Analysis of A Grid Connected Low-Voltage Distributed Generation System In A Microgrid Environment

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Abstract— **Technological advancements in the field of power generation especially the renewable energies have made it possible to think of microgrids. This technology is proving to be beneficial in making localized areas self-sufficient in power management. Being at low-voltage (440v-11kV for 3Ø and 230V for 1Ø networks), the microgrid can deliver the needs of domestic as well as small-scale industries which together consume a few kilowatts of power. This paper focuses on a single phase grid connected system catering the needs of a few domestic as well as a small scale industry. Solar energy coupled with a storage system is considered here so that the reliability of the system is improved. Analysis will be made on the system performance illustrating the power consumption at various stages. Matlab R2015 a simulink is used to simulate the model.**

Index Terms— **Microgrid, Renewable energy, Battery management, grid-connected system.**

I. Introduction

The grid-connected low-voltage (LV) and medium-voltage (MV) networks, which are getting prominent due to the penetration of the distributed resources, are playing a vital role in the utility market. The scenario is now changing from the decentralized markets as distributed generation is taking over. The resources that are available at the premises are now focused upon power generation. The technological advancements in the energy-conversion sector are boosting the utilization of the resources distributed along the geographical area concerned for a grid. The traditional grid commutes power in the range of Giga-Watts whereas the localized grids carry powers in kilo-watt range (Hence the name Micro-Grid, as 'kilo' is a micro-version of 'giga'). These microgrids can be of different types based on the network. Firstly, it can be a 3Ø system to cater to the needs of three phase loads and single phase loads if any. Secondly the grid can be a single phase network, as most of the domestic loads are single phase. The generation, transmission (if required) and distribution all work in single phase. Most recently, the concept of DC microgrids has come up to overcome the efficiency issues of power converters. Based on the modes of operation, it can either be a grid-connected mode or an islanded (off-grid) mode. Former requires the monitoring of power flow from and to the grid in order to maintain stability. The concept of net-metering is gaining focus as there is a market availability to sell power from establishments as low as 1kW (like roof-top solar plant defined by the IEEE Std 1547.4-2011 [1]) to the grid. The loads draw power from the grid only when there is no generation available at the site or if the cost of generation is more than the tariff offered by the grid. The finances of microgrids are discussed by Barker, et al [2] where the authors present a comparison with the grid tariff and convincing results show that it is profitable. A very dynamic system has to be intelligently operated by a Market-Operator. The second mode does not exchange power with the grid. The planning is such that the generation is equal to the losses plus the total load on the system, at any given point of time. This system is said to be self-sufficient. A grid connected mode can switch to an offline mode to avoid in-surges due to faults and under system stability issues. In both the modes, energy storage is usually done conventionally through batteries. Presence of these will greatly improve the reliability of the system. The State-of-Charge (SOC) of the battery and the State-of-Health (SOH), which depends on charging and discharging cycles would be a main concern for the operator. Battery can be a substitute to the generating sources when there is no power generation available.

In this paper a single phase Grid-connected LV microgrid is considered. Photovoltaic power shall be injected in parallel to the grid power where a group of domestic loads and a Small-Scale Industry (SSI) are powered up. Loads are dynamically switched on and off and the effect of this on the micro-grid system will be studied.

Section II deals with the modelling of a Solar panel and the lookup table corresponding to the solar irradiation levels for a period of one day. Section III describes the battery capacity estimation and the charge control technique used. Section IV describes the single phase LV microgrid and the loads used in this paper. Section V illustrates the load management issues. Section VI describes the test system used for simulation and section VII analyses the results obtained.

II. Photo -Voltaic Solar Panel Modelling

A. PV cell as a current source

The working of a photovoltaic cell is a well-known technology. The solar cells are designed to accept the

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energy present in the sun's rays for a particular wavelength range called visible light.

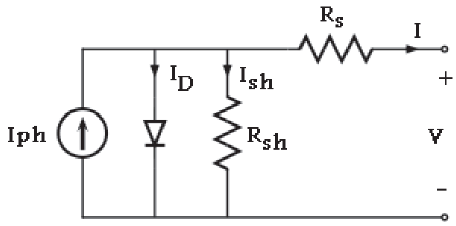

Figure 1. Solar Photo-Voltaic Cell Equivalent Circuit

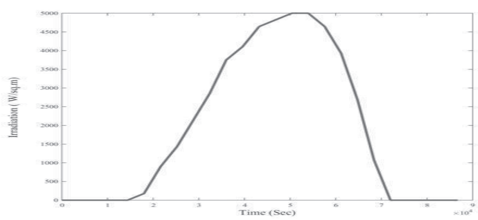

Figure 2. The Solar Irradiation during a day

The equation corresponding to the current output from a solar cell can be written as:

$$I = I_{ph} - I_s\left[exp\,\frac{q(V+R_sI)}{NKT} - 1\right] - \frac{V-R_sI}{R_{sh}} \qquad (1)$$

Where
I_{ph} is the photocurrent,
I_s is the reverse saturation current of the diode,
q is the electron charge
V is the voltage across the diode,
K is the Boltzmann's constant,
T is the junction temperature,
N is the ideality factor of the diode, and
R_s and R_{sh} are the series and shunt resistors of the cell, respectively.

The equivalent circuit can be shown as in Fig. 1.

B. Solar Radiation Data

The solar insolation levels for a sample period of one day at a resolution of one second is taken as shown in Fig. 2

The sunrise is taken approximately at 9 AM and has a peak insolation during the noon time, i.e. 2 PM to 3PM and the sunset is expected to be around 5:30PM. The irradiation is shown in W/m^2.

This data is presented to the solar cell as an input which, according to the above equation develops current and hence a potential difference across the terminals. The outputs of it will be shown in the Section VI.

III. Battery Capacity And Charge Control

A 1000AH battery is taken for the system and the charging and discharging of it are controlled based on the power flow at the Point of Common Coupling (PCC) of the microgrid to the Grid [3].

The direction of power flow will decide the current injected by the battery into the system. Hence the battery here is considered as a current source in parallel with a high resistance acting as a power source. The type of battery is not of concern in this study as the focus is towards the management of it. The PCC current and voltages are continuously monitored. The real power flow is calculated and the direction of flow is taken to be negative if the value goes less than zero. A PI controller is used to calculate the control signal (the equivalent current signal) input to the battery by comparing the present power flow to the reference value [4] (i.e. zero, not to depend on the grid). The battery is also working as a sink for the surplus power produced by the microgrid, where it gets charged up. As the capacity of the battery is set, the Ampere-hour discharge or charging is hence calculated by a simple integrated circuit and a fraction converting the time signal in seconds to hour. Similarly, the State-Of-Charge (SOC) is also calculated.

IV. Single Phase LV Microgrid AND Loads

The single phase LV microgrids need a separate study as the traditional analysis such as the protection, stability and sensitivity of the system is not as the conventional modelled grids [5]. Being operated at low voltage poses problems related to the efficient power transfer, placement of the generating plants closer to the loads (to minimize transmission). The present system considered in the paper is powered up by a solar Photo-voltaic source as the distributed generator supplying a set of domestic loads and a SSI. The voltage across the lines is continuously monitored. The grid is considered to be infinite in nature and hence the magnitude and phase of the grid voltage is not supposed to change even for a variation at the PLL [6]. A three phase step-up transformer of 10MVA, 66KV/6.6KV is used in the generating plant considered in the grid. A pi sectional transmission is considered in the grid of 1km length associated with a three-phase load. At the PLL, a three phase to single phase conversion is done using a transformer working on one of the line to line voltage (here A&C lines are used). The power grid considered is shown in Fig. 3.

The distribution is done on a single phase since the load considered also works on the single phase

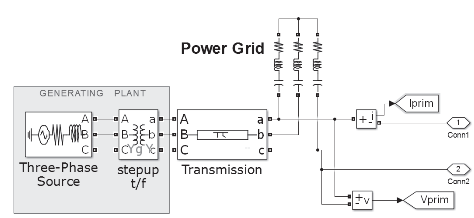

Figure 3. The power grid considered for simulation

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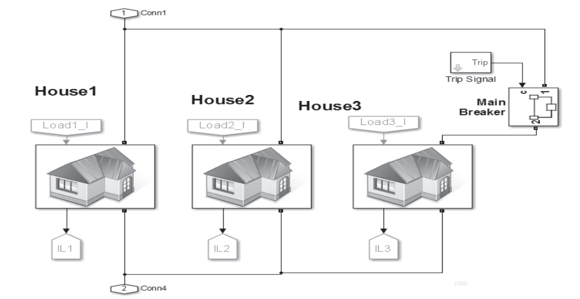

Figure 4. Domestic Load connected to the grid

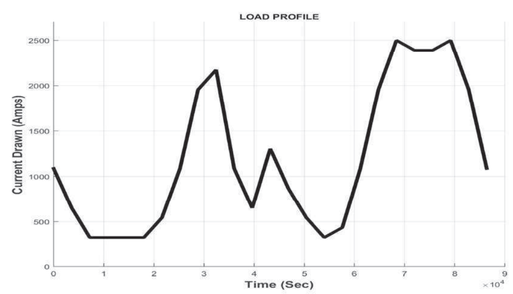

Figure 5. Load profile considered for each house

A domestic load of three houses is considered. The loads are assumed to consume power at the voltage of the microgrid and depending on the switching on or off the loads in a house, the current consumption changes. Hence the profile of the current is taken as the basis and the loads are designed to be current sources taking the signal of the load profile. The behavior of the loads is considered as an internal aspect and represented in the load profiling. The load change is calculated on a per-minute basis (or for every sixty seconds). The domestic loads considered and the current profile are shown in Fig. 4 and Fig. 5 respectively.

The SSI discussed here is considered to have a solar PV plant setup on its roof-top, which is half of the size of the plant considered previously. This is now represented as half of the solar radiation considered previously in Fig. 2, so that the power output also is half. The load here is approximately five times the power drawn by a house. The industrial load and the solar PV connected are modelled in the simulink as shown in Fig. 6.

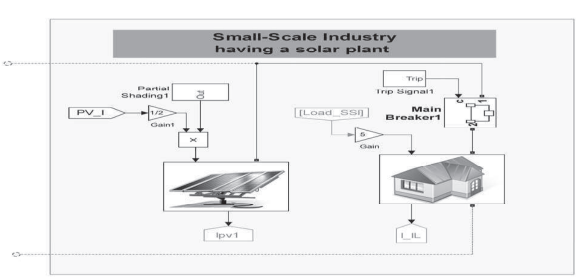

Figure 6. Load profile considered for SSI

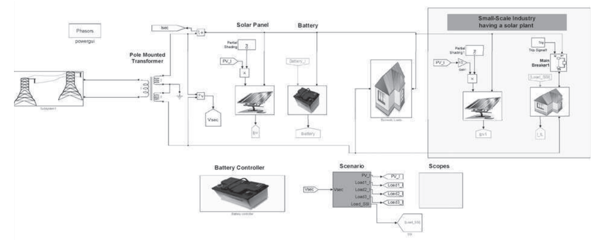

Figure 7. Simulation diagram for the system considered

V. Load Scheduling

The loads considered are switched on and off at definite times. The term scheduling here applies to the programmed usage of the loads. In the system considered, one of the domestic loads is switched off suddenly at 8:00 AM and the SSI is scheduled so as not to consume power between 10:00 PM to 4:00AM in the morning. There is also a partial shading (a factor of 0.3, for a short duration of time) applied on the solar panels due to the cloud cover or the shadowing effects during the day.

VI. Test System Description

The system considered is shown in Fig. 7. The microgrid network is configured to be 1Ø, AC (200 V at 50 Hz). A maximum of 7.5kW of power generation is available from renewable energy source (PV). The battery (operating at 200V, at 100% SOC, 1000Ah, and at 0.2C discharge rate). The battery shall also work in a charging mode when there is excessive power being generated in the microgrid. This is constrained to the upper limit of 100%SOC. The domestic load consists of three houses consuming power (maximum 2.5kW) from the microgrid.

The pole mounted transformer has a transformation ratio defined by the voltages of 6.6kV / (2 x 115V) on the primary and secondary. Hence a 230V RMS is available at the PCC from the grid. The solar power is available from 4:00AM to 8:00PM on a typical day. The peak solar irradiation is available from 2:00 PM to 3:00PM. The loads, which are a combination of domestic and industrial consumer power with its peak values occurring at 9:00AM, then at 7:00PM to 10:00PM.

As the solar energy available is enough to meet the demands during the noon times, the battery remains in off mode and the SOC is maintained during that time as constant.

A small surgical disturbance is created by switching off the domestic load (3rd house) to observe the transient reaction of the grid, so that the real power flow can be studied at the PCC. The results obtained by simulating the above system are described below.

VII. Simulation Results

The above system (Fig-7) is simulated using MATLAB 2015a. The time period is taken to be 1-day i.e. 24*60*60 seconds. The simulation is carried out in

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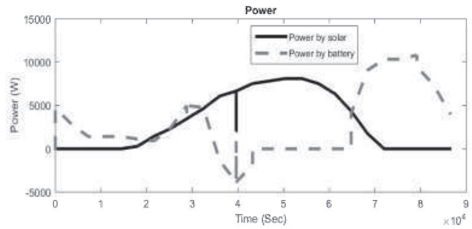

Figure 8. Load profile considered for SSI

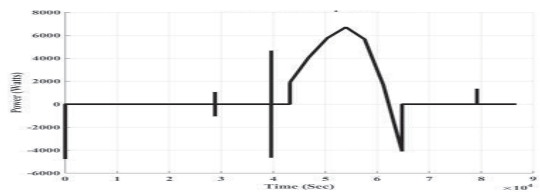

Figure 9. Representation of the power balance equation

Phasor mode with a frequency of 50Hz to match the system's requirement of Indian sub-continent. The simulation is carried out with an aim to make the microgrid self-sufficient i.e. to be able to meet the demand by the distributed sources within the microgrid. There are four loads (3 domestic and one industrial) and two sources (solar PV) and an energy storing element (Battery) in the microgrid. At the PCC, voltage and currents are measured so that the power exchange between the grid and the microgrid can be studied. Analysis is specifically made on a few points of interest that are detailed below.

The power generated by the two solar panels during the day and the power delivered/consumed by the battery are shown in Fig. 8. The zero state of the battery power shows that it is idle.

The power generation from solar PV can be seen to be maximum during the noon times. When the solar power is not present, the battery is taking over the load during evenings and morning.

It is a usual practice that any self-sufficient system will have total power generation equal to the total load on the system. This is the basis on which the PI controller is designed to work. This relationship can be mathematically written as:

$$P_{Solar\ PV} + P_{Battery} = P_{Load} \quad (2)$$

Eq. 2 can be rewritten as

$$P_{Solar\ PV} + P_{Battery} - P_{Load} = 0 \quad (3)$$

The system's response to the Eq. 3 is shown in Fig. 9

The above figure shows that Eq. 3 is almost satisfied, but not during the period 12:00PM to 6:00PM. The graph is positive from 12:00Pm to 5:30PM, because the generation is more than the total demand, while the negative values show that the grid is supplying power to the micro-grid.

The excess power generated by the microgrid has to be fed to the grid through the PCC. The power monitored at the PCC is observed to match the Power transfer at PCC.

If the battery is available all the time, i.e. the controlling on the battery is overlooked, then the power balance equation would be satisfied and the battery is seen to be charging from the microgrid power. There is no exchange of power from the grid, as the PI controller in the battery controller circuit is proving to be effective. The SOC of the battery is also maintained high i.e. 80% - 60%. The ampere hour discharge of the battery can be monitored and this can decide the capacity of the battery needed in the system. Here a peak of more than 210Ah is observed as shown in Fig. 11.

An analysis can also be made to estimate the capacity of the solar panel needed for the SSI, so that the microgrid would still be self-sufficient. An efficient battery management algorithm can be implemented so as to see that the battery SOC would not violate the standard values of 20-80% at any given point of time in a day. This is beyond the scope of this paper and may be included in the future works.

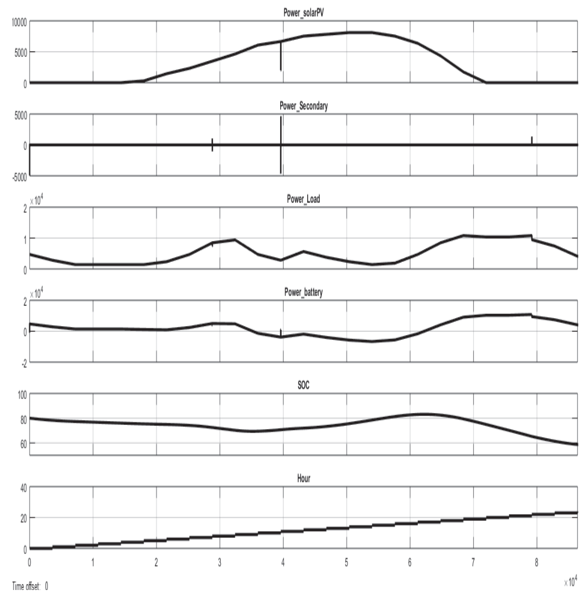

Figure 10. Illustrates the various values

Figure 8. Load profile considered for SSI

VIII. Conclusion

This paper analyses a single phase microgrid connected to the grid, under a distributed generation environment and loads considered in the domestic and small scale industrial levels. The efficiency and the self-sufficiency of the microgrid is studied under two different scenarios depending on the control of the battery. The importance of the energy storage system in increasing the reliability of the system is studied. A design which is flexible to determine the capacities of the storage elements and the power sources is framed so as to facilitate future research.

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