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Research Article

Energy Balance in AC Is-landed Micro-grid by Frequency Bus Signalling Method

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I N F O

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A B S T R A C T

To keep the frequency stable and maintain stability of AC Is-landed micro-grid, power exchange among Distributed Generators (DGs), Energy Storage Systems (ESS) and loads should be balanced. Many innovative control techniques have been proposed and used for enhancing the stability of micro-grid for proper energy balance. In this paper, a self governing autonomous power control strategy based on Frequency Bus Signalling is proposed in order to achieve power management. The main objective of proposed strategy is to control the state of charge of battery reservoir limiting the voltage on its terminals by controlling the power generated by the Renewable Energy Sources (RES). The frequency of the micro-grid is used to inform the DGs to generate the power to maintain the ESS state of charge below or equal its maximum allowable limit. This method uses only local measurements for power distribution. Main power management function is implemented locally in primary level, while bounded frequency control can be achieved by using additional controller system.

Keywords: Distributed Generators (DGs), Energy Storage Systems (ESS), Frequency Bus Signalling, Renewable Energy Sources (RES)

Introduction

We are observing extraordinary growth and challenges in power generation, transmission and usage. New technologies include power generation from Renewable Energy Sources (RES). Renewable Energy Sources often come in the form of tailored Distributed Generation (DG) systems in grid-connected or standalone configuration.[5] Power electronics plays vital role to achieve this revolutionary technology. Future grid will be number of interconnected micro-grids in which every user is responsible for the generation and storage of the energy. Hence, micro-grids are major elements to integrate renewable/ distributed energy resources as well as distributed energy storage systems. Now, technocrats have to face a new scenario in which small distributed power generators and dispersed energy storage devices have to be integrated together into the grid. With this idea, whole energy system will be more efficient, intelligent, and wide-distributed. The use of distributed generation makes no sense without using distributed storage systems to cope with energy balances.[2] Technological advancement in power electronics has led to a condition where renewable energy sources can be virtually considered as completely controllable, within the limits imposed by natural phenomenon. Also, it was envisaged that a large-scale integration of new technologies into a smart grid will be quite critical if it is done independently. Thus, an idea of merging small variable nature sources with Energy Storage System (ESS) into a singular controllable entity that can work independently or grid-connected brought to a Micro- grid concept.[3]

In an islanded operation of Micro-grid having few micro-sources, the local frequency and the voltage control is not straight forward. During is-landing, the power balance between supply and demand does not match. As a result, the frequency and the voltage of the Micro-grid will deviate, and the system can experience a blackout unless there is an adequate power-balance matching process. The frequency of the Micro-grid may change rapidly due to the low inertia present; hence frequency control at local level is one of the main issues in islanded operation. The ESS based on power electronic device has a very fast time response. Therefore, a properly designed ESS can allow a system to stabilize by absorbing and injecting instantaneous power.[6]

Extracting all available Maximum power from RESs (MPPT) is desirable, but not always appropriate in isolated systems, as it can lead to an unmanageable excess of energy, resulting in possible overcharging of ESS. On the other hand, a battery, an ESS has specific requirements for recharging to obtain optimum life. So, there should be an option to control the units in the system according to their specific features as well.[3]

In is-landed Micro-grid comprised of the ESS and PV generation, the ESS unit is usually operated as a grid forming unit that regulates ac bus, while the PV systems work as grid feeding units that inject all available power into the system. ESS plays an important role for achieving the goal of power balance and grid frequency support in a safe range of State of Charge (SOC). However, this active power regulation strategy will make SOC out of safe control region if imbalance between consumption and generation lasts longer. These situations are referred as over charge and over discharge conditions, and it is well known that they may bring permanent damage to the ESS. On the other hand, auto power regulation of the ESS to maintain it within the SOC limits with ignoring the imbalance of power generation & consumption will deteriorate the frequency regulation function. Hence, the coordinated active power control strategy should take into account status of all Micro-grid elements such as the SOC of ESS, power available from the PV systems, and demand of power consumption.

Energy Balance Techniques

Many techniques have been proposed for coordination of RES and ESS in ac & dc standalone systems. Some of them are based on central supervisory controller with enabled communication interface to every unit. Although, it offers the best control capability, the reliability of this is low as its proper operation relies on a single component. Also, with an increase in the number of units, their connectivity may require extensive hardware. Most popular cooperative control strategy of micro-sources and ESS is based on centralized two layered control structure[6] wherein ESS handles frequency and voltage as a primary control and then secondary control in micro-grid management system returns the current power output of the ESS into zero. The ESS absorbs or injects the power through the droop characteristic and the frequency deviation is removed by Automatic Generation Control (AGC) of supervisory controller. Due to limited data that it can process and inherent single point of failure, this method can be implemented in concentrated systems only.[6] There is an alternative strategy i.e modified droop control strategy to control the generated power within an isolated micro-grid with distributed RES.[3] It is to control the terminal voltage of the existing battery banks below or equal its maximum allowable value. This is done by limiting the amount of power that each energy source can generate at each instant using a modified droop control strategy.[3] But, switching actions of droop curve may trigger stability problems induced by sudden bus frequency changes in micro-grid.

In Co-ordinated control strategy, each unit can operate in different operation modes taking into account the resource limitation.[10] By introducing a Primary-Frequency-Signalling (PFS), coordinated control between units is realised. An interesting way of communication is suggested using the information of AC bus for coordinated operation. Bus signalling concept can be utilized with bus frequency deviation as Primary Frequency Signalling (PFS) to enable system achieving source scheduling automatically. Co-ordinated control based on PFS requires each unit to be capable to regulate output frequency based on its source condition and output power. The PFS principle is introduced to achieve the coordinated control without communication link. Then control strategy based on droop method and virtual impedance can be implemented.[10] However, when no. of DGs increases, it becomes difficult to determine the bus voltage/frequency threshold.

Subsequently, Power Line Signalling method which is a distributed control strategy[7] in which the units inject sinusoidal signals of specific frequency into the common bus in order to communicate with each other was proposed. 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 controllers that are switched ON only during injection period. As the main focus for PLC is data transmission, frequencies from a few kilo- hertz up to several hundred mega-hertz have been used achieve acceptable physical layer rate. Here, the power lines are used as a carrier of sinusoidal logic signals only. The advantage is that instead of having fixed voltage deviation through-out the particular operating mode, PLS signals are used as triggers for mode transitions where deviation can be alternatively cancelled by secondary control action without affecting proper operation. The multiple resonant frequencies of these signals should be properly designed to avoid overlapping, and the coordinated signals may introduce noises into the distributed units.[7]

Recently, an autonomous active and reactive power distribution strategy[9] that can be applied directly on current

Control Mode (CCM) inverters, being compatible as well with conventional droop-controlled Voltage Control Mode (VCM) converters is proposed wherein active power distribution is based on unified local control algorithm which ignores the inherent power regulation difference between ESS and RES. To ensure efficient utilization of PV, to avoid Over-charge and over-discharge conditions of ESS by keeping SOC of ESS in a safe range, to deliver constant power to load at any point of time with adequate power from PV, to prioritize the load to avoid voltage instability, to ensue frequency stability by ensuring power exchange balance among DG, ESS and load, to maintain system Energy balance without using dump loads and to avoid sudden bus frequency changes, self-governing autonomous power control strategy based on Frequency Bus Signalling is suggested.

System Description

In this study, self-governing autonomous power control strategy compatible with a hierarchical control scheme is proposed for islanded ac micro-grids formed by the distributed ESS, the PV systems, and loads.

The Proposed method is based on the frequency bus-signalling of ESS and uses only local measurements for power distribution among micro-grid elements. Basic power management function is achieved locally at primary level, while strict frequency regulation can be achieved by using additional secondary controller.

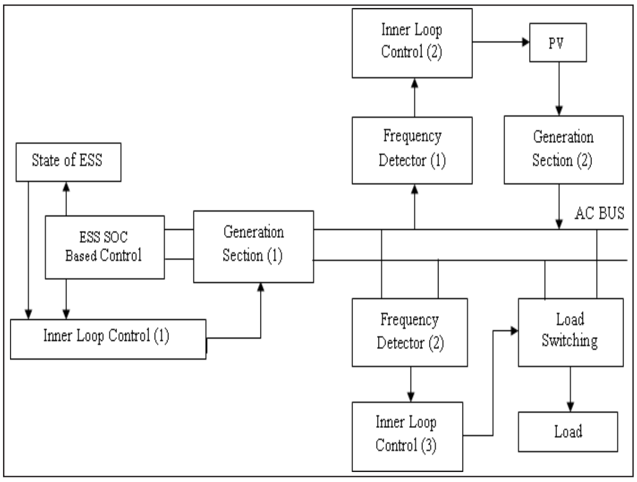


Figure 1.Block diagram of proposed system

Figure 1, shows the block diagram of the system consist of three main sub-divided blocks. ESS (SOC Based Control) and state of ESS unit serves the power to bus lines. It will store the energy with pre-defined threshold. Typically lead acid battery is used. Overcharge and deep-discharge protection is incorporated in the battery sensing unit. SOC state generates output according to the inner state of the battery bank.

Inner Loop Control (1) is sub system block used as a feedback loop between ESS SOC state and generation section. Based upon ESS threshold level (high 95%, low 45%) this block generates a signal, frequency of which will be modified by generation section. This section will maintain ESS in proper condition. Generation Section (1) is having digitally controlled inverter. A PWM signal is fed to this section, which will change the generation frequency with pre-defined levels. A feedback is provided to inner circuit which will automatically bring up the output frequency to desire level depends on input PWM signal.

Frequency Detector is used on bus sensor point as bus line communication is carried out with frequency signalling method. 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 frequency. Inner Loop Control (2) section is connected between bus frequency sensor and PV generation part. When feedback signal will be arrived from frequency detector, this section will control amount of power generated by PV. This will help to avoid the use of dump load which affects the overall efficiency. Also, with smooth switching sudden spikes can be avoided in the bus.

Generation Section (2) is Similar to generation section (1). It generates output power which is linked to ESS and load. Based on SOC, the overall output of PV is combined with this section and optimized. In practice, this section considers to be a line connected inverter to maintain the overall power to the bus. Inner Loop Control (3) receives inputs from frequency detector which is continuously monitoring bus frequency. It is equipped with a demand control which will decide the switching state of the load. Load Switching Section is a final load control section which will connect or disconnect the supply fed to the load according to the priorities.

Control Methods

ESS and Inner Loop Control(1)

In this part, AVR controller (ATMEGA328) based control system is implemented. Input is given from ESS battery sensing circuit, all values are scaled in order to get actual ESS state. According to the algorithm, system will sense input values and change output firing frequency. MOSFET driving section gives the supply input to transformer which step it up till required voltage. Frequency is controlled with the help of gate pulses to the MOSFET as shown in Figure 2.

A charging Section, is auto controlled with respect to over charge/ deep discharge states of the system as to limit the voltage fed to the battery section for different conditions of charge cycle.

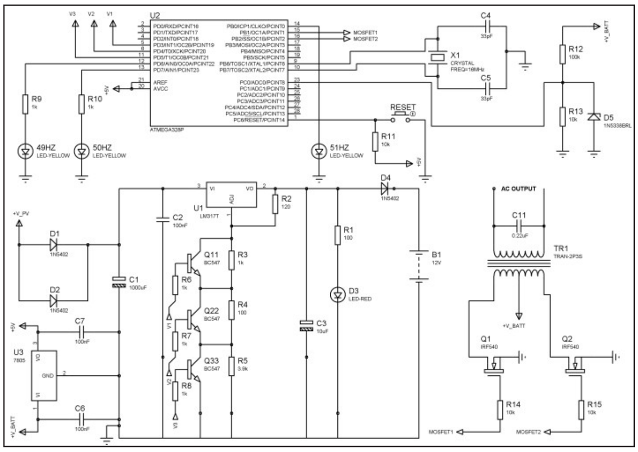


Figure 2.ESS and Inner Loop Control Circuit B.PV and Frequency Detection

[Inner Loop Control(2)]

This is the second main section of the system. It contains PV generation station with the demonstration capacity of 20W continues with 12-14V floating voltage/ OC voltage. A schimitt trigger based circuit is implemented in the main sensing part along with step down voltage converter in order to detect the line frequency to switch the controller modes. Input wave is primilary conveted into square wave and time period of both high & low levels is measured in order to detect the signal frequency.

Depending on the detected frequency value, controller will control the output getting generated by the PV source with the help of feed control to line so that power can be mainatained. A PWM technique is used in combination with MOSFET to implement power control. Figure 3, Shows the base circuit diagram.

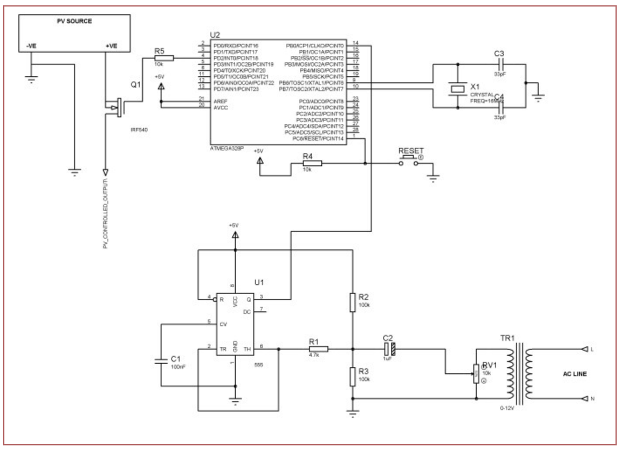


Figure 3.PV and Frequency Detector Circuit

In order to make system more efficient, a load switching is used as to make lower priority load off in case if critical ESS state. For that a frequency detector is implemented similar to block (2), where as in this section the predefined frequency values are continue sly checked, and according to the case a lower priority loads are switched OFF in order to mainitain the minimum critical level of the ESS. The load switching can be achieved with the help of electromagnetic relay with transistorized driver or even we can use SSRs for smooth switching.

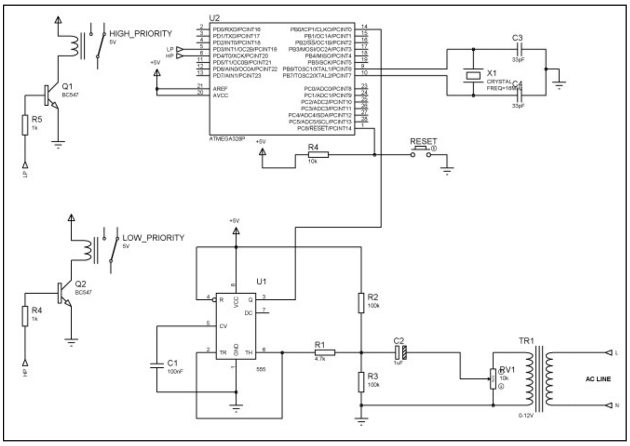


Figure 4.Load Switching and Frequency Detector Circuit

Simulation Results

ESS and Inner Loop Control Circuit

CASE 1: SOC LOW

Frequency is auto-selected as 49Hz, and charger section voltage is set to High by controller to charge battery at faster rate.

CASE 2: SOC HIGH

Frequency is auto-selected as 51Hz, and charger section voltage is set to LOW by controller to prevent battery overcharge condition.

Output waveform for MOSFET gate firing & sine wave generation:

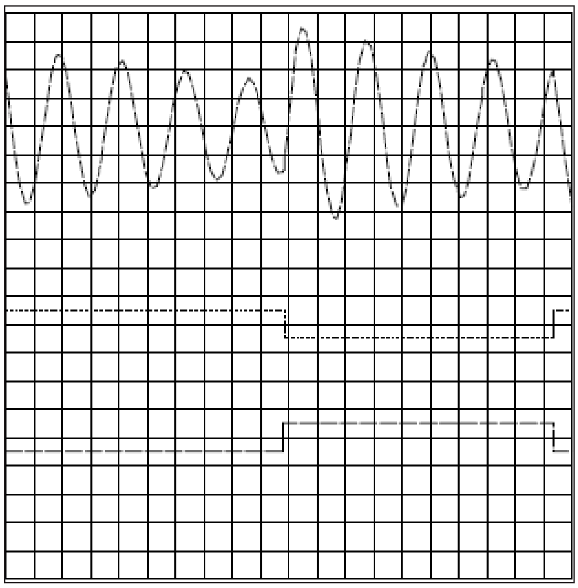
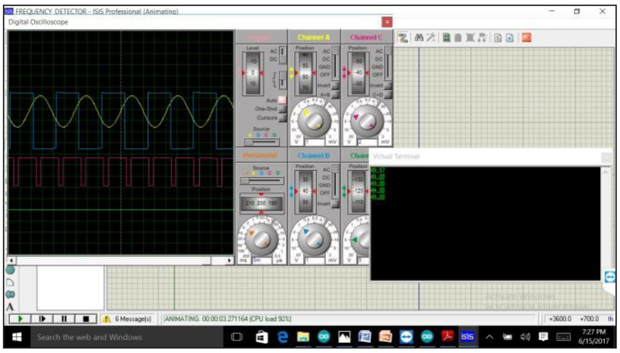


Figure 5.Stage I output waveform

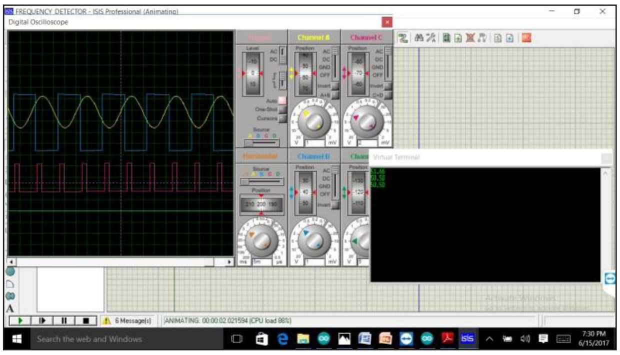
PV and Frequency Detector Circuit

CASE 1: Bus Signal Frequency LOW



Comment: Frequency detected as 49Hz; corresponding waveform shows the conversion, Also PWM signal duty cycle is high to allow more power from PV.

CASE 2: Bus Signal Frequency HIGH



Comment: Frequency detected as 50.5Hz; corresponding waveform shows the conversion, Also PWM signal duty cycle is low to limit the power from PV.

Output Waveform for PWM gate firing & Schmitt Trigger:

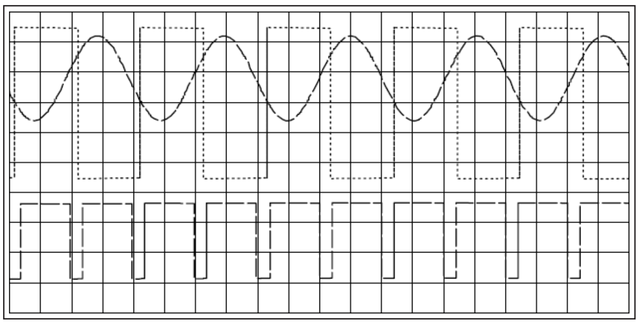


Figure 6.Low ESS; High Duty Cycle PWM

Load Switching and Frequency Detector Circuit

CASE 1 : Bus Signal Frequency LOW

Frequency detected as 49Hz; corresponding LED indicator shows the priority switch state, Also we can observe relay driver logic level state change for LP (lower priority) & HP (higher priority).

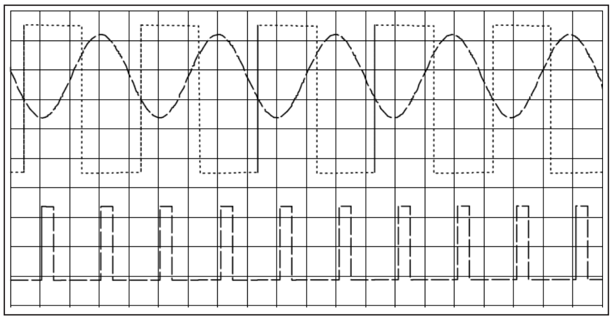


Figure 7.High ESS; Low Duty Cycle PWM

CASE 2 : Bus Signal Frequency HIGH

Frequency detected as 51Hz; corresponding LED indicator shows the priority switch state, Also we can observe relay driver logic level state change for LP (lower priority) & HP (higher priority).

Condition: For simulation & analysis purpose, we have defined and feeded input as variable voltage values corresponding to the ESS state in primary block. Thus based on these state bus signal frequency will change from 49 – 51Hz. This Frequency signals are then applied to each next block as input in order to check functionality & validate their reponce the system state. During switching of the bsu frequency the operation mode of each section is getting changed successfully as per the algorithm of system.

Conclusion

This paper proposes coordinated strategies based on frequency bus signaling for micro grids with PV generator and battery storage. The proposed control algorithms are capable of handling the battery SOC constraint by balancing the power generation from the PV systems and load. The electrical frequency of the micro-grid is used to inform the power sources to generate the power in order to maintain the ESS state of charge below or equal its maximum allowable limit. This coordination performance was obtained by using only local controllers and does not rely on external communication links. Therefore, the risk induced by the failure of the communication links can be avoided and the reliability of the system is enhanced. Also, a centralized secondary control was applied to effectively eliminate deviation of the bus frequency.

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