# The Effect of Inverter Efficiency on Stand-Alone Residential PV System Sizing

Onur ELMA[1], Uğur Savaş SELAMOĞULLARI[1]

[1]Yildiz Technical University, Istanbul, Turkey
onurelma@yildiz.edu.tr, selam@yildiz.edu.tr

## Abstract

**Renewable energy resources have been widely adopted in the world due to environmental concerns, energy shortage, and decreasing cost of system components. Among these renewable energy sources, solar energy generation has attracted significant interest due to its easy implementation. Solar energy is especially good for residential buildings that are far from existing electrical grid. In such a solar powered stand-alone residential system, a backup source such as battery/supercapacitor is required for uninterrupted energy. The DC energy from solar panels is converted to AC energy thorough a power conditioning system. In this study, the effect of inverter efficiency on the backup size is analyzed. It is shown that for a reliable and correct sizing, the inverter efficiency that varies with loading conditions must be taken into account for stand-alone house where the demand changes within a wide range over a day.**

## 1. Introduction

With the affinity to the renewable energy resources all around the world, the photovoltaic (PV) systems those produce electricity from solar radiation became one of the most preferred systems due to their environmentally friendly characteristics and easy implementation [1].

In a solar powered residential house, there are three main components: a solar panel, a power conditioning equipment and an energy backup unit. Solar panels are used to produce electricity from solar radiation. The power conditioning unit composed of a DC-DC converter and power inverter is employed to transform the DC energy form solar panels to AC energy used in the house. The energy backup is used to store excess energy from solar panels as well as to provide continuous energy service to the house.

In this study, the effect of inverter efficiency on energy backup size for a stand alone solar powered house is investigated. Generally the inverter efficiency is taken as constant [2,3]. However, when a stand-alone house is considered, the electrical demand is highly dynamic [4]. Thus, when determining the backup size for such a system, constant inverter efficiency consideration will introduce an error and a comparative study needs to be completed.

This paper is organized as follows: in Section 2, the systems components in solar powered residential house are explained and Matlab/Simulink models are given. In section 3, systems simulation results are given. The effect of inverter efficiency (constant and variable) on backup size is given. In section 4, conclusions are given.

## 2. Main System Components and Modeling

For system simulation of considered house, Matlab/Simulink models of PV system, energy backup and inverter are developed and explained below.

### 2.1. PV System Modeling

Generally, solar panel manufacturers provides maximum power (Pm), open circuit voltage ($V_{oc}$) and short circuit current ($I_{sc}$) of a solar panel under ideal test conditions (1000 W/m2 radiation, 25 $^oC$ temperature) [5]. However, in real life both the solar radiation and the temperature are highly dynamic. Therefore, the output power of a panel is also highly dynamic. The PV panel short circuit current and open circuit voltage depending on the solar radiation and the temperature can be calculated as [5]:

$$I_{sc} = \frac{I_{sc}^*}{G^*} G \left[ 1 + (T_c - T_c^*) \frac{dI_{sc}}{dT_c} \right] \quad (1)$$

$$V_{oc} = V_{oc}^* + (T_c - T_c^*) \frac{dV_{oc}}{dT_c} + V_t . \ln(\frac{G}{G^*}) \quad (2)$$

In Equation 1 and 2, the letters with '*' reflects the reference values. G is the measured solar radiation. $I_{sc}$* is the short circuit current and $V_{oc}$* is the open circuit voltage provided by panel manufacturers. G* indicates the reference radiation value and is taken as 1000 W/m$^2$. $T_c$* reflects the reference cell temperature which is 25 $^oC$. The $V_t$ value in the equation is constructed by the combination of constants. The temperature of a PV cell ($T_c$) can be found by the following equation [5]:

$$T_c = T_a + C_t . G \quad (3)$$

Here, $T_a$ is ambient temperature and $C_t$ is equation constant which can be found by:

$$C_t = \frac{NOCT(^o C) - 20}{800} \quad (4)$$

The NOCT value in the equation varies between 42 and 46 $^oC$ for today's PV modules. As a result, the $C_t$ value varies between 0.0272 ile 0.0321 $^oC/(W/m^2)$ [5] .

In real PV system, an MMPT circuit (Maximum Power Point Tracking) is generally used to maximize the obtained energy from the available solar radiation. The maximum power point (Pm=Vm*Im) can be calculated based on the open circuit voltage and the short circuit current values found by Equation 1 and Equation 2 [5]:

$$V_m = V_{oc}\cdot\left[1 - \frac{b}{v_{oc}}\ln a - r_s(1-a^{-b})\right] \quad (5)$$

$$I_m = I_{sc}.(1-a^{-b}) \quad (6)$$

Here, the a and b coefficients are given by

$$a = v_{oc} + 1 - 2v_{oc}r_s \quad (7)$$

$$b = \frac{a}{1+a} \quad (8)$$

$v_{oc}$ and $r_s$ values can be found using $v_{oc}=V_{oc}/V_t$ and $r_s=R_s/(V_{oc}/I_{sc})$ [5].

A Simulink block diagram is built based on the Equations given in this section to model the PV system.

### 2.2. Battery Modeling

Since we are only interested in system analysis, a simple battery model is developed. The state of the charge of the energy backup is calculated based on power difference between the load demand and the produced solar power. In this calculation, the backup initial energy is defined a parameter and can be changed by the user. When the produced solar power is bigger than the load demand, the energy backup is charged. When the produced solar power is lower than load demand the energy backup is discharged. An integrator with initial value is used to model the energy backup and to calculate the state of charge (SOC) of the backup source. It is assumed that the minimum SOC can be 30% and maximum SOC can be 110% of the initial backup energy.

### 2.3. Inverter Modeling

Since the produced energy from solar panels is DC, a power inverter is employed to transform this DC energy to AC energy with desired frequency and amplitude. The real inverter efficiency changes depending on the processed power level as shown in Fig. 2. In a stand-alone residential house the load demand is also highly dynamic [4]. Therefore, for a proper system analysis, the change in the inverter efficiency with loading should be considered. Here, a power versus efficiency look-up table is used to model the inverter.

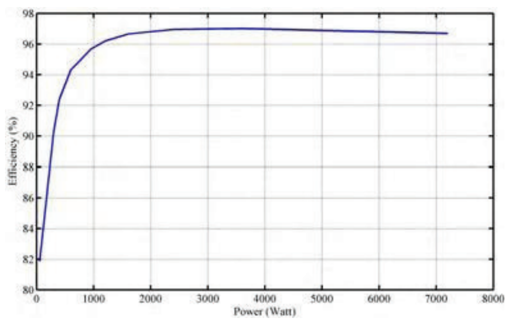


**Fig. 1.** Inverter efficiency curve with respect to loading [4].

## 3. Systems Simulations

A solar powered stand alone residential building (Fig. 2) is simulated using the developed models in Section 2. The purpose of the hybrid system is to supply the electrical demand of the house without interruption.

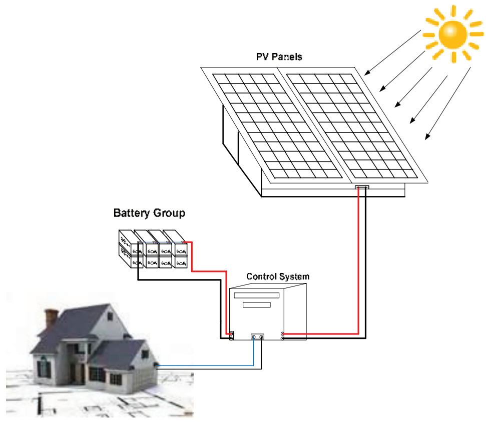


**Fig. 2.** Considered PV/Battery Hybrid Power System

Both voltage and current measurements are recorded at every minute for a week at a 4 person family house in Istanbul, Turkey to obtain the residential electrical demand characteristics. Also, solar radiation and ambient temperature values are also recorded at every minute using Davis VantagePro2 weather station at Besiktas, Istanbul and shown in Fig. 3.

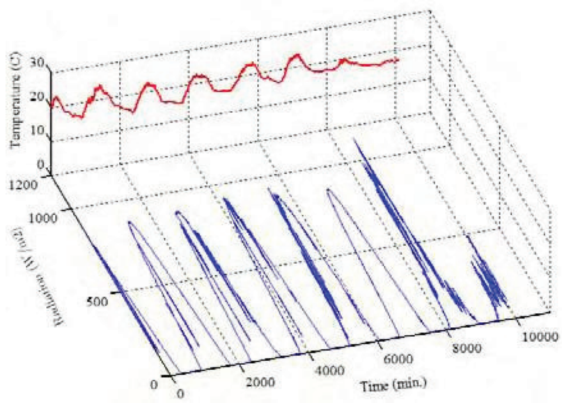


**Fig. 3.** Measured solar radiation and ambient temperature data for a week

Two different scenarios are simulated using the weekly measured electrical load demand, solar radiation, and temperature values as input to Simulink system model:
(i) an inverter with a constant efficiency (%95) [2,3],
(ii) an inverter with variable efficiency with loading [4].

For each case, the backup size is determined in such a way that the minimum SOC is 30% at maximum loading conditions. To prevent an overcharge condition when solar power is larger than the load demand, a relay is used to turn the solar panels off in simulations. A total of 2.5 kW solar panels are used in the simulations. The SOC change for each case is shown in Fig. 5.

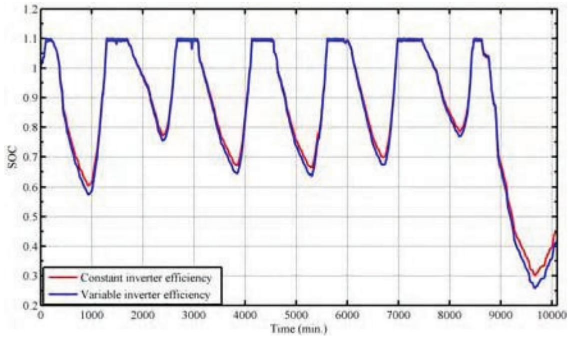


**Fig. 5.** Backup SOC for constant and variable inverter efficiency cases.

The required backup size, that satisfies SOC ≥ 30%, for the constant inverter efficiency case is found as 40.5 MJ. When the variable inverter efficiency with loading is considered the SOC ≥ 30% cannot be achieved with 40.5 MJ backup size as shown in Fig. 6.

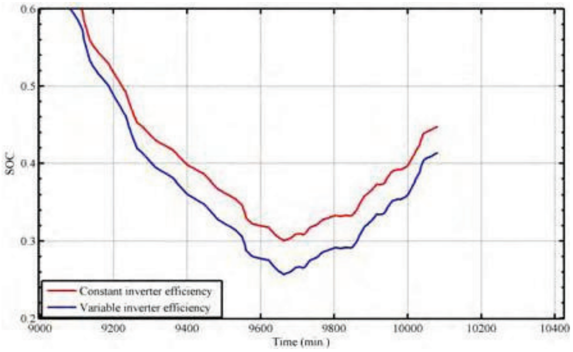


**Fig. 6.** Battery SOC-zoomed

Then, with all other variables kept constant backup initial size is increased for variable inverter efficiency case to obtain SOC ≥ 30% condition. In this case the backup size is found as 43.2 MJ.

## 4. Conclusions

A solar powered stand-alone residential house with backup support is analyzed to find the required backup size for continuous operation of the house. In real inverter systems, the inverter efficiency varies depending on the processed power level. However, it is usually considered as constant in system analyses [2,3].

Using weekly measured high resolution residential electrical demand, solar radiation, and temperature data as input to system simulations, it is found that approximately 7% more energy backup is needed to provide continuous operation of the house with the assumption of the minimum SOC is 30%.

Since the electrical demand of the stand-alone house varies within a wide range during the day, the variation of inverter efficiency with loading must be taken into account for a proper system analysis. Here, only the inverter efficiency is considered. In real systems, however, a DC-DC converter is also employed for boosting the low DC voltages to higher voltage values suitable for the inverter input and its efficiency variation with loading should also be taken into account for more accurate sizing study.

## Acknowledgements

This study is supported by Yıldız Technical University Research Projects Fund under Grant 2010-04-02-KAP04.

## 5. References

[1] Razykov, T.M., et al. “Solar photovoltaic electricity: Current status and future prospects.” Sol. Energy (2011), doi:10.1016/j.solener.2010.12.002.

[2] J.K. Kaldellis, “Optimum Hybrid Photvoltaic –based solution for remote telecommunication stations”, Renewable Energy, Vol. 35, pp. 2307-2315, 2010.

[3] C.H. Tan, T. C. Green, C. A. Hernandez-Aramburo, “A Stochastic Method for Battery Sizing With Uninterruptable-power and Demand Shift Capabilities in PV (Photovoltaic) Systems”, Energy, Vol. 35, pp.5082-5092, 2010.

[4] U.S. Selamogullari, D.A. Torrey and S. Salon, “A Systems Approach for a Stand-Alone Residential Fuel Cell Power Inverter Design” IEEE Transactions on Energy Conversion, vol. 25, no. 3, pp. 741-749, September 2010.

[5] A. Luque and S. Hegedus, “Handbook of Photovoltaic Science and Engineering”, Wiley, West Sussex-England, 2003.