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International
Journal
Of Modern Engineering Research (IJMER)

Impact of Solar Distributed Generation on Lt Grid of Kerala

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ABSTRACT:- The paper discusses issues faced while implementing solar generators in Kerala Grid. A fault analysis is done using PSAT MATLAB. There is an increase of 20% fault current in grid with every 10% penetration of PV. Use of adaptive relays thermal protection and underground cables are suggested here. The Battery Intervention Power Supply (BIPS) used here with solar inverter greatly help in reducing the current harmonics in the output waveform of the inverter. It also helps in improving the performance of the inverter during low irradiance levels. BIPS is intervened as and when required only in order that the system is economically affordable.

Index Terms:- **Distributed Generation (DG), Grid Tied Inverter, Solar, BIPS.**

I. NOMENCLATURE

CEA - Central Electricity Authority
PVSG - Photovoltaic Solar Generator
PCC - Point of Common Coupling
BIPS - Battery Intervention Power Supply
FFT W AVR - Fourier Frequency Transform with Automatic Voltage Regulation
FFT W.O. AVR- Fourier Frequency Transform without Automatic Voltage Regulation
SOC - State Of Charge
DISCOMMS - Distribution Company
IPP - Independent Power Producer

II. INTRODUCTION

With the demand for energy growing rapidly, Nations all over the world are keen on resorting to renewable sources. Along with or may be ahead of many States in India, Kerala has also been keen on focusing on the development of the renewable sources mainly Solar and wind forms.

During 1990s standalone sources began to gain importance in the State of Kerala. Solar Photovoltaic Power Plants, SolarThermal Power Plants, Waste to Energy Plants and some others are the outstanding schemes under this. It is during 2000s that the renewable sources energizing the conventional Grid came into commercial existence. Micro Grids such as small hydro power plants, solar roof-top power plants, wind Energy systems, Waste-to-Energy plants are the few among the others. Distributed Generation (DG) systems also began to get widely accepted in Kerala during this era. DGs from micro scale to utility scale applications are there. They are more accepted nowadays. Recent application of renewable energy is the networked sources or Smart Grid technologies where various renewables are interfaced via intelligent communication networks.

Solar energy and wind energy technologies have a bright future in our state. Solar energy is abundantly available. Even canals and backwaters are the place for solar. In case of wind energy, Kerala has an identified potential of around 700 MWp.

Newer technologies such as Hybrid systems and stand alone battery packs are being experimented in many developed Nations.

In accordance with CEA regulations, Solar Grid connected projects in Kerala is limited to 80% of the minimum connected load at a PCC. In Urban areas the minimum connected load at a PCC during peak hours can reach around 200kWp. When the percentage of solar penetration is low, the ability of a solar power plant to impact the grid is minimal, but as solar power continues to expand, the potential for grid impact increases as connected solar capacity can reach as far as 200kWp.

A solar load of 200kWp at a PCC has minimum effect on a distribution transformer with 1MVA capacity and connected conventional grid. When the connected load is maximum during peak hours, the total generating capacity of the grid including solar becomes 1.2MVA. This would inadvertently affect the Grid. The effect is mainly to happen in urban areas in the state.

Among the above mentioned technologies it is the solar that has been widely accepted at present because of its green nature, environmental friendliness and abundance.

With the installation of more and more solar to the grid, the DISCOMMS and IPPS should ensure that solar plants should be harnessed in a safe and reliable manner. As a result, there is increasing codes and regulations announced by the Government of India from time to time on connecting solar power (and other renewable energy sources) to the grid.

We know that conventional grid is capable of providing reactive power and easily absorbs voltage sags and swells. This is not the case with solar. In our state, voltage sags and swells are frequent with frequent power outages (disruptions). So, it is important that solar plants should be capable of injecting or absorbing reactive power to the grid. Single micro DGs have a capacity less than 5kVA. However, they are also significant as their connected total capacity to the grid increases.

New grid interconnection requirements in Kerala say that solar should not produce undue flicker, should be stable against transients, reduce harmonic effects and manage voltage sag and swell of grid within the limits of 80-110 %.

An impact assessment is therefore done to find the performance of solar inverters under different conditions. The following analyses are done in order to study the impact of solar DG on the distribution Grid of Kerala.

III. PERFORMANCE ANALYSIS

Kerala is often faced with the problem that the every year demands for electricity often out weights the availability. Hence the introduction of SPV generation in micro levels in the form of roof top installations can be an accepting step in mitigating this problem. Notably, Kerala has a higher population density and thus rooftop installation can be considered as a positive step in this direction. However, increased penetration of solar can raise the following issues:

1. Kerala is often cloudy and clouds pass by every 5 -10 minutes. This can lead to ramping effect of solar irradiance which would in turn result in injection of current harmonics in the output waveform of the inverter.
2. Power disruptions are frequent in Kerala. Hence the solar generation can go underutilized.
3. Because of fluctuation in solar energy, the base demand hydel stations of Kerala cannot be fully backed out of grid.
4. Kerala is faced with almost five months monsoon. Hence, the power flow pattern from storage less solar generation is not reliable.
5. The voltage limits set by CEA India is not at all applicable to Kerala grid.
6. As the number of solar generators connected to grid increases the fault current also increases.

The following analyses are done to assess the performance of solar generators on the grid.

A. Fault Analysis

The model of Photo-Voltaic Generation in the grid can be described by two ways: active voltage controlled model and reactive power controlled model. The reactive power can be controlled directly as a preset value or indirectly through controlling the voltage magnitude at the point of common coupling (PCC). Based on these models, studies of the effect on the system's voltage and angle stability of integrating PVSG into the grid with three fault are presented and discussed for the IEEE 14-bus benchmark system. The analyses are performed at the transmission system level and from the system operator's perspective. The following are the models that can be considered for the PVSG, as per [7]:

- Model 1: Constant P and constant Q control.
- Model 2: Constant P and constant V control.

The single-line diagrams of the PVSG models according to the control modes and their capabilities are depicted in Figs.1and 2 for Models 1 and 2, respectively.

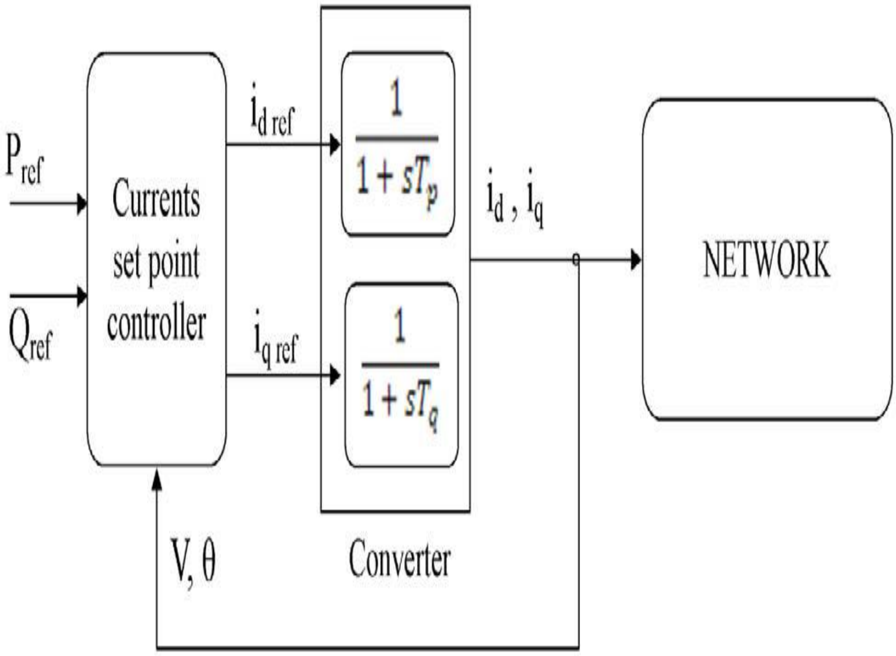

Fig 1. Single line diagram of Model1 of PVSG

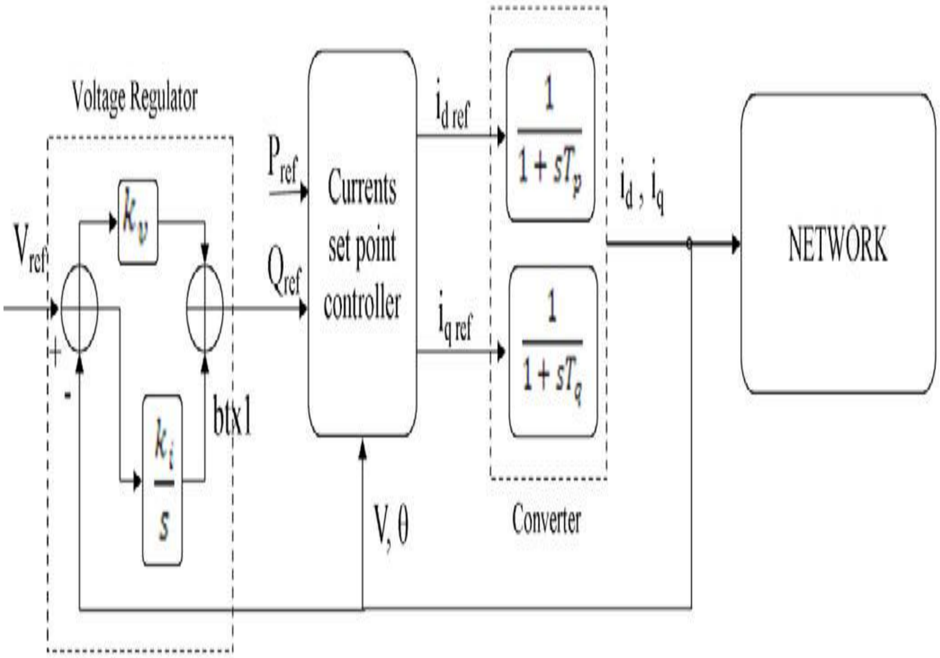

Fig 2. Single line diagram of Model2 of PVSG

Fig 3 depicts the IEEE 14-bus test system used here The system uses three 300 MVA synchronous generators at Bus 1,3 & 8 and a 30 MW PVSG, to allow a realistic modeling of the effect of adding an PVSG to an existent system (solar-power generation would be less than 10% of the installed capacity in this case). The base system load is 362.6 MW and 113.96 MVAr, with the loads being represented using an exponential load recovery (ER) model, since this model is appropriate for voltage stability studies; the recovery time constant for both active and reactive powers was set to 60 seconds.

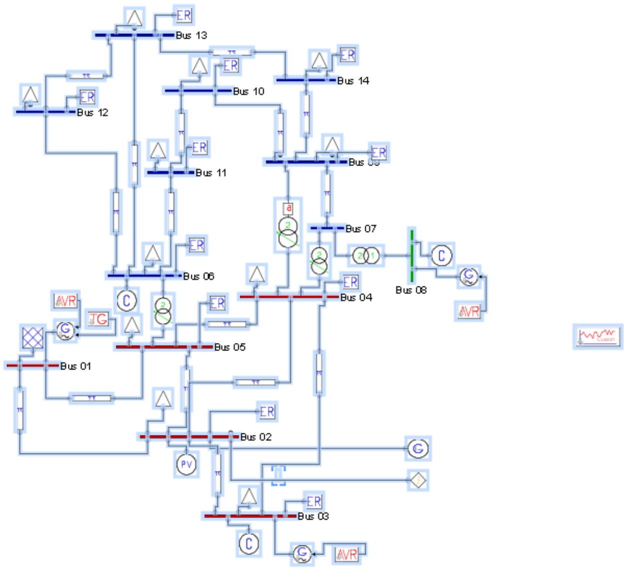

Fig 3. IEEE 14 bus network connected with PV model 2.

All numerical studies were performed in PSAT 2.8.1, which is a MATLAB-based toolbox for power system studies.

From Fig 4 and 6, the behavior of the grid with and without PVSG is very clear. Bus 14 shows considerably reduced oscillations with PVSG for normal operation. Fig 5 depicts the behavior of PVSG with fault. The bus 14 is taking more than 2s to recover from fault. The voltage setting of the relays has to accordingly set to accommodate this anomalous behavior. Fig 8 and 9 gives an idea of amount of current generated by PVSG with and without fault. There is a rise of 20% in current during fault with every 10% penetration of solar power. The over-current relays should be preset to accommodate this rise. The short circuit current of the feeder is 1.25 times nominal current. So, the relay settings have to be accordingly set. The feeder ratings are also significant when grid is charged with PV. There is a significant improvement in power factor of the bus with PVSG. While qualifying a PVSG for installation, time and parameter settings of the over-current and fault detecting relays are henceforth important. It is suggested that in order to adjust with the values, the relays on the PVSG side should tackle the feeder short circuit current. The best solution is to go *for adaptive relays*. The feeders should be underground cables and connected directly to the Distribution Transformer in order that the feeders are designed and sized appropriately. Short circuit condition creates thermal runaway problems that have to be tackled using thermal relays.

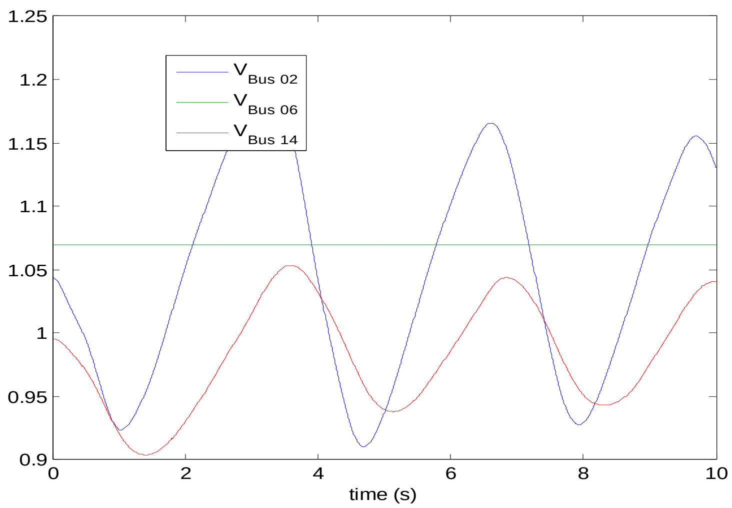

Fig 4. Voltage profile at buses with PVSG and without fault

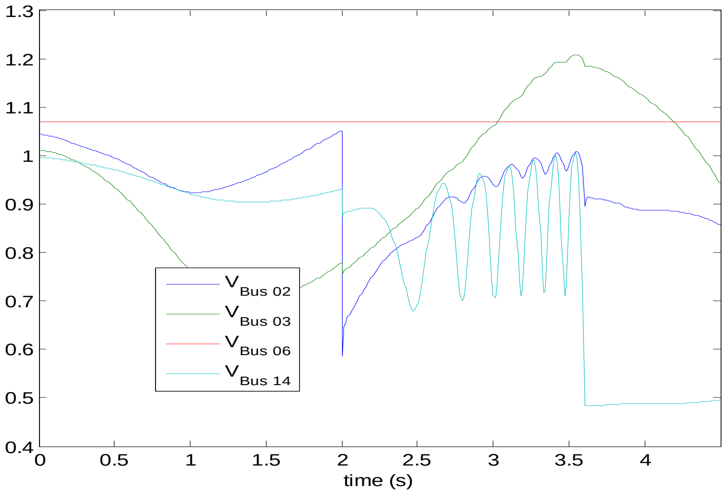

Fig 5. Voltage profile of grid at three phase fault with PVSG (fault time: 2 sec , fault clearing time:4.5sec)

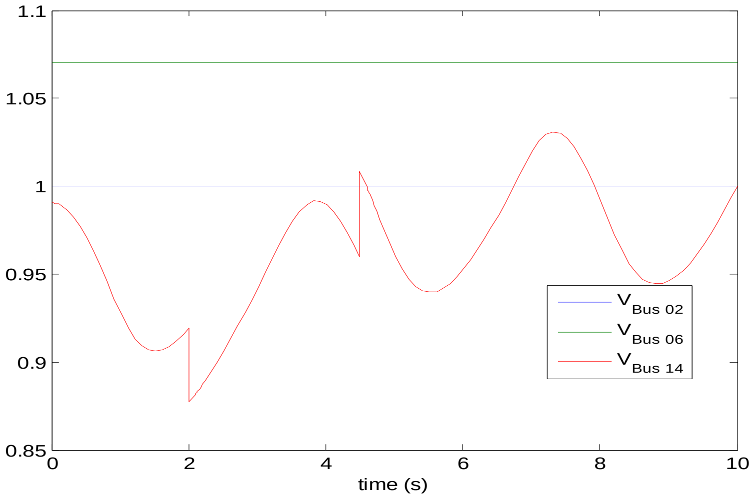

Fig 6. Voltage profile without PVSG and without fault

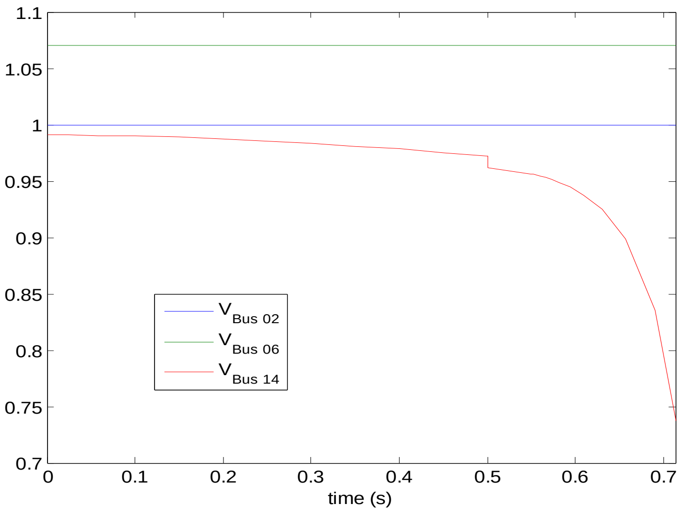

Fig 7. Voltage profile without PVSG and with fault set at 0.4 s and cleared at 2s.

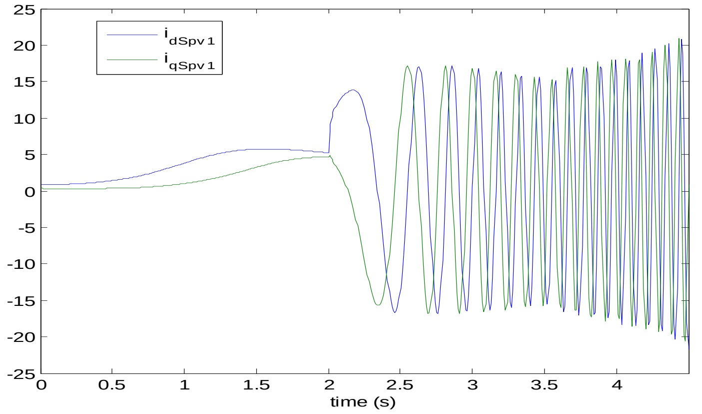

Fig 8. Current generated by PVSG at fault.

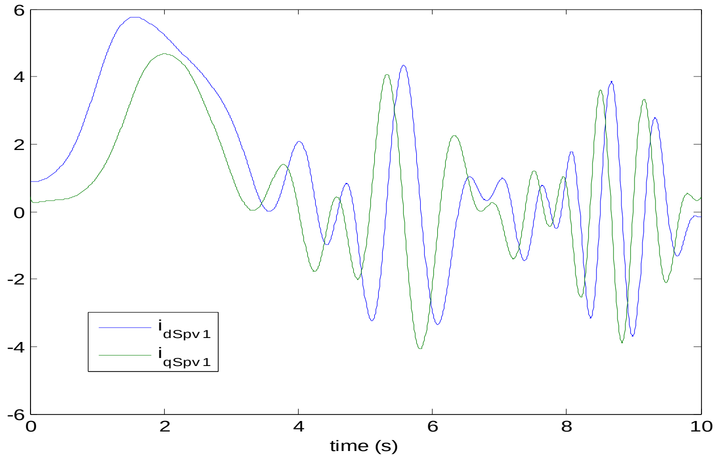

Fig 9. Current generated by PVSG without fault.

B. Steady state performance

Steady state performance deals with how much reactive compensation needs to be accounted in the solar plant to meet the power factor or voltage control requirements. This can be achieved by installing a reactive VAr compensation control in the algorithm of the solar plant.

An analysis has been done after and before building in the algorithm for reactive VAr compensation. The comparative chart is given below. It is taken at various insolation levels of solar radiation. From the figure it is clear that the harmonic injection at steady state is improved with VAr compensation. Here the L filter values are changed each time with different insolation levels. An adaptive logic is employed in the L Filter to control the output. This has not only improved the efficiency but also has reduced harmonic injection.

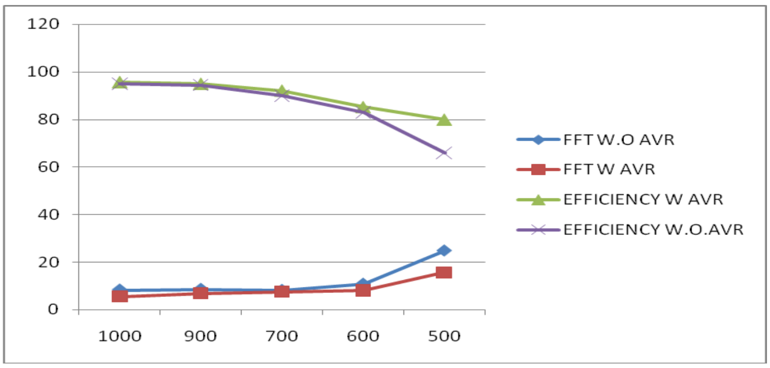

Fig 10. Variation of efficiency and steady state harmonics with different values of L filter and solar insolation (Irradiance vs. efficiency)

Thus, in case of solar micro DG, controls installed within the solar inverter are enough to meet utility requirements. However, if there is a high penetration of renewables, more complex solutions like use of static VArs, STATCOMMS, switched capacitors etc are needed.

C. Voltage Fluctuation effects in detail

7. According to CEA (Central Electricity Authority, India) codes and regulations for grid connected solar systems, the grid tied inverters shall perform in the range of grid voltage from 110%-80%. In order to study this effect in-depth, the paper has selected four regions in Kerala namely, ANDOORKONAM coastal area, POOVANTHURUTHY rural area, PAPPANAMCODE urban area and MUKKUNNIMALA hilly area. The areas clearly represent four major divisions within the state. The hourly data related to feeder voltages in the four major areas are collected for 24 hours (Energy meter reading of the substations of a selected feeder). The graph plotted against the RMS value of voltage and time in hours is given below. From the figure it can be noted that the coastal area is most vulnerable to voltage fluctuations followed by hilly, urban and finally the rural area. When grid tied inverters are installed in such vulnerable areas, their period of operation is ultimately reduced. Thus, the investment cost on inverters installed in such areas cannot be recovered within their operating life time. This would reduce the 'fairness' of solar towards the beneficiaries of Kerala. So, the voltage fluctuation limits should be between 115-70% for the solar generation to pump considerable energy in to Kerala grid.

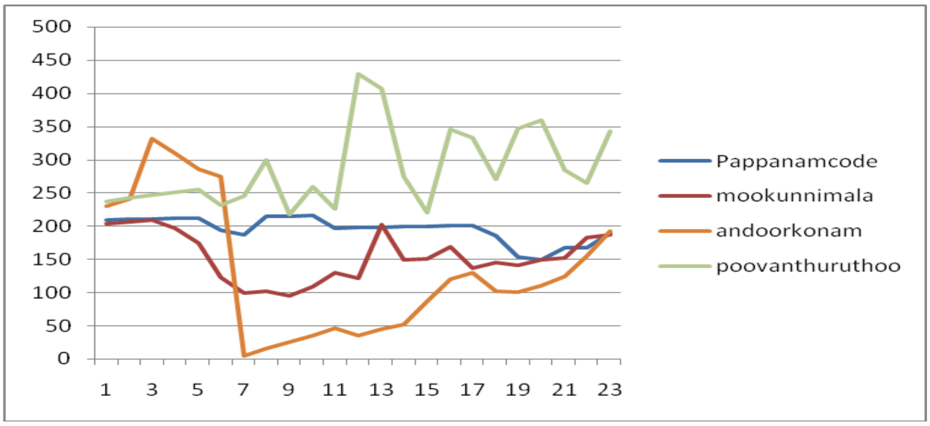

Fig 11. Voltage fluctuation data in selected regions within the state (time in hrs vs. V rms)

D. Harmonic Injection and Transient Disturbances

Harmonics in the waveform may be mainly due to two reasons: 1. Steady state harmonics. This type of harmonics is engrossed in the output current waveform due to high frequency switching of IGBTs, MOSFETs etc at PWM frequencies. They are normally suppressed using tuned ac filters placed at the output of the inverter. In this paper we illustrated the use of adaptive L filters. Adaptive filters help in increasing efficiency and reducing Steady State Harmonics. Also built-in active VAr compensation increased the power factor and efficiency of the inverter. 2. Transient Harmonics: Transient disturbances can be due to the solar plant or from the grid. Normally, AC filters are provided to absorb transients and reduce their effects. When the solar irradiance ramps abruptly, the output power from the solar array also does. This results in transient effects at the output of the solar inverter. This produces heat losses, neutral heating and electromagnetic interferences. Machineries and equipment working near the plant may malfunction. Paper mills require exceptionally precise frequencies may be affected. Therefore ramping effect of solar plants should be mitigated. Otherwise the Power Quality and also the grid stability itself will be affected.

In Kerala, solar grid tied inverters are being installed in various regions. Hence in order that the performance of grid tied inverters are fair towards the beneficiaries and that the power quality of the grid is not affected, there should be a solution to solve the above issues.

IV. BATTERY INTERVENTION POWER SUPPLY (BIPS)

When storage batteries are used at the output of the solar array they act as voltage stabilizers. Battery units absorb unwanted fluctuations at the same time help to absorb and store excess power during off peak hours. BIPS perform using a small capacity battery pack attached to it. As the design of grid tied inverters is economical and affordable, the battery pack is intervened as and when required only so that its capacity is optimized and economically affordable. The block diagram of the BIPS functioning with grid tied inverter is shown below.

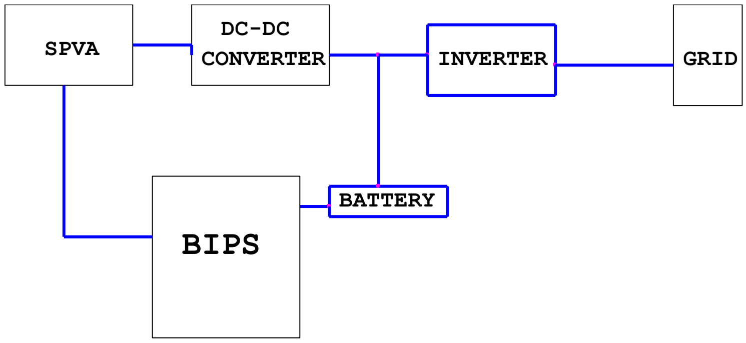

Fig 12. Block Diagram of Grid tied solar inverter performing with BIPS

A. The working of BIPS

BIPS mainly does five functions.

1. Whenever there is an abrupt variation in solar insolation injecting harmonics in the current waveform, the BIPS intervene the battery pack to the inverter input. In the mean time the solar array charges the battery pack and conserves the generated renewable energy power. Thus, the inverter functions by drawing a stable DC power from the battery pack. Due to the stable nature of dc pack, the inverter output waveform becomes improved thereby improving both efficiency and harmonics. Thus, BIPS mitigates the effect of surges and transient harmonics.
2. During power disruptions, the inverter works in anti islanding mode and switches itself to off mode. During this period the BIPS allows the battery pack to get charged from the solar array. If the State Of Charge (SOC) of the pack is sufficiently high, the BIPS allows the pack to energize the priority loads banked to it.
3. When the grid voltage fluctuates beyond the limits said in codes and regulations to be pursued, the inverter switches to off mode. During this time, the BIPS again allows the battery pack to store the solar energy getting generated or if SOC is sufficiently high, BIPS allows the pack to energize the priority loads.
4. When the solar irradiance is below 500 W/m^2, the output current shows distortions and this is due to harmonic injection. Correspondingly there will be reduction in efficiency of operation as illustrated in fig 1 above. During this time also BIPS intervenes the battery pack to the inverter inputs and supports stability in output waveform.
5. During voltage sag and swell the BIPS try to regulate the output voltage by phase shifting the output current making it lead or lag accordingly. The regulation is done by using the concept that the active power of the inverter is directly proportional to load angle of the current.
6. The BIPS also sees that the stored power in the pack during the above periods is supplied to the utility during peak hours or evenings.

Thus BIPS allows power disruptions be handled and solar energy becomes a more meaningful replacement to conventional grid power. In addition to mitigating transient power variances, BIPS are also used to shift peak power. They are able to absorb power that is otherwise limited by the power rates set by the utilities.

V. IMPLEMENTATION IN SIMULINK MATLAB

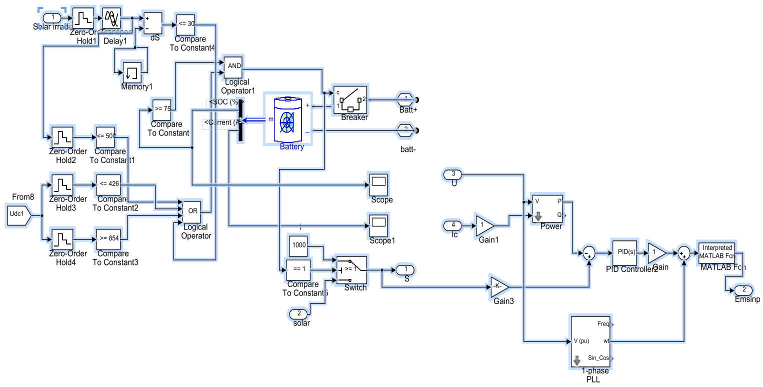

Fig 13. SIMULINK Model of BIPS

The BIPS is implemented in MATLAB using SIMILUNK as in fig 3 above. Here the solar irradiance is sensed using a pyranometer or using a reference solar cell. The corresponding change in solar radiation after a time delay of 1minute is noted. If the change is greater than $30W/m^2$, it is assumed that erratic change in solar radiation at that instant is high enough to cause unwanted harmonics in the output current waveform so that battery pack is intervened to the inverter. Also the variation in DC link voltage at the output of the converter is noted. Corresponding limit of DC link voltage if exceeded is noticed and the battery pack is intervened. This time the voltage sag and swell due to DC link voltage variation is controlled by the BIPS. The BIPS also implements an active VAr compensation.
Here

$$\Delta Pactive \rightarrow V_1 \times I_1 \times COS\delta 2 - V_2 \times I_2 \times COS\delta 1 \cong \delta$$

δ is the load angle is adjusted so that the output current leads or lags to control the voltage sag and swell due to Grid thereby implementing active VAr compensation.

The BIPS also sees that when the grid is absent, it charges the battery pack and supply the priority loads if SOC is sufficiently high. Also, if the voltage fluctuation is beyond the CEA regulations (grid side), the BIPS isolates the grid and intervenes the battery pack to the inverter which is ready to power priority loads.

VI. DISCUSSION

Since there is a rise of 20% in current during fault with every 10% penetration of solar power, adaptive relays are suggested. Properly sized underground cables and thermal relays are a must.
While designing the BIPS, the capacity of the battery pack is so selected that it is optimum. Two parameters are taken into consideration. They are:

- It should absorb the transients and supply power to the inverter when the solar insolation varies erratically.
- The pack shall provide at least one hour back up to power priority loads.
- It provides at least three days autonomy.
- It is assumed that every 1kWp grid tied inverter requires a 100Ah battery pack.

Thus the BIPS acts as a shock absorber in the grid. It handles power disruptions, reduces harmonics, improves grid stability improves power quality, and it is economical in design when compared with off-grid inverters.

VII. CONCLUSION

The effect of instability of grid that result in voltage sag and swell can be mitigated by the solar inverter. Underground cables, thermal relays and adaptive fault detection relays are better solutions to improve stability. Transient effects and current harmonics are reduced by ac filters and the BIPS. Therefore the paper presents a better solution to overcome the de-merits of the non-conventional grid tied inverters used in micro solar distributed generation in LT Grid of Kerala This inverter could manage power disruptions and can mitigate the effect of voltage fluctuations which are dominant in the Kerala Grid. Effect of increased fault currents, current harmonics and requirement of additional filters are also reduced that reduces heat losses and EMI effects. Here the steady state response of the inverter matches with that of its transient response. The use of adaptive relays and BIPS is therefore a simple solution to overcome the demerits of grid tying operation of renewable energy and a better start towards a smart future.

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BIOGRAPHIES

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