FREQUENCY-BASED ENERGY MANAGEMENT IN ISLANDED MICROGRID

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Abstract - *The proposed implemented system with a frequency-based energy management can be used when the grid is facing overproduction and underproduction. At a certain moment in time the sun is shining very bright the battery is almost fully loaded and there is a low power consumption. In this situation the grid frequency will rise and that will be a signal for the renewable energy systems (RES) to curtail their power production. On the contrary, if there is not enough energy from RES and the battery state of charge is reaching its minimum, the grid frequency will decrease and the mechanism will start to decouple or shed the demand of controllable loads from the microgrid. The results of implementation and experimentation has shown the proposed system and platform can be efficient and simple technique for energy management in Islanded Microgrids.*

Key Words: Energy Storage Systems (ESS), Renewable Energy Sources (RES), State of charge (SOC), Distributed Generation (DG), Pulse Width Modulation (PWM)

1. INTRODUCTION

The evolution of the traditional power grid towards smart grids involves the grid decentralization into microgrids. A microgrid is a cluster of generators (typically from renewable energy resources), storage systems and loads, which is capable of operating independently (i.e., in an islanded mode) and connected to the rest of the grid. Microgrids allow for easier incorporation of distributed energy resources, like wind and solar power generators, as well as more robust and stable operation.

Two operation modes of microgrid can be defined as follows

Grid-connected Mode: The microgrid (MG) is connected to the upstream network. The MG can receive totally or partially the energy by the main grid (depending on the power sharing). On the other hand, the power excess can be sent to the main grid (when the total production exceeds consumption).

Island Mode: When the upstream network has a failure, or there are some planned actions (for example, in order to perform maintenance actions), the MG can smoothly move to islanded operation. Thus, the MG operate autonomously, is called island mode, in a similar way to the electric power systems of the physical islands.

Recently, there is increasing interest in designing control solutions where the feedback of the control loop is not enabled with external communication links. Examples of such systems are small MGs where the deployment of communication network might prove to be inefficient in terms of cost, implementation complexity and overall system stability. It is therefore more practical to try to use the MG itself to enable coordination and information exchange capabilities. A straightforward solution would be to use Power Line Communications (PLC) to inject information signals in the MG using the existing power lines [14]. Although eliminating the need for using external communication network, the PLC concept still requires installation of additional communication hardware (such as modems) in the MG. In recent work, another interesting and promising approach has emerged, namely the bus signaling method [15][16]. The main idea is to exploit the variations of the common bus parameters (voltage/frequency). These parameters vary dynamically with different MG entities, thus providing inherent coordination signals between these entities. The bus signaling method can be implemented in the power electronic interfaces using Digital Signal Processing (DSP), thus virtually providing "modemless" communication facility to the MG. The bus signaling method was initially introduced in [16] for low voltage DC MGs. The basic implementation consists of assigning different voltage thresholds to different nodes in the MG (such as renewables, non-renewables, and loads for load shading) so they can react as the bus voltage varies. The voltage thresholds are assigned uniformly by including some local voltage estimation error margin. For each voltage threshold, the operating mode of each MG node changes. As defined in [16], the sources can be either off or discharge and the storages can go off, charge or discharge. Although this is the earliest paper on bus signaling, it still remains one of the most comprehensive works on the topic, offering insights for various different generalization and extension opportunities.

The bus signaling method has also been successfully adapted and applied to AC MGs using the bus frequency as a signaling medium [10][11][1]. In [10] the authors observe a simple AC MG with RES and single node ESS and assign different operating frequency thresholds depending exclusively on the State-of-Charge of the battery. The motivation lies in the common fact that when the battery approaches high State-of-Charge, it becomes dangerous to continue to charge it because it might damage the battery.

The paper also uses adaptive P-ω droop characteristic to put both the battery and the RES in different modes. Similarly, [11][1] observe simple AC MG system with battery bank as ESS and PV panels as RES. [1] extends [11] and assigns two different frequency thresholds for each battery through which it signals the State-of-Charge of the battery; upper threshold to indicate that the battery is nearly full and lower threshold to indicate that the battery is nearly empty. The frequency variations are used as mode change triggers for each node.

2. RELATED WORK

In this section, we would be discussing briefly on various literatures available pertaining to energy balancing in Islanded Microgrids. Dan Wu, Fen Tang, Tomialav Dragicevic proposed an autonomous active power control to coordinate distributed components of microgrid consisting of the ESS, the PV systems and loads. Additionally, a centralized secondary control was applied to effectively eliminate steady state deviation of the bus frequency. By the proposed active power control, by automatically adjusting the power generation from the PV systems and load consumption SoC of the ESS can be kept within the safe limits [1] Josep M. Guerrero, Mukul Chandorkar presented a review of advanced control techniques for microgrids. This proposed paper utilizes decentralized, distributed, and hierarchical control of grid connected and islanded microgrids. Current status of microgrid decentralized control and methods to analyze and assess microgrid stability hierarchical control for microgrids related to energy management systems (EMS), giving references from and to the tertiary control in order to optimize the efficiency of the microgrid [2]. Jose Gomes de Matos1, Luiz Antonio de Souza Ribeiro1 proposed system use modified droop control to limit SoC of battery of ESS. The electrical frequency of the microgrid is used to inform to the power sources and their respective converters the amount of power they need to generate in order to maintain the battery-bank state of charge below or equal its maximum allowable limit [3].

Manoj Datta, Tomonobu Senjyu, and Chul-Hwan Kim, proposed a simple fuzzy-based frequency control method is proposed for the PV generator in a PV–diesel hybrid system without the smoothing of PV output power fluctuations. Here, fuzzy control is used to generate the PV output power command. This fuzzy control has average insolation, change of insolation, and frequency deviation as inputs [4].

Tomislav Dragicevic, Josep M. Guerrero, Juan C. Vasquez, and Davor Skrlec, proposed control strategy for autonomous dc Microgrids. Avoidance of considerable voltage deviation and ability of coordinated charging of multiple batteries are the main advantages achieved from proposed control when compared with traditional methods. An adaptive droop calculation method was proposed and incorporated within the supervisory control to assure the asymptotic SOC approaching for arbitrary number of batteries [5].

Jong-Yul Kim, Jin-Hong Jeon, Seul-Ki Kim, Changhee Cho, June Ho Park proposed paper, the cooperative control strategy of microsources and the energy storage system (ESS) during islanded operation is presented and evaluated by a simulation and experiment. Dynamic modeling and simulations of the microgrid under the proposed control strategy were carried out using PSCAD/EMTDC [6].

Tomislav Dragicevic, Josep M. Guerrero, Juan C. Vasquez proposes a method for coordination of an autonomous low-voltage direct-current (LVDC) Microgrid that consists of a number of sources using power-line signaling (PLS), a distributed control strategy in which the units inject sinusoidal signals of specific frequency into the common bus in order to communicate with each other. The control structure that allows the application of this method is revealed and the optimal range of operating PLS frequencies is specified. In order to achieve a zero steady-state error of injected signals in the common bus, primary control of batteries has been extended with dedicated proportional-resonant (PR) [7]. Dan Wu1, Fen Tang, Josep M. Guerrero, and Juan C. Vasquez proposed a microgrid, since renewable energy sources units these regulates different active power, the proposed reactive power distribution is adaptively controlled according to the active power distribution among energy storage systems (ESS) and RES units. In order to achieve the power sharing in a fully decentralized way, conventional reactive power-to-voltage (Q-V) droop method is mostly used on VCM inverters, which is difficult to be applied directly on RES inverters since they are often current controlled mode (CCM) inverters with only current inner loop [9]. In most of the above papers simulated parameters are stated, but we have implemented and realized proof of concept model.
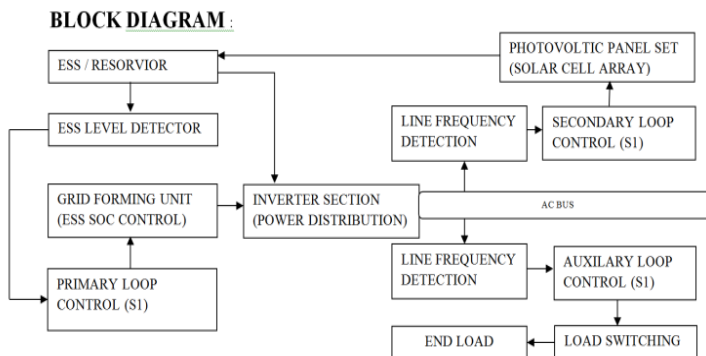
3. BLOCK DIAGRAM & EXPLAINATION

To obtain efficient utilization of PV, to avoid over-charge and over-discharge situations of battery reservoir of ESS by keeping SoC of ESS in a safe range, to deliver constant power to load at any point of time with adequate utilization of power from PV, to prioritize the load to avoid voltage instability, to control power balance among DG, ESS and load and to avoid sudden bus frequency changes, smart coordinated power control strategy based on Frequency Bus Signaling is suggested.

The main objective of this proposed is to use line frequency of the microgrid is used as communication link between power sources and their respective converters

the amount of power they need to generate and prioritized loads in order to maintain the ESS state of charge below or equal its maximum allowable limit. Following Fig. 1 shows the basic block diagram of the proposed system.

FIGURE -1: BLOCK DIAGRAM OF PROPOSED SYSTEM

Block Diagram of proposed system consists of three main units.

    1) ESS SOC Control unit
    2) PV Generation Control unit
    3) Load Control unit

1. ESS unit serves the power to bus lines. PV panel cell charges ESS reservoir. It will store the energy with pre-defined threshold. Typically, in ESS reservoir is lead acid battery is used. Overcharge and over-discharge protection is incorporated in the reservoir unit. ESS SoC unit generates signal for inverter according to the SoC of the reservoir.

Primary Loop Control is sub system block used as a feedback loop between ESS SOC state and generation section. Depending upon ESS SoC threshold level (high, medium, low) this block generates a signal for ESS SoC control block, which will modify frequency of AC line through inverter. Inverter Section is digitally controlled inverter. A PWM signal is fed to this section, which will change the frequency of AC signal depending upon level of SoC.

Two Line Frequency Detectors are used, one at PV unit other at loads unit as a sensor for detecting change in AC bus frequency as communication between ESS, Generator and Loads is carried out with AC line frequency. AC line frequency will be sensed and compared with pre-defined set values between threshold limits. This section will generate proportional output signal based on input sensed line frequency.

2. Secondary Loop Control section is connected between Line frequency detector and Photovoltaic (PV) panel set. According to sensed frequency by frequency detector, Secondary loop control block will generate signal to control amount of power to be generated by PV panel. This section will generate PWM signal for controlling PV output power.

3. Auxiliary Loop Control gets feedback signal from Line frequency detector which will continuously monitoring bus frequency. According to the sensed line frequency Auxiliary loop control block will generate signal for Load switching section to priotarize the load. Load Switching Section is a final load control section which will connect or disconnect the supply to the loads according to their priorities.

4. ALGORITHM

A. Algorithm of ESS SOC Based Grid forming unit

   I.   Initialize the system.
   II.   Load input / output values of voltage into the system.
   III.   Initialize sensors.
   IV.   Take voltage sample for battery level.
   V.   Convert & Scale sensed input into battery.
   VI.   Check converted values with predefined levels.
   VII.   If values are matching with lower threshold, output MOSFET driving frequency is set to higher defined values.
   VIII.   If values are matching with upper threshold, output MOSFET driving frequency is set to lower defined values.
   IX.   If values are matching with lower threshold, charging section output voltage is set to higher values.
   X.   If values are matching with higher threshold, charging section output voltage is set to lower values. If values are between upper & lower threshold, charging section output voltage is set to idle values.

B. Algorithm of Frequency Detection and PV Generation Control

   I.   Initialize the system.
   II.   Load input / output values into the system.
   III.   Initialize sensors.
   IV.   Take voltage sample readings for PV level and
   V.   Convert & scale sensed input into PV % values
   VI.   Take frequency sample readings for signal input
   VII.   Convert & Scale sensed input into frequency Hz values
   VIII.   Check converted values with predefined levels
   IX.   If values match with lower threshold, output PV power control driving is set to higher defined values.
   X.   If values match with upper threshold, output PV power control driving is set to lower defined values.

XI. Controls the amount of power generated by PV using feedback signal received.

XII. Feedback is the frequency of generated AC waveform

XIII. Output power is linked to ESS charging circuit according to frequency status.

XIV. Based on ESS SOC, the overall output of PV is combined with this section and optimized.

C. Algorithm of Frequency Detection and Load Switching

I. Initialize the system.

II. Load system input / output values into the system.

III. Initialize sensors.

IV. Take frequency sample readings for signal input.

V. Convert & Scale sensed input into frequency Hz values.

VI. Check converted values with predefined levels.

VII. If values matched with lower threshold, switch lower priority load to low state, higher priority load to high state.

VIII. If values match with upper threshold, switch higher priority load to high state, higher priority load to high state.
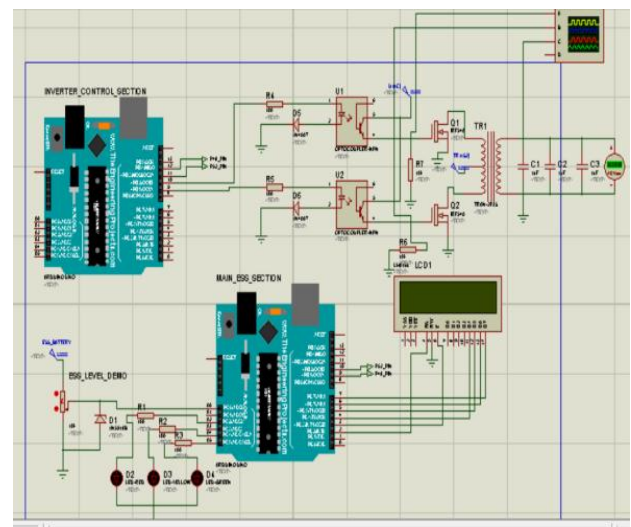
5. SIMULATION RESULT AND OBSERVATION

For circuit designing and simulation we are using Proteus simulation and design software tool. As system is divided into several sections, following shows designed circuits in distributed form.

A. SOC Based Grid Forming Unit

The main component of the control section of the circuit is microcontroller from AVR family i.e. ATMEGA328P. During initial state, ESS level is sensed and determined by a voltage sensor interfaced with battery health monitor. Depending on control algorithm designed for the controller, signal is generated to the controller, which will take appropriate action i.e. changing the output frequency and loop is executed to generate a particular frequency for output AC waveform generation. When an ESS level is dropped below lower threshold or raised higher than upper threshold a controller will take action in terms of change in MOSFET ring frequency/ time period. These MOSFETs are connected in Inverter circuitry which will change output frequency of transformer. The typical transitions in frequency are between 49 Hz and 51 Hz.

A charging Section is auto controlled with respect to cover charge/deep discharge states of the system as to limit the voltage feeded to the battery section for different conditions of charge cycle. Also, indicator is included into the system show the current status of the system.
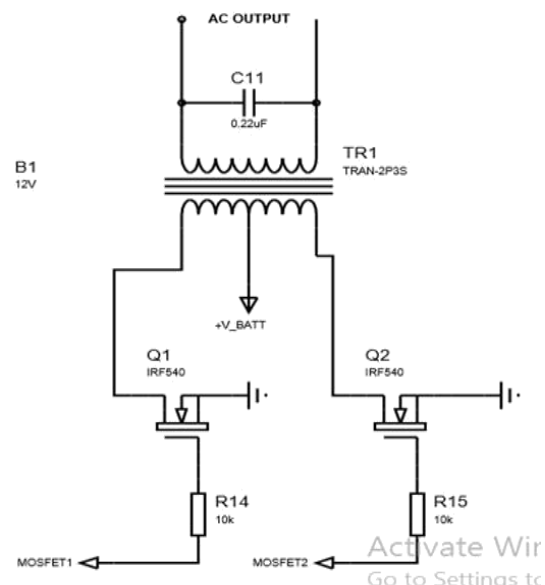
FIGURE -2:SIMULATED CIRCUIT OF ESS GRID FORMING UNIT
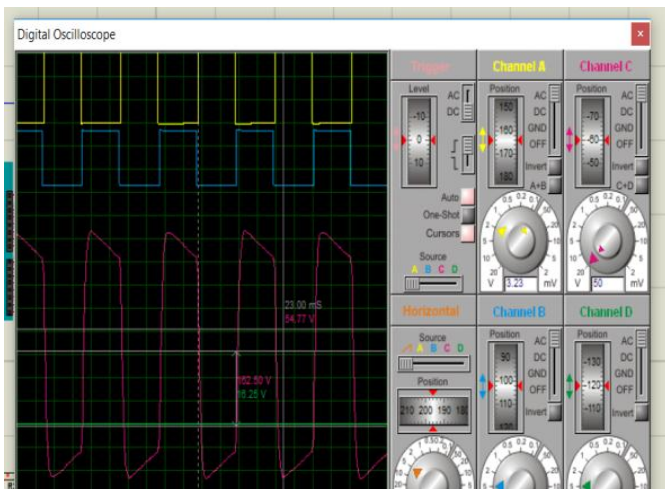

B. Inverter circuit design

In our system, as output PV is DC which charges the battery/reservoir. SoC of battery is sense by Microcontroller ATMEGA328 and it varies the ON and OFF time periods of both MOSFET's in inverter circuit through PWM technique in order to set AC line frequency low/medium/high. We are using Half Bridge Inverter with two MOSFET's. In our system we are using MOSFET IRF540 inverter circuit as a main switching component at high frequency with high power. Following Fig.3 shows circuit diagram of Half Bridge Inverter circuit.

FIGURE -3: HALF BRIDGE INVERTER CIRCUIT

Following shows PWM waveforms at MOSFET's and inverter output waveform.

FIGURE -4: SIMULATED PWM WAVEFORMS AND INVERTER OUTPUT WAVEFORM

C. Frequency Detection and PV Generation Control

This is the second main section of the system, it contains of PV panels a generation station with the demonstration capacity of 20W continues with 12-14V floating voltage and Chopper circuit to control PV output power. This section also includes ATMEGA328 microcontroller based circuit to generate PWM control waveform for Chopper circuit.

FIGURE -5: SIMULATED CIRCUIT OF PV GENERATION CONTROL

CIRCUIT USING MOSFET

The Chopper MOSFET allows current to flow to battery is governed by the pulse wave modulator (PWM). The purpose of the pulse wave modulator (PWM) is to provide a gating signal to the MOSFET to turn it on and off. The

PWM creates a square pulse whose duty cycle (time in high state divided by its period) is controlled .The microcontroller ATMEGA328 generates PWM pulses, and the high section of these pulses turns on the MOSFET. The longer the MOSFET is turned on, the larger the PV output power. Thus, by varying the ON period i.e. duty cycle, it is possible to vary the PV power generation. The MOSFET in Chopper circuit acts as a switch. It allows current to flow through it for certain periods of time. These periods are controlled by the PWM current waveforms that flow to the gate of the MOSFET. The MOSFET conducts for the ON period of the gating signal, and does not conduct for the OFF period of the gating signal. The higher the duty cycle of these input waves, the longer the MOSFET acts as a closed switch, connecting the PV source to the battery. We attached a large heatsink to the MOSFET to prevent overheating and breakdown due to large currents.
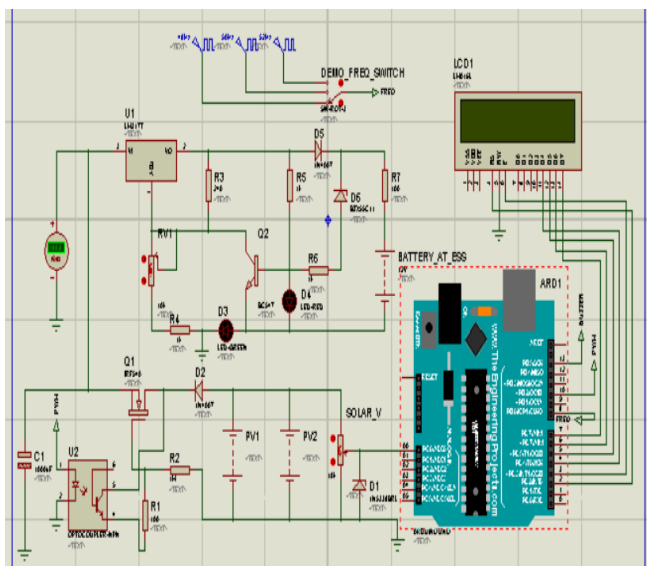
BATTERY CHARGING CIRCUIT

A variable voltage charger circuit is implemented using LM317, which has current dependent voltage changing facility with output and input adjustment span of 1.2 V to 35 V. A three level resistive - transistorized circuitry is used. A base signals are voltage generated in particular sequence to maintain the output of charger circuit in particular regions like cut o idle and boost mode. A PV input is fed to the input of this charging section.

FREQUENCY DETECTION AND LOAD SWITCHING

Frequency detector circuit is used to detect the line frequency with the help of step down transformer, along with Schmitt trigger (555 timer based) section. AC line waveform is reduced and converted into square-wave while keeping frequency same with this circuit. Time period of the wave is calculated with the help of time mode of AVR ATMEGA328 controller. This time period or frequency of the signal is compared with predefined threshold values. Based on comparison results, controller will switch relay loads in ON state or OFF state. Priority of the load can be defined in controller algorithm for specific operation. We can use different switching drive sections as transistor driven electro-mechanical switching or opto-driven solid state relay switching but our system we are using optocoupler solid state switching using TRIAC called Solid State Relay.

Following Fig.6 shows use of SSR in our system used to connect /disconnect loads from AC supply according to availability of battery voltage i.e. SoC of battery. Microcontroller ATMEGA328 connected to High Priority and Low Priority Loads through optocoupler based SSR.

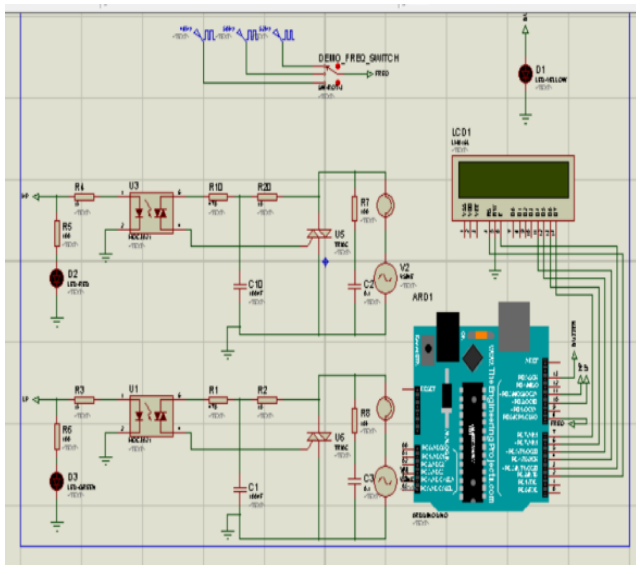FIGURE -6: SIMULATED CIRCUIT OF LOAD SWITCHING CONTROL
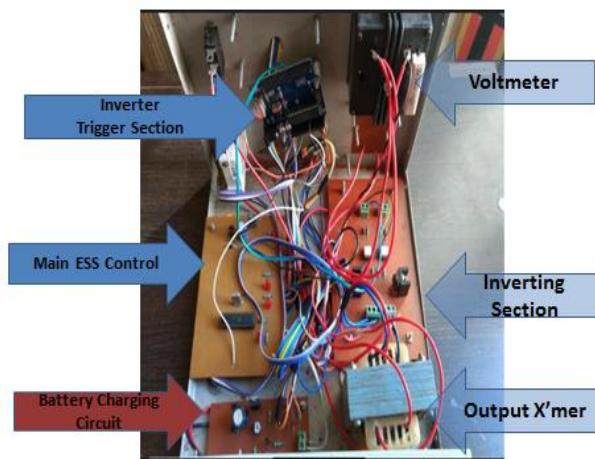

FIGURE -6: ESS CONTROL SECTION PROTOTYPE

FIGURE -7: FREQUENCY DETECTION AND PV CONTROL SECTION PROTOTYPE

SOLID STATE RELAY AND ITS ADVANTAGE

The main advantages solid state relays (SSR) is made of either SCR or TRIAC along with optocoupler it do not have any moving parts to wear out, and therefore no contact bounce issues, are able to switch both "ON" and "OFF" much faster than conventional electro-magnetic relays.

Like Electro-magnetic relay , SSR also require small input voltage, typically 3 to 32 volts DC can be used to control a much large output voltage, or current, for example 240V, 10Amps. This makes them ideal for microcontroller, PIC and Arduino interfacing as a low-current, 5volt signal from say a microcontroller or logic gate can be used to control a particular circuit load, and this is achieved with the use of opto-isolators/optocoupler.

One of the main components of a solid state relay (SSR) is an opto-isolator consist LED light source, and a photo sensitive device within a single case used to isolates the input from the output.

6. HARDWARE PROTOTYPE

For proof of the concept, simple, more reliable, high efficient and off the shelf electronics hardware is used to setup the test bench. ESS, PV Generation Control and Load Switching units hardware prototype and the overall complete prototype diagram is illustrated following fig.7, fig.8, fig.9 and fig.10.
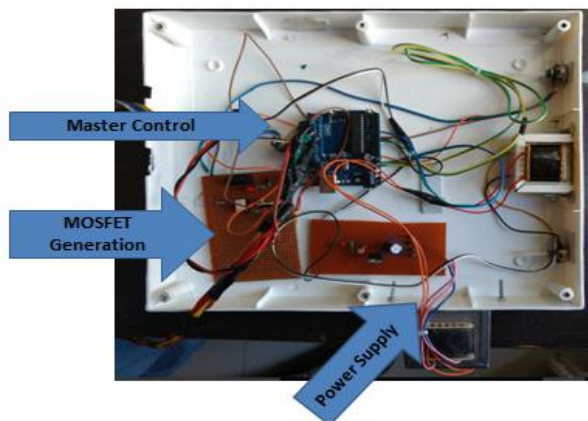

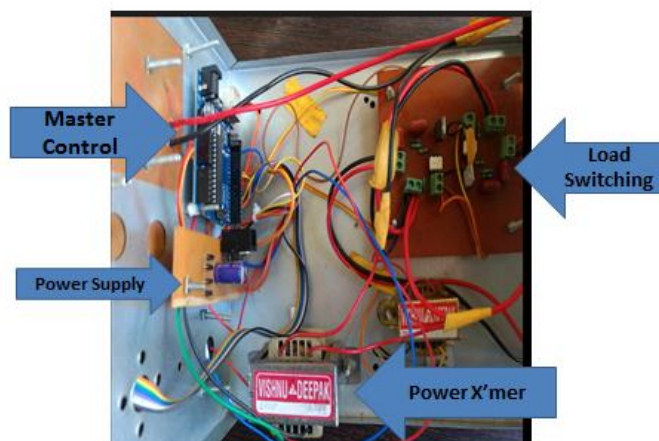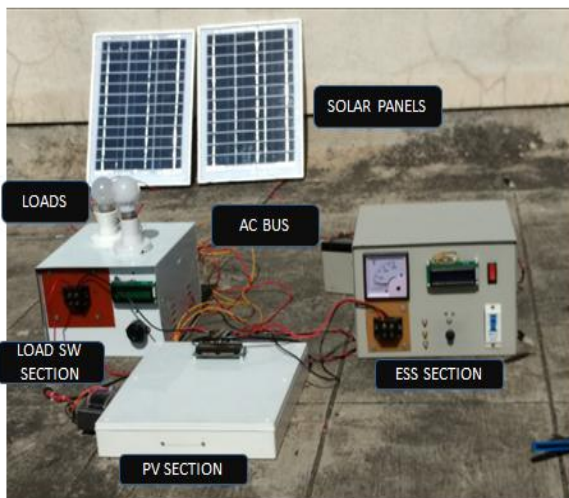FIGURE -8: FREQUENCY DETECTION AND LOAD SWITCHING SECTION PROTOTYPE

FIGURE -9: OVERALL COMPLETE PROTOTYPE

7. EXPERIMENTAL OBSERVATION

After designing, developing and implementing we got following experimental observation of following parameters shown in table 7.2.

Table 7.2 System's Experimental Observations

Sr.No.	Parameter	Value
1	PV OC Voltage	20.61V
2	PV Voltage: PWM HIGH	16.03V
3	PV Voltage : PWM LOW	14.59V
4	ESS O/P Voltage [AC]	240-260V
5	ESS O/P Frequency : [LOW ESS]	48.4Hz
6	ESS O/P Frequency : [MED ESS]	50.06Hz
7	ESS O/P Frequency : [HIGH ESS]	51.97Hz
8	Frequency Detection Error	±2%

8. CONCLUSION

In this paper, design and implementation of frequency bus signaling strategy is used for Energy Balancing in Islanded Microgrid. It is equipped with ESS, the PV systems, and loads based on smart frequency bus signaling method to coordinate distributed components of islanded microgrid to meet supply-demand balance. The proposed system is capable of controlling the PV generation during overcharge condition of battery and cutoff low priority loads during over discharge condition of battery. So this proposed frequency bus signaling is simple, reliable and efficient energy balancing technique as it does not require lump loads to dissipate excess energy and external communication links and network.

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