t = 5,26,560/-
Salvage value L_T 10% of initial cost = 2,44,324.50/-
Interest value i=10%
Substituting the assumed values in the dynamic indicators we obtain
Net Present Value (NPV) =4,11,41,873.38/-
Annuity (A) =45,25,606.07/-
Cost Annuity (A_k) =2,97,454.11/-
Dynamic Pay Back Period =9.67Yrs
Cost in Rs/KWh =8.15/-

Economic Indicators	PV System	Diesel System	Hybrid (PV+Diesel)
NPV	3,10,43,830.19	1,00,86,865.49	4,11,41,873.38
Annuity	34,14,821.32	11,09,555.20	45,25,606.07
Cost Annuity	1,96,307.27	3,37,143.10	2,97,454.15
Cost of KWH	11.44	15.39	8.15
DPB period	10.84	6.63	9.66

VI CONCLUSION

The following conclusions can be made based on the above results:

A. The simulation results shows that the proposed system gives a stable operation of the system under pulse load influence in an islanding mode of operation.

B. From the above economic indicators comparison table, the NPV is high for hybrid system, also the per unit(kWh) production cost is low for hybrid system.

Therefore the Hybrid (PV+Diesel) system is more economically feasible for the electrification of the remote Indian villages and Islands like Andaman & Nicobar.

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