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Analysis of the energy consumption of a novel DC power supplied industrial robot

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Abstract

The energy consumption and electrical characteristics of a novel direct current (DC) power supplied industrial robot prototype are compared and analyzed with a state of the art alternating current (AC) supplied industrial robot. An extensive set of experiments shows an important reduction of the total energy consumption for different electrical power profiles measured in various robot trajectories with specific working temperatures. The recuperated energy is also analyzed in the different scenarios. Experimental results show that a DC type robot can be up to 12.5% more energy-efficient than an equivalent AC type robot.

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Keywords: sustainable manufacturing; AC/DC micro-grids; energy efficient robotics, energy measurements; energy consumption.

1. Introduction

Industry 4.0 leverages digitalization, artificial intelligence and robotics to realize intelligent manufacturing systems and processes. An underestimated drawback of the Industry 4.0 extensive use of industrial robotics and Cyber Physical Production Systems (CPPS) is related with the inevitable drastic rise of the total Energy

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Consumption (EC), which risks to compromise the overall sustainability of the factories of the future. Then, there is a strong need of engineering methods and technologies able to improve the energy efficiency of industrial robots. To this purpose, the AREUS project [1], a European Commission funded research project, developed a novel generation of energy-efficient direct current (DC) supplied robots to overcome current industrial robots energetic limitations and to leverage the exchange, storage and recovery of energy at factory level. In fact, since industrial robots and mechatronic machinery operate on DC, a rectification power conversion stage is necessary with the state of the art alternating current (AC) supply grid, with a consequent loss of energy. For example, state of the art robots actuators are permanent magnet synchronous motors (PMSM). PMSM are controlled by separate servo inverters that are supplied by a common rectifier using a coupled DC-bus [2]. This means that internally, the system is DC supplied already. By using a DC power grid, the rectification stage at AC mains could be eliminated in many applications, thus saving the energy of the power conversion losses. Furthermore, also renewable energy sources operate in DC, then, the adoption of a DC supplied sub-grid would avoid further conversion stages, with the related costs, energy losses and energy quality problem.

DC systems and DC power grids have been extensively discussed in literature, DC sub-grids improve sustainability and energy efficiency by reducing material usage and weight [3], regenerating and recuperating energy and easing the optimization of trajectories and position accuracy for industrial applications [4]. In fact, one of the DC sub-grids main advantage is the capability to recuperate and regenerate energy efficiently, enabling bidirectional DC power flow, as well described with the motor drive system developed in [5], in which the system replicates the dynamics of industrial robot power flow. Furthermore, a DC grid may harvest and store all the recuperated energy, as demonstrated in [6] by using supercapacitor storage and power smoothing. All of these previous works found in literature confirm the systems energy efficiency improvements achievable with DC sub-grids, ideal to recuperate energy from the actuators with regenerative approaches, while in AC systems such recuperation would be harder and more expensive, often with important losses of the AC network quality [7].

Then, the novel DC supplied robots developed with the AREUS project (www.areus-project.eu) may enable DC industrial smart grids, with full regenerative bidirectional DC power flow and seamless integration of renewable energy sources. This paper presents the energy efficiency experimental assessment of a DC supplied KUKA Quantec KR210 R2700 prime DC supplied prototype robot, and the performance are compared with the ones achievable by the same model AC supplied.

The paper is organized as follows: in section 2 the experimental setup is presented, in section 3 the measurement and data acquisition process are described and in section 4 the experimental results are compared and analyzed.

2. Experimental testing setup

Two industrial 6-axes robots, KUKA Quantec KR210 R2700 prime [8], have been tested in different conditions to measure their energy consumption and trajectories power profile. Both robots are identical, excepting for the power supply system. Each robot weights 1100 kg, has a payload up to 210 kg, and a maximum power rating of 22 kW [8, 9]. In the state of the art AC robot version, a single rectifier creates a common DC-bus from which six inverters draw the energy for the motors (Fig. 1), while in the AREUS project robot prototype the rectifier is removed, allowing the direct connection of the internal DC-bus to a prototype factory DC-grid, (Fig. 2). The DC prototype robot, is supplied by an experimental 600 V DC power grid generated by a 55 kW active frond-end unit (AC/DC converter), developed by Riga Technical University [10].