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Energy Management and Load Dispatch Flow using K-Map for Battery Storage System integrated with Solar Micro Grid Tied Inverters

Kamala Devi V, Premkumar K, Bisharathu Beevi A

Abstract: ***Intermittency of wind and solar potential necessitate for development of new systems, bringing additional co3mplexity to power system operations and planning. This has led to a new framework for improving the performance of solar Grid Tied inverters installed on the Low Tension Grid of Kerala. The aim is to introduce a Battery Intervention Power Supply (BIPS) integrated with the solar inverter that helps in smoothening the energy output of the inverter and in reducing the sub-harmonic oscillations in the output current waveform. It also helps to improve the performance of the inverter during the low irradiance levels. The excess power is stored in the BIPS during Peak Source Accumulation, power disruptions and when outside the safe operating region of the inverter. This can also be utilized to meet local priority loads. The model of the battery used to study the performance is derived using non-linear regression analysis method of curve fitting. The paper introduces an improved solar plant that reduces the length of distribuion lines delivering good power quality and maintaining grid stability with reduced intermittency of power flow.***

Index Terms**:** ***Grid Tied Inverter with battery storage, Distributed Generation (DG); Solar, Fuzzy-Logic***

I. INTRODUCTION

The development of renewable energy resources faced the issue of developing electric transmission infrastructure. This is mainly because of the unevenness of terrains that requires longer distances to cover. Building of dams faced de-forestation threats and other important environmental factors. WET (Wind Energy Transmission) faced evacuation problems. Solar Energy faced non-shadow wide area requirements and grid integration, grid stability and power quality issues. CSP faced technology problems and are yet to be exploited fully.

Transmission lines were set up mainly to link large stationary power plants to nearby electricity demand centers like cities. For renewable energy, however, state mandates and policies are driving investment in wind—and to a lesser extent solar—energy, creating a need for long distance transmission lines to link these scattered resources with electric load dispatch centers.[1].

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II. NOMENCLATURE

BESS	-Battery Energy Storage System
BIPS	-Battery Intervention Power Supply
DGS	-Distributed Generation System
DOD	-Depth Of Discharge
PCC	-Point of Common Coupling
FFT W AVR	-Fourier Frequency Transform with Automatic Voltage Regulation
FFT W.O. AVR	Fourier Frequency Transform without Automatic Voltage Regulation
MP&O	-Modified Perturb & Observe
LT	-Low Tension
SOC	-State Of Charge
LAB	-Lead Acid Battery
CSP	-Concentrated Solar Power
WET	-Wind Energy Transmission
LC	-Logic Controller
VEKM	-Variable Entity Karnaugh Map
KLC	-K-map Logic Controller
LP	-Linear Programming
MPP	-Maximum Power Point Tracking

III. PRELUDE

A. Energy Status in Kerala

Demand for energy is growing day by day. This has resulted in wide acceptance of renewable energy all over the world. Kerala is also keen on utilizing renewable energy sources especially Solar and Wind. In Kerala Wind farms,

Solar Photovoltaic Power plants and Solar Grid Tied power plants are being installed by the Government under various socially oriented schemes. Solar energy is available in abundant in almost all parts of the state. Even backwaters, large ponds and canals are being considered to implement Solar Power Plants.

Kerala has been largely depending on hydel power plants for electricity power generation. During the last six years, we noticed that the mother Earth is ghastly affected by global warming. Global warming has resulted in climatic changes such as raised ambient temperature, change in weather conditions, and has even affected wind flows. It may be due to global warming that Kerala received a poor monsoon during 2010-11. Lack of rainfall during 2010-11 had greatly affected the management of electric grid in Kerala during that period. Kerala then realized the need for alternate source of electricity. It is during 2012 that the planning Board of the state has decided to go into realization of non-conventional energy sources. The Board decided to install new technologies to generate electricity and give incentives to such new schemes. Solar Photovoltaic (PV) Power Plants and Wind Mills began to emerge as the two alternate energy sources to generate power in Kerala. When Wind Mills were commissioned in the state it was noticed the terrain is not at all suitable for it. Because the terrain of Kerala is covered with hilly regions, when wind mills are installed in such areas drafting of roads and cutting hills were the major hinders. Moreover, evacuation of grid also found problems. So the state looked forward to Solar PV Power Plants. Through KSEBL and ANERT two bodies of the Government, the state commissioned

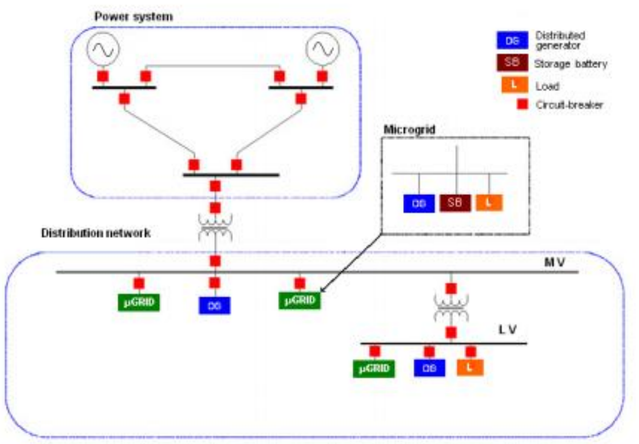

Fig 1 Existing Design for Micro Grid [12]

PV Power Plants. Initially off-Grid power plants were installed. 10000 roof-top programme was launched to install 10MW SPV Power Plants of off-grid type. The codes for installation of on-grid PV Power Plants were formulated for the state. While commissioning power plants the foremost work of ANERT is the verification and pre-feasibility study of the site for the suitability of a project. ANERT has to go through pre-certification standards for evaluating the suitability of a plant in a region. Technical specification of a power plant has to be evaluated before commissioning. Also the standards of the Grid have to be set. The protective relay set points, voltage fluctuation limits, frequency standards, fault relay set points, voltage imbalance, islanding issues are some of the points to be highlighted for evaluation. Before giving connection to the KSEBL's grid, certain grid standards are to be noted.

Conventionally designed Solar PV Power Plants are generally; provided with an inverter or bank of independent inverters, battery bank and SPV array to form a complete plant. There are trends to use AC Modules that uses single panel attached with micro inverter. Here each module generates separate power and supplies to grid. There are many advantages for such a system. Micro inverter Integrated Systems or MIS they are called eliminates or mitigates the effect of islanding. It actively responds to faults and short-circuits. At off-peak hours MIS work effectively. Overall performance is better compared to a conventional PV system. However, its use is limited to single phase i.e.; less than 5kW.

Indian regulations [2, 3] says that Solar Grid connected projects shall not exceed 80% of the minimum connected load at a PCC. Micro level installations have minimal impact on the Grid, but as the penetration increases, the possibility for grid impact increases.

Table 1 Comparison of Solar Technologies

Solar Technology	Functions	Merits	De-Merits
Off-grid	Energizes priority loads. Does not support grid	Continuous supply of power, stable output, low harmonic injection	Costlier, maintenance cost involved, capital cost higher, reliability lesser, frequent replacements or repairs.
On-grid	Feeds into grid	Lower cost, lower maintenance, reliability more	Power quality of grid affected, more comprehensive design to handle harmonics, operating period less.
Hybrid	Works in islanding mode to power the load as well as feeds into grid when the grid is available	Operating period more.	Costlier, frequent and periodic maintenance.

A brief literature survey has been done here to understand the amount of work carried out in this field so far both nationally and internationally.[4] compares a 1kWp grid connected PV plant of series string type with 1kWp micro inverter based grid-tied PV plant.

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Simulation results highlight the advantages of micro inverter system over the other. European standards, market and research and development goals of a prototype grid tied micro inverter have been analysed in detail [5]. An inference has been derived from [6] that describe a better and effective control method in micro inverters where the current supplied to the utility line can be independently controlled apart from line voltage. This improves current harmonics.

Reliability of integrated PV inverter plant has been validated using Mean Time between failure aspects. Inverter reliability is evaluated and various methods suggested improving it [7]. Ref [8] studies advantages, disadvantages, past developments and future developments. The paper suggests that there is need for reducing cost and improved design. [9] Illustrates a new wire free concept of PV array interconnection. Transient stability issue has been studied in detail in [10].In Germany and many developed countries, Grid stability is an important issue. They have tackled this issue in many ways. One of the technologies adopted is microgrid. Here renewable energy sources like PV and Wind Turbine are integrated along with battery packs. Research is still going on in this area to achieve full scale grid integration [11].

IV. FOCUS OF THE PAPER

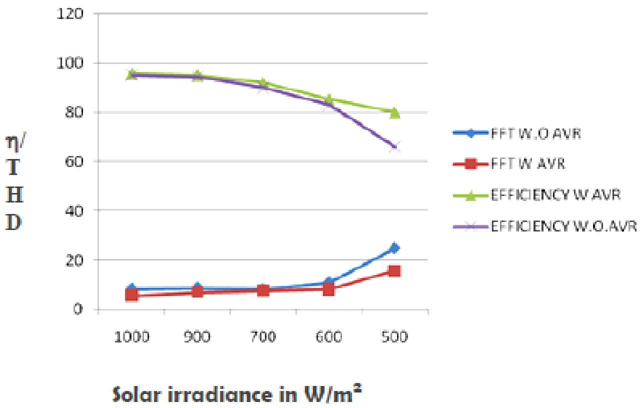

Fig 2 Variation of efficiency and steady state harmonics with different values of L filter and solar insolation (Irradiance vs. efficiency/% THD)

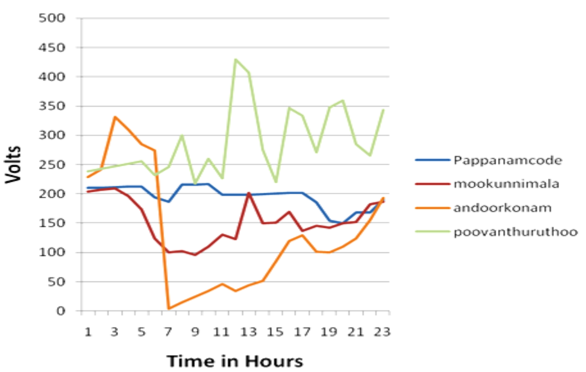

Fig 3 Daily average voltage distribution in selected regions of Kerala

There are different kinds of renewable energy sources. This paper focuses on solar technology in grid tied operation.

Solar technologies are classified into three groups, namely off-grid, on-grid and hybrid systems. General functions of each systems and their merits and de-merits are illustrated in the Table 1.

On-Grid Solar power plants are often called Solar Grid Tied Inverters. Grid tied inverters work in synchronous with grid. The frequency and phase are synchronized here and operate only when the grid is available. During power disruptions they are off. They are also affected by voltage sag and swell of the grid. They work only in the range of 110% to 80% of the voltage range of grid. Moreover the power quality especially harmonics are to be given due importance in their designs. Notably, the conventional grid can provide reactive power and can absorb voltage sags and swells. This is not the case with solar generators. Solar is intermittent in nature, they cannot ensure constant power supply to grid. Moreover, in Kerala, voltage fluctuations on LT grid are very frequent. So, it is important that solar generators installed here should be able to inject or absorb reactive power to the grid.

A micro model of solar micro DGS is considered to study its performance towards the conventional LT grid. Solar micro DGS has a capacity less than 5 KVa. It works in anti-islanding mode during power disruptions and voltage fluctuations beyond limits wasting solar energy generated. There is no energy smoothing at the output which varies in accordance with solar irradiance.

Table 2 Median, Mean and Skew of the Distribution

Median1	237.91	Mean1	212.696	Skew1	-0.354986
Median2	960.04	Mean2	936.358	Skew2	-0.15589
Median3	200.47	Mean3	196.540	Skew3	-0.15589
Median4	239.4	Mean4	221.7	Skew4	-0.4765

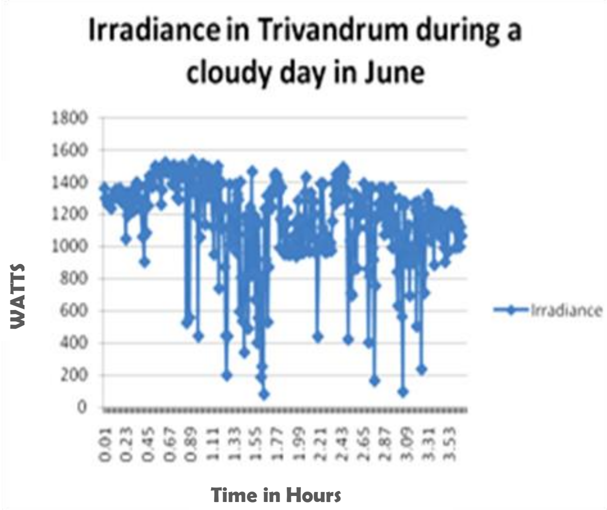

Fig 4. Daily Average hourly RMS Voltage data in selected regions within the state

To overcome these challenges, a new design is proposed where BIPS is considered as an effective option. BIPS uses solar power integrated with energy storage. Energy storage used here often gets confused with that in a micro grid. Here BIPS are smaller units that do not suffer from limitations that exist for micro grid applications that integrate larger systems and uses BESS as independent units see Fig 1.

The proposed system is designed for roof top installations without distribution and transmission networks where only the energy and load management is needed.

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In effect, BIPS is a de-centralized installation with built-in controls for load dispatch. The micro DGS proposed by us is schematically represented in appendix1.1.

A performance analysis without BIPS is considered here and the importance of BIPS is highlighted. Later, the design of a robust logic controller is presented that controls the power flow from BIPS. The capacity of the BIPS is determined considering various factors of significance. During anti-islanding mode, BIPS supply power to local priority loads after isolating the grid.

V.PERFORMANCE ANALYSIS OF THE DGS

A. Steady state performance

Here, the power factor or voltage control requirements of the solar generator are studied. A reactive VAr compensation control is implemented in the algorithm [13, 14]. An analysis has been done at different insolation levels and with or without the active VAr compensation (Fig 2). L-filter value has been changed each time with different insolation levels to analyze an adaptive logic. The improvement in performance can be seen in Fig 2.

In case of micro DG, utility requirements can be met with controls installed within the solar inverter. Storage batteries help in absorbing/delivering power which can be integrated with the micro DG. For larger installations of renewables, more comprehensive and costlier solutions such as static condensors, STATCOMMS, switched capacitors etc are needed.

B. Voltage Fluctuation effect in detail

Frequent voltage fluctuations are a major problem in our state. To study this effect in detail, four regions in Kerala namely, ANDOORKONAM coastal rural area, POOVANTHURUTHY midland rural area, PAPPANAMCODE midland urban area and MUKKUNNIMALA rural hilly area were selected. The areas represent four major land-population regions. The average hourly data of the feeder voltages on LT side in the four major regions are collected for 24 hours. See Fig 3. The normal distribution of voltage profile in the selected districts is given in the plot. The median, mean and skew are found out and given in the Table 2. The skew is negative indicating that data has higher values around the noon time. The voltage fluctuation is a daily average of 7.57% maximum. The BIPS is designed to control voltage fluctuation in the minimal range of ± 10 % since, the PV array responds from a minimum of 10% of its maximum capacity @ STC.

From the data distribution, the mean, median and skew values show that the coastal rural area is most affected by voltage fluctuations followed by rural hilly, midland urban and finally the midland rural area. When grid tied inverters are installed in such areas, their period of operation gets reduced. Thus, the energy generation is reduced and the returns on the investment are realized over a long period of time. And, to control voltage fluctuation to an extent, storage batteries can be intervened at the input of the inverter. This increases the domain of operation and more power is sold. Also during anti-islanding mode battery supplies power to local priority loads.

C. Harmonic Injection and Transient Disturbances

Harmonics in the inverter output current waveform can be mainly due to two reasons: 1. Steady state harmonics injected in the output due to switching of IGBTs, MOSFETs etc at PWM high frequencies [15]. They are normally reduced by using tuned ac filters at the output side of the inverter. In this paper we discuss the use of adaptive L filters. Such filters help in increasing efficiency and reducing Steady State Harmonics. 2. Transient Disturbances: Transient disturbances are mainly due to the solar irradiance or from the grid. When the solar irradiance ramps up and down [see Fig 4], the output power from the solar array also does. This results in sub-harmonic oscillations and power/energy fluctuations at the output of the inverter. This may lead to heat losses, neutral heating and electromagnetic interferences. Machineries and equipment working near the plant may get affected. Paper mills that require exceptionally precise frequencies may get affected.

Also in most developing countries there is no check on the standards of switching devices/rectifiers/SMPS/CFLs etc. These devices induce unwonted frequencies in the grid injecting harmonics in the waveform. Grid tied inverters working in such a grid will be often in OFF mode due to nuisance tripping of threshold relays. Implementation of a logic controller with a storage battery integrated to the DGS to control the power output of the storage device is important in this perspective since this type of controllers are not very sensitive to sudden variations and hence suitable for non-linear loads. Also it helps to smooth power fluctuations at the output caused by transient disturbances. The simulation study on the behavior of the plant to varying solar irradiance is done in SIMULINK which revealed that THD is as high as 10.92%. As depicted in the Fig 5 (a) & (b), the inverted current is showing sub-harmonic oscillations. The tuned L-C filters alone cannot attenuate these current harmonics. Therefore, a different approach is designed by the authors to curtail current harmonics.

1) Frequency Change

Frequency fluctuations of the grid can affect frequency dependant loads. The disruption of the balance between supply and demand leads to frequency fluctuation. Frequency is one of the most important factors in power quality and it must be kept equal throughout the grid. A stable frequency is needed for the smooth operation of paper mills, oil mills, automotive industries etc. Induction machines working on the principle of V/f ratio speed control will be affected by frequency instability. Also, a frequency change will result in change in active power generated by PV generators. Most importantly a frequency change may be due to grid outage and this is an indication to islanding state. For analyzing the behavior of the DGS towards varying frequency, the frequency domain and time domain of the plant are considered. Jones & Milsum (1965) utilized the corresponding transfer function

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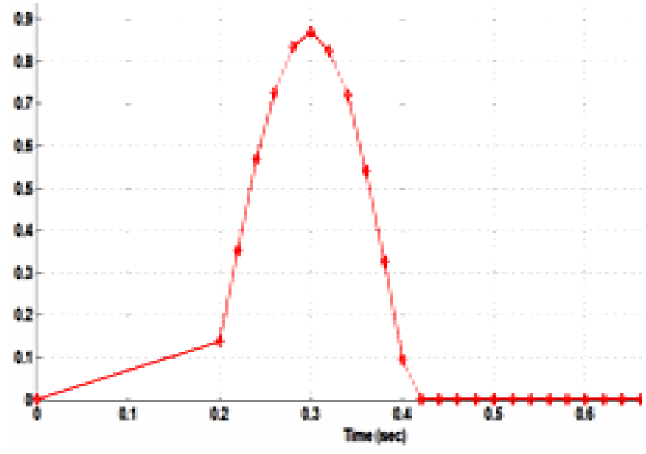
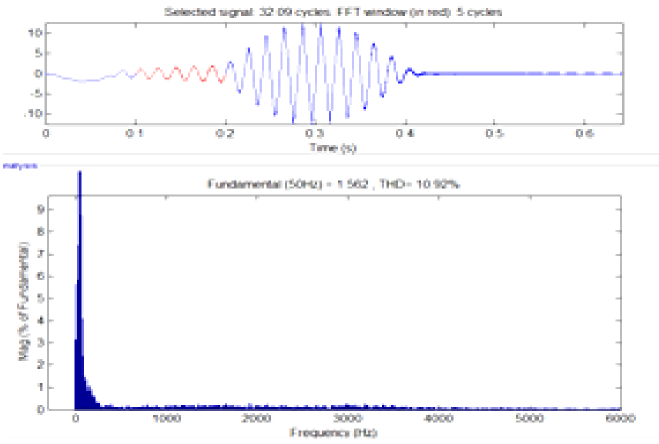


(a)



(b)

Fig 5 (a) Variation of solar irradiance kW/m2simulated for sunny day and (b) the inverter current and corresponding THD

(S) =T1T2s/ (T1s + 1) (T2s+ 1) in which slow and fast time constants T1 and T2 appear in the denominator owing to the under damped characteristics imposed by the small dimensions. In consequence, the frequency-response of this transfer function naturally falls into frequency ranges, termed here low (LF), and high (HF). The Bode plot of gain and phase for the transfer function with the two ranges are separated by frequencies defined numerically as T1 = ω1 and T2 = ω2 rad/sec (rad/sec = 2πHz).

2) Frequency domain and Time domain analysis

Most of the analysis of a system domain and the performance of a system under variable frequency have been carried out either in time or Laplace domain. In fact, once a system is converted to Laplace domains as in Fig 6 (a), its frequency response can be easily studied in MATLAB. Working in frequency domain one can study closed loop stability of a system. The frequency domain shows stability of closed loop system to be evaluated from the frequency response of open loop system. The characteristic equation is derived using the condition that the error of the plant is zero. The L-C model in Fig 6 (a) gives the L-C-L-C line filter placed in the output of the solar generator. Here, the C filters are designed to be a value lower than the under- ground cable impedance so that the impedance of the cable forming the transmission line can be neglected To study the behavior of the Solar DGS towards the variable frequency and impedance, the impedance of the transmission line is also taken into account. The transfer function model of the system is given in Fig 6 (a) and the corresponding model in SIMULINK is given in Fig 6 (b). The above model enables to design the plant in a stable operation by analysing the frequency and time domain in a larger bandwidth. The analysis is based on a non-linear feedback control. The loop gain and phase is checked using bode plot. The step response and impulse response are checked to determine whether the plant is under damped, over damped or critically damped. The transfer function of the plant is (I2/Vpv) =1/D(1+sL/R + s^2LC), here D is the duty cycle of the inverter, L and C are the plant inductance and capacitance respectively with R being the active load of the plant.This is the non-linear model of the plant depicted in Fig 7 (b). The input of the plant is Vpv which is the sinusoidal PWM switching pulses generated by the inverter.

To study the frequency stability of the plant, bode plot is obtained by linearising the model. The plot in Fig 7(a) shows the response is a low pass filter with two resonant peaks at crossover frequencies 2.5x10^6 rad/sec and 2.5x10^8 rad/sec and the phase angles at this point are -180^0 and -360^0 respectively. The gain margin is -65.5. Since, the resonant peaks are at very high frequencies, larger than the switching frequency and resonant frequencies of underground cable and transmission line, the system is therefore stable.

An impulse response function measures the time profile of the effect of shocks at a given point in time on the (expected) future values of variables in a dynamical system. The plant frequency depends on the linear components. The response at system at f_{system} realises the peak current under time domain. The response in Fig 7 (b) shows that the output of the plant cannot reach beyond 17.5A and the settling time is within 0.15s. Indian rules and regulations 2014 and its amendments states that the plant when subjected to transients should reach stability within 0.2s. The step response analysis provides a dominant time constant approximation for monotonic step responses. RLC circuits with non-equilibrium initial conditions may have response waveforms which are non monotonic. The RLC circuits may contain floating capacitors, grounded resistors, inductors, and linear controlled sources. The step input is fed as the inverter voltage and the output is obtained in the inverter current. It can be seen in Fig 7 (c) that the output saturates to 0.45A and the plant operation is critically damped without oscillating away from the operating point. At 0.02 secs, the output response is 0.03A showing that the inverter current at the operating frequency of 50HZ is 6.9A. The characteristic show the system is stable at its operating frequency. For a step change in voltage in the range of 1Volt, the inverter responses with an output current of 0.45A with a time response delay of 0.2s, also, the inverter current is balanced at 103.5A at an input voltage of 230V. It is found that there is a need to adjust damping factor L/RC. In the circuit this ration is kept at 50 (1/T= 50 HZ) so that the oscillations are damped within one cycle.

3) Variable Load Analysis using Q factor

High ramp rate of load is an important parameter in deciding the stability of the plant. The Q factor determines the amount of lag or lead of the load with respect to grid voltage. For analyzing the conditions with Q=1, 2 being the worst case conditions,

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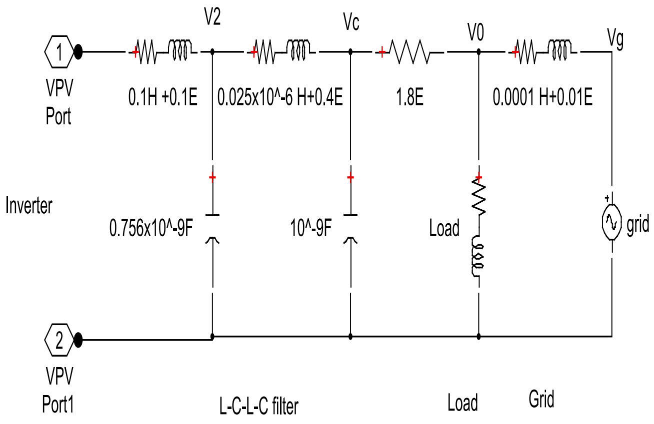
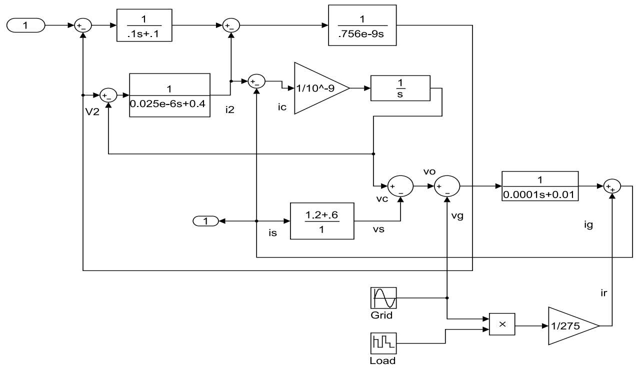


(a)



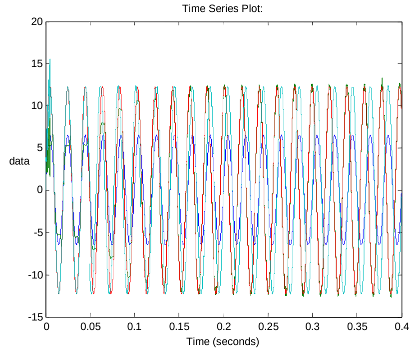
(b)

Fig 6 (a) Transfer Function Model of the DGS; (b) SIMULINK model of the transfer function

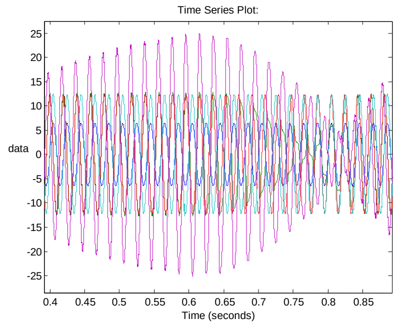
R-L-C load in parallel combination is considered. Here, R= 2000W corresponding to 26.45E. At Q=1, R/(ωL-1/ωC) =1; at Q=2, R/(ωL-1/ωC) = 2. The Q factor analysis not only helps to analyse the performance of the plant to variable load but also for frequency change. Q=1 is a condition for output frequency of the plant equal to resonant frequency of load. Q=2 is a condition for resonant frequency of load equal to half of the plant frequency. Here, R-L-C parallel combination is considered .The obtained results for Q=1, 2 are given in Fig 8 (a) & (b) respectively. It can be seen that the output current follows the reference current irrespective of the load peak value and frequency condition. Here the inferences are drawn with steady state DC input voltage source intervened to the plant. The output current is controlled using load angle control and the hysteresis bang-bang control built in the plant.

D. Impact of other grid parameters

The grid stability is not only affected by steady-state variations, voltage fluctuation, harmonics, frequency change Q factor of the load but also by the type of feedback provided in the inverter, DC current injection, intermittency of power, over-voltage, under-voltage, over-current, over and under frequency, phase-shift and transients. The load angle control implemented in the BIPS (detailed in the coming section) controls voltage fluctuations reduces harmonics and helps in steady performance. Its sluggish behavior mitigates transients. The inverter is provided with negative feedback which curtails shifting of parameters away from stable conditions. Symmetrical impedance matching inductors are provided at the output of the plant to mitigate DC current injection. Fault Detecting Relays are provided to arrest voltage-current-frequency-phase-shift jumps from their threshold values. Hysteresis bang-bang control installed in the inverter curtails the transient transformations. Finally, the intermittency of power is wisely managed by load-scheduling and energy management by the BIPS.



(a)



(b)

--- Scaled Grid voltage --- Reference current --- Output current
--- Load current

Fig 8 (a) & (b) The load profile diagram at Q=1 and Q=2 respectively

In the coming analysis, investigations are done to design the BIPS using a robust variable entity K-map.

VI. DESIGN OF BIPS

At present, in Kerala, grid tied PV inverters are designed without Energy Storage Systems (ESS). The Distributed Generation System serves a part of the load coming at a PCC, reduces stress on distribution feeders, and improves grid stability by reducing burden. However, they poses some issues such as injection of lower order harmonics, intermittency of power, prolonged shutdowns, voltage rise/fall at PCC during reduced or increased load hours, reverse power flow. If penetration of PV is greater than the local demand at the PCC, the excess power from PV may produce reverse flow in the feeder that would create rise in voltage. However, there will be a voltage droop if the grid voltage sags due to excess load flow. Active power curtailment [16] and reactive power consumption has been proposed for voltage rise mitigation. M.J.E. Alam et.al, have proposed a method to curtail voltage rise by managing power flow during peak/off peak hours. The introduction of ESS has been suggested by [16] to store excess flow from solar during noon time.

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$$E = U + jX_S I \tag{1}$$

$$E\sin(\delta) = X_S I\cos(\varphi) \tag{2}$$

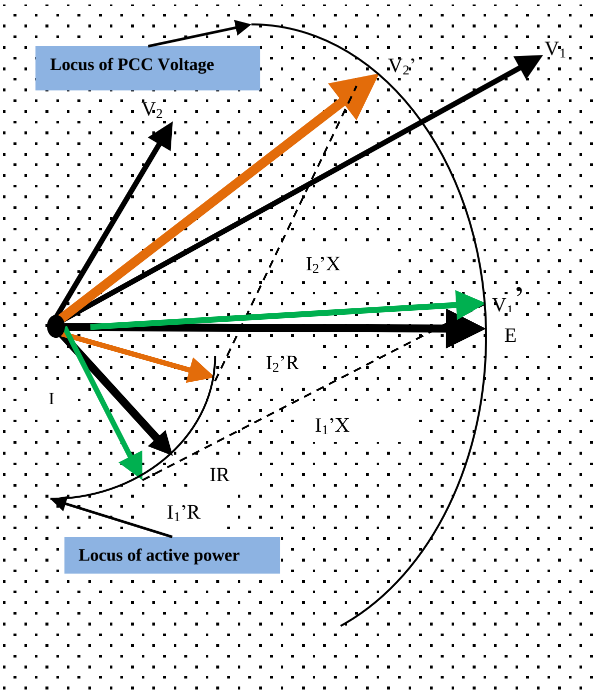

Fig 9 Phasor diagram with load angle control

The authors have also reduced reverse flow by injecting less In this paper, the authors have controlled active power flow in to and fro direction by using ESS. The operation using phasor diagram and four quadrant illustrations show the plant operates without curtailing active power. The authors have compensated for rise in voltage at a PCC by adjusting the load angle of the load profile. As illustrated in Fig 9, when there is a rise in PCC voltage (V1), the controller implemented in BIPS shifts the load angle in such a direction so as to bring the PCC voltage to V1'. There is no curtailment of active power as can be seen from the phasor diagram. Fig 8 also illustrates this condition. Here, the solar generator was operating in Quadrant I, while an increase in voltage at PCC is handled by a shift in operation to Quadrant IV where the inverter acts as a reactive power sink (see Fig 10)where the load angle changes in a direction to increase the lag (from IR to I1'R). Similarly, voltage sag due to overload is handled by change in load angle in a direction so as to reduce the lag angle. Here, the solar generator shifts from Q-sink to Q-source depending on whether the solar generator is operating in Quadrant III or IV.

In Quadrant III, the solar generator acts as a load since it sinks active and reactive power. So, in order that the operating point is shifted to Quadrant IV, the ESS discharges as illustrated in Fig 10. Similarly, when the operation is in Quadrant I, if the active power generated is in excess, the ESS stores the excess energy by charging and the operating point shifts to the left Quadrant II.

The BIPS has mainly three characteristics: 1) load angle control 2) load dispatching 3) Charge-discharge control. Each characteristic is depicted separately in Fig 11 & 12 respectively. The concept of load angle control is depicted in equations below and simulated in SIMULINK using the simulink version R 2013a (MATLAB 1.7) Fig. 11 depicts this concept in SIMULINK. We know,

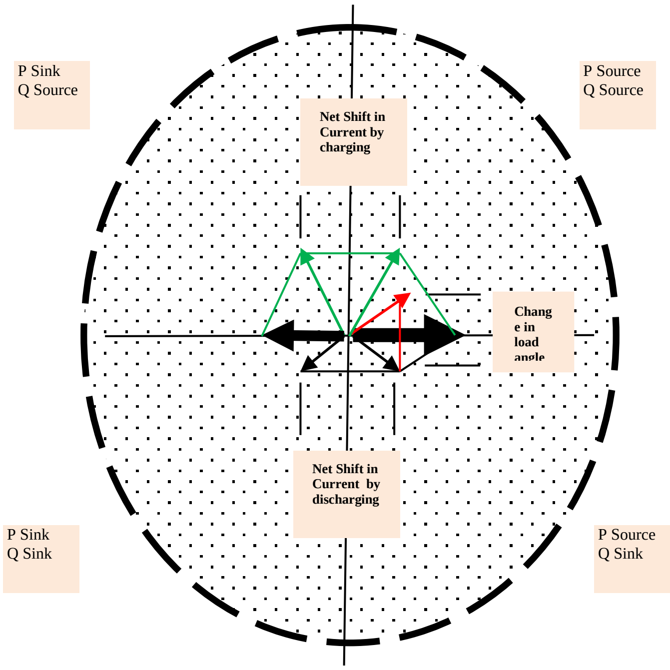

Fig 10 P-Q operation of the Solar Generator with Battery Storage

$$P - UI\cos(\varphi) = \frac{UE}{X_S}\sin(\delta) \tag{3}$$

$$Q = \frac{UE}{X_S}COS(\delta) - \frac{U^2}{X_S} = \frac{U}{X_S}(Eos(\delta) - U) \tag{4}$$

$$\Delta P_{active} \rightarrow V_1 \times I_1 \times COS(\delta 1) - V_2 \times I_2 \times COS(\delta 2) \cong \delta \tag{5}$$

δ is the load angle which is adjusted according to change in active power of the inverter . As the voltage of the grid increases, the power handled by the inverter suddenly increases resulting in an immediate change in active power. The BIPS algorithm senses this change and reduces the load angle thereby creating a lag in load current that immediately contributes to decrease in voltage. This regulates the active power at the same time the inverter output voltage as well. When there is a decrease in grid voltage the vice versa happens. It may be noted that the change in load angle is reflected in the reference current that is derived from E_mSin(wt) , the output of this block of BIPS as shown in Fig 11. In this figure P_{LOAD} is the forecasted load profile.

A. Karnaugh map method of load dispatch optimization

This section presents the use of K-map to convert Solar Grid Tied inverter to one integrated with ESS. It is assumed that the Distributed Generation System (DGS) has enough capacity to satisfy the local demand. In this configuration DGS maximizes the revenue of the beneficiary by exchanging power to the grid. The DGS takes part as energy service provider.

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It optimizes load dispatch using forecasted PV power, SOC, Grid Voltage, load, Peak shaving, Peak demand hours, upper bound and lower bound of Grid voltage. A de-centralized concept is used for scheduling the charge-discharge operation. Each DGS individually controls the load flow depending on the voltage level at PCC.

Four Quadrant operations are implemented by checking the condition of the P_{pv}, Battery, Grid, Peak time, Voltage fluctuation, and the load condition. An optimal load dispatch scheduling is done as illustrated in the coming section.

B. Problem formulation

The built in local controller gives commands to the inverter in order to control charge-discharge of the battery as obtained from the optimization stage. This stage works on data obtained from 1min to 1ms. The problem formulation objective is to convert the variables to logic 0 or1. This is illustrated Fig 13. By applying VEKM method of K-mapping, an optimum schedule for $P_{BATT(t)}$ can be obtained. This method of scheduling is simple and significantly representative of the constraints defined for optimum load dispatch. Let us talk about a fuzzy control system that is a control system based on fuzzy logic—a mathematical formulation that analyzes analogue input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively). The fuzzy engine works on a set of pre-defined rules, the number of rules to be defined is proportional to the number of inputs and outputs For example, if the number of inputs is seven, the number of membership functions are five, the output is 35. We have to pre-define 35 rules. As the number of inputs increases, the number of rules also increases. This is one of the major de-merits with Fuzzy engine. Another drawback is that the output membership function takes values anywhere between 0 and 1 depending of the conditions of the inputs. The output is always analog. For utilizing a digital logic to control the system, it is desired to develop a new controller. The fuzzy engine is henceforth limited in application where the modern engineering wants digital output. Fuzzy Sets and Fuzzy Logic Theory and Applications G. J. Klir, B. Yuan has defined the fuzzy scrip sets and the

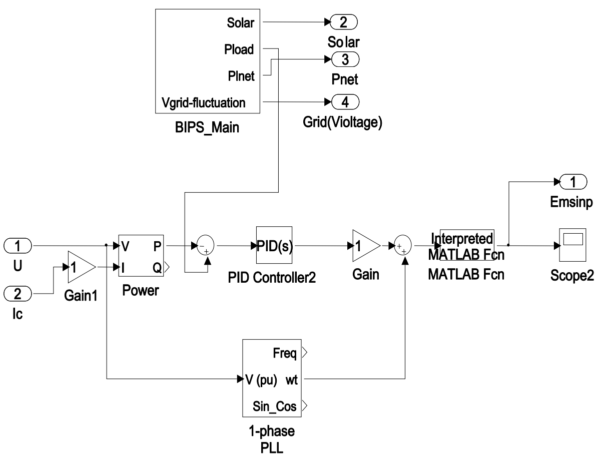

Fig 11 Load -angle control of BIPS

mathematical analysis with different fuzzy inputs and variable outputs. Probability theory is capable of representing only one of several distinct types of uncertainty. When A is a fuzzy set and x is a relevant object, the proposition "x is a member of A" is not necessarily either true or false. It may be true only to some degree, the degree to which x is actually a

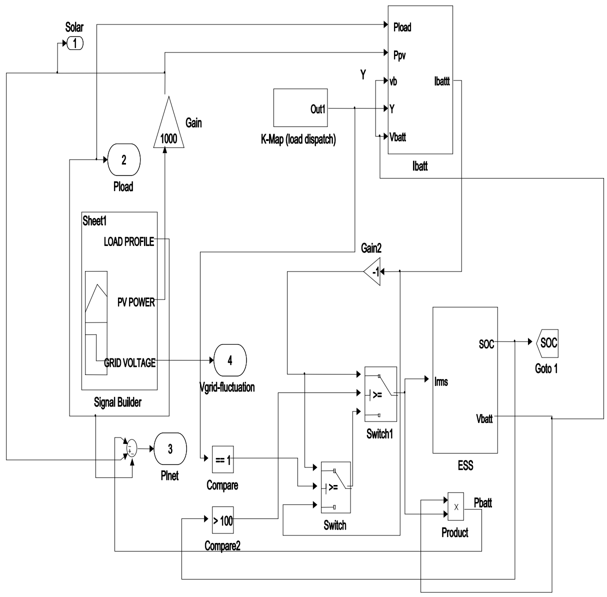

Fig 12 Power balance diagram using k-map

member of A. In the new engine we define an hypothesis function A: X= [0, 1]. For any input, the output variable X take value 0 &1, a degree for all types of inputs. This causes certainty in the membership functions. The de-fuzzification methods are based on mean values and hence the output variable is approximated from the inputs. The membership functions have uncertainties. Human reasoning is to derive the outputs that are limited in number of inputs. For utilizing a digital logic to control the system, it is desired to develop a new controller. The fuzzy engine is henceforth limited in application where the modern engineering wants digital output. The new controller minimises uncertainties and maximises inputs. Hence, Variable Entity K-map logic is introduced to improve the behaviour of the fuzzy logic system. Here, each variable takes the value 1 or 0 based on conditions. The variables can be expressed as a Boolean function, where ∫b =∑ min (A, B, C, D, E, F, G). We can write,

$$A = P_{PV}(t) = \begin{Bmatrix} 1 & for & P_{pv} \le P_{pv}^{low} \\ 0 & for & P_{pv} \rhd P_{pv}^{low} \end{Bmatrix} \quad (6)$$

$$B = SOC(t) = \begin{Bmatrix} 0 & for & SOC_{\min} \ge SOC(t) \\ 1 & for & SOC(t) \ge SOC_{\min} \end{Bmatrix} \quad (7)$$

$$C = U_g = \begin{Bmatrix} 0 & for & power \quad outage \\ 1 & for & on-grid \end{Bmatrix} \quad (8)$$

$$D = P_{load}(t) = \begin{Bmatrix} 1 & for & P_{load}(t) > P_{PV}(t) \\ 0 & for & P_{load}(t) < P_{PV}(t) \end{Bmatrix} \quad (9)$$

$$E = P_{shaving}(t) = \begin{Bmatrix} 1 & for & P_{PV}(t) \le P_{grid}^{\max}(t) \\ 0 \; for & & P_{PV}(t) \ge P_{grid}^{\max}(t) \end{Bmatrix} \quad (10)$$

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Groups

(32.33.34.35.36.37.38.39.40.41.42.43.44.45.46.47.48.49.50.51.52.53.54.55.56.57.58.59.60.61.62.63)	$\bar{A}.B$
(50.51.54.55.58.59.62.63.114.115.118.119.122.123.126.127)	B.C.F
(52.53.54.55.60.61.62.63.116.117.118.119.124.125.126.127)	B.C.E
(49.51.53.55.113.115.117.119)	$B.C.\bar{D}.G$

$y = \bar{A}.B - B.C.F - B.C.E + B.C.\bar{D}.G$

Fig 13 Representative picture for parameters of K-map and its output Y

$$F = Peak(t) = \begin{cases} 0 & for \quad off-peak \quad hours \\ 1 & for \quad peak \quad hours \end{cases} \qquad (11)$$

$$G = U_g \lim it(t) = \begin{cases} 0 & for \quad 80\% \geq U_g \geq 110\% \\ 1 & for \quad 80\% \leq U_g \leq 110\% \end{cases} \qquad (12)$$

$$Y = P_{BATT}(t) = \begin{cases} 0 & for \quad ch\arg ing \\ 1 & for \quad disch\arg ing \end{cases} \qquad (13)$$

$$C = U_g = \begin{cases} 0 & for \quad power \quad outage \\ 1 & for \quad on-grid \end{cases} \qquad (8)$$

$$D = P_{load}(t) = \begin{cases} 1 & for \quad P_{load}(t) > P_{PV}(t) \\ 0 & for \quad P_{load}(t) < P_{PV}(t) \end{cases} \qquad (9)$$

$$E = P_{shaving}(t) = \begin{cases} 1 & for \quad P_{PV}(t) \leq P_{grid}^{\max}(t) \\ 0 & for \quad P_{PV}(t) \geq P_{grid}^{\max}(t) \end{cases} \qquad (10)$$

$$F = Peak(t) = \begin{cases} 0 & for \quad off-peak \quad hours \\ 1 & for \quad peak \quad hours \end{cases} \qquad (11)$$

$$G = U_g \lim it(t) = \begin{cases} 0 & for \quad 80\% \geq U_g \geq 110\% \\ 1 & for \quad 80\% \leq U_g \leq 110\% \end{cases} \qquad (12)$$

$$Y = P_{BATT}(t) = \begin{cases} 0 & for \quad ch\arg ing \\ 1 & for \quad disch\arg ing \end{cases} \qquad (13)$$

As far as Kerala is concerned, the base demand hydel stations cannot be fully backed out of grid during day time. To reduce the capacity of this back up, the BIPS is integrated with the grid tied inverter to respond to the demand.

The combinational logic circuit outputs 1 or 0 in accordance with the inputs from 7 parameters. The simulated model of ESS (see Fig 12) generates the net power flow balance. The ESS charge-discharge profile is implemented as per the ESS equation generated in SectionVII (b). The optimal scheduled demand is a price –based schedule that takes care of Time-of-use and critical pricing. The variable mapping in K-map and the corresponding output Y is illustrated in equations (6)-(13) and Fig 13.

The optimal scheduling maximizes revenue over a given period of time by finding best possible control output from the BIPS, taking into account all possible values of the parameters considered. The BIPS compensates the forecasting errors by comparing with real time power fluctuations. The time steps in the scheduling instants are for the whole time horizons, looking for the N time steps. The schedule layer determines the optimal control sequences for each time step including the operation step and planned power of controllable units. For each time step of the scheduled layer, the power of controllable units based on operation state to optimize power flow and regulate voltage is adjusted by the dispatch layer. As the time step moves to t+i, the dispatch layer will optimize the power flow.

The forecasting data available in 6 min or 1h slot is used to schedule the parameters initially. It is then compared with the current state which is available in nth time step. If there is an error, the ESS reserve is adjusted and again comparison is done. If there is no error the load is dispatched according to the schedule, output of the dispatch is 1 or 0. If it is 1, adjust discharge rate according to the equation (14). Otherwise adjust charge rate according to the equation (15).

$$P_{net} = P_L - \eta_{inv} P_{PV} - (DR \times V_B \times DOD)\eta_B \qquad (14)$$

Here Pnet is the power injected to the grid, PL is the load power. DR is discharging rate of battery current. VB is the battery voltage; DOD is the Depth Of Discharge. From equation it is clear that by adjusting DR net power can be reduced to zero. In other words, the power injected to the grid can be controlled by adjusting discharging current of the battery.

$$P_{net} = \eta_{inv}(P_{PV} - CR \times V_B) - P_L \qquad (15)$$

where CR is the charging rate of ESS current. The power injected to the grid can be controlled by adjusting charging current of the ESS.

C. Energy Management

Equation (14) and (15) can be used to explain the proposed energy management in the system. When the grid is connected, the power needed to charge the ESS can be obtained from Ppv or grid. When the PV power is lesser than that needed by the ESS, Pnet becomes negative that is the grid energises the ESS. When the PV power is more than that required by the load, it charges from the PV source. When the ESS is fully charged, excess power is injected into the grid. Similarly, the ESS discharges when the PV power is lesser than that of the load power to compensate for the difference in power. ESS pumps excess energy into grid during peak hours when the ESS power is available in excess. The model used to simulate the solar micro grid-tied inverter with BIPS is shown in 1.1 in appendix. It consists of 2 kWp solar array, MPPT (MP&O algorithm), Current controlled inverter, PLL, Hysteresis Controller, ESS Intervention Power Supply (BIPS), Utility grid, Non-linear load and Anti-islanding system.

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The K-map is implemented to control ESS in BIPS. To study the performance, a typical load profile of a selected village in Kerala is used. The capacity of the ESS is sized using the procedure explained below.

VII. THE WORKING OF BIPS

The BIPS mainly functions in three control modes: (a) Active and reactive Power control during grid-tied operation (load angle control); (b) delivers power to grid and absorbs in storage during dynamic variation in solar irradiance (load During power disruptions, the inverter gets power from BIPS and supplies local priority loads if the State Of Charge (SOC) of the ESS pack is sufficiently high.

- When the grid voltage fluctuation is beyond the limits in [2], the inverter goes to off mode and energizes the local priority loads thru BIPS if SOC is sufficiently high.
- When the solar irradiance is below 500 W/m2, the output current shows distortions due to poor regulation. Also, there will be reduction in efficiency of the inverter as illustrated in Fig 3. During this time also BIPS connects the ESS pack to the inverter input and supports the output waveform.
- When there is a voltage sag or swell, the BIPS tries to regulate the output voltage by shifting the phase of the output current so that it leads or lags accordingly.
- When the load angle changes thereby changing the load frequency and power, the BIPS regulates the output using P-Q control.

VIII. SIZING OF BIPS

The capacity of BIPS can be identified by its characteristics such as power capacity, location, efficiency and charge/discharge response time available. More complex solutions [20] are available for large energy storage systems integrated with micro grid. However, for micro DGS for optimization of BIPS a simple approach is described. This approach optimizes the BIPS capacity by taking into account its characteristics mentioned above and on an economic perspective. In order to size the ESS in the BIPS, the corresponding Linear Programming (LP) is given below. The LP is limited by two constraints P(t)max and P(t)min. The upper and lower boundaries of the ESS capacity are obtained. The ESS capacity selected can lie anywhere within these limits.

```
Pmax=Vmpp*Impp;
Do P(t)max=Max{ABS(P(t-1)-Pmax)/(DOD*ηd)}
while(t<=N)
P(t)min= Min{(Pmax-P(t-1))*ηc};
//Pimax is the maximum capacity of DGS

batt capacitymax=Round{(P(t)max /Vbatt),0}*Cb;
batt capacitymin=Round{(P(t)min/Vbatt),0}*Cb;
Average Batt Capacity = (batt capacitymax+ batt
capacitymin)/2;
```
(16)

Pmax is the maximam power of the MPP; Vbatt the rated ESS terminal voltage at 100% SOC; Cb the discharge capacity of the ESS taking into account the time of availability of irradiance; N number of iterations, ηd is discharge efficiency of the ESS, DOD the Depth Of Discharge of the ESS; ηc the Ah efficiency of the ESS; This software also helps in optimization of demand and life cycle of the ESS. Under-sizing of storage ESS will increase distortion in output of DGS, reduce the ESS lifetime but minimizes the cost and vice versa. In the capacity validation step, the ESS DOD, ampere-hour efficiency and autonomy are considered. From an economic perspective the location wise design optimization ensures that the ESS capacity is optimally sized. Techno-economical sizing of the ESS is adopted here. A reduced step design method is done here.

A. Capacity Determination verification

Today, satellite data of solar irradiance at most locations is easily available on-line. From the data, minimum irradiance (W min) available in a region during a worst affected month is determined. The daily average hourly voltage fluctuation data of the feeder to be energized with the DGS is collected from the Power Distribution Company. The optimum capacity is then determined by simple steps given below:

$$I_{batt(max)} = \frac{W_{rated} - W_{min}}{V_{batt}} \tag{17}$$

$$C_{batt} = \frac{I_{batt(max)}}{DOD \times \eta_a} \times \left(K_a + K_i\right) \times \mathrm{K_e} \times 3 \tag{18}$$

$I_{batt(max)}$ is the maximum value of ESS current, W_{rated} the rated power of the SPV Array, W_{min} the minimum power generated by SPV Array corresponding to the location of installation, V_{batt} the daily average voltage at PCC, C_{batt} the discharge capacity of the ESS, Ka a constant proportional to daily average hours during which the inverter is disconnected from grid due to voltage fluctuation/power disruptions, Ke an economic factor, DOD the Depth Of Discharge of the ESS, ηa the Ah efficiency of the ESS, Ki a constant proportional to daily average hours during which the solar irradiance stays below 500W/m^2.

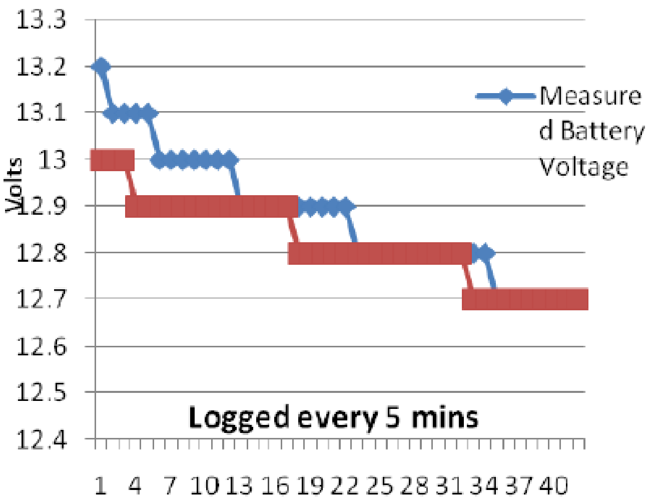

Fig 14 Simulated and measured behavior of ESS discharge profile

B. ESS Modeling, Simulation and experimentation

The ESS voltage at any instant Vb after a charge/discharge time t is given by (19) [21]

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$$Vb = Voc \pm i \times \left((r0 + (kd1 \times t \times i^2 \times r0) + \left(\frac{kd2 \times i \times t}{Vbatt - Voc} \right) \right) \pm kd3 \times i \times t \qquad (19)$$

Voc is the initial voltage before a charge/discharge; i the ESS rated current, t the duration of discharge, ro the internal resistance of the ESS. The constants kd1, kd2 and kd3 are given in Table 3 below. These are three unknowns that are obtained by non-linear regression analysis curve fitting method using a ESS model AMCO, 12V, 20 Ah VRLA. r0 is obtained by the following procedure. Discharge the ESS at constant current of 500mA by 75%. The final voltage V1 is noted. It is then charged at constant current of 500mA. After one second, the corresponding voltage V2 is noted.

Ro = (V2-V1)/0.5 is obtained.

Table 3 Curve fitting parameters obtained for AMCO (Indian), 12V, 20 AH glass mat VRLA.

Kd1	Kd2	Kd3	ro @ 10.75 V
3.17E-05	1.00E-06	4.58E-05	0.005Ω

The model of the ESS in (19) is validated and produced in Fig 14. The 34 numbers of AMCO 12V, 14.5 Ah ESS model (designed using [(17) & (18)]) is connected in series. The following questions are answered in simulation using MSEXCEL spreadsheet (appendix 1.3): What is the role of BIPS? Whether the BIPS gets properly charged during a day? Whether it is over discharged during a day? Whether proper cut off is there to prevent over discharging? Whether charging and discharging is controlled? For answering these questions, the following inputs are applied to the logic controller designed in MSEXCEL spreadsheet. A typical variation pattern of solar profile in watts in a region is shown in Fig 4. A typical voltage fluctuation pattern is generated as given in Fig 15. These data are applied to the input of the LC simulated in MSEXCEL see appendix 1.3. Here, the solar load profile falls below 500W for an aggregate value of 1.1 hours and the grid fails for an aggregate value of 36 mins. Thus, a 2 kwp grid tied inverter with input voltage at 360V (where minimum irradiance falls around 200W), requires a ESS pack of 360V, 14.5Ah @C/10 sized using (17) & (18). The simulated behavior is given in Fig 16. It is clear that the role of BIPS is to deliver maximum energy during minimum solar insolation levels. It is clear that the BIPS discharges during large changes in solar irradiance. It is disconnected from the system during normal irradiance levels, during stable grid and lower SOC levels as shown in Fig 16 by switching to 'zero' output or to local priority loads. It charges during low SOC levels/grid failure/voltage fluctuations and peaking of solar radiation as shown in Fig 16 & 17. Power output of the DGS is smoothed by the action of BIPS as given in Fig 17. Finally, the ESS level is reasonably not high enough to participate in powering local loads. On a daily average, BIPS has to store 2.7 units of energy to be utilized locally or to be sold to grid.

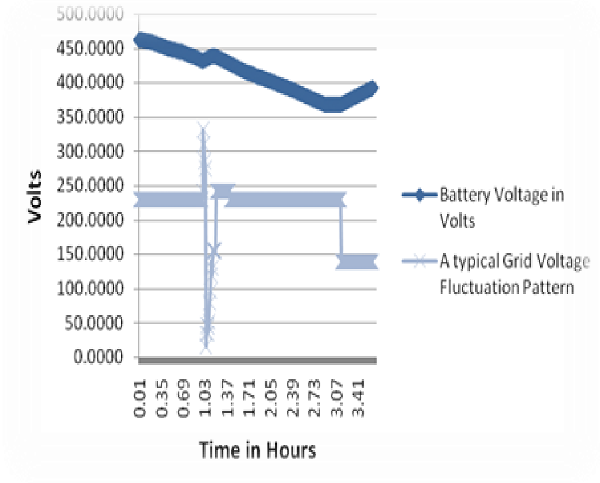

Fig 15 A typical grid voltage fluctuation pattern applied to FLC input and the corresponding output voltage of the ESS

When the LAB for 7Ah @C/3 sized by LP, is put, the DGS output is steady throughout as simulated in MSEXCEL spreadsheet (see appendix 1.3), for the grid is stable and performs with high power quality and even during zero zone the BIPS output is enough to load the grid, see Fig 18, the DGS supplies power to loads connected to it. Thus, a 2kWp grid tied inverter with input voltage at 360V (where minimum irradiance falls around 200W/m^2), requires a ESS pack of 360V, 7Ah.@ C/3 high density ESS. The optimized design of the ESS capacity provides 24 hour energy and as well the excess power can be stored and to be regained during shadow/rainy/foggy states.

IX. RESULT AND DISCUSSION

This paper has done the preliminary analysis on how to design the control of solar irradiance with a simulated ESS logic. The sizing of ESS in BIPS is checked using simple steps in MSEXCEL spreadsheet. For a 2kWp solar array the ESS capacity is 360V, 7Ah @C/3. The sized ESS is put in VEKM controller. The charge-discharge control generated by the BIPS tragically and automatically controls the solar radiation to give a smooth output.

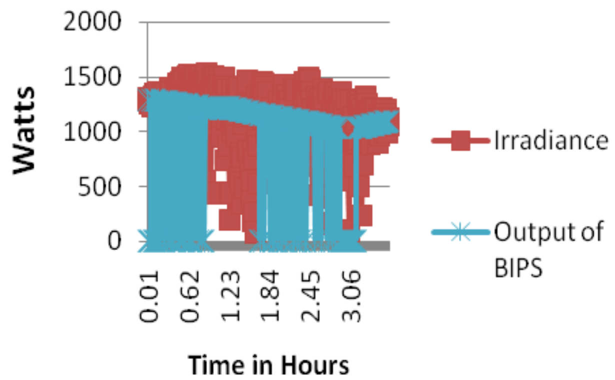

Fig 16 Simulated behavior of the BIPS to solar irradiance variation with undersized ESS

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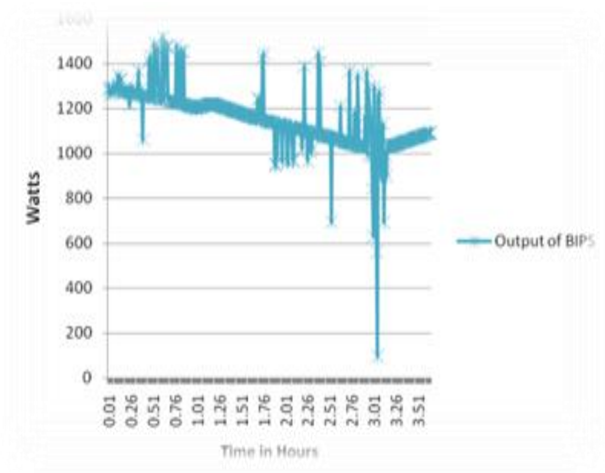

Fig 17 . Smoothed Power Output of the BIPS

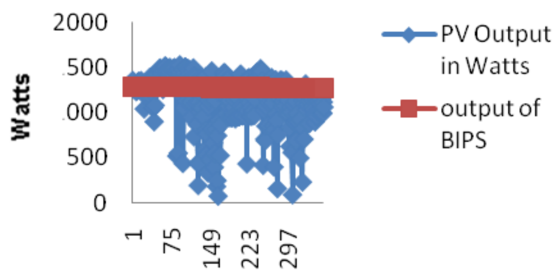

Fig 18 Experimental output of the BIPS for the program given in (6)

The charge-discharge component represents the corresponding absorption-expulsion energy of the DGS. Thus BIPS in effect smoothes the output to an extent, however, for avoiding the erratic changes in the output of the DGS. The behavior of the control strategy towards varying load profile, grid profile, and solar profile in watts is studied in detail. The profiles used are data from a typical village in Kerala. The net power Pnet that follows equation (14) & (15) and the plot of forecasted data are illustrated in appendix in 1.2. The proposal is implemented to the planning of ESS in a distributed network with rated active load of 2000 watts, and volt ampere reactive load of 1400 VAr with a base voltage of 230V.Two types of net power control is depicted in appendix 1.2 (a) & (b) in appendix. The sampling period for the forecasted data is 6 minutes. The daily curves of load and solar power are shown in Appendix 1.2 in the figures. The net power profile for constant ESS current is shown in appendix 1.2 (a). LAB is used in this planning study. The capacity of ESS is kept at 7Ah, 360V. The upper and lower limits of SOC are 100 & 50% respectively. The overall round-trip efficiency of ESS is set to be 70%. The capacity of ESS is set by the LP method (6). Upper and lower limits of grid voltage is set at 110 and 80% respectively appendix1.2 show the optimum results of the proposed method. The ESS controls energy management by charge-discharge. The charge-discharge of the ESS with a constant ESS current kept at 3A for a 2000Watt load profile show that the net power can inject lower order harmonics and will more or less closely follow the erratic variation in PV power such that Pnet =Pload-Ppv+PBatt. From appendix 1.2(a) when Pnet is positive, power is pump to grid and when Pnet is negative, power is drawn from grid. To analyse in detail, initially ESS charge/discharge current is kept constant at 3A. The net power flow is decided by the PV profile, load profile and ESS wattage profile using energy management by KLC. Here, appendix 1.2(a) shows disturbances in output power Pnet due to erratic behavior of the profiles. In order that this disturbance is curtailed, Pnet is kept zero. Appendix1.2(b) is depicting the condition with net power set to zero. Here it is clear that the ESS absorbs the erratic variation during load dispatching operation at the PCC, thereby the ESS easily manages the disturbances. For the given load profile, it is seen that a 350V, 7Ah @C/3 high density ESS could provide continuous back-up with zero net injected power. During critical condition where ESS cannot support the load the DGS powers the load through the grid. However a properly designed ESS in accordance with linear programming method (16) and with Optimum Energy management will yield the required results. To investigate the effect of rise in grid voltage at the output of the DGS on PCC operation, the grid voltage is enhanced to 400 Vp (Appendix 1.4)(a)). The active power output varies for reactive power injection and brings the DGS current to the reference value. The net active power does not change whereas voltage at PCC is controlled. To investigate the effect of fall in grid voltage at the output of DGS on PCC operation, the grid voltage is reduced to 200 Vp (Appendix 1.4 (b)). The load angle of DGS current shifts (leads) to make the net change in active power to zero and PCC voltage is controlled.

X.CONCLUSION

The ESS in BIPS is modeled for C/3 discharge rate in this typical configuration where the irradiance is available in an average period of 3h. The SIMULINK model of ESS is given in appendix 1.1. Here the internal resistance of ESS is 0.00075x7E. The simulation results reveal that the energy management of BIPS in four quadrants leads to improvement in grid stability. Controlling of unwonted frequencies, voltage fluctuation, mitigation of DC injection, improvement in power quality, improvement in time of use of DGS are finally achieved. This new approach controls the solar powered households independently. As the penetration of the system increases, voltage fluctuation and power disruption gets controlled and the overall generation becomes stable. Here, the Micro Distributed Generation System has been introduced not as an alternative to micro grid. Micro grids have ESS Energy Storage Systems (BESS) but are interdependent, used along with renewable energy units where a central management system controls the energy flow and load management with the use of distribution and transmission networks. BESS is generally designed to control frequency and power flow in the overall system. In the proposed system, Solar PV and simulated ESS is an integrated solution to stabilize grid and improves power quality. Thus this contribution stands unique towards micro grid and is a distributed generation system working with and without utility grids on electrical regional basis. In India, Micro DGS integrated with BIPS is yet to be implemented. This would ensure energy smoothing and enhanced power quality to grid. The effect of voltage fluctuations of grid has been tackled by BIPS. Transient disturbances and sub- harmonic oscillations are reduced by tuned ac filters and the BIPS.

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BIPS enhances the generation performance of Grid Tied Inverters. Therefore this paper proposes a better solution to overcome the demerits of the conventional grid tied inverters used in micro solar distributed generation in power Grid of Kerala. Introduction of roof-top installations of BIPS integrated inverters would lead to reduced length of feeders and also reduces the need for higher ratings. For meeting the future demand of each house-hold, the conventional grid can be augmented with renewable as and when grid parity is achieved. Concluding, use of BIPS would greatly help in higher penetration of solar in the energy scenario and reduces the length of transmission lines.

FURTHER WORK

A. Inverter/Controller

Development of the inverter/controller shall now a central element of the future program. The inverter transforms dc power from the PV array to grid-quality ac power. The inverter may also charge and discharge energy storage, and may control smart loads, e.g. smart appliances, especially in residential systems. The inverter/controller, if it contains adaptive logic, may also determine when excess energy is dispatched to the grid or stored.

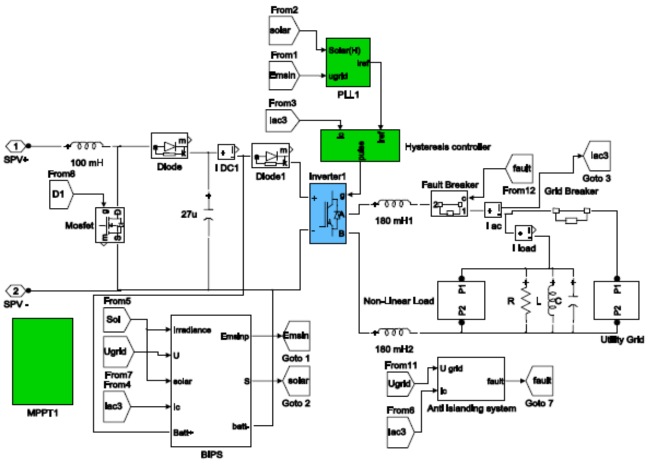
A number of elements have been identified for research and development and possible inclusion in the inverter and other elements of the Solar Energy Grid Integration System: Integrated circuitries (such as monolithic electronic modules), layouts and packages to improve applications flexibility, facilitate thermal management, survive high-temperature operation, and to ease building integrations, thermal management through innovative technology e.g. Micro Electro Mechanical Systems (MEMS) or innovative components and engineering, engineered transient over-voltage surge protection on both the AC and DC sides utilizing new devices and complete system designs that minimize inductive coupling and induced surges. DC-side over-voltage suppression devices must be capable of clamping transients of up to 300 V/module and 100 V/sec, open communication protocols and determination of the optimal inverter/controller "intelligence" for PV applications, elimination of least reliable components (currently electrolytic capacitors) or the use of selective redundancy that results in low-cost reliability improvements, utilization of new but proven state-of-the-art devices (such as wide-band-gap devices, new long-lived capacitors, advanced low-loss magnetics, and innovative packaging and circuitry layouts), reduced cost and complexity of installation through innovative installation methods, reduction in DC-side component count, and reductions in on-site programming and engineering requirements (Plug-n-Play goals), innovative integration of electronics/control and communications with PV modules or within listed PV module packages, self diagnostics for the inverter/controller/energy management and the system with reporting capabilities for remaining lifetime predictions, micro-grid-ready controls that can enable intelligent electrical grid support such as dispatchable or intentional islanding, integrated energy storage control and optimization to maximize the benefits of the renewable energy resource, integration with residential and commercial building energy systems for the retrofit and the new buildings market (e.g. Zero Energy Homes), smart, integrated system controls with algorithms and secure communication capabilities to optimize system value and energy efficiency, compliance with "National Electrical" and "Building" codes and domestic and international standards and certifications.

B. Adaptive logic controller for net metering

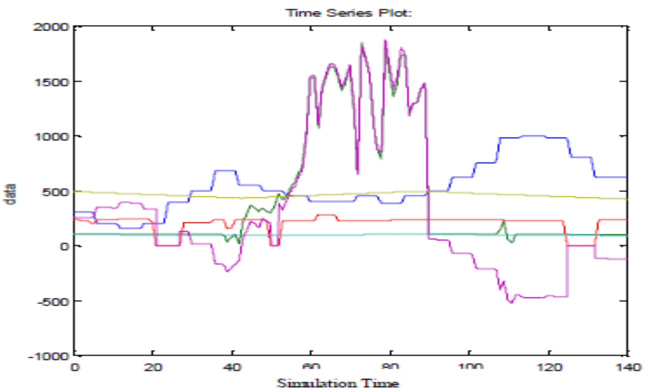
Controlling loads and managing the flow of available energy from the solar system, the flow of energy to and from the grid, to and from storage, and to loads for the purpose of ensuring system value is not a trivial task. Both the solar resource and utility demand, including real-time pricing, is a function of weather as well as the time of day, day of the week, and day of the year. To avoid the need for power during high time-of-use rates or having high demand for just 30 minutes a month that can significantly increase the utility bill requires anticipation of the energy consumption relative to the level of energy stored and likely future energy needs. An adaptive logic controller that also monitors weather forecasts could increase system value by managing these power flows. An adaptive logic controller is able to learn. Thus, instead of relying only on pre-programmed energy management strategies, it develops its own optimization algorithms from past energy demand, utility pricing signals, and Renewable Energy resource availability relative to weather patterns, time of day, etc. Such a controller has to be a part of the inverter that can communicate with it, the smart meter/energy portal, and the internet.

APPENDIX

Micro Model of DGS



1.2 Load Dispatch Profile (a) for Constant ESS Current (b) for Pnet set as zero



(A)

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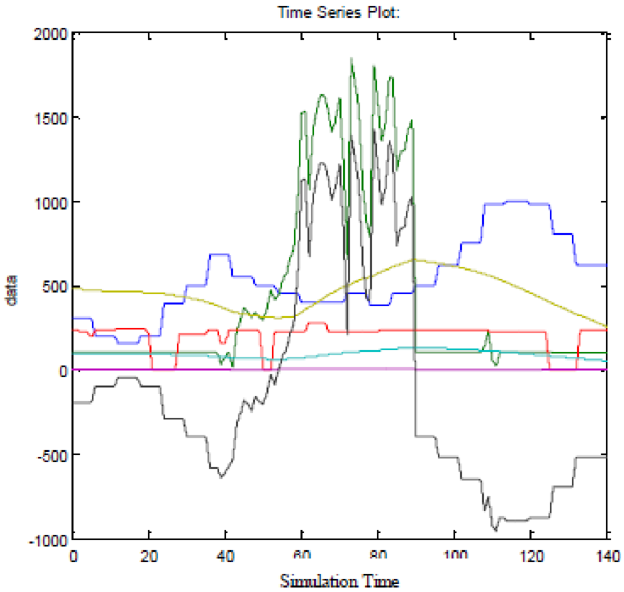


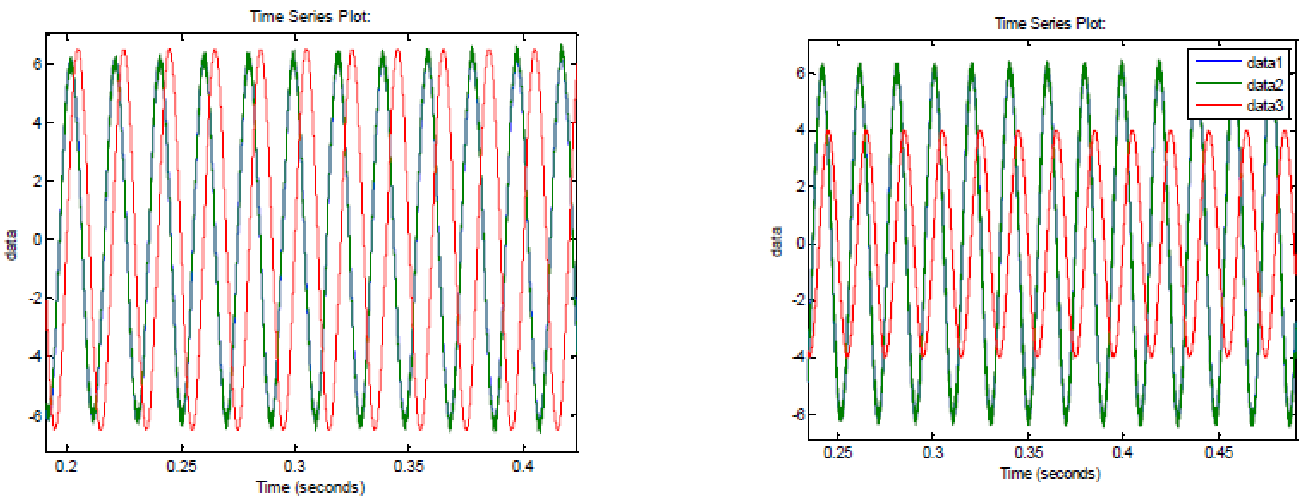
----- Load Profile ----- PV Profile ----- Grid Voltage Profile ----- Pbatt Profile ----- Vbatt Profile ----- SOC ----- Pnet

(B)

1.3 MSEXCEL Program for checking the design of the ESS

The program is written in MSEXCEL spreadsheet for simulating the logic control of the BIPS. Here, B-> Ppv; E-> Pbatt; Q-> Vgrid Conditionallogic=IF(AND(ABS(B2-B3)>=30,E2>368.9,Q3<264.5,Q3>161),E2-irms*((rdo+(_kd1*t*irms^2*rdo))+(_kd2*irms*t)/(489.6-E2))-_kd3*irms*t,IF(AND(B2<=500,E2>368.9,Q3<264.5,Q3>161),E2-irms*((rdo+(_kd1*t*irms^2*rdo))+(_kd2*irms*t)/(489.6-E2))-_kd3*irms*t,IF(AND(OR(264.5<Q3,Q3<161),E2>438.6),E2-irms*((rdo+(_kd1*t*irms^2*rdo))+(_kd2*irms*t)/(489.6-E2))-_kd3*irms*t,IF(AND(OR(264.5<Q3,Q3<161),E2<462.4),E2+irms*((rdo+(_kd1*t*irms^2*rdo))+(_kd2*irms*t)/(489.6-E2))+_kd3*irms*t,E2))))

1.4 (a) Current Profile of the DGS @400Vp grid voltage. (b) Current Profile of the DGS @200Vpgrid voltage.



(A) **(B)**

---- Reference Current ---- Inverter Current ---- Scaled Grid Voltage

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