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Research Article

Embarked electrical network robust control based on singular perturbation model

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ABSTRACT

This paper deals with an approach of modelling in view of control for embarked networks which can be described as strongly coupled multi-sources, multi-loads systems with nonlinear and badly known characteristics. This model has to be representative of the system behaviour and easy to handle for easy regulators synthesis. As a first step, each alternator is modelled and linearized around an operating point and then it is subdivided into two lower order systems according to the singular perturbation theory. RST regulators are designed for each subsystem and tested by means of a software test-bench which allows predicting network behaviour in both steady and transient states. Finally, the designed controllers are implanted on an experimental benchmark constituted by two alternators supplying loads in order to test the dynamic performances in realistic conditions.

1. Introduction

Embarked and islanded networks are widespread in various fields. Embarked networks are found in ships, cars or air planes and islanded networks can be found in a factory or a house with their own electricity production. These lasts may be operating in islanded conditions or connected to the infinite power electrical network.

An embarked network is constituted of strongly coupled sources and passive, active, linear or nonlinear loads with variable and badly known characteristics. The diversity of the entities constituting the system, their interactions and its variable topology require the development of specific modelling approaches. All electrical ship networks is an example (Fig. 1) where the mechanical power is produced by gas turbines or diesel engines and alternators provide the electrical power to linear and nonlinear loads like: propulsion, light and rotating loads which are almost asynchronous machines in elevators or pumps.

Embarked networks modelling may have various goals. On the one hand, models can be developed in view of simulation. They must reproduce network behaviour with a good compromise between accuracy and computation time. Indeed, in literature, various approaches of modelling have been explored like those based on circuit models [1,2]. However, these approaches do not allow easy analysis of the whole systems model. In this study, we use the developed simulator detailed in [3]. It can predict network behaviour while coupling and decoupling an alternator, connecting and disconnecting a load (topology variation). Therefore, this software test-bench is a powerful tool to predict the network behaviour in various conditions of working. It will be used to test the control in realistic conditions before the implementation in the real benchmark.

On the other hand, models can be developed in view of control. They have to be representative of the system and easy to handle for easy voltage and frequency regulators synthesis.

The main aim of this study is to obtain a simple and realistic model using singular perturbation approach. This model can be easily used to tune any type of controller, even in the case of adaptive controllers.

This paper is organized into various sections. In the first part, we briefly present the principle of modelling in view of control based on the singular perturbation theory. Then, the second part details the RST automatic voltage regulators synthesis and the tests using the software test-bench in order to ensure the desired performances. In the final part, the regulators are tested on the experimental test-bench constituted by two alternators supplying a varying electrical load and driven by two DC machines emulating turbines behaviour.

2. Network model in view of control

The network is a multivariable system strongly coupled where it is necessary to ensure constant effective voltage and constant

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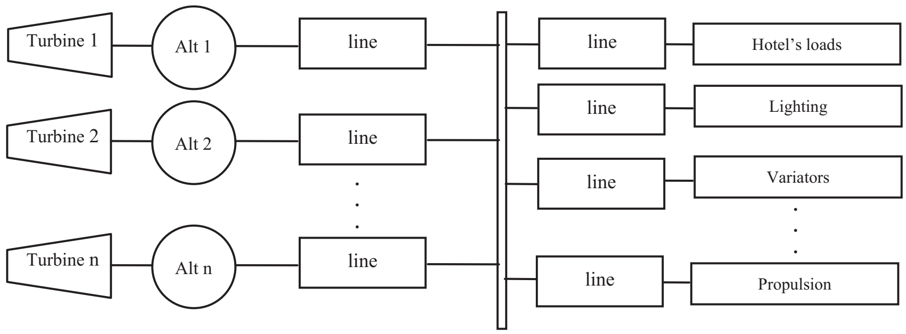

Fig. 1. Structure of shipboard electric network.

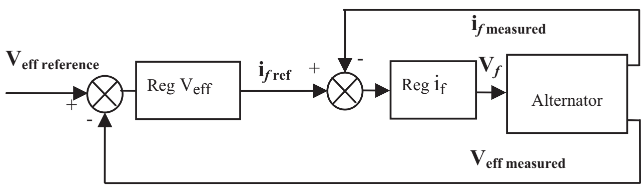

Fig. 2. Cascade control of network voltage.

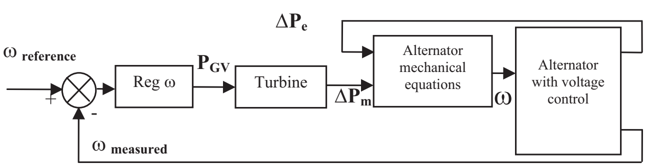

Fig. 3. Pulsation (frequency) control.

frequency. This operation is respectively realized using regulators by an action on the supply of the alternators rotors and the provided mechanical powers.

In our case, the studied network is constituted by two alternators supplying an electrical "PQ" load and driven by two turbines.

Alternators voltage control is obtained thanks to a cascade control with alternator stator voltage variation around the operating point as a primary variable (ΔV_{eff}) and the rotor current variation as the intermediate one (Δi_f) as presented in Fig. 2. The control is achieved by acting on the rotor voltage variation (ΔV_f). Frequency control (proportional to pulsation) is realized by acting on the DC machines speeds (mechanical power variation ΔP_m) Fig. 3.

The singular perturbation model development is detailed in [4]. You will find in the following parts the main steps of the model building.

2.1. Modelling principle

Each alternator is modelled separately from the others to ensure their regulators independence.

Let us consider the alternator load characterized by its active power "P" and reactive power "Q". Around an operating point described by the voltage "V_0" and the frequency "f_0", the active and reactive powers can be represented by an equivalent résistance and inductance "RL" or resistance and capacitance "RC" circuit. Therefore, the system we have to model is constituted by an alternator connected to an equivalent load.

From the alternator point of view, for produced active and reactive powers the equivalent "RL" load is defined at an operating point (V_0, f_0) as follows:

$$R = \frac{P{V_0}^2}{P^2+Q^2}, \quad L\omega_0 = \frac{Q{V_0}^2}{P^2+Q^2} \tag{1}$$

For produced active power and absorbed reactive power, the equivalent "RC" load at an operating point (V_0, f_0) is defined as follows:

$$R = \frac{P{V_0}^2}{P^2+Q^2}, \quad \frac{1}{C\omega_0} = \frac{|Q|{V_0}^2}{P^2+Q^2} \tag{2}$$

Tan (φ) is another representation of the power factor which is defined as reactive power divided by active power. Generally, Tan (φ) is fixed around 0.4 in the French electrical network [5]. Therefore, the "RL" load will be presented in this study.

2.2. Model building

The described system (alternator and equivalent "PQ" load) is composed of electrical and mechanical parts. It is interesting to notice that these two subsystems behave with very different time constants. In the following calculations, the state space model of the whole system is developed as described in [4]. The Park model is used for the alternator and the order is reduced by neglecting damper windings effect. The state space model can be presented as follows.

$$\begin{aligned} \frac{dX}{dt} &= \left[f_1(X,U) \quad f_2(X,U) \quad f_3(X,U) \quad f_4(X,U) \right]^T \\ &= f(X,U) \\ Y &= [\omega \quad V_{eff}]^T = g(X,U) \end{aligned} \tag{3}$$

with

$$[X] = \left[i_d \quad i_q \quad i_f \quad \omega \right]^T \text{ and } [U] = \left[V_f \quad P_m \right]^T$$

V_f, i_f are rotor voltage and current, i_d, i_q are respectively d and q axis alternator currents, ω is the alternator pulsation (proportional to its speed) and P_m is the mechanical power provided to the alternator.

The first step for the model building is handling the electrical part. The state space model of the electrical part is based on the alternator Park model (axes d and q), the "RL" load model in the alternator Park frame and the equalities of alternator and load voltages and currents [4].

$$\begin{aligned} \frac{d[I_1]}{dt} &= [A_1][I_1]+[B_1][V_1] \\ &= \left[f_1(X,U) \quad f_2(X,U) \quad f_3(X,U) \right]^T \end{aligned} \tag{4}$$