Control of PV and Diesel hybrid system

Daniel B. Andersen, Jacob N. Pedersen, Krisztian M. Balla, Nicolaj V. Christensen and Thomas H. Pilgaard.
Department of Control Engineering, Aalborg University, Fredrik Bajers Vej 7C,
9220 Aalborg East, Denmark

***Abstract*—The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here. The abstract goes here.**

I. Introduction

Delivering electricity in remote locations where a grid is unavailable, has for many years been achieved by deploying diesel generators (gensets). These are setup in what is called island operation to form micro grids that fulfill the power demands. As the global awareness of sustainability and carbon footprint is increasing, the interest of introducing sustainable energy sources to these micro grids is also increasing. By doing this the fuel consumption can be decreased and both the running cost and the carbon footprint can be reduced. A way of achieving this is by adding photovoltaics (PV) which will convert sun power into electricity. This is done by inverters that convert DC from solar panels into AC which can be integrated in the micro gird resulting in a hybrid power plant. The basic structure of a hybrid power plant containing PV consists of a genset and an inverter connected to solar panels. The number of gensets and inverters can be scaled to fit the specific load criteria. This paper will focus on a power plant consisting of one genset and one inverter.

The plant management of a hybrid power plant can however not be carried out in the same manner as for a power plant consisting purely of a genset. When introducing PV, new control challenges arise from the nature of PV. One challenge is the availability of the power that is directly related to the sun radiation and can therefore vary. Furthermore, the inverter acts as a power source in the system setup while the role of the genset is to maintain the correct voltage and frequency. Based on this, load changes have more significant effects on the grid stability for hybrid power plants as a part of the power production is changed from gensets to PV. These challenges should be handled by the main power plant controller which should ensure a stable grid and fulfil the load demands of the micro grid. These demands have to be fulfilled under a maximized PV power ration to reduce the fuel consumption.

Previous work with the intention of optimizing the individual genset control has led to a detailed model of a genset [1]. This model can be used to develop new advanced controller types that can improve the efficiency and running costs. Based on this, some of the initial work has been done to ease the creation of a main power plant controller that can adapt the PV behavior and ensure smooth operation on a hybrid power plant [2].

In this paper, made in collaboration with the company DEIF, control aspects of implementing PV in a power plant will be covered and a state space controller will be designed for the prototype of the system. Furthermore, the controller will be implemented on a DSpace unit and tested on a hybrid power plant consisting of a 60 KVA/48 kW genset [3, 4] and a 20 kW SMA STP inverter[5]. The paper is structured with ***Section (II)*** describing the physical system which will cover the hybrid power plant and the components in it. ***Section (III)*** will contain the state space controller and describe the chosen design approach. ***Section (IV)*** will present the controller testing done both in simulation and on the hybrid power plant. Lastly ***Section (V)*** will contain a discussion and conclusion.

II. Physical system description

The genset in the hybrid power plant consists of a diesel motor that is mechanically linked to a generator. As the genset maintains frequency and voltage of the power plants output, two controllers are present. These are called the governor and automatic voltage regulator (AVR), which get their references from the automatic genset controller (AGC), which thus handles the main genset control. The other component in the power plant is the inverter, that simply acts as a power source. This results in the inverter power on the output which follows the frequency and voltage of the grid. The inverter is controlled via Modbus and is capable of adjusting both the power output level with respect to the rated power and shift between active and reactive power. The reference to the inverter is provided by the main plant controller which will also set the reference to the AGC and thereby having the overview of the ration between PV power and genset power. An overview of the plant structure is shown on *Figure 1*.

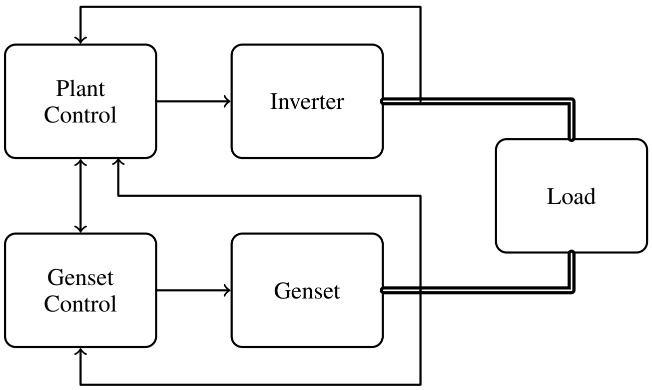

Fig. 1. Figure showing the hybrid power plant structure.

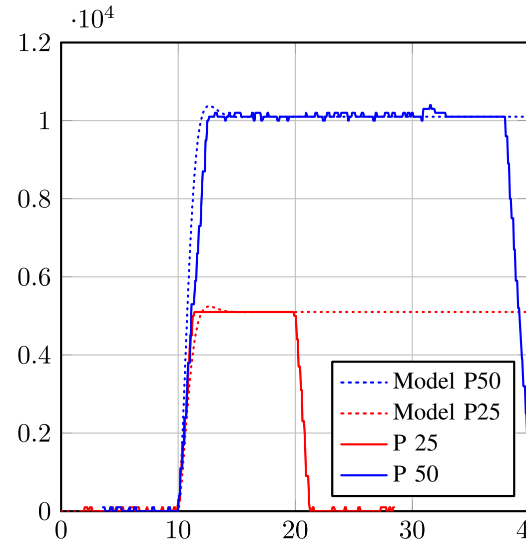

Fig. 2. Graph showing step responses, where P 25 is a real load of 25% inverter capacity.

A. Derivation of the inverter model

The available inverter is a SMA - STP20000 PWM inverter[5] which is a commercial available unit where the construction specifications and internal controllers remain unknown. Therefore the derivation of the inverter model was done by using measurements from the provided inverter and thus the model is an approximation. The model is afterwards optimized with the MATLAB tool called senstool. Two steps are applied to the inverter, these can be seen in *Figure 2*. The model is chosen to be low order, in order to limit the complexity. However, this will limit the obtainable dynamics of the model. The inverter will be modelled as a second-order system with one zero. This is done to keep the model simple but still get a fast step response. This will result in an unwanted overshoot. A generalization of the model can be seen in *Equation: (1)*.

$$G_1(s) = \frac{b_1 \cdot s + \omega_n^2}{s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + \omega_n^2} \tag{1}$$

The first parameter that will be estimated is ω_n. The initial guess is done by using the rule $\omega_n \approx \frac{1.8}{t_r}$ and thereby $\omega_n = 0.8491$. ζ decides the maximum allowed overshot and therefore ζ is chosen to 0.85 as this will lead to very little overshot. b_1 is then estimated with senstool. Afterwards senstools is used to estimate all three parameters with the initial values, and the estimated value of b_1, as estimates. This is done for all six data sets and then a weighted average determines the final parameter. The DC-gain will be one as ω_n is added to the numerator and thereby becoming the last part of both the numerator and denominator. This gives a model as seen in *Equation: (2)*.

$$G_1(s) = \frac{0.1845s + 3.089}{s^2 + 1.3238s + 3.089} \tag{2}$$

The step response of the model to a 50% real power step, is shown as the blue dotted curve in *Figure 2*.

As it can be seen this results in very little overshot and a model that fits the measurements. This model will be used to develop the controller.

B. Derivation of the genset model

The available genset consists of an SDP60D5S diesel engine [3] and LSA 42.3 alternator [4]. The basis of which the model is derived is data form a high order model previously made by Jesper Viese Knudsen[1]. To limit complexity, a low order model is required. The data can be seen as the solid lines in *Figure 3*.

The approach for deriving a model is a curve fit from different step sizes. As for the inverter model the base will be a second order model, but this time with two zeros. This is done to make the model faster and thereby fit the high order model better. The general structure of the model can be seen in *Equation: (3)*

$$G_2(s) = \frac{b_2 \cdot s^2 + b_1 \cdot s + \omega_n^2}{s^2 + 2 \cdot \zeta \cdot \omega_n \cdot s + \omega_n^2} \tag{3}$$

To estimate the parameters of the model, senstool is used. An initial guess of ω_n is made and the last three parameters are estimated. Afterwards another iteration is made for ω_n to improve the accuracy. This is done to multiple step sizes in order to make the parameter b_1 adjusted and therefore get a better overall fit. This results in a model seen in *Equation: (4)*

$$G_2(s) = \frac{s^2 \cdot 0.9645 + s \cdot 3.7 + 8.8948^2}{s^2 + 2 \cdot 0.2932 \cdot 8.8948 \cdot s + 8.8948^2} \tag{4}$$

In *Figure 3* both the high order and the low order curve fit can be seen.

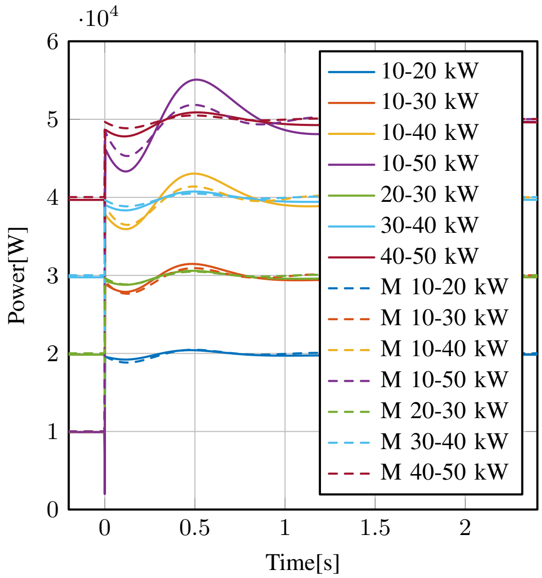

Fig. 3. Different step responses for the high order model between 10 kW and 50 kW, solid lines, compared with steps applied to the low order model, dashed lines.

As it can be seen, the low order model mimics the behaviour of the high order model, but with some amount of deviation for larger step sizes. This model will be used to develop the controller.

III. Controller

Based on the derived models the system can be represented in a state space form. The system plant will be represented by the genset model whereas the inverter model and load are seen as disturbances. The derived transfer function of the genset is transformed into statespace. This results in a number of states which for continuous time can be written as:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned} \tag{5}$$

The state space model contains a system matrix A, an input matrix B, an output matrix C and a feedforward matrix D. Furthermore x(t) represents the state vector and u(t) the input vector. This representation can be obtained in Matlab by the function $tf2ss(A, B, C, D)$ which converts a transfer function to state space.
The disturbance represented by the load and the inverter are uncontrollable and can therefore be seen as exogenous inputs. An effective way of rejecting these disturbances for state space systems is by describing them as an exosystem. This exosystem is in general given by:

$$\begin{aligned} \dot{x_d} &= A_d x_d \\ d &= C_d x_d \end{aligned} \tag{6}$$

The exosystems output d will then be added to the state space input vector u and thereby included in the system model.

Controller design for such a system that suppresses the disturbance can be described by the following structure:

$$\begin{aligned} \dot{x_c} &= A_c x_c + B_c y \\ u &= C_c x_c + D_c y \end{aligned} \tag{7}$$

These concepts will be used in order to develop a main controller for the hybrid power plant.

A. *Description of controller*

B. *Simulations of system with controller*

IV. Implementation and Experimental Setup

A. *Plans on implementation*

The designed controller will be implemented and tested on a real hybrid power plant. In order to allow controller prototype testing on such a platform a DSpace unit is used. This unit is capable of linking a matlab based controller to a real test plant. The particular DSpace board used is a DS1103 which features both digital I/O, A/D converters and D/A converters. The controller is implemented via the DSpace Real-Time Interface (RTI), which transfers the matlab based controller into real time code that is used to control the plant. The genset will be controlled via this method over a canbus communication link.

B. *Description of final test*

The test will be preformed on the provided hybrid power plant at DEIF which consists of a 25 kW inverter and a 60kVA/48kW genset. The power plant will be disconnected from the grid and thereby operated in island mode. At the facility a total ohmic load of 50 kW is present and will be used in the test. The load is divided into steps of 5 kW and can be engaged independently, thereby offering the possibility to simulate a varying load behavior.
The test has yet to be conducted, and no results are therefore available. It is expected to test the controllers ability to stabilize the power output of the genset, even trough varying load scenarios are applied. Furthermore is it expected to test if the controller can keep voltage and frequency fluctuations caused by load variance to a minimum. The controller should ensure this purely by controlling the genset trough the canbus interface. These expectations should be obtained under conditions which at all time ensure the amount of PV power to be as close as possible to the available PV power. Based on this structure PV power will be maximized. A lower load limit will though be implement during the test in order to avoid under loading the genset as this requires a certain minimum load level.

V. Conclusion

The conclusion goes here.

Acknowledgment

The authors would like to thank Kjeld K. Madsen and Claes H. Sterregaard from DEIF for the help and cooperation through the project.

References

[1] J. Kundsen, "Control-oriented first principles-based model of a diesel generator," 2016. Aalborg University.

[2] DEIF, "Hybrid introduction," 2016. Automatic Sustainable Controller.

[3] Potise, "Diesel generator sets, sdp60d5s," 2016. datasheet.

[4] Emerson, "Lsa 42.3 low voltage alternator," 2015. datasheet.

[5] SMA, "Sma sunny tripower 15k, 20k and 25k," 2016. datasheet.