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A Study on Actuator and Power Electronics for Low Voltage

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Abstract

The goal of this review article is to learn about the power electronics, linear actuators in the current platform, and then to provide a solution to improve the controller and also presents the problem formulation for the low voltage power electronics. This must be both quicker than the present controller and consume no more CPU recurses than are required. Three new regulators were implemented and tested based on the current controller's understanding. To create the control signal, one utilises a PI regulator, while the other two use an adaptive algorithm. All were faster than the existing one, and the PI approach requires the fewest CPU recurses; however, this must be tuned for various hardware and output frequencies.

Keywords: *WPT, PTE, Dielectric resonator, MRC.*

1. Introduction

Aiming to modernize the traditional power systems, smart grids are emerging, supported by power electronics and digital technologies, as the next-generation of power systems with the objective of satisfying a set of relevant growing concerns, while ensuring environmentally-friendly principles. Evidently, the pathway targeting such a reality is complex and, among others, the key concerns are related to flexibility among systems, efficiency in the production and consumption, distributed generation (DG) and energy storage, reliability of power electronics, smart metering systems, power management, smart homes and cities, communication infrastructures, battery charging systems for more electric mobility, microgrids, controllable electrical appliances, and embracing all of these topics the power quality, both from the power grid and the final-user perspectives [1].

Additionally, in this context, cities are changing toward smart cities and their concepts, and concerning the evaluation of technologies, cost-benefit analysis and societal impacts are presented in [2]. Additionally, a survey about the fundamental management systems in terms of the request for advanced metering infrastructures for future grids is presented in [3]. Globally, considering that the new technologies require more and more power electronics systems, new opportunities for power management are also emerging, where the intercommunication between all of them reinforces the major role of information and communication technologies. However, the widespread use of power electronics converters leads, inevitably, to issues associated with power quality. In fact, power quality is recognized as a standout among the greatest indispensable issues for the successful implementation of smart grids, despite power quality being a well-known concern presented in the conventional power grids [4]. This new importance of power quality is due to several factors, including the increasing use of electrical appliances, mainly in the industrial sector, and the electrical appliances with nonlinear behavior in the residential sector. The essential concerns of power quality are associated with additional costs, losses in product quality, and malfunctioning of electrical appliances, both in terms of premature fails and total failure [5]. Consequently, power quality can represent an enormous harmful effect regarding several sectors, mainly industrial, commercial, and residential, each one presenting different requirements from a power quality perspective. Moreover, e.g., within the industrial sector, particular attributes in terms of power quality can be identified, forcing the adoption of specific solutions to mitigate power quality problems. Aligned with this perspective, the implementation of these solutions reflects additional costs. Regarding the residential sector, in principle, the conventional electrical appliances tend not to be harmfully affected due to power quality issues, i.e., they depend less on the power quality offered by the power grid during its normal operation. Nevertheless, by considering the sophisticated advances of technologies for new and emerging electrical appliances, presenting new functionalities (e.g., IoT technologies and communications), it is predictable that they can be more susceptible to power quality problems soon [6].

2. Power Electronics

The power electronics system handles the transformation from the input voltage V_i and input current I_i to either producing a higher or lower output voltage V_o and output current I_o. It can also handle the transition from AC to DC,

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DC to AC, AC to AC and DC to DC making the power electronics a highly interesting research area. Increase efficiency for the transformation in for example solar cells that produce a DC voltage and needs to be converted to AC before going out in the power network is a hot research topic.

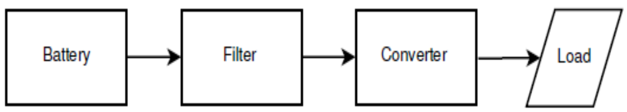

Fig. 1 General block diagram of a power converter

There are two main topologies that are used when designing power electronics for DC-DC, the buck converters that step-downs or reduces the input voltage and the boost converter that step-ups or increases the input voltage. Then there is a combination of the two when both step-down and step-up is needed. In figure 1 a general block diagram of a power system can be found. In any converter there is always one or more switch/switches (transistor) and diode. These are used to control the transformation from the input to the output. Because of this a controller is needed, its task is to make the output follow a reference as precisely as possible. This is done by opening and closing the switch. The purpose of the diode is to discharge the inductance and capacitance that also is needed to complete the converter when the switch is in its off state. The simplest technique that can be used to produce this is the Pulse-Width Modulation (PWM). The control signal has a fixed pulse-width that is split into two states, a one ”on” state and one ”off” state. The ratio between the on and of the on state, which is a fraction of the total pulse width is called the duty cycle.

Buck converter

The buck converter is used to produce a lower output voltage than the input voltage. In figure 2 of the buck converter can be seen. The converter can simply be described by equation 1, if the switch and diode is ideal and a resistive load is used. Where D is the duty cycle, Ts is the time period of the total pulse and ton is the time when the switch is closed. Equation 1 is only used in the continuously conducting mode.

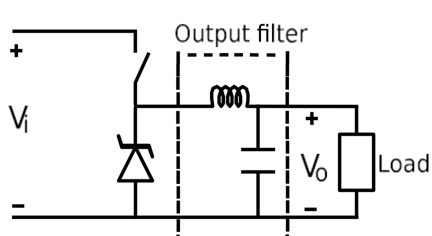

Fig. 2: A generic buck converter with output filter

$$V_o = \int_0^{T_s} v_0(t)dt = \frac{1}{T_s}\left(\int_0^{t_{on}} V_i(t) + \int_{t_{on}}^{T_s} 0dt\right) = \frac{t_{on}}{T_s}V_i = DV_i$$

Continuous Conducting Mode

The converter can work in two modes; continuous conducting, discontinuous con- ducting and also in the boundary between the two. In the continuous mode the current always flows through the inductor. During the time period when the switch is on, the current (I_L) flowing through the inductor L, rises with the slope during the on time period the total amount the current will increase. And during the off time period the decreases with the slope and the total decreases of the current can be described When the switch is turned off the current stored in the inductance will now flows through the diode instead.

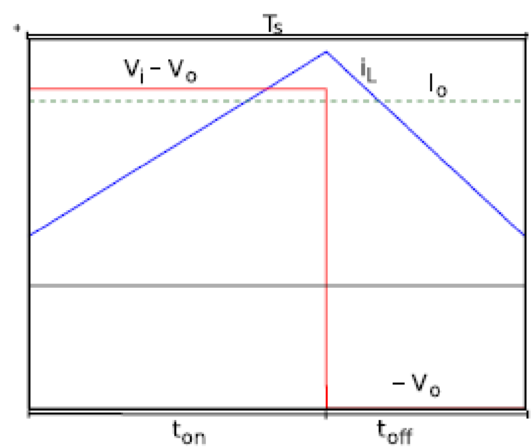

Fig.3: The current and voltage over the inductance for a time period

Using this information together with the knowledge that the converter is used in the steady state (the integral of the inductor voltage v_L is zero over one-time period) and figure.3 we get (2.3). It can be shown that equation 2.4 holds, but only in the continuous conduction mode. Also in the steady state the average current over the capacitor is zero, [7]. This will make the output current Io equal to the average inductor current I_L.

Discontinuous-Conducting Mode

If the ton is too short to charge the inductor L with enough energy to output current during the whole t_{off} time period, the converter is said to work in discontinuous conducting mode.

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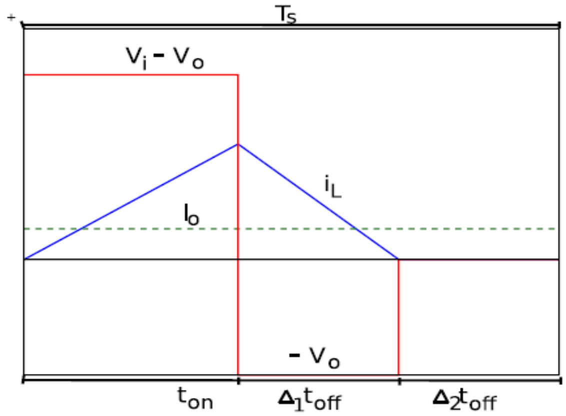

Fig. 4The current and voltage over the inductance for a time period

The waveform for the inductor current can be seen in figure 4. Now when the inductor current is zero for a time a new variable Δ_1 is needed, it is the fraction of the 1-D (which represents the off time period) when the current still flows through the inductor. This will change the total decreases in the current during the off period. To calculate the average output current (I_0), the peak value of the i_L is needed [8].

3. Actuator in Power Electronics

An actuator is a part of a device or machine that helps it to achieve physical movements by converting energy, often electrical, air, or hydraulic, into mechanical force. Simply put, it is the component in any machine that enables movement.

Actuators are present in almost every machine around us, from simple electronic access control systems, the vibrator on your mobile phone and household appliances to vehicles, industrial devices, and robots. Common examples of actuators include electric motors, stepper motors, jackscrews, electric muscular stimulators in robots, etc.

Linear Actuator

An actuator is a device that converts energy, which may be electric, hydraulic, pneumatic, etc., to mechanical in such a way that it can be controlled. The quantity and the nature of input depend on the kind of energy to be converted and the function of the actuator. Electric and piezoelectric actuators, for instance, work on the input of electric current or voltage, for hydraulic actuators, its incompressible liquid, and for pneumatic actuators, the input is air. The output is always mechanical energy.

Actuators are not something you would read about every day in media, unlike artificial intelligence and machine learning. But the reality is that it plays a critical role in the modern world almost like no other device ever invented.

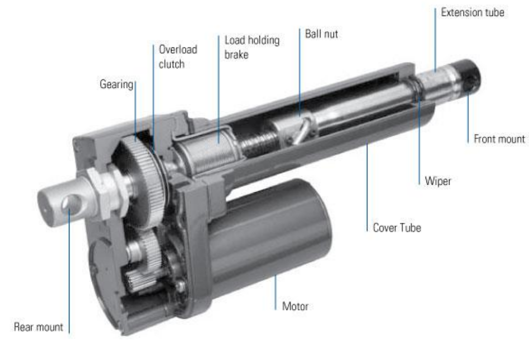

Fig. 4: Electric Actuator

In the industrial mechatronics systems, for instance, they are solely responsible for ensuring a device such as a robotic arm is able to move when electric input is provided. Your car uses actuators in the engine control system to regulate air flaps for torque and optimization of power, idle speed, and fuel management for ideal combustion.

As we have seen already, actuators have myriad applications in different fields. But this doesn’t mean that all actuators are made equal. When purchasing an actuator, you should be able to know which suits your requirements best. Here is a comprehensive guide on how to choose the right actuator for your needs.

Step 1. Assess the movement required:

Does the object you need to move in your project require linear or rotary movement? Linear actuators are useful in exerting a mechanical force that would move an object in a straight line while rotary actuators, as the name suggests, generate circular motion.

Step 2: Consider the energy input:

Electrical actuators are becoming more and more popular due to their increasing sophistication and flexibility in handling various kinds of operations. But that doesn’t mean it's suited for every work out there. Consider hydraulic or pneumatic actuators if your work does not include electrical voltage input.

Step 3: Assess the precision level required:

Some actuators are ideal for heavy-duty work in rough environments, but they may not work well when it comes to handling smaller work like packaging which requires precision and the ability to repeat the same action hundreds or thousands of times.

Step 4 : Find out how much force you need:

The purpose of an actuator is to move or lift an object. Find out, in your case, how much this object weighs. The load capacity of an actuator decides how much it can lift, and although many actuators may look similar, their load capacity will vary. Before you buy an actuator, make sure the weight of your object matches the capacity of the actuator.

Step 5: Find out how far you need the object moved:

Distance, or stroke length as it is technically known, matters here. The stroke length decides how far your object can be moved. Manufacturers often sell actuators of varying stroke length.

Step 6: How fast do you want the movement to be:

The speed of the actuator is often an important factor for most people, depending on their project. Usually, projects that require actuators to exert high force would move slower than those that generate low force. Speed of an actuator is measured in distance per second.

Step 7: Consider the operating environment:

Does the actuator need to work in a rugged or rough environment, where dust or humidity is a concern? If this is the case, you would want to choose a product with higher protection rating.

Step 8: Decide on the mounting style:

Actuators in the market come in different mounting styles and understanding their benefits is necessary before buying an actuator. For instance, a dual-pivot mounting method in a linear electric actuator allows the device to pivot on both sides while extending and retracting. With this, the application gets to have two free pivot points while moving on a fixed path.

Conversely, stationary mounting, which secures the actuator to an object along the shaft, is useful for actions such as pushing a button. At this stage, you should be able to narrow down your options to a significantly smaller pool from where you started. From here, you will need to narrow down further. For instance, linear actuators come in different styles for different kinds of functions. Rod-style, for instance, is the most common and simple among them, with a shaft that expands and retracts. Track style, which does not change its overall length or size during operations are more suited when space constraints are an issue. There are also column lifts and other actuators that would be ideal for setting up TV and table lifts. Factors such as operating voltage and motor type may also be worth considering.

Capabilities of a Linear Actuator

Performance metrics are quantifiable outputs that help you evaluate the quality of a particular product. Actuators can be considered under several performance metrics. Traditionally, most common among them have been torque, speed, and durability. These days, energy efficiency is also considered equally important. Other factors that may be considered include volume, mass, operating conditions, etc.

Torque or force

Naturally, torque is one of the most important aspects to consider in the performance of an actuator. A key factor here is to note that there are two kinds of torque metric to consider, static and dynamic load. Static load torque or force refers to the actuator's capacity when it is at rest. The dynamic metric refers to the device's torque capacity when it is in motion.

Speed

Speed of an actuator differs depending on the weight of the load it is supposed to carry. Usually, the higher the weight, the lower the speed. Hence the speed metric should first be looked at when the actuator is not carrying any load.

Durability

The type of actuator and the manufacturer's design decides the durability of an actuator. Although those such as hydraulic actuators are considered more durable and rugged compared to electric actuators, the detail specs on the quality of the material used will be up to the manufacturer.

Energy efficiency

With increasing concerns on energy conservation and its direct impact on operational costs, energy efficiency is becoming more and more a decisive metric in all kinds of machinery. Here the lesser the quantity of energy required for an actuator to achieve its goal, the better.

4. Related Work

Perinpanayagam et al. (2021) highlights the salient emerging state-of-the-art Wide Band Gap (WBG) technologies such as Gallium Nitride (GaN) and Silicon Carbide (SiC) and draws an extensive comparison with their Silicon counterparts. A comprehensive examination of techniques employed for the estimation of the reliability of WBG power devices has revealed a number of areas that merit due consideration. For instance, the physics-based models that have been developed to assess the operational lifetime of silicon-based devices for given failure modes require revamping in light of the new materials and the unique electrical and physical characteristics the WBG devices possess. Similarly, the condition monitoring techniques, with respect to the primary and secondary parameters, require further investigation to determine highly representative feature vectors that best describe the degradation within these devices. More significantly, optimization of the proposed techniques for the health assessment of these devices needs to be pursued through the optimal use of vital parameters. Keeping these critical findings in perspective, a road map highlighting various avenues for power electronics optimization in MEA is put forth to apprise the aerospace fraternity of its growing significance [9].

Maroti et al. (2021) In this paper, the role of power electronics converters in an electric vehicle is elaborated. The bidirectional DC-DC converter plays a vital role in the power conversion process of electric vehicles. The existing bidirectional DC-DC converter topologies are discussed with a comprehensive review, comparison and application. Additionally, the advancement in power electronics converters to improve the efficiency and reliability of the vehicular system is elaborated.

Atoosa Majlesi et al. (2021) a PV source as a unified interphase power controller (UIPC) is used to enhance the low voltage ride through (LVRT) and transient stability of a multi-machine power system. The suggested PV-based UIPC consists of two series voltage inverters and a parallel inverter. The UIPC injects the required active and reactive power to prevent voltage drop under grid fault conditions. Accordingly, a dynamic control system is designed based on proportional-integral (PI) controllers for the PV-based UIPC to operate in both normal and fault conditions. Simulations are done using Matlab/Simulink software, and the performance of the PV-based UIPC is compared with the conventional unified power flow controller (UPFC). The results of this study indicate the more favorable impact of the PV-based UIPC on the system compared to UPFC in improving LVRT capabilities and transient stability [11].

Woongkul Lee et al (2018) An integration of an electric motor and a drive with wide bandgap (WBG) devices possesses numerous attractive features for electrified and decentralized actuation systems. The WBG devices can operate at high junction temperature (>170℃) with improved efficiency due to fast switching speed and low on-state resistance. It also leads to better performance and higher power density electrohydrostatic actuators than the traditional solutions, which are being widely adopted in industrial applications such as aerospace, robotics, automobiles, manufacturing, wind turbine, and off-road vehicles. This paper introduces and investigates the benefits of the integrated motor drive (IMD) with the WBG-based power electronics for the electrohydrostatic actuation systems [12].

Michael Karpelson et al.(2008) explores the design space of flapping-wing microrobots weighing 1g and under by determining mechanical requirements for the actuation mechanism, analyzing potential actuation technologies, and discussing the design and realization of the required power electronics. Promising combinations of actuators and power circuits are identified and used to estimate microrobot performance [13].

Jun Dai et al. (2021) presents a V-shaped metal-silicon actuator with low voltage, low power consumption and large displacement. The electro-thermal conversion and heat conduction mechanism of the actuator are improved by optimizing the architecture design of the actuator. An innovative method utilizing the double-sided inductively coupled plasma etching technique is developed for the fabrication. The motion of the actuator is characterized with a microscope-based dynamic test system. Finite element analysis is conducted to verify the device design and experimental results. The transient dynamic behaviour of the actuator is modelled for future control strategy. A rectilinear displacement as high as 80.7 μm is achieved at a voltage of 4.0 V and power of 1.12 W. The displacement per unit length to voltage ratio of the metal-silicon actuator is the largest among existing silicon actuators. The displacement per unit length to power of the actuator is also comparative to the highest value of existing actuators, demonstrating that the metal-silicon actuator can achieve large displacement with low voltage and power consumption. The proposed actuator has great potential for the applications in the miniature mechatronic systems such as cell phone, camera, safety and arming device [14].

Problem Description

The current control strategy described in section 1.1 is rough but can handle different loads without much effort and drops on the battery voltage. There are properties that need to be converted to the new strategy. Also the new strategy should be more robust and hopefully faster than the current strategy. The new implementation shall also be able to handle different fault cases to signal to the application that something is wrong.

The goal for this new controller is the following, but is not necessarily limited to:

- To have a steady state error of max 1 mA.
- To have a maximal overshoot of max 5% of requested current.
- To have a settling time of at most 20 t.u. within 5 mA of the requested current.
- To detect an open circuit, short to GND, above requested- and below re- quested current.

5. Conclusion

This research gives a state-of-the-art review of PECs' current status and possibilities in electric and actuator applications. The impact of PECs on the cost, efficiency, and performance of electric vehicles was summarised in this research. The control system has the perfect combination of two energy sources for propelling and other functions, according to an assessment of low voltage power electronics and actuator. With the progress of the vehicle electrical system, there is a greater requirement for varied rated supply, which can no longer be met by a single battery or a two-battery system. Finally, the study discusses the numerous issues that PECs face in terms of increasing efficiency, durability, performance, and cost savings.

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