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Stability Assessment of Isolated Micro-grids Powered by Distributed Combined Heat and Power Micro-units [⋆]

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Abstract: It is expected that combined heat and power (CHP) micro-units will soon play a significant role in the energy supply of private households. To increase the reliability of the system the isolated operation of this micro-grid should be possible. It is assumed that the electrical load is the reference input variable of the local grid to reduce the necessity of electrical energy storages. The produced thermal energy will be stored. The paper presents a study of the voltage and frequency stability in micro-grids powered by CHP micro-units. The simulation model of the micro-co-generation plant is based on a combustion engine and brush-less synchronous generator. The example network represents an urban residential neighbourhood. The electrical household loads are based on probabilistic modelling, with high time resolution. Several scenarios for normal and disturbed operation are defined, which vary in electrical load, number and size of the CHP units and the generation schedule. For these scenarios the stability and voltage limits during normal operation and for selected three phase faults are investigated. The voltage and frequency stability of the micro-grid is determined by dynamic simulations.

Keywords: distributed generation, micro-grid, dynamic models, combined heat and power micro-units, power system stability

1. INTRODUCTION

The worldwide increase in demand for electrical energy, exhaustible resources and the climatic changes are currently the central challenge of the energy system. A discussed and promising approach to these challenges is the development and operation of micro-grids to ensure the shift to decentralized production structures with maximum efficiency, energy security and environmental sustainability. Combined heat and power (CHP) is seen as an integral part of such networks. A CHP power-plant allows predictable and secure control and regulation of power production. Thus they can assist to integrate limited predictable renewable energy sources, such as wind power and photovoltaics. In the Integrated Energy and Climate Programme of the German government CHP units are encouraged. Therefore a high penetration of CHP micro-units in Germany is expected in the next few years.

In this case the isolated operation of the micro grid will increase the reliability of the system. Until now there are only a few experiences with small isolated operated networks with distributed generation. The aim of this paper is to study the stability in such systems. Therefore a small residential low voltage network is modelled. To evaluate the dynamic operation behaviour a detailed model of the CHP micro units is created as well as the necessary controllers for islanded grid operation. The stability assessment is then done under normal and disturbed operation with several scenarios.

2. SIMULATION MODEL

2.1 Combined heat and power micro-unit

There are several different technical designs of CHP micro-units. In this paper the CHP is modelled as a micro-cogeneration plant based on a combustion engine and a brush-less synchronous generator is chosen. This design is widely used due to high operational experience, low costs and a low amount of maintenance. The synchronous generator allows operation in an isolated network. The main components of the CHP unit which have to be modelled are (see figure 1):

- ○ combustion engine
- ○ elastic clutch
- ○ generator
- ○ controller for engine and generator

Combustion engine The predominant fuel for cogeneration micro-plants is natural gas. So, gas spark ignition

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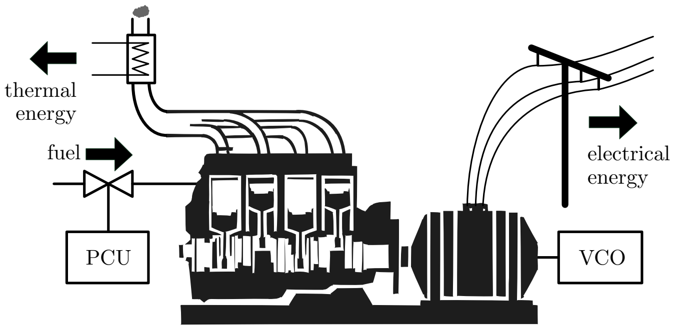

Fig. 1. Schematic of CHP micro-unit with combustion engine, generator, power control unit (PCU) and voltage controller (VCO)

engines are mainly used. Thereby the torque is regulated by a quantity control of the fuel mixture. The amount of mixture with a nearly constant combustion-air ratio is set by a throttle mechanism. The fuel mixture flows into the cylinder and produces the torque, see van Basshuysen (2007).

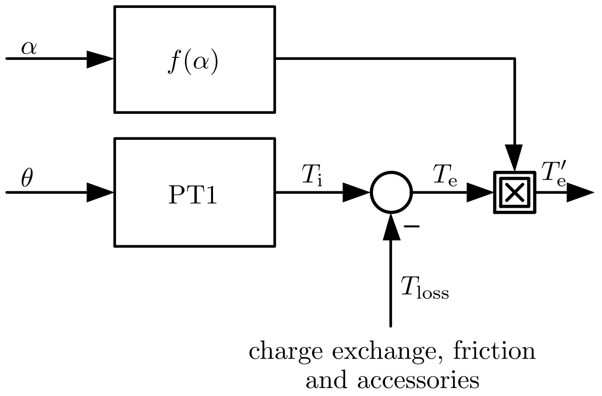

Fig. 2. Signal flow plan of the combustion engine

To model the internal engine process a PT1 element is used to transfer the throttle angle θ to the internal engine torque T_i. The external engine torque T_e is calculated by subtracting a to the engine losses equivalent torque T_loss at the current operation point, which includes the losses of charge exchange, friction and accessories (see figure 2).

Combustion engines produce a discontinuous torque. Each ignition of the fuel mixture in the cylinder creates a powerful torque kick. To model the torque characteristics of the engine the external engine torque T_e is multiplied by a function of the angle of rotation α.

Elastic clutch To homogenise the engine torque for electric power generation, mostly an elastic clutch is used. Figure 3 shows the elastic coupled two-mass system which reproduces the transfer behaviour of the elastic clutch. J_e represents the inertia of the engines rotor. It is affected by the engine torque T_e. J_g stands for the inertia, which is affected by the electrical torque T_el. The elastic clutch is between engine and generator. It is modelled with the spring rate C and damping d.

Synchronous generator To model the synchronous generator the model in DigSILENT Powerfactory is used. It takes on filed winding and one damper winding on the d-axis and two damper windings on the q-axis into account. The differential equation system of the synchronous generator model thus consists of two motion and four voltage equations, see DigSILENT GmbH (2009). This equation system is a widely used for stability analysis, see Kundur (1994). The model parameters of the synchronous generator are derived from manufacturer's data of small synchronous generator and CHP micro-units.

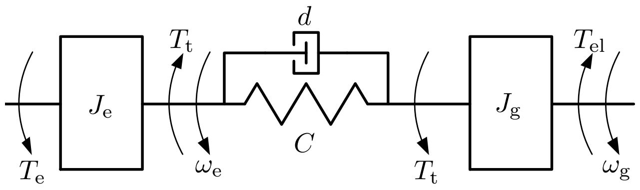

Fig. 3. Schematic of elastic clutch

Controller To realize the stable operation of synchronous generators in the electrical network, voltage and frequency must be controlled. Within this research project following controllers are used and modelled.

- Voltage regulator and excitation control system: For reliability reasons brush-less exciter are usually used in CHP micro-units with synchronous generator. To represent the exciter IEEE Type AC1A is used, which is widely used in stability researches, see IEEE Std 421.5 (2005).
- Reactive power controller: It overlay the voltage regulator in order to achieve a constant power factor or reactive power output. This is used at generators which are not participating in the direct voltage control in the micro grid. The IEEE Var controller Type II is used to model the reactive power controller, see IEEE Std 421.5 (2005) .
- Frequency power controller: To control the frequency, which is equivalent to the active power control, the common two-stage approach with primary and secondary control is used. The controllers are modelled according to Kundur (1994).

Parameters The parameters of the Engine and the Generator are derived from data sheets. The used engine is *MAN E0834 E302* and the generator is *mecc alte ECO 32-3L/4*. The parameters of the controllers are tuned to perform a good step response.

2.2 Low voltage network

On the basis of a small urban residential area the low voltage network and the load of the household are designed. Table 1 gives an overview and the residential area structure. Altogether there are 12 buildings with 320 households. A schematic plan of the residential area with the electrical network is shown in figure 4.

Based on the residential area structure in table 1 different household classes are defined. They differ in the number of tenants, in the electrification level and consumer habits. According to this classes a load profile of each household is calculated with a probabilistic load modelling tool in a time base of 30 s see Dickert and Schegner (2010). By shifting each load profile between 0 and 30 s a time