Controls of solar power systems for grid connected and islanded mode operations

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***Abstract*—Continuous supply of electricity, when there are supply constrains is a major challenge. Environmental concerns and non-availability of fossil fuels increases the demand for the use of renewable energy sources such as solar. A domestic or an institutional customer can support the country by the proper usage of solar Resources. Further the usage of a battery storage combined with the solar panel can improve this. This paper analyses the domestic/ institutional usage of solar panels, (i) with and (ii) without a battery storage, for both cases of (i) with grid and (ii) standalone operation, depends on the availability of solar irradiation in a day. Here a typical domestic/institutional solar power system taken into the study and suitable sizes of solar panel, battery storage were selected to achieve a reliable and smooth operation of the system. The whole system is modeled using PSCAD simulation. The design of the controllers ensured the proper operations of grid connected and standalone mode of the system. Further MPPT control also used in such a way to ensure the optimum usage of solar power. The simulation results shows that this arrangement improves the power availability for domestic/institutional customers even during the power failure periods.**

***Keywords*—** *domestic solar panels, MPPT control, standalone operation, payback.*

I. INTRODUCTION

Energy crises, due to the non-availability of traditional fossil fuel and environmental pollution issues caused by the fossil fuel usages, created demand for the Renewable Energy resources. Solar, wind, biomass, hydro and wave power are the most considerable renewable energy resources available all over the world. But tropical countries, like Sri Lanka, have huge potential of solar power throughout the year. Even though the availability of solar radiations is only at day time, it is freely available for the usage of, not only by the utility but also by each and every domestic customers.

With a fairly small attractive investment, a domestic customer can utilize the free solar radiations available at their house for the production of electricity. This ensure the reliability of power with and without the grid connection for a domestic house or any other institution.

But on the other hand, the solar irradiance value in a day, zero at early morning around 6.00 AM, depends on the sunrise time of the city, then peak at noon and again zero at evening, depends on the sunset time of the city, i.e. around 6.00 PM. Further the solar irradiance can vary within a minute by around 800W/m² [1]. This intermittent behavior of solar irradiance can be compensated by the usage of a battery or in different hybrid operations with other power generating plants. Therefore this paper analysis the usage of a domestic/ institutional solar power system with grid connected and islanded/standalone mode. This is also further divided into, with and without battery operated modes.

The whole systems modeled using PSCAD simulation and analyzed under the following modes, where with and without grid analyzed using one simulation file.

i. Standalone, without grid without battery
ii. Standalone, without grid with battery
iii. Grid connected, without battery
iv. Grid connected, with battery.

Further MPPT or relevant control is used to get the optimum energy OR to match the power requirement. Therefore, the objective of this research study is to increase the utilization of the solar power plants during power failure time.

II. LITERATURE REVIEW

There are many related works discussed about the usage of solar power for domestic purpose.

The proposed work by Rui Li and Fangyuan Shi with the optimized system oriented 1500 V DC bus showed that high DC bus voltage reduces the losses and hence improve the efficiency of the system. Here the State of Charge (SOC) of the battery and Time of Use (ToU) tariff considered for various operational modes and the economic benefits can gained by the consideration of sun light hours and ToU Tariff [2].

A Standalone domestic usage of solar panel with battery storage proved, effectiveness in supplying power to all the household and also showed that energy storage of the battery is maximum when 65% of solar power used to supply loads and 35% of solar power used to charge the battery. Further the payback period of 13.14kW solar panel with a 27kWh battery to supply a 2502kWh monthly consumption house can be achieved in about 9 to 12 years [3]. A technical and economic analysis was done for a residential house hold, with the capacity of 5.9kWh/day in Faisalabad, Pakistan, proved that a Stand-alone PV system is cheaper than the conventional electricity supplied by centralized grid [4].

Another work presents a grid-tied photovoltaic (PV) power conversion topology with a unique resynchronization mechanism. The goal of the scheme is to provide continuous power to load while providing power to the grid. The control strategy assists in harmonic reduction and power quality improvement while extracting the optimum power from the PV system. Three control approaches used. Grid current control, point of common coupling voltage control and intentional islanding with re-synchronization. The system's stability in the presence of variable solar insolation, load power and grid supply disturbances makes it as a good fit for a home application [5].

Further, fast and under frequency automatic load sheading and restoration techniques can be applied in such a way that the rate of change of frequency used to determine the amount of load to be disconnected. In this work, IEEE12 bus system modeled in PSCAD simulation, and the results showed smooth and proper operation [6].

When there are increased penetration of photovoltaic power into a LV grid, this produces voltage rise issues, which can be mitigated by a coordinated volt-Var control system. The coordination between LV distribution transformer and the solar inverters, optimizes the PV power penetration level in Bornholm Island in Denmark [7]. Usually batteries are used with PV systems. A control and power management system used in a PV, battery based hybrid micro grid showed a better performance under various operating conditions in with and without grid modes [8]. Further a novel converter control used with a solar PV and battery installation for a single phase residential premises studied for with and without grid operations [9].

III. SYSTEM DESCRIPTION

A simplified grid connected solar power system considered for this study. Figure 1 shows the block representation of the grid connected solar power system. Here the 132kV transmission line and above grid system has been modelled as a source. This was connected to a 400 V bus through two step down transformers of capacity 100MVA and 0.5MVA respectively. Further the 400 V AC bus supplied power to 6 number of load feeders with various capacities from 4kVA to 9kVA and the overall load capacity is 42kVA. The power factors of the feeders vary from 0.8 to 0.9.

On the other hand a total power capacity of 100kW, solar systems connected to the same 400V AC bus through a DC/AC power converter. The capacity of the battery bank, which directly connected to the solar panel system, is 100kWh (To supply for a period of 2 hours).

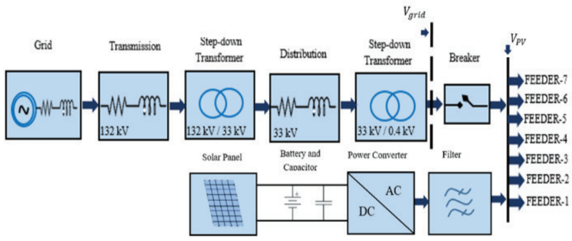

Figure 1: Block representation of grid connected solar panel system.

A. Phase Lock Loop (PLL)

Phase lock loop is used to measure the phase angle. Figure 2 shows the phase lock loop block diagram.

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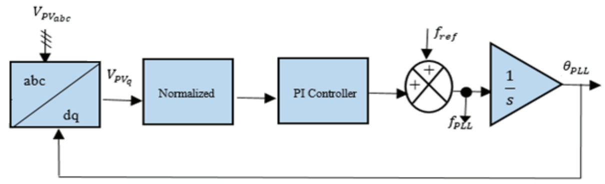

Figure 2: Phase Lock Loop Block diagram.

Here Vpv_{abc} is the measured three phase AC voltage at the grid connected point where the solar power connected. Vpv_q is the 'q' axis component of the park transformation, which then normalized and processed to the PI controller and added with the reference frequency of 50 Hz. Finally the phase angle derived by integrating the frequency f_{PLL}. Here the control is designed in such a way, when the power from grid is disconnected, it is to hold the frequency value as a constant.

B. Maximum Power Point Tracker (MPPT) Control

MPPT operation is shown in Figure 3. Here the filtered solar panel DC link voltage (V_f), solar panel open circuit voltage (1.2pu) and the current used to derive V_{MPPT}

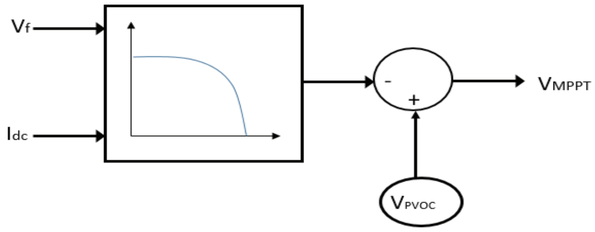

Figure 3: Maximum Power Point Tracker (MPPT) Control.

C. Active power control

Active power control / DC link voltage regulation is shown in Figure 4. Here the DC link voltage of the solar panel system (V_{dclink}) and the MPPT voltage (V_{MPPT}) used to derive angle 'α', which then used to ON/OFF the IGBT switches and control the active power flow to the 400 V AC load Bus.

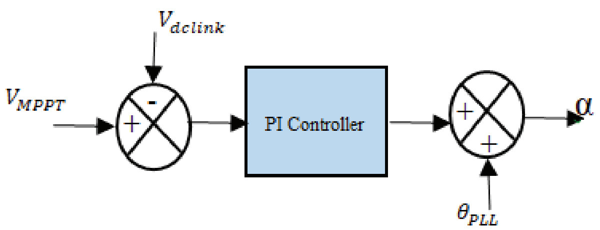

Figure 4: Active Power Control

D. PV terminal Voltage droop control

As per the power system standard adopted by Sri Lanka, the voltage variation should be 6% of tolerance that is in between 0.94 to 1.06 pu. This is achieved by reactive power injection. Accordingly, the V_{Mag} value is varied in between 0.152 to 0.5 kV this shown in figure 5, with the variation of V_{PV} vs. V_{Mag}.

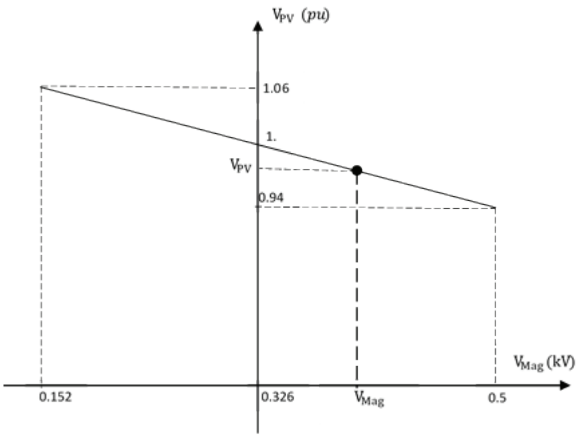

Figure 5: Variation of V_{PV} Vs. V_{Mag}.

From Figure 5, the following equation can be derived.

$$\frac{1-V_{PV}}{V_{Mag}-0.326} = \frac{0.06}{0.174} \quad (1)$$

Hence, in the PV terminal voltage droop control an adder circuit compares the V_{PV} voltage to $V_{pv_{ref}}$, and the error value is processed through the PI controller. The output of the PI controller is compared to the $V_{Mag_{ref}}$ reference value, then multiplied by the needed gain value and added to the adder circuit through a feedback loop. The process is illustrated in the block diagram shown in Figure 6.

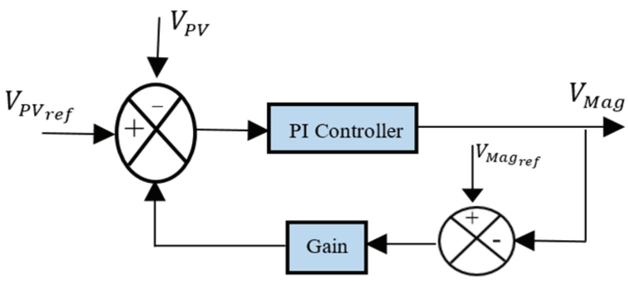

Figure 5: PV terminal Voltage Droop Control

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E. Load sheading control

Load sheading control based on DC link voltage V_{dclink} shown in Figure 6. Here the DC link voltage, which is filtered through low pass filter, fed to the comparator to control the load sheading function of BRK1. When solar irradiance is low, this causes the voltage V_{dclink} to reduce. When the voltage reduces below 0.90pu (Lower trigger point), the comparator output becomes '0' and trigger the BRK1 to 'OPEN'. On the other hand, when V_{dclink} increases, due to the increase of solar irradiance and when the value is more than 1.12pu (Higher trigger), comparator output becomes '1' and 'BRK1' closes and deliver the power to the load.

In this control the hysteresis component is introduced by subtracting the output from gain box of 0.22, which is multiplying the comparator output. This will introduce the hysteresis effect to the B input terminal value of the comparator. This will prevent any repetitive on-off operations of the breaker due to its switching transients. Here the threshold value of switching operation of breaker (the value at input terminal B) varies accordingly.

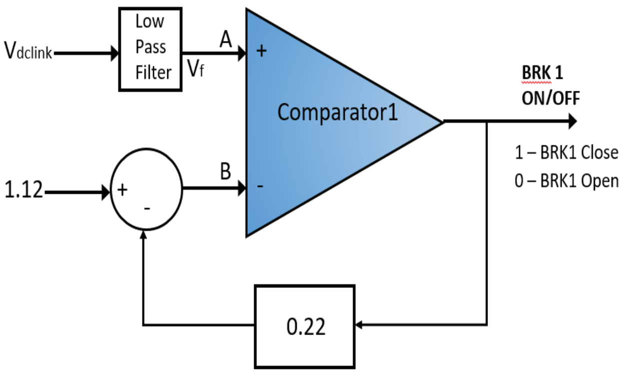

Figure 6: BRK1 load sheading control

Similarly BRK2, BRK3 and BRK4 load sheading operations defined for various DC Link voltage levels. It is shown in Table 1.

TABLE 1: BRK1, BRK2, BRK3 and BRK4 load sheading voltages.

DC link Voltage (pu)	Breaker Status							
	BRK1 OPEN	BRK1 CLOSE	BRK2 OPEN	BRK2 CLOSE	BRK3 OPEN	BRK3 CLOSE	BRK4 OPEN	BRK4 CLOSE
Vdclink< 0.71	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN
0.71 <Vdclink < 0.78	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSE
0.78 <Vdclink < 0.84	OPEN	OPEN	OPEN	OPEN	OPEN	CLOSE	OPEN	CLOSE
0.84 <Vdclink < 0.90	OPEN	OPEN	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
0.90 <Vdclink < 1.09	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE
1.09 <Vdclink < 1.10	OPEN	CLOSE	OPEN	CLOSE	OPEN	CLOSE	CLOSE	CLOSE
1.10 <Vdclink < 1.11	OPEN	CLOSE	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
1.11 <Vdclink < 1.12	OPEN	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE
Vdclink >1.12	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE	CLOSE

Lower trigger point and higher trigger for BRK1 to BRK4 differs, it designed such that for a particular breaker when the DC link voltage reduces below its lower threshold value to open and to close, when it increases above the higher threshold value. It is shown in Figure 7.

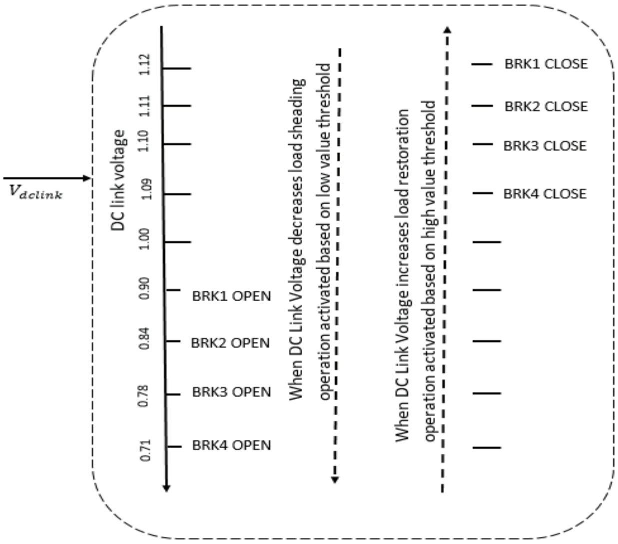

Figure 7: Low value threshold and higher value threshold for BRK1, BRK2, BRK3 and BRK4.

IV. SIMULATION RESULTS

Among the four modes, discussed earlier, the worst case scenario of the solar plant operation is, without grid without battery. Here the grid connected solar panel system shown in Figure 1 modelled using PSCAD simulation and tested for without grid and without battery scenario. The simulation results shows that after the grid disconnected near to 3.5 seconds, the DC link voltage immediately increased to the open circuit voltage. It is because the solar power generation is much greater than the loads. Hence the active power generation supposed to be reduced by around 60 kW and it is done by increasing the DC link voltage. Further when solar radiations reduced from 1000W/m² to 350 W/m², DC link voltage continuously reduced and when the value reaches below 0.9 pu, BRK1 is opened. Similarly when solar radiations reduced from 350W/m² to 300 W/m², and when the DC link voltage reduced below 0.84 pu, BRK2 is opened and when DC link voltage further reduced due to the reduction of solar radiations from 300W/m² to 250 W/m², below 0.78 pu, BRK2 is opened and below 0.1pu BRK4 is opened. But the voltage at the grid connected point almost controlled at 1.0 pu. This is shown in Figure 8.

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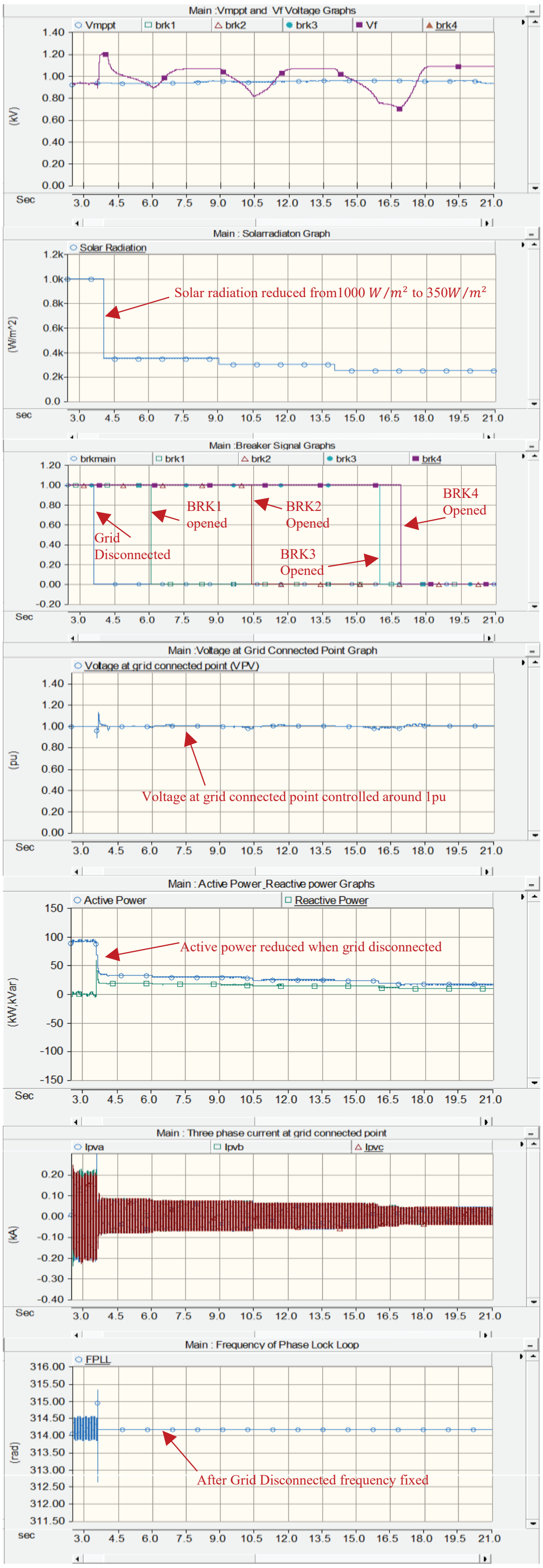

Figure 8: After grid disconnected when solar radiation changed from 1000 W/m^2 to $350W/m^2$, 300 W/m^2 and 250 W/m^2.

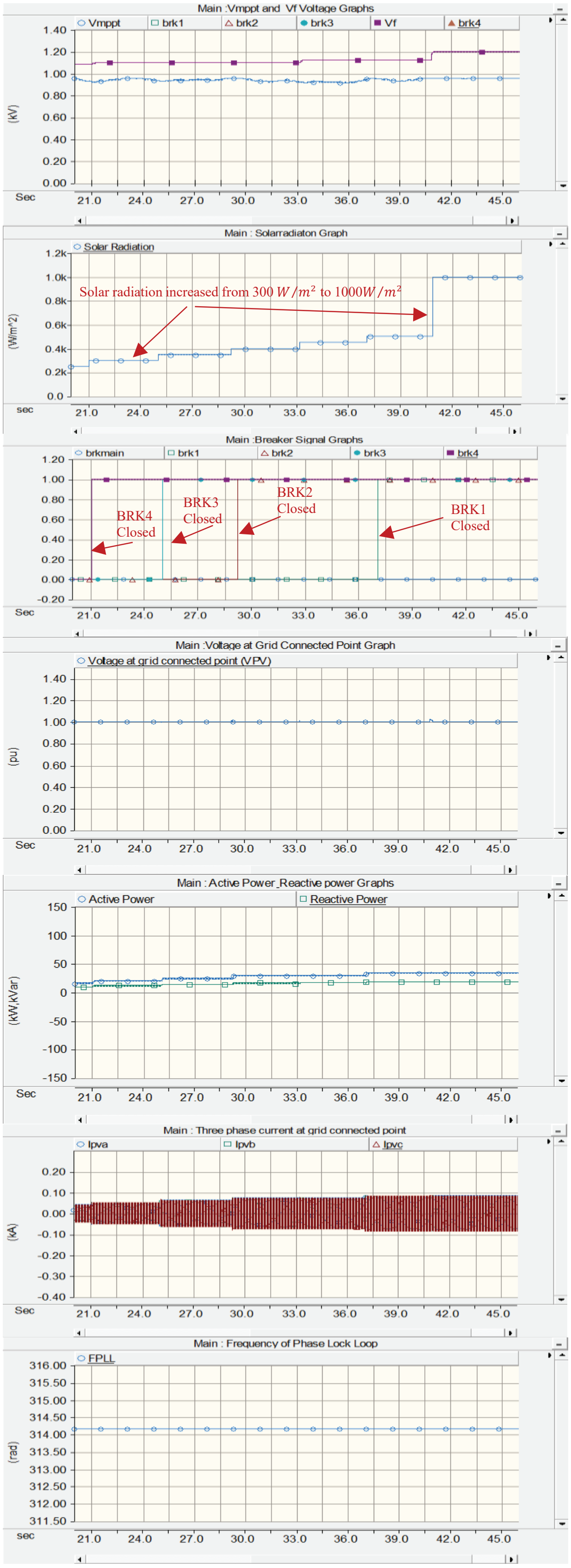

Figure 9: In off grid operation when solar radiation changed from 250 W/m^2, $350W/m^2$, 300 W/m^2 to 1000 W/m^2.

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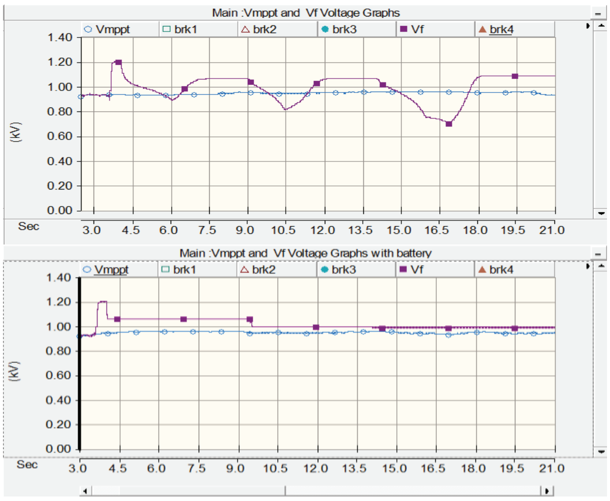

Figure 10: After grid disconnected variations of V_{MPPT} and V_f for without and with battery operations.

Similarly when solar radiations increased from 250W/m² to 300 W/m², DC link voltage increased and when reached 1.09pu, BRK4 is closed. Further due to the increment of solar radiation from 300W/m² to 1000 W/m² and, BRK3, BRK2 and BRK1 are closed above 1.10pu, 1.11pu and 1.12 pu respectively. This shown in Figure 9.

The simulation was extended to do further study with the battery (Very simplify model) just to confirm that the performance of the system will improve with the battery. This shown in Figure 10. Here the variations of V_{MPPT} and V_f was studied with and without battery scenario after grid disconnected and when the solar radiation changed from 1000 W/m^2 to 350W/m^2, 300 W/m^2 and 250 W/m^2. The system operation with battery maintain better values of DC link voltage. This avoid load sheading.

V. CONCLUSIONS

The energy crises demanded the development of RE sources as urgent needs. Here a solar power system with some dump loads is studied in simulation and confirmed its possible operations. The proposed control techniques and the simulation results showed smooth operation of the standalone solar power system with some dump loads and with essential loads connected, when it is disconnected from the grid.

The intermittent nature of solar radiation is a negative factor considered and reliable solutions achieved by the disconnecting/varying the dump loads accordingly. This ensured the continuous and smooth operations of essential loads, which were connected continuously to the solar systems. Here the four combinations were considered: solar power and the loads operated, with and without grid, and it is combined, with and without battery.

Among this the worst case system scenario was studied in detailed and it showed a better operation. Further, the system with the battery, definitely show improved results. The investment cost and the payback period will be an attractive one, as the system can successfully work for without battery scenario. As a future work the realistic battery model with optimized energy storage capacity will be studied in details. Further the hardware model of these controls are under study and will be implemented in near future.

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