EXAMINING SOLAR SYSTEM BEHAVIOR AND SINGLE-PHASE ENERGY STORAGE BATTERIES IN A SMALL-SCALED MICRO-GRID TO DECREASE RELIANCE ON AC NETWORK POWER

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ABSTRACT

In the last decade, with an increase in growing demand of electric power consumers, the use of solar energy is significantly increased for power supply to the urban and rural residential buildings and houses. The solar systems are operated independent from network or connected to distribution network. The power generation of solar systems depends on atmospheric conditions (solar radiation and ambient temperature), therefore, in the network-independent solar systems, the energy storage batteries are used for reliable and stable power supply, but in the solar systems connected to the network, for lack of energy storage, the surplus energy generated by the system is directly transmitted to the distribution network. The power generation of single-phase household solar systems is between 1-5kW, while the peak of electrical consumption in a residential house is less than 2.5kW. Hence, by adopting an appropriate strategy such as storage batteries (capacity of 1000Ah), the power consumption of other residential homes that are located near the microarrays can be supplied with no reliance on power of network distribution. In this article, it has been attempted to model a micro-grid including a single-phase AC distribution system, solar system, storage batteries, and household load using Matlab/Simulink capabilities. The microarrays are connected to the distribution network through a single-phase distribution transformer of 20/0.24kV. The charging and discharging management of storage batteries are done through a control system. The control system strategy of the storage batteries is designed with minimum dependence on power generation of network, so that the solar system and storage batteries can supply total power at all periods under every conditions. The control system strategy of the storage batteries is planned in such a way that absorbed the surplus power generation of microarrays and can compensate for lack of power at peak consumption times. The current tracking by the storage battery control system made the transient active power to be approximately zero on secondary side of the transformer. However, at the times when control system is not in the circuit, the state of charge will be constant, and there will be no power storage or discharging, and surplus generation is transmitted to the network, and lack of power will also be obtained from the distribution network. The simulation has been done in two different scenarios, in the first scenario, the storage battery control system is in the circuit 24 hours a day, and in the second scenario, the storage battery control system is removed from the circuit at hours 12-18. The simulation results for a 24-hour period in the first scenario show that the micro-arrays can supply the total power without reliance on network power, and the exchange power from distribution network is almost zero, in the second scenario, merely 12.5% of power is supplied by the network, and the rest is supplied through micro-arrays.

INTRODUCTION

Today, the energy is one of the most important and controversial issues in the economics [1]. The population growth, energy loss, and pollution caused by fossil fuels are factors pointing out the future human constraints and hazards [2]. Due to the present constraints, only the appropriate consumption methods, optimization of energy consumption equipment, and newfound energies can inhibit the energy crisis. Today, for lack of fossil fuel resources and increased costs of power generated from such resources and some environmental issues, the renewable distributed power resources is the priority. For this reason, in the last decade, the power plants and solar systems have has been increasingly used. The integration of low-power solar systems (at 1-5kW) at residential buildings and houses for electric energy supply can reduce power consumption costs [3]. The solar systems are used for general use as network-independent power plants or systems connected to distribution network with static or movable installation structure in low-power small buildings for electric energy supply [4]. By installing solar systems, every household consumer is a small distributed generator (DG) that in addition to providing a part of the electrical energy of a building can transmit surplus power generation to the global network [5]. However, in a small-scaled micro-grid, with a change in structure and proposing an appropriate strategy, the stable and reliable power supply with the minimum reliance on power of global network is possible. Installing low-capacity storage batteries (1000Ah) with appropriate control system is one of the appropriate techniques in small-scaled micro-grids.

In this paper, it has been attempted to model a micro-grid including a single-phase AC distribution system, solar system, energy storage batteries, and household load using Matlab/Simulink capabilities. The microarrays are connected to the distribution network through a single-phase distribution transformer of 20/0.24kV. The charging and discharging management of storage batteries are done through a control system. The control system strategy of the storage batteries is designed with minimum dependence on power generation of network, so that the solar system and storage batteries can supply total power at all periods under every conditions. The control system strategy of the storage batteries is planned in such a way that absorbed the surplus power generation of microarrays and can compensate for lack of power at peak consumption times. The current tracking by the storage battery control system made the transient active power to be approximately zero on secondary side of the transformer. At the times when control system is not in the circuit, the state of charge will be constant, and there will be no power charging or discharging, and surplus generation is transmitted to the network, and lack of power will also be obtained from the distribution network. The simulation has been done in two different scenarios, in the first scenario, the storage battery control system is in the circuit 24 hours a day, and in the second scenario, the storage battery control system is removed from the circuit at hours 12-18. The simulation results for a 24-hour period in the first scenario show that the micro-arrays can supply the total power without reliance on network power, and the exchange power from distribution network is almost zero, in the second scenario, merely 12.5% of power is supplied by the network, and the rest is supplied through micro-arrays.

SOLAR SYSTEM MODELING

Often, the voltage generated by distributed power resources such as solar systems is DC, therefore, they cannot be directly connected to the urban AC network, and hence, the static converters (DC-AC inverters) are used to connect to the network [6-7]. An example of integration of solar systems and battery support system to AC networks is shown in Figure 1 [8]. These networks are known as hybrid micro-grids with AC bus.

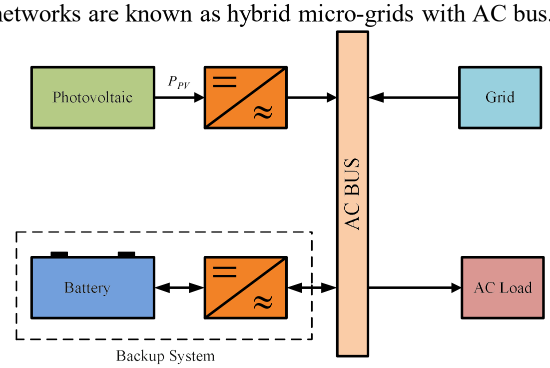

Figure. 1. Hybrid system with AC bus

The output voltage of the static converters used in single-phase solar systems is approximately sinusoid, therefore, there will be [9]:

$$v_{Inverter} = \sqrt{2}V \sin \omega t \qquad (1)$$

Since the solar systems are actually used in active power mode ($Q_{PV} = 0$), therefore, the maximum power seen in output of single-phase static converter of solar systems will be defined as follows [10]:

$$P_{Out\_Inverter} = \frac{v_{Inverter}}{\sqrt{2}} \times i_{\max} \cos \varphi \qquad (2)$$

Using the equations (1) and (2), the AC current of solar systems injected to the micro-grid can be estimated follows:

$$i_{Out}(t) = \frac{\sqrt{2}P_{Out\_Inverter}(t)}{v_{Inverter} \times \cos \varphi} \qquad (3)$$

Solar system modeling is shown in Figure 2.

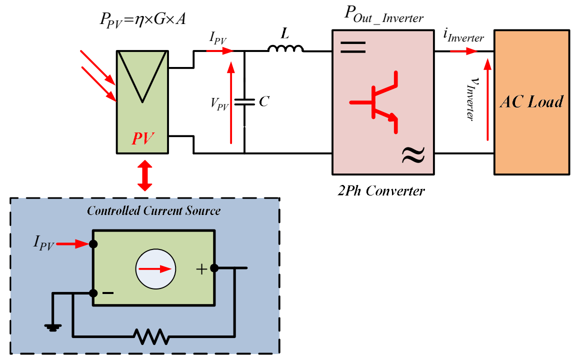

Figure. 2. Solar system modeling based on active power mode in Matlab

STORAGE BATTERY CONTROL SYSTEM

In micro-grid networks, the first priority is stable and reliable power supply [11], this principle must be respected in all working conditions. In the next stage, the surplus of microarray generation is used merely for storage in battery and transmission to the network is prevented, and network should be isolated from power exchange [12]. To provide the first principle in the microarray, the following equations must be established [13]:

$$\sum_{i=1}^{n} P_{Load\_i} = P_{PV} + P_{Batt} = P_{Load\_tot} \qquad (4)$$

$$P_{Batt,Ch}(0 < t < 24)\Big|_{P_{Grid-inject}=0} = P_{PV} - P_{Load\_tot} \qquad (5)$$

To meet the above conditions, the power injected from network to microarray or vice versa must be zero, therefore, $P_{ref} = 0kW$ is considered. Thus, there will be:

$$P_{ref} = P_{PV} + P_{Batt} - P_{Load\_tot} = P_{Grid-inject} \qquad (6)$$

The regulatory flow for storage battery control is calculated as follows:

$$I_{Batt} = K\int_0^t (P_{ref} - P_{Grid-inject}).dt \qquad (7)$$

$$K = \begin{cases} -\dfrac{1}{\eta_{Batt} \times C_{Batt}} \Rightarrow P_{Batt} > 0 \\ -\dfrac{\eta_{Batt}}{C_{Batt}} \Rightarrow P_{Batt} \le 0 \end{cases} \qquad (8)$$

η_{Batt}	: Storage battery efficiency
C_{Batt}	: Storage capacity (Ah)

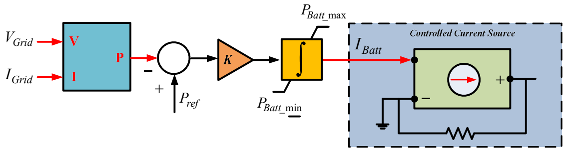

Figure. 3. Storage battery control system

RESULTS

The diagram of studied micro-grid is shown in Figure 4. This system includes a 20KV distribution network that is connected to the microarrays through a single-phase transformer. The microarrays include a 5kW solar power plant, household load with a variable load in time with peak consumption of 2.5kW, and storage battery with capacity of 1000Ah.

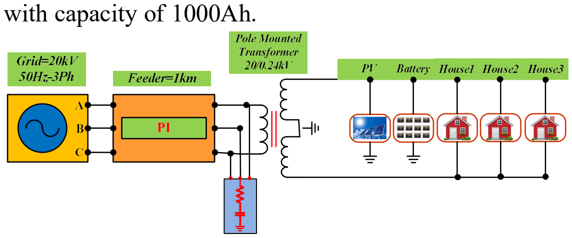

Figure. 4. Studied system [14]

Simulation results in the first scenario: The control system is in circuit 24 hours a day.

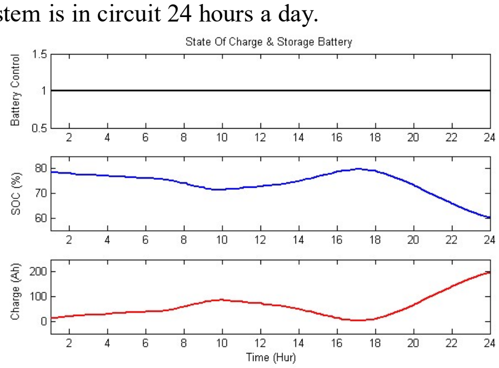

Figure. 5. State of charge, power storage percentage, and charging level

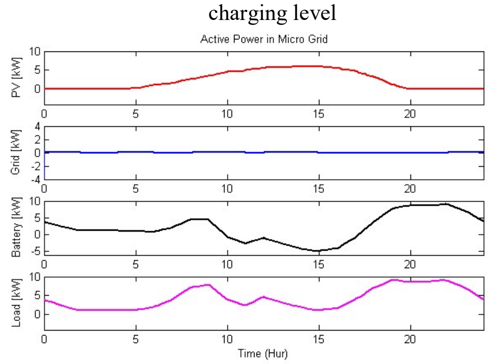

Figure. 6. PV power, network, battery, and power consumption

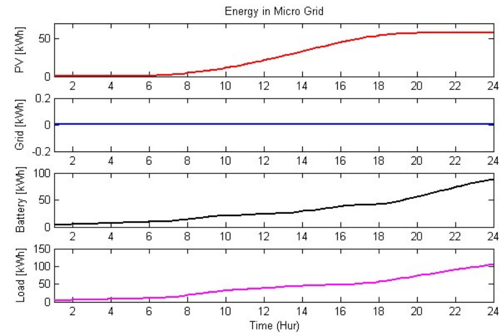

Figure. 7. PV energy, network, battery, and power consumption

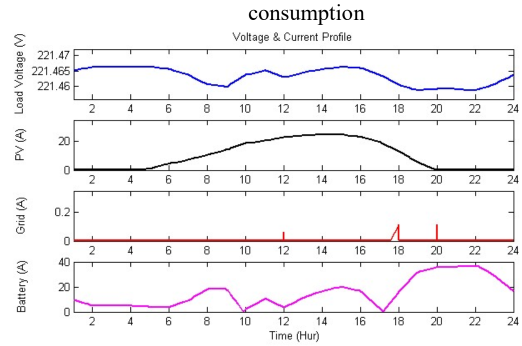

Figure. 8. Load voltage, PV current, network and battery

As seen in Figures (5) through (8), the control system prevents the power transfer from the microarray to the secondary side of transformer. In this period, the power generation of the solar system and power storage in battery are used for reliable power supply of system. During 24 hours of uninterrupted work, the system supplied the energy required for household loads without reliance on network power.

In the second scenario, the control system is removed from circuit between the hours of 12-18 for six hours, the simulation results will be as follows:

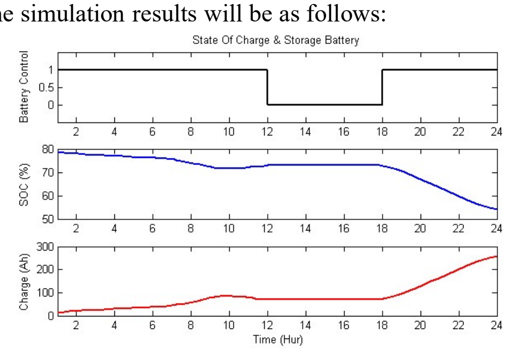

Figure. 9. State of charge, power storage percentage, charging level

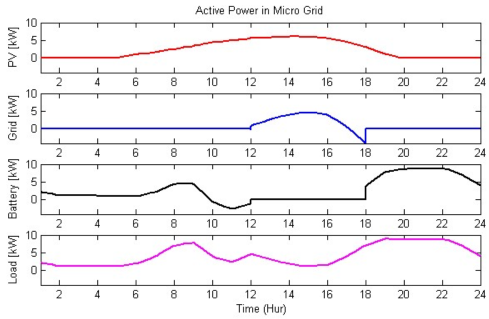

Figure. 10. PV power, network, battery, and power consumption

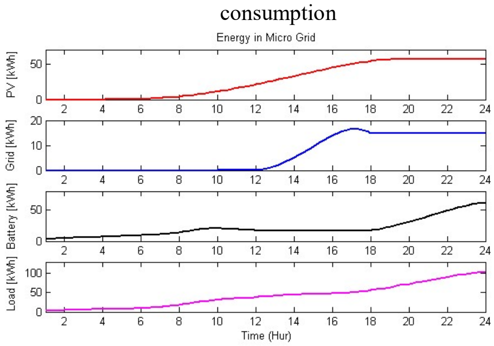

Figure. 11. PV energy, network, battery, and power consumption

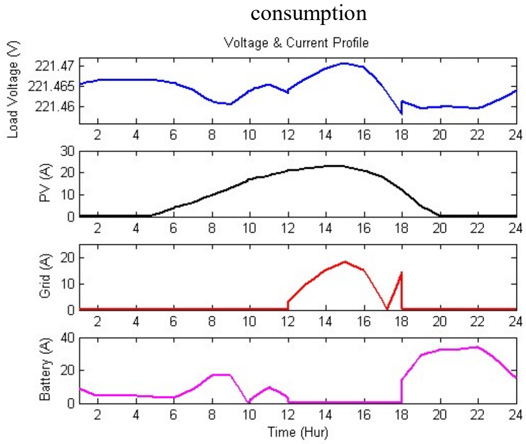

Figure. 12. Load voltage, PV current, network, and battery

As shown in Figures (9) through (12), in this scenario, the power exchange is only between network and microarray only at certain times when the control system is not in the circuit. However, the purpose of system is the minimum power exchange between microarray and network.

The energy level of each of the microarrays is shown in two different scenarios in Table (I). As can be seen, in both scenarios, the maximum energy is supplied by the storage system.

Table I. Comparing energy level in different scenarios

second scenario		first scenario	
micro-arrays	**Energy(kWh)**	micro-arrays	**Energy(kWh)**
PV	**56.9**	PV	**56.9**
Grid	**18.1**	Grid	**0**
Battery	**69.1**	Battery	**87.25**
Load	**104.4**	Load	**104.4**

CONCLUSION

In this paper, a small-scaled micro-grid including single-phase AC network, 5kW solar system, energy storage battery, which were used for power supply of three residential houses were simulated in in the Matlab/Simulink. The strategy used for battery charge control is designed in such a way to absorb the minimum network power, and system can receive the energy of consuming loads through a storage battery and solar system without reliance on network power generation. The simulation results showed that the strategy predicted in the storage battery control system received the minimum power from network. The consuming load was also supplied in a stable and reliable manner under all conditions.

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