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Fuzzy-logic assisted power management for electrified mobile machinery

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ABSTRACT

The major elements of a mobile machine – engine and drives – are a crucial subject of control. Implementation of electric drives in mobile machinery is an emerging field of research and industry. Apart from conventional mechanical drives, they allow for wide control and power management possibilities. This paper considers a tractor-implement as a mobile power grid and addresses the problem of smart engine power management for sustainable operation by using power feedback of electric drives. The main focus lies in providing stable operation of the electrically driven implement. This is achieved by an engine power reserve dynamically adjusted according to power demands and their rate of change. To quantitatively evaluate the power demands, a supervisor approach based on the fuzzy logic theory is suggested. The supervisor has the structure of the Mamdani fuzzy system and computes the amount of the diesel engine power reserve as output. An adaptively changing power reserve providing sustainable operation is demonstrated in a partially stochastic simulation model of an electrified tractor with a rotary swather.

1. Introduction

1.1. Power management in mobile machinery

Implementation of electric drives in mobile machinery has been an emerging field of research in the recent years [3,2,1,11,14,13,6,16]. It is a particular realization of a continuously variable transmission (CVT) for which there exist a number of efficient power management solutions which utilize variable gear ratios. For example, energy management of an electrified vehicle with a CVT has been studied by Bowles et al. [5]. He determines the optimal engine throttle angle and CVT gear ratio to minimize fuel consumption and generate desired drive train power. Smith et al. [29] have suggested a strategy for the gear ratio scheduling based on optimization of fuel consumption and improving driveability. To achieve the latter, a so-called horsepower reserve has been proposed resulting from the driver's power request. It is defined in terms of the change in engine power and in the throttle angle. The horsepower reserve allows for better reaction to changing driving conditions. Wu et al. [32] have used dynamic programming (DP) for a diesel-hydraulic truck to optimize fuel consumption in a finite driving cycle. The generated control inputs include engine power and hydraulic power along with gear shifting strategy. DP has been used for hybrid electric truck by Lin et al. [18]. Here, the objective optionally includes emission rates as well and a trade-off with fuel consumption can be achieved.

In the power management of mobile machines with implements, not only efficient fuel usage and emission reduction, but also (and more importantly) sustainable operation of the implement must be considered. There is a whole variety of engine power management systems (EPM) for tractors. A number of manufacturers including John Deere, New Holland, Massey Fergusson, Fendt, Challenger use EPM to optimize power usage. EPM reserves a certain fixed amount of power which is utilized on demand [4]. Consequently, the engine does not work constantly at the full power and fuel consumption is therefore reduced. Development of electrical drives in mobile machinery extends also to implements [26]. Fig. 1 briefly illustrates the principal of an electrified mobile machine with an electrified implement.

Here, generator being driven by the primary power source produces necessary electric energy for the consumers such as drive trains and auxiliaries. The rectifier converts alternating current (AC) into direct current (DC) which is transmitted to the inverter via an intermediate circuit (IC). The braking resistor is needed to absorb excessively generated electric energy and convert it into heat. The controller network μC maintains all levels of control ranging from traction control to engine power management. Filser [9] has developed a priority-based approach to power management of a

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hybrid diesel-electric mobile machine with implements. He has specified that the total power demand may not overcome the currently available and maximal power of the system. Priorities assigned to the consumers are needed to determine in which order power demands are limited if the available power is exceeded. Some aspects of modular concepts of mobile machines have also been addressed by Herlitzius et al. [15].

1.2. Contributions of the present work

The major concept of a mobile power management proposed in the current paper takes into account the complexity of modular power grid design and suggests to use smart techniques to adaptively govern the grid energy source. The existing approaches to power management of mobile machines either do not consider implements or do not use adaptive adjustment according to dynamical properties of power demand such as rate of change (RoT). For example, the most of the EPMs for tractors use a fixed power reserve. The current research suggests to improve the efficiency of power management by fully utilizing controllability and feedback of electric drives. To achieve this, a similar idea of a dynamically adjusted power reserve as in [29] is used. However, the highest priority is assigned to sustainable operation rather than driveability. The approach developed by Wünsche [33] for electric single wheel drive tractor, which is similar to the EPM, is used as the basis. The goal of the improved method is to adjust the power reserve to provide stable operation, i. e. to avoid IC voltage drops. For the power reserve adjustment, a fuzzy-logic system is used. It allows power demand RoT to be quantitatively evaluated. The resulting approach is called fuzzy-logic assisted power management for mobile power grids. The main advantages of such a strategy lie in guaranteeing stable operation of implements on one hand, and avoiding excessive usage of engine power followed by fuel consumption and emissions on the other.

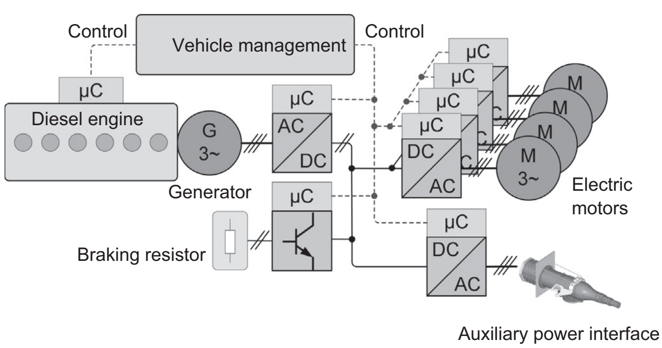

Fig. 1. Architecture of the mobile power grid based on the single wheel drive.

1.3. Outline

The next section describes the approach of power management of an electrified tractor-implement, which is used as the basis in this paper, followed by its extension in the form of a fuzzy-logic supervisor. Section 3 discusses the fuzzy rule base design and the simulation model. Section 4 demonstrates the results of the electrified tractor-implement under different dynamical phases. Aspects of experimental set-up for power management verification are discussed.

2. Theory

2.1. Basis approach

Current state-of-the-art aspects of the power management for electric single wheel drive tractors with auxiliary interfaces are discussed by Wünsche [33]. His approach is illustrated in Fig. 2. Here, the desired traction power P_{ref} is determined by the reference hitch draft force $F_{d,ref}$ and the traveling velocity v. The desired engine speed n_{ref} is determined from the characteristic line $n_{ref}(P_{gen})$ where P_{gen} is the current generator power. The generator load voltage $U_{IC,ref}$ from the intermediate circuit (IC) depends on the needs of the power consumers which include the drives and auxiliaries. The parallel line $P_{max}(n)$ characterizes how much additional power can be pulled at the actual engine speed n_{DE} without an intermediate circuit voltage drop. The difference between the parallel lines $n_{ref}(P_{gen})$ and $P_{max}(n)$ determines the engine power reserve which was fixed at 4 kW for the test vehicle used by Wünsche [33]. This value was chosen empirically.

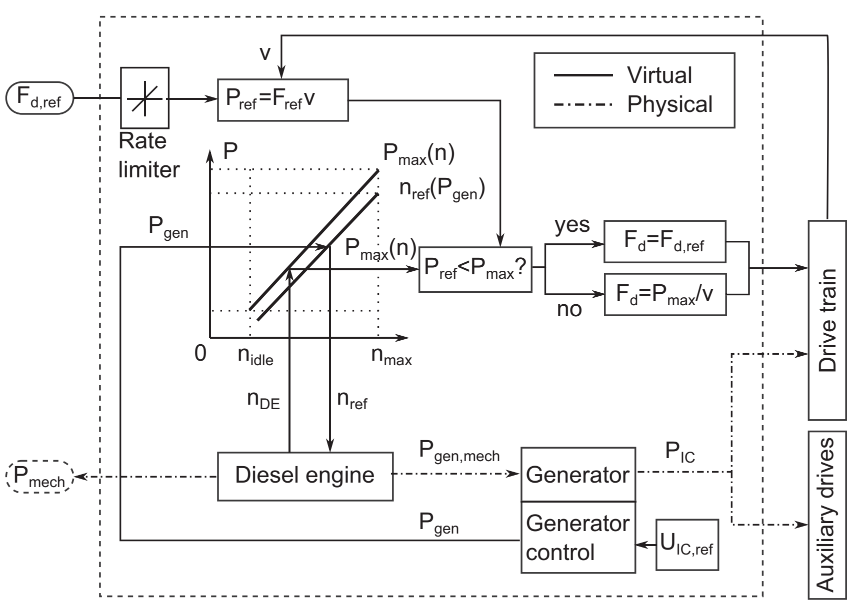

Fig. 2. Power management for an electric single wheel drive tractor [33].