Linear power for automated industrial systems

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Designing a robust power management system for industrial automated equipment requires thorough understanding of the surroundings and conditions that affect the functionality.

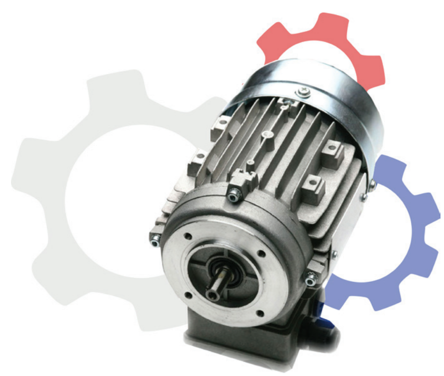
During the past few decades, industrial and factory automation systems have become more robust, intelligent and connected, which has drastically increased the footprint for semiconductor components. This change has created an amalgamation of different designs and system structures. As a result, engineers were required to retain the tried and true designs and interface them with modern or newer designs in order to enable better functionality.

Out with the old, in with the new?

Although designs are improving and a vast number of systems are being updated, the environment and the conditions surrounding these devices have not changed much. Unlike many of the electronic devices we interface with on a day-to-day basis, systems within an industrial environment require working within high temperatures, high-voltage conditions, and various external factors that can cause wear, tear and stress.

This means that in order to support the micro-controller, sensors and other devices mounted on the PCBs, power management must be able to fully operate in these conditions. At the same time, there must be a steady supply of power, efficiency and reliability for very long periods of time, even decades. Note that many designs created today must interact directly or indirectly with a lot of previous generation or high-voltage systems and machinery. Therefore, it is also very important to identify and address the faults and events that may cause harm to any sensitive electronics components.

When it comes to power management there is a wide variety of topologies that can be employed. However, in automation systems it is common to find a high DC voltage already being used for a motor or in the system's control lines, most commonly 12V or 24V. While a large number of systems benefit from high-power efficiency DC/DC architectures in order to achieve a lower voltage, there is a great demand for linear regulators (LDOs) to provide voltage regulation to other semiconductor systems in charge of metering, sensing and to control major motor functions. This paper reviews the requirements for linear regulators intended for use within industrial or factory automation systems and their benefits.



Industrial automation systems and high voltages

A standard industrial automation system consists of a CPU or central controller, analog and digital inputs and outputs that interact with all subsystems, a communications protocol that allows very long wire lengths, and branching or stacked I/O modules for added functionality. **Figure 1** shows a very popular, very simplified programmable logic controller (PLC) configuration currently being used in many automated structures.

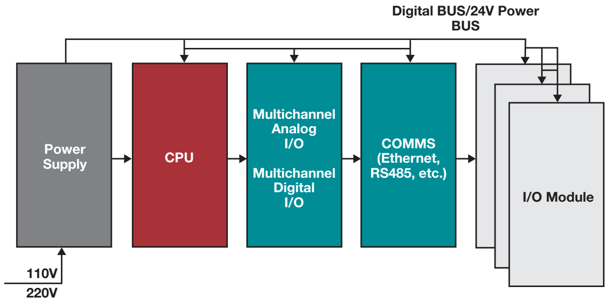


Figure 1: Standard 24V PLC system.

In most cases the devices in each block or section can be powered directly from the main supply while others can take advantage of the 24V rail and regulate what is needed. This scenario requires the designer to take into consideration all possible devices that are or may be connected, as the power supply needs to compensate or have power to spare. Also, as more and more devices are connected to the power BUS, noise on the line increases and, thus, the noise in the subsystems. Note that while the standard PLC functions at 12V and 24V, there is always the possibility that one of the system's devices, boards or interfaced peripherals needs to operate beyond this range. In such a case, the required power supply must be able to reach these high voltages that often are in the range 40V or higher.

Linear versus a switching regulator

In a plethora of automated systems, condition sensing, communications and precision analog-to-digital conversion are key factors and the base of functionality. These converters and communication devices, for the most part, are sensitive to noise. For these noise-sensitive devices it is important to minimize the supply noise as this ultimately affects the accuracy or stability of the communication or conversion [1].

Switching regulators can change the input voltage by turning or switching on and off an internal element. However, this creates an output voltage ripple that can be seen by the receiving component as noise or a fluctuation in the input voltage, thus, affecting their functionality. Alternatively, linear regulators have a very low output voltage ripple because none of its internal elements are switching on and off. They can also have a very high bandwidth with very little electromagnetic interference (EMI) in the system. Furthermore, low drop-out (LDO) linear regulator devices are much simpler and easier to use. Most of them are 3 to 4 pin devices with very small packages and do not require external inductors in order to function (**Figure 2**).

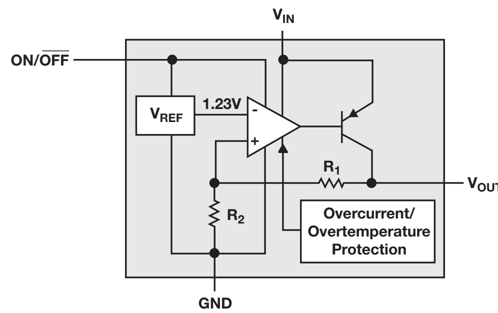


Figure 2: Standard linear regulator.

High temperature compatibility

Motors in most systems, whether mechanical or electrical, dissipate a great deal of power through heat. This heat is dissipated through the housing which, in most cases, is made of metal. This means that in order to survive and function properly, all internal electronics must be rated for very high temperatures – even up to 125°C. This range has now become the new standard of ambient temperature for semiconductors intended for industrial systems. This also works well in the opposite manner where equipment intended for use outdoors is faced with temperatures well below freezing, such as –40°C. Although it is not always the case that both conditions are met, many devices have to be tested at both extremes in order to comply.

One drawback for a linear regulator is the amount of power dissipated through the system almost entirely as heat [2]. The power dissipated by a linear regulator can be determined as follows:

$$PD = (V_{IN} - V_{OUT}) \bullet I_{OUT} \quad (1)$$

This means that the higher the voltage difference between your input and output voltages, the greater the heat that will be dissipated, and the higher the temperature around the LDO. In such cases, a better way to dissipate this system heat is by using a pad or contact. The designer can benefit from regulators fitted with ON/OFF switches to control the length of time the device is active. Other devices also can be fitted with over temperature shutdown functionality to prevent the device from reaching unsafe temperatures. Another way to compensate for power dissipation is to choose a very low-voltage dropout regulator and keep the V_{OUT} as close to V_{IN} as possible. This is the most common scenario for low-current power within the range of 100mA or less.

Risk conditions and faults

While heat, voltage and power are important factors for the power management design in an automated system such as in vehicle assembly sites **(Figure 3)**, other factors may be present that can significantly impact the system, particularly when integrating motors in the design. If a given motor within the system gets shut or stuck, it draws more current into the system, increasing the power demand on the regulators. While many discrete solutions can be used to dissipate this current through the electrical ground, there are a variety of linear regulators available today that can sense the output current and shutdown in an event of exceeded current. In many instances this causes the device to overheat, in which case over temperature can help. The increase in heat is progressive while the increase in current demand is almost immediate.

Over-temperature conditions

Although we can compensate and design around thermal and power dissipation, faults may exist where the load exceeds our set parameters. It is recommended to have a way of shutting down the system to prevent permanent damage in case the power dissipated may increase unexpectedly. Many linear regulators and LDOs feature internal thermal shutdown structures that can turn off the device whenever junction temperature is exceeded as shown previously in Figure 2. In a standard linear regulator, thermal protection disables the output when the junction temperature rises to approximately 170°C, allowing the device to cool. When the junction temperature cools to approximately 150°C, the output circuitry is enabled allowing for regulation to resume. This protection circuitry is not intended to replace proper heatsinking, but allows for additional protection.

Figure 3: Automated vehicle assembly.

Current limit and short circuit protection

Similar to a rise in operating temperature, an unexpected rise in output current in power management may lead to severe damage that could transmit across the entire power rail. Multiple conditions could lead to an increase in output current ranging from stalled motors, too many nodes attached to the power rail and even short circuits from electrically and physically damaged equipment. This increase in supply current is harmful to most electronic systems as well as the host power management circuit and can cause irreparable damage to very expensive machinery or production delays. Selecting an LDO with internal protection from short circuit and current limit can help prevent this harmful effect from transmitting and provide additional protection to the overall power management.

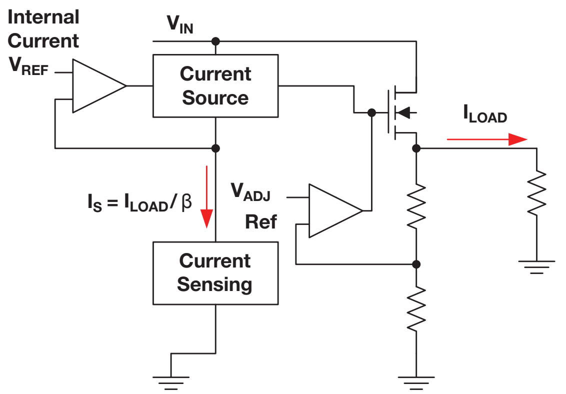


Figure 4: Internal LDO current Llimit structure.

Current limit in a linear regulator (LDO) is defined by establishing an upper boundary for the current supplied. This is achieved through internal circuitry which controls the output stage transistors inside the LDO as seen in **Figure 4**. The internal current measures and mimics the output current so that when the output load's current increases, so will the sensed current. Finally the internal comparator will sample this and take control of the output to maintain this current within its safe operation. Once the current limit is reached, the output voltage is no longer regulated and will be defined by the load impedance:

$$V_{OUT} = I_{LIMIT} \ x \ R_{LOAD}$$

The pass transistor will continue this operation and will dissipate power as long as the thermal resistance (θJA) allows for healthy power dissipation (TJ < 125 °C).

Conclusion

A great deal of consideration and precaution must be taken when designing a power supply for any type of automated industrial/factory system. However, many features have been widely adopted in linear regulator designs that make them a great, if not perfect, fit for all environments. While there is no one-size fits all, there is definitely a linear regulator that can meet all the requirements for any particular system while remaining an easy-to-use and cost-effective power management solution.

References

1. F. Barzegr, S. Cuk, and R.D. Middlebrook, " Using Small Computers to Model and Measure Magnitude and Phase of Regulator Transfer Functions and Loop Gain," Proceedings of Powercon 8, April 1981
2. Bruce Hunter and Patrick Rowland, Linear Regulator Design Guide For LDOs, Application Report (SLVA118A), Texas Instruments, June 2008

Here's more information about linear regulators Download these datasheets: TPS709, TPS7A16 and TPS7A4001

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