Designing and Simulation of an Energy Control Algorithm for Photovoltaic based Active Generator using State Flow Analysis

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Extended Abstract (5 page limit)

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Designing and Simulation of an Energy Control Algorithm for Photovoltaic based Active Generator using State Flow Analysis

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Abstract

Most of the grid connected Photo Voltaic (PV) systems operate at maximum power points and inject power in an uncontrolled manner. Therefore, in order to maintain the quality of output power with controllable power injection, active generator concept is utilized. But, it needs to be enhanced to provide innovative power management. Therefore, this research paper would suggest an energy controlling system capable of managing energy among PV based active generator, load and interconnected grid considering the availability of the solar resources, storage system and load requirements. The energy controller concerned will operate in three modes namely the intermediate mode, constraint mode and unconnected mode according to three situations of the storage system. It will use available energy information from PV array, battery storage with Super Capacitors (SCs) and load requirements in order to manage the energy flow thus providing control signals to the power conditioning devices.

Keywords:

Energy controller; Photovoltaic; PV active generator; Stateflow.

1. Introduction

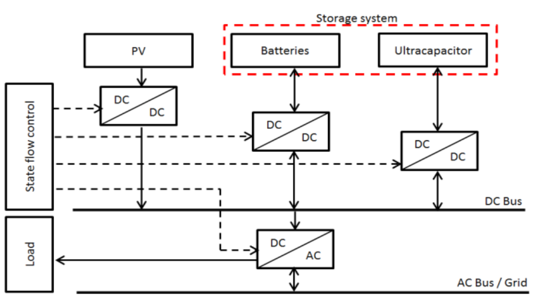


Figure 1: Basic Structure of the PV based Active Generator

This work proposes an energy controlling algorithm for PV based active generator using state flow analysis. Grid connected PV arrays are always affected by continuously varying weather conditions. For example, it may produce excess energy on some time of the clear sunny days with reference to the load time. The excessive energy so produced can be stored in local energy storages or it can be provided to the grid. But in most cases, this excessive energy is wasted due to the lack of a proper controlling mechanism implemented in PV systems. The most appropriate solution to this would be the implementation of energy storages which is capable of utilizing these energy storages in combination with PV array for delivering the energy to the load as well as in participating in grid operation as an active generator. Also during the cloudy days and night time, the power availability can be guaranteed through locally generated power. Therefore, techniques like embedded storage with active generator has been developed in recent years to avoid most of the drawbacks prevalent in grid connected PV systems. It will be an approachable solution since it can store exceed solar energy. In the storage part of the active generator, batteries with a long time range (from minutes to hours) and a SC with a shorter time range (from second to minutes) are included to smooth solar power production and distribute electricity to customers. Thus, a long and stable power supply of the grid system can be ensured. But, it is necessary to provide an optimal power management for storage and PV system for the distribution process. Therefore, the main goal of this research is to propose a good power management algorithm for an active generator which consists of PV panels and storage systems connected with the grid using state flow analysis. The basic architecture of the PV based active generator with local load and grid is illustrated in Figure 1.

2. Materials and Methods

Matlab simulink diagram designed in order to represent the PV based active generator is shown in Figure 2. No 1 in Fig. 2 represents the storage system while No 2 represents the PV array. The boost converters from No 3 connect the PV array to boost the voltage. SC and lead-acid batteries connect to buck-boost converters where the power flow is bi-directional as shown in No 4. The DC/AC inverter is shown as No 5. A load continuously supplied with power is connected to the inverter output and it is given the first priority when designing constraints in the power controlling algorithm. Storage units alongside the PV array must be properly designed in order to work it as an active generator.

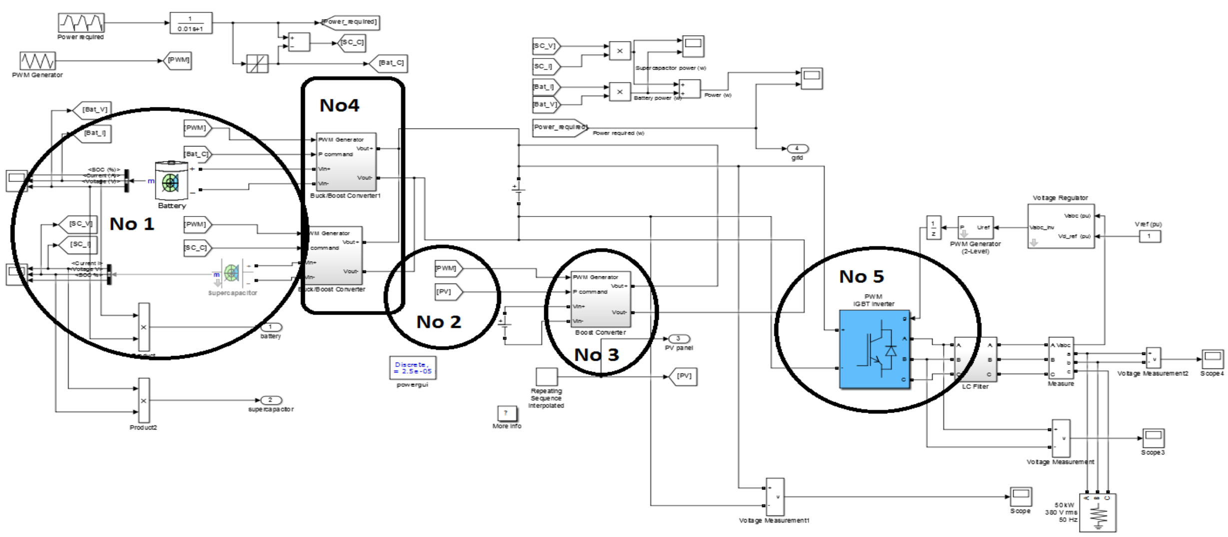


Figure 2: Matlab Simulink Diagram of the PV based Active Generator

A. PV Array

The solar radiation data of Kristiansand which has the Latitude: 58° 15' 3521" N and Longitude: 8° 00' 2497" E have considered as the output of the PV array in this work. For this purpose, monthly Global Tilted Irradiance (GTI) values of Kristiansand in year 2012 have recorded and since, month May had recorded the highest GTI of 310.88 W/m^2 a sample time period from 10:56 to 15:11 from the last day of May was selected as the input to the PV array.

In this work, 18 solar modules of specifications 3160 N are arranged in 3x6 form in connection with a DC/DC boost converter as the PV panel. The rated total voltage is maintained in such a way that it is not much bigger or smaller than the rated voltage of battery and SC. The efficiency and dimensions of these solar panels are given in Table I.

The solar power production Ppv is calculated for each 15 minutes interval by using the equation,

$$Ppv = GTI * \acute{\eta} * A \qquad (1)$$

Where η is the efficiency of a single BP solar panel and A is the total area of the solar panels.

Table I: Technical Data of Solar BP 3160N Module

Electrical data	**Parameters**
Nominal output Pmpp	160 [W]
Max. Voltage system	1000 [V]
Nominal Voltage Umpp	35.1 [V]
Nominal current Impp	4.55 [A]
Module conversion efficieny	12.7 [%]

B. **Battery Model**

For long term energy storage purpose, a lead acid battery is used in this work. A simple lead-acid battery model has selected as given in [2]. The charge /discharge models of the lead acid battery can be stated as follows.

Discharge voltage model (i* > 0)

$$\text{Edischarge}=f1(it,i*,Exp)=Eo-K*(\frac{\text{Q}}{\text{Q}-\text{it}})*i*-K*(\frac{\text{Q}}{\text{Q}-\text{it}})*it+\frac{1}{\text{Laplace}(\frac{\text{Exp(s)}}{\text{(Sel(s)}})*0} \qquad (2)$$

Charge voltage Model (i* < 0)

$$\text{Echarge}=f2(it,i*,\text{Exp})=\text{Eo}-\text{K}*\frac{\text{Q}}{\text{it}+0.1*\text{Q}}*\text{i}-\text{K}*\frac{\text{Q}}{\text{Q}-\text{it}}+Laplace^{-1}*(\frac{\text{Exp(s)}}{\text{Sel(s)}*}*\frac{1}{\text{s}}) \qquad (3)$$

where,

E_{Batt} : Nonlinear voltage (V)
E0 : Constant voltage (V)
$Exp_{(s)}$: Exponential zone dynamics (V)
$Sel_{(s)}$: Represents the battery mode. $Sel_{(s)}$ = 0 during battery discharge, $Sel_{(s)}$ = 1 during battery charging.
K : Polarization constant
i* : Low frequency current dynamics (A)
I : Battery current (A)
It : Extracted capacity (Ah)
Q : Maximum battery capacity (Ah)

i*, which is the low frequency current dynamics shows whether the main source voltage is in charging or discharging mode. If i* is positive, the battery is considered to be discharging. Otherwise, the battery is considered to be charging. The rated capacity of the battery is obtained from the equation,

$$Rated\ Capacity=\text{(Max stored energy)/(Nominal voltage)} \qquad (4)$$

Parameters of the lead acid battery are given in Table II.

Table II: Parameters of the Lead-Acid Battery

Parameters	**Data**
Nominal Voltage	144V
Rated Capacity	69.4Ah
Initial State Of Charge	100%
Fully Charged Voltage	156.8V
Nominal Discharge Current	13.9V
Internal Resistance	0.02Ohms
Capacity(Ah)@Nominal Voltage	21.53Ah

Several assumptions are made in this battery model. One such assumption is that the internal resistance is supposed constant during the charge and the discharge cycles and the amplitude of the current will not affect it. Also, the parameters of the model are determined from discharge characteristics and assumed to be the same for charging. It is assumed that the capacity of the battery doesn't change with the amplitude of current. Furthermore, the model doesn't take the battery operating temperature into account.

C. SC Model

Eight SC units, each having a rated voltage of 75V have used in the SC model. Two of them are arranged in series while four are parallely connected. Table III shows the technical parameters of the SC used.

Table III: SC Specifications

Parameters	**Data**
Rated capacitance	198F
Equivalent DC series resistance	2.1×10^{-3} Ohms
Rated voltage	150V
Number of series capacitors	2
Number of parallel capacitors	4
Initial voltage	16V
Leakage current	5x10-2A
Operating temperature(Celsius)	15

Several assumptions have made before initializing the SC model as well. One such assumption is that during charging, the internal resistance and capacitance are presumed to be stable. Also, the affect caused by temperature changes and the aging problem are neglected. It is also assumed to have a continuously varying SC current.

II. Selection of the Working Mode

Three states are defined as intermediate, constraint and unconnected for the task of efficient power management in the storage system.These three modes can be described as follows.

A. Mode 1 – Intermediate/Normal

In this working mode, the power of battery and SC lie within their maximum and minimum limitations. If PV produced power is more or less than the load power, the batteries and SCs can be utilized. As the load is our first priority, load should be always supplied with a continuous supply of power. Therefore, in this mode, the grid is disconnected and the supply from storage and PV is given only to the load.

B. Mode 2 –Constraint

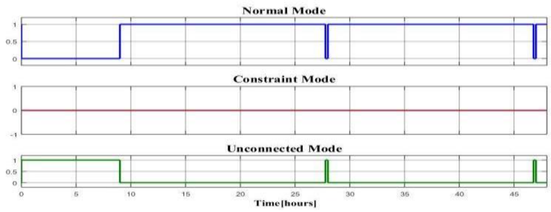
In this working mode, the SC and battery are fully charged. But, required load power is lower than PV produced power. For this reason, an excess of PV power is produced as it is impossible to be stored in storage since both SC and battery are fully charged. Therefore, the main task of the management system at this mode is to limit PV power production to avoid this situation commanding the PV panels to work in constraint mode. In this mode, supply is given both to the grid and the load since power is available excessively.

C. Mode 3 –Unconnected

In this working mode, battery and SC power are below their respective minimum capacities. Therefore, the battery and the SC are unable to deliver power in this situation. And, the produced PV power is not enough to supply the load. Therefore, no power source is available to offer power to the load and the grid. Thus, in this working mode, inverter is disconnected and power is obtained from the grid in order to supply the load and to charge the batteries and SCs.

3. Results and Discussion

Figure 3 shows the behavior of the storage system during t=50s simulation period. The results have obtained by developing the model in such a way that it works for 24 hours by entering estimated values for PV array output for a day in Sri Lanka.Value one in the above graphs indicates that the system has operated in that mode at that time and value zero indicates that the system has operated in another mode at that time other than that. According to Figure 3, it can be seen that the system has operated in all three modes during 50s simulation period. Figure 4 shows the behavior of the load power during the time period we consider. As seen in Figure 4, supply to the load is continuous during the period. But, it varies with time. Since, the load is our first priority, load is supplied with power continuously without any interrupt even though the grid power requirement and the storage power fluctuate. During unconnected mode, since the storage is not capable of supplying power to the grid, supply is given from grid to the load and this continuous supply of power is maintained.



Figuew 3:. Bahavior of the Storage System during the Period concerned

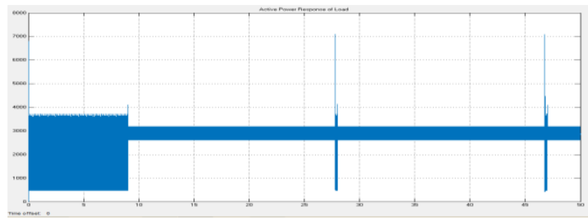


Figure 4: Load Power Response

Figure 5, 6 and 7 show the battery power, SC power, and the produced PV power during the period we concern.

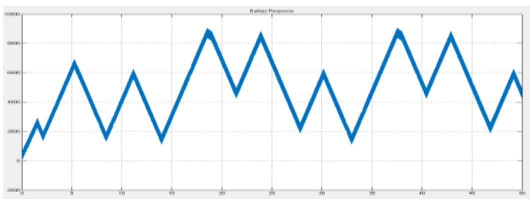


Figure 5: Battery Power Response

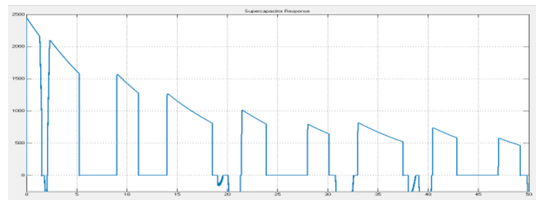


Figure 6: SC Power Response

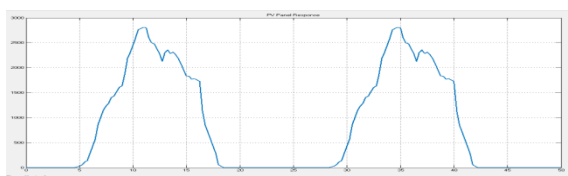


Figure 7: PV Power Response

4. Conclusions

In this research, an energy controlling algorithm for PV based active generator has designed and simulated using Matlab state flow analysis. The designed system consists of an overall power management system for an active geenrator that includes storages as batteries and SCs along with PV power. In order to organize and identify the level of control system, a hierarchical control algorithm is utilized in this work.Almost all the possible states that each power source can achieve during operation are modeled in state-flow and three main working modes as intermediate, constraint and unconnected are defined for the confirmation of working mode. After selecting the relevant working mode, power management system computes the power reference for each source. It will signal the intended action to take place in order to control power efficiently thus saving energy and preventing the wastage of excessive energy. As a suggestion, this system can be extended to supply power to several loads according to the requirement. Furthermore, the grid requirement which is given the second priority in this design can also be taken in to account when desigining the controlling algorithm in such a way that the system is optimized in accordance with grid power variations as well.

5. References

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[2] M. Simulink, “Implement generic battery model,” MATLAB Simulink, 2013.