A REALISED CONTROL SYSTEM FOR A HYBRIDSYSTEM CONSISTING OF A PV-PLANT AND STEAM ENGINE WITH COMBINED HEAT AND POWER

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ABSTRACT

This paper presents a part of a research project done at the chair of electrical power engineering of the FernUniversität of Hagen / Germany and describes a practical realised control system for a hybridsystem, consisting of a PV-plant linked to a steam engine. This is a special complex self-sufficient energy supply system with combined heat and power, which enables the usage of a highest possible portion of renewable energy. The control system bases on a µ-Controller and is implemented in a self-made box to get an independent unit. The underlying control concept as well as the hardware realisation ought to give a high degree of flexibility for extension and adaptation to similar hybridsystems. The most important information concerning concept, hard- and software are presented.

INTRODUCTION

It could be shown, that it is possible to provide private households self sufficient with heat and power by the help of a hybridsystem consisting of a PV-plant linked to a steam engine. A major part of this research project was the fundamental analysis of this energy-supply system for summer/winter or mixed conditions, including a PV-system and a piston-type steam engine with combined heat and power [1], as shown in (Fig. 1.). This hybridsystem has been examined with the help of experimental investigations [2]. Additional theoretical analysis and computational simulations were helpful to build up a process scheme with all necessary components and to determine their sizes [3].

The choice of a piston type steam engine for the combined heat and power does not mean, that the technical standard of the beginning of the industrial area has to be taken over. It is self-evident, that the hybridsystem as shown in figure 1 needs a 'modern' steam engine with respect to today's possibilities of the mechanical engineering. An impressing example for such a development, which encourages to snatch up older technologies, is the success-story of the modern wind energy converter.

The combination of a PV-Plant to a combined power helps primarily to save fuels effectively.

In future, an increasing amount of biomass has to be used, because of its CO_2-neutrality; with respect to efficiency, as far as possible without preceding preparations. This implies shortest possible transportation and in the most cases solid biomass like chopped wood [4]. These arguments support decentralised energy-supply systems with external combustion. A hybridsystem with a PV-plant linked to a piston-type steam engine with combined heat and power could be one possible option.

Energy-Supply System for Summer and Winter

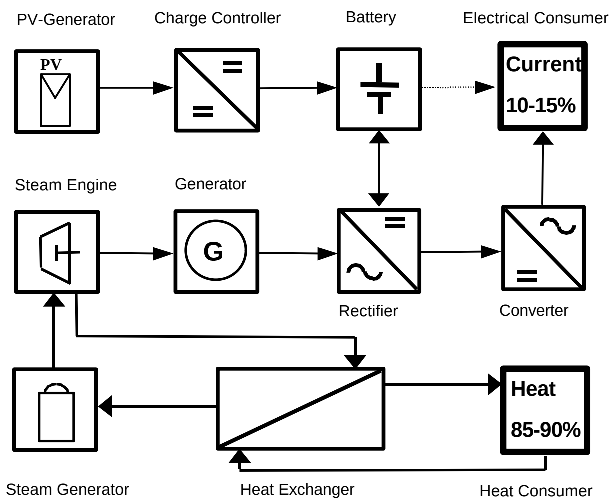

Fig. 1. Simplified Process Scheme of the Hybridsystem

Additional considerations concerning other important properties like longevity, simple construction, rigidity, low susceptibility to trouble, the remaining necessary degree of efficiency and controllability of the ratio of power to heat, supported the decision to think about a PV-hybridsystem with a steam engine to provide private households. To achieve an operation of the hybridsystem with a maximum degree of over-all efficiency, the control system is one of the most important system-components [5].

HYBRIDSYSTEM

The today's annual ratio of electrical to heat energy consumption of average private households in Germany is nearly one to ten. Important for a successful implementation of such a hybridsystem is to guarantee a gap free energy supply. Provided that the sizes of the steam engine, the steam generator and the heat exchanger are correct determined, depending on the time correlated functions of the insolation for the PV-plant as well as on the energy consumption of the private household, the control system is the key-component for an effective operation of the whole hybridsystem. With respect to the stochastic behaviour of the energy production of the PV-plant, storage batteries for electrical energy are involved.

Hybridsystem "Photovoltaic + Combined Heat and Power with Steam Engine"

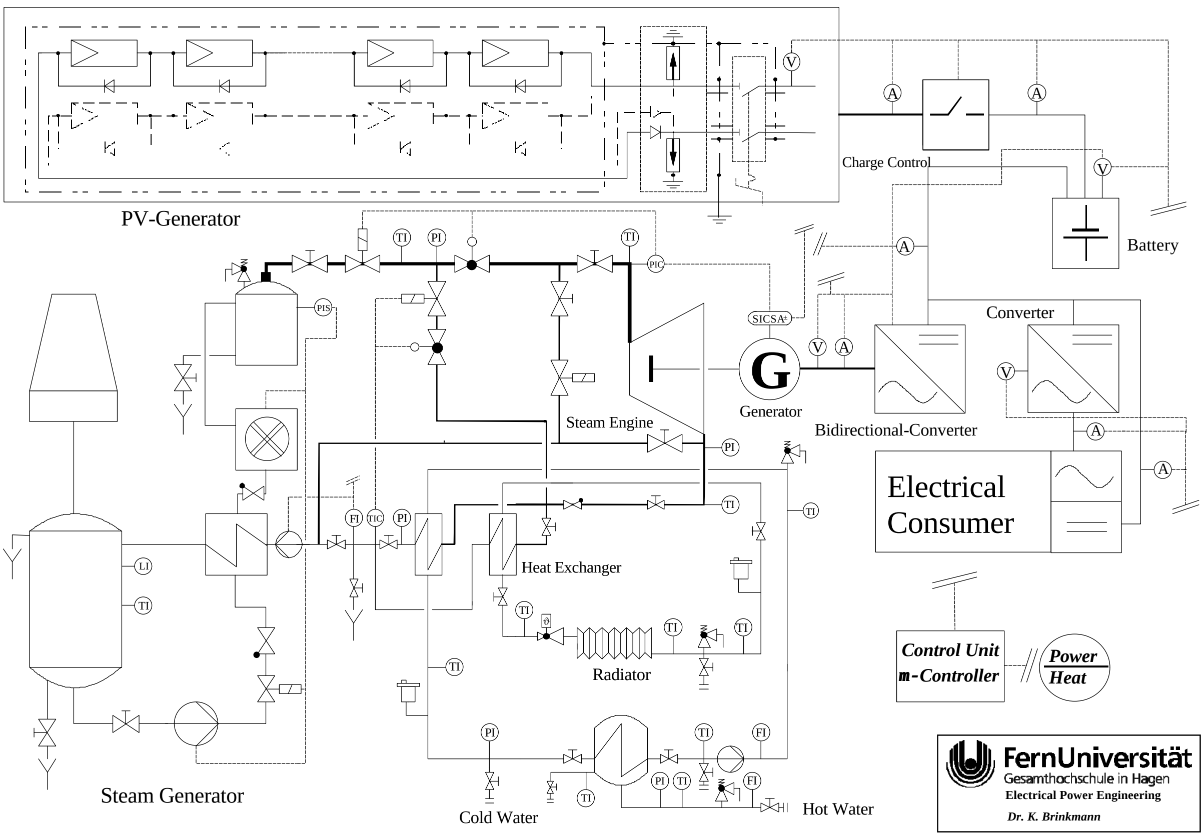

Fig. 2. Process Scheme of the Test Setup

The state of charge, the energy production of the PV-Plant, the thermodynamically data of the heat exchange circuits as well as the momentary ratio of electrical current to heat of the energy demand are key-functions and give an impression of the complexity.

(Fig. 2.) presents the process scheme of the hybridsystem, as realised for experimental investigations, to demonstrate the implementation of the control system. Inherent for the correct operation is the permanent registration of the energy balances with the help of sensors and calculations.

For this purpose an integrated data registration system with the possibility of data transfer to a personal computer was developed and realised. The manipulability of this control system is given by a graphic display and a touch-screen panel. The realised practical control system was mounted is a 19"-assambly.

For experimental investigations a test setup with a real steam engine for approximately 2.5kW from the beginning of this century has been built up and connected to a PV-Generator-Simulator, which could be co-ordinated to the results of the photovoltaic plant of the FernUniversität building. The installed PV-Generator-Simulator with a power output of maximum 2,5 kW enables an independence of the momentary weather conditions and time-lapsed investigations.

For the storage of electrical energy, four batteries with a capacitance of 120Ah respectively were implemented in series, with a voltage of 48V totally.

For simplicity concerning installation and measurements, the steam generator works with electrical energy and produces maximum 18 kW saturated steam at 6 bar and 159°C. Two control valves split up the steam flow in two directions, one of them to the steam engine and the other bypassed directly to the condenser. This gives the possibility to regulate the ratio of power to heat and enables to produce only heat without the steam engine, which is necessary if the batteries are sufficiently charged. The self-made condenser consists of tube heat exchanger, which are implemented in two different heat circuits, one for a radiator and the main part for the production of hot water in a 50 l water vessel. A pump in the condense water pipe was installed to reduce the back pressure, which results in a greater efficiency of the steam engine [2]. The shaft of the steam engine is coupled to an electrical generator via a cone belt. The nominal power of the generator is 1,3 kW and it is connected to a 3-phase bi-directional converter. This converter allows to switch between motor and generator mode. Because a steam engine with only one piston is in the most cases not able to start by itself, the motor mode can be used to give the first rotations. The implemented measuring technique is based on 4-20 mA signals, which are used by the self-made control box with a µ-controller.

CONTROL SYSTEM

The process scheme in (Fig. 2.) indicates the fundamental electrical connections, which were responsible for the control and regulation of the above mentioned components.

Fig. 3. Developed Control System Apparatus

With respect to the requirements of the test setup, a control system based on a µ-controller has been developed, in the sense of modern modular conceptions for industrial digital control systems. (Fig. 3.) shows the practical realised 19"-apparatus.

Heart of this system is a commercial controller-board (Phytec MiniCon-Module, Controller SAB80C517A).

This module has a graphic display with touch screen, which enables a good monitoring and an easy programme-selection including the settings of all control and regulation values.

The electronic periphery for the implementation of the controller into the physical process is self-made and integrated in the apparatus. An essential point for this development was the electromagnetic compatibility (EMC) of the components concerning the internal and external wirings.

All control and regulating functions for the hybridsystem are realised with the help of an assembler programme (A51, Keil Elektronik) consisting of many subroutines with changeable parameters. So, valuable tools for generalised applications were developed as by-products, which could be useful for similar problems.

Also field applications with more energy converter components or consumer are possible, because of sufficient reserves in the implemented hard- and software. This aspect is supported by an integrated serial connection to a personal computer (RS232 / Modem).

Therefore, the developed apparatus is able to be used as data processing equipment and builds in principle a foundation for exactly detail- and long term measurements.

This apparatus is in summary a universal usable tool and builds a foundation for apparatus especially for control and regulation of processes in hybrid energy supply systems, grid-connected as well as stand-alone. In consequence it is useful for research projects concerning problems in hybridsystem technology.

The different supply voltages, used by the electronic devices, was realised with the help of a wide-range 24 V DC power supply. This implies the advantage of a possible grid independent operation. The hybridsystem is, a sufficient battery load presupposed, always controllable.

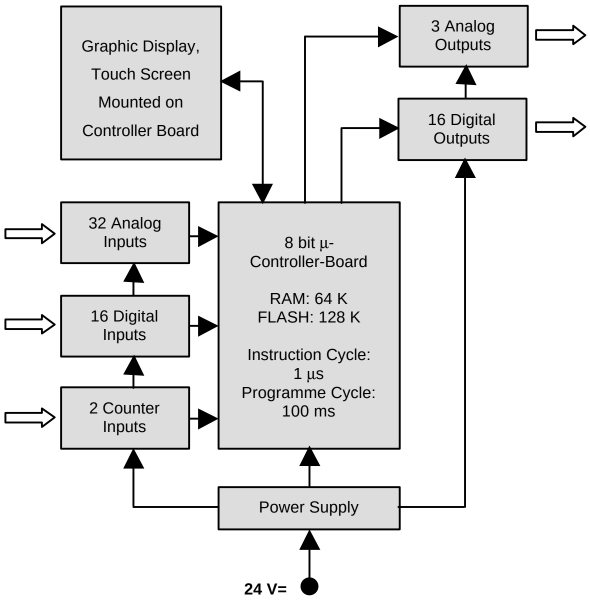

Fig. 4. Structure of the Control System

Technical Data			
Hardware		Software	
Power Supply	18-36 V, 2 A max., average Power approx. 20 W	Programme-Structur	4 Tasks (Display, Control, Regulation, RS232), 4x25=100ms
Digital Inputs	16, separate supply 24V, 0,5A	Menu Structur	Choise Menu with 6 (up to 12) Submenus
Digital Outputs	16, separate supply 24 V, 4 A	Control	Steam Engine and Hotwater-Cycle
Counter Inputs	2, 0-25 kHz, 3-wire 24 V	Regulation	Rotation Speed, Outlet Steam Temperatur
Analog Inputs	32, 4...20 mA, 2-wire 24V, symmetric, Burden 2x 100 Ohm, Error: +/-0,5/0,3% (10/12Bit), range: 0-50 °C	Additional-Programme	Text, Fixpoint-Values,Touch-Screen-Input, Setpoint-Input (incl. Limits), PI-Reglulation, scaled In-/Output Periphery
Analog Outputs	3, 4...20 mA, 2-wire, 30V integr., Error: +/- 0,25 % (14 Bit), Range: 0-50 °C, max. Burden 800 Ohm	System-Programme (Phytec)	Character-Output, Text-Switch, Pixel-/Line-/Rectangular, TouchScreen-Interrupt, and misc.
Display	32x15 Character (Large Char), {40x30 Character (Small Char)}, 320x240 Pixel	Communi-cation	Send all Prozess-variables via RS232 during one Cycle possible
TouchScreen	10 x 6 Fields, digital	Progr.-Language	Assembler A51 (Keil)
RS 232	Baud Rate 38500 (variabel), 1 Start-/Stopbit 8 Date bits, Xon/Xoff		

Table 1. Technical Data of the Control System

The rotation speed measurement gives pulses for one of the counters and is used for the PI-regulation to control the two motor-driven steam throttle valves via pulse width modulated analog outputs. The digital outputs are used for the switching of the solenoid valves, to give alarm signals and to activate illuminated indicators. Additional outputs for LED's have been implemented to indicate the monetary operational status, in connection with the text realised on the TouchScreen-Display. 16 digital inputs were prepared for mechanical switching devices, momentary-contact switches and possibly for limit comparators for security reasons concerning overpressure and excess temperature.

With a program cycle of 100 ms and an instruction cycle of 1 µs, it is possible to run the whole program within one single task, even if the program size will increase up to 300% of ist current value. The program cycle time determines directly the minimum reaction time of the control system. This guarantees a control with a sufficient real time character.

CONCLUSION

This paper presents a practical realised control system for a hybridsystem, consisting of a PV-plant linked to a steam engine for combined heat and power as a self-sufficient energy supply for private households. This includes a process scheme, control concept and details of the realised 19"—assambly.

REFERENCES

[1] K. Brinkmann, "PV-Generator linked to a Piston-Type Steam Engine with Combined Heat and Power as a Hybridsystem for a completely self-sufficient Energy-Supply", *2nd World Conference on Photovoltaic Solar Energy Conversion, Vienna Austria, July 1998.*

[2] K. Brinkmann, "Systemtechnische Untersuchung eines Hybridsystems bestehend aus Photovoltaikanlage und Dampfmaschine mit Kraft-Wärme-Kopplung", *Dissertation 1999, FernUniversität Hagen, Chair of Electrical Power Engineering.*

[3] K. Brinkmann, "Dimensioning of a Hybridsystem Consisting of a PV-Generator and a Steam Engine with Combined Heat and Power for Private Households", *16th European Photovoltaic Solar Energy Conference, Glasgow United Kingdom, May 2000.*

[4] K. Brinkmann, "Combined Heat and Power with Biomass and Solar Energy for Private Households with a Hybridsystem consisting of a PV-Generator linked to a Steam Engine", *1st World Conference and Exhibition on Biomass, Sevilla Spain, June 2000.*

[5] M. Viedenz, "Steuerungselektronik für ein Hybridsystem bestehend aus Kraftwärmekopplung mit Photovoltaik", *Diplomarbeit 1999, FernUniversität Hagen, Chair of Electrical Power Engineering.*