Application Note

Reliable Start-up with Large and Unknown Capacitive Loads

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ABSTRACT

Industrial equipment such as a Programmable Logic Controller (PLC) need large capacitors for storing energy to provide backup time for storing critical information before equipment shutdown. In the case of DIN power supplies, the output capacitance of the load is unknown and the power supply designer has to design for a wide range of output capacitance. This application note describes how large and unknown capacitors can be powered using the TPS2663 and TPS1663 devices.

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1 Introduction

The Programmable Logic Controllers (PLCs) are widely used for automation in industries. The PLC collects data from sensors, analyzes this data using CPU, and controls the industrial process through actuators. The PLC CPU needs energy storage to provide a backup for storing critical information in case of loss of power. The energy storage is either provided by a battery or a large capacitor. A large capacitor is preferred over a battery for energy storage due to its lower cost. Figure 1-1 provides a block diagram for the PLC CPU.

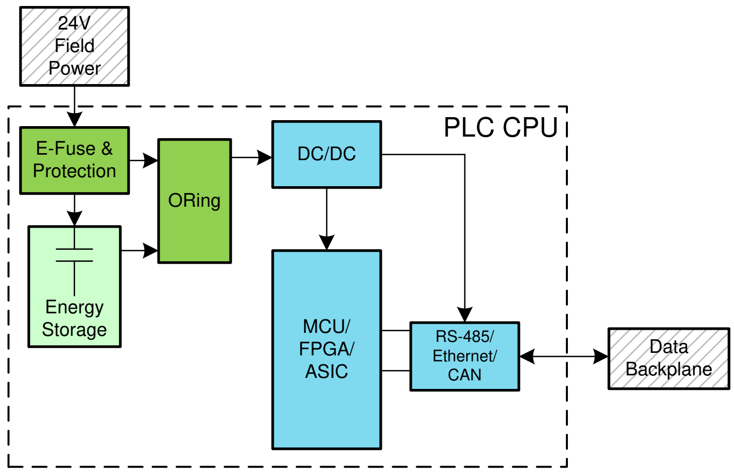

Figure 1-1. Block Diagram of a PLC CPU

The 24-V field power is the primary source of power for the PLC CPU. An eFUSE device with integrated MOSFETs and protection features can be used at the power input of PLC CPU to protect from surges and faults on a field power bus. The energy storage capacitor is used to power the DC/DC converter during an event of failure of power on a field power bus. A capacitor of value typically more than 1 mF is used to provide power to PLC CPU during failure. This capacitor draws large current during start-up and can cause the eFUSE to go into shutdown due to overload or due to excessive thermal dissipation. Another similar application of energy storage requiring large capacitance is for motor and servo drives. TI Design *Compact, Efficient, 24-V Input Auxiliary Power Supply Reference Design for Servo Drives* provides the complete design procedure and test results for power supply in servo drives.

In PLC systems, there is a 24-V power bus which provides power to modules in the PLC system. This power bus is powered from DIN power supply. The number of modules connected on this power bus varies with architecture of PLC systems. The output capacitance seen by DIN power supply is unknown. Typically, a DIN power supply of less than 250 W is designed for a maximum capacitive load of 10 mF. Figure 1-2 provides a block diagram of DIN power supply.

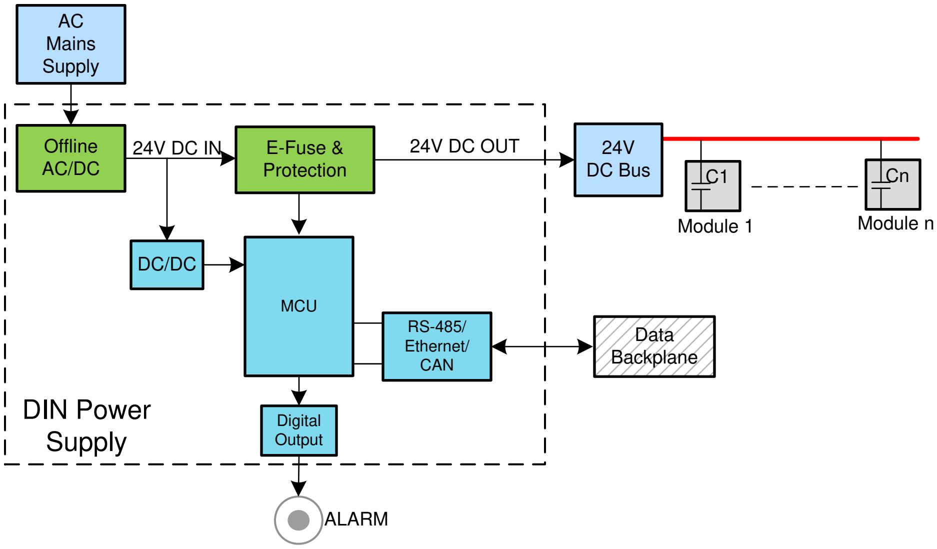

Figure 1-2. Block Diagram of a DIN Power Supply

2 Powering Capacitive Loads with Constant Inrush Current and Output Slew Rate at Start-up

Capacitors draw large currents from the power source at start-up, which can lead to tripping of the power source due to overload. To limit the inrush current into capacitors, power switches implement constant current charging of capacitors at start-up. To charge the capacitors with inrush current, the output voltage is increased linearly with time. As an example, the TPS2660 device has a capacitor on the dVdT pin to control the output slew rate and limit the inrush current for output capacitor. Figure 2-1 provides the application circuit with the TPS2660 for charging capacitors with constant inrush current.

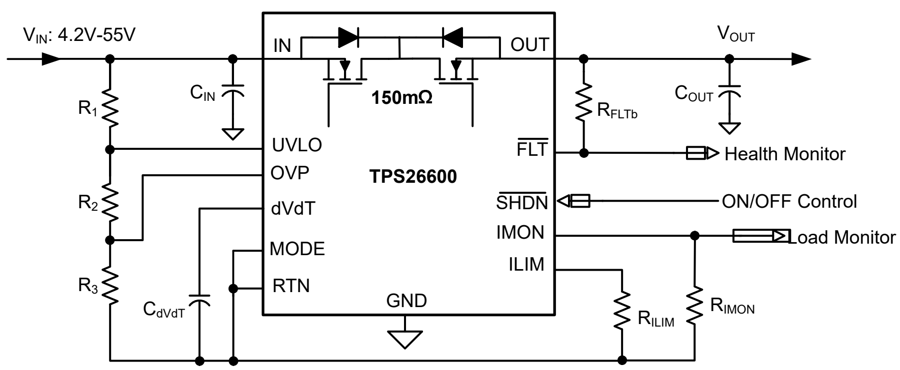

Figure 2-1. TPS26600 Application Circuit for Charging Capacitor with Constant Inrush Current

At power up, the output capacitor has zero voltage and there is power dissipation of (V_{IN} X I_{INRUSH}). As the capacitor gets charged, the voltage drop across the power device and the power dissipation decreases. For charging the output capacitor to V_{IN} voltage, an average power of (0.5 × V_{IN} X I_{INRUSH}])is dissipated in the power switch during the start-up. Figure 2-2 provides power dissipation for C_{OUT} of 1 mF and I_{INRUSH} of 115 mA.

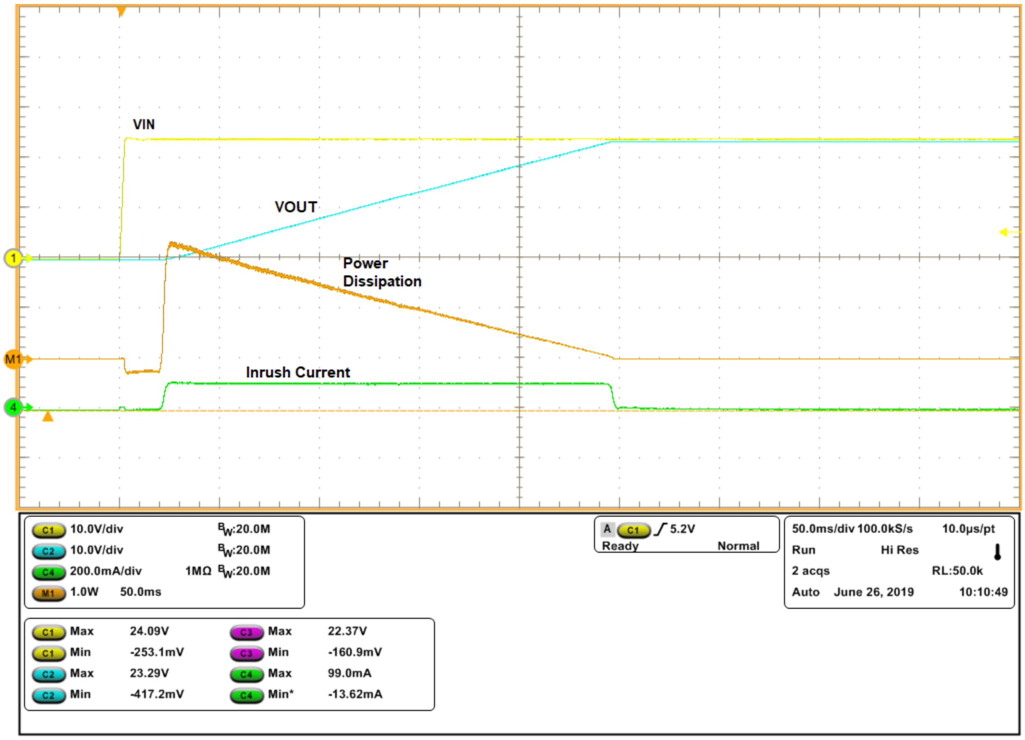

Figure 2-2. Power Dissipation for C_{OUT} = 1 mF with I_{INRUSH} = 115 mA

For lower voltages and lower output capacitance, the capacitors can be charged with constant inrush current and constant output slew rate. But as the output capacitance and input voltage increases, the power dissipation in the power switch at power up increases and can lead to thermal shutdown and hiccup in start-up. Table 2-1 provides the power dissipated for a start-up time of 209 ms and constant output slew rate of 115 V/s.

Table 2-1. Power Dissipated with Load Capacitance

V_{IN}	I_{INRUSH}	C_{OUT}	AVERAGE POWER DISSIPATED
24 V	115 mA	1 mF	1.38 W
24 V	250 mA	2.2 mF	3 W
24 V	540 mA	4.7 mF	6.5 W
24 V	1725 mA	15 mF	20.7 W

With increased power dissipation at higher voltage and increased output capacitance, the power switch goes into thermal shutdown and leads to hiccups in start-up. Figure 2-3 shows the hiccups in start-up with output capacitance of 15 mF and V_{IN} of 24 V due to thermal shutdown of power switch.

See the *TPS26600 Design Calculator* to design with TPS2660x devices with clean start-up.

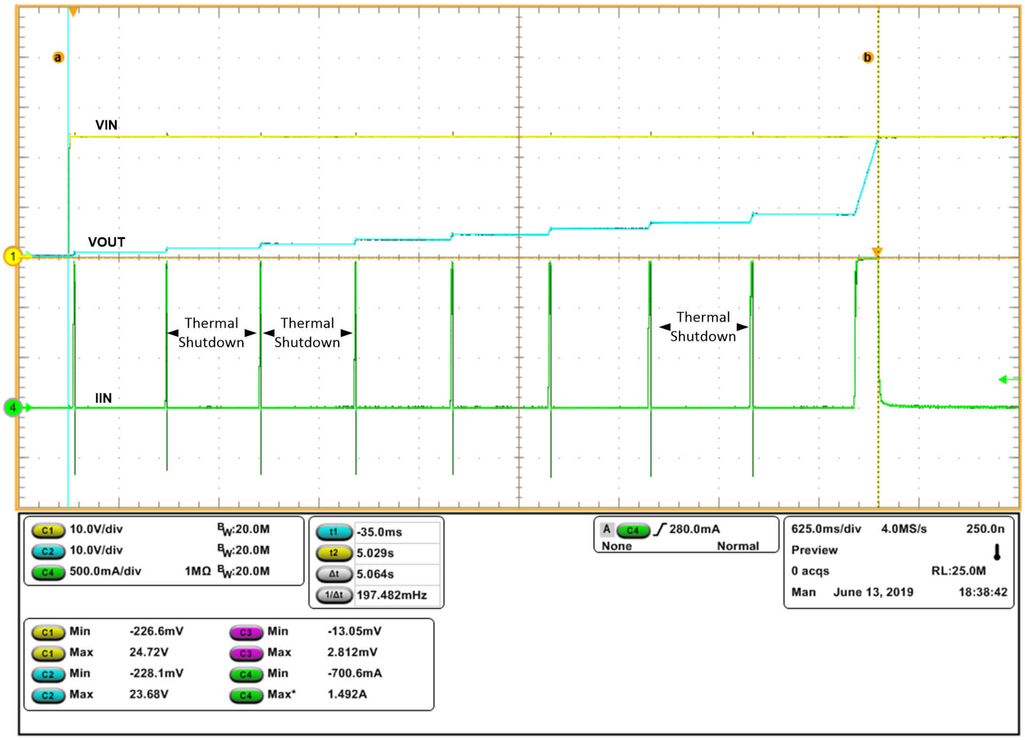

Figure 2-3. Hiccups in Start-up with Constant Inrush Current

3 Powering Capacitive Loads with Constant Power Dissipation in Power Switch at Start-up

Hot-swap controllers like the TPS2471x can provide the charging of output capacitors with constant power dissipation in power switch. As illustrated in Figure 3-1, resistor R_{PROG} sets the power dissipation limit for power switch M1 and capacitor C_T sets the maximum time for power limiting and overcurrent faults.

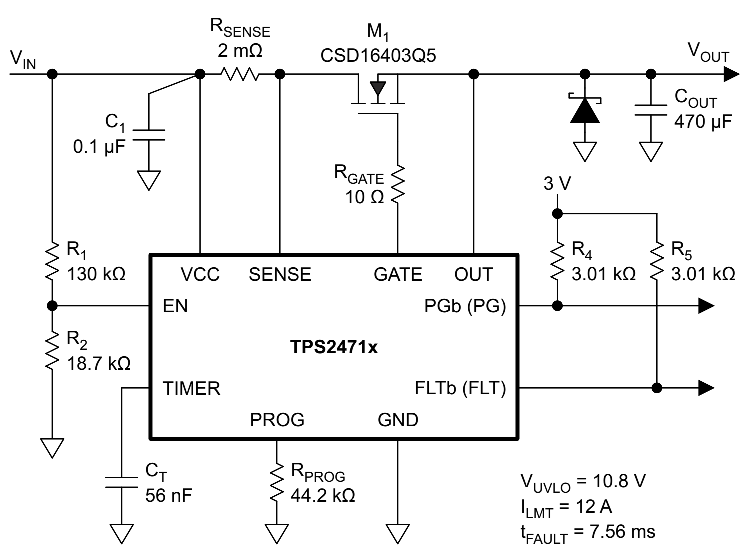

Figure 3-1. TPS2471x Application Circuit for Start up with Constant Power Dissipation in Power Switch

Figure 3-2 shows start-up with capacitance of 1 mF and VIN of 12 V. The inrush current is at its lowest value initially but increases as the drop across the power switch reduces with charging of output capacitor. These devices can provide clean start-up with higher output capacitance and higher input voltage but these devices require external MOSFET to handle the power dissipation during start-up. External MOSFET needs more area on the board and leads to increased solution size.

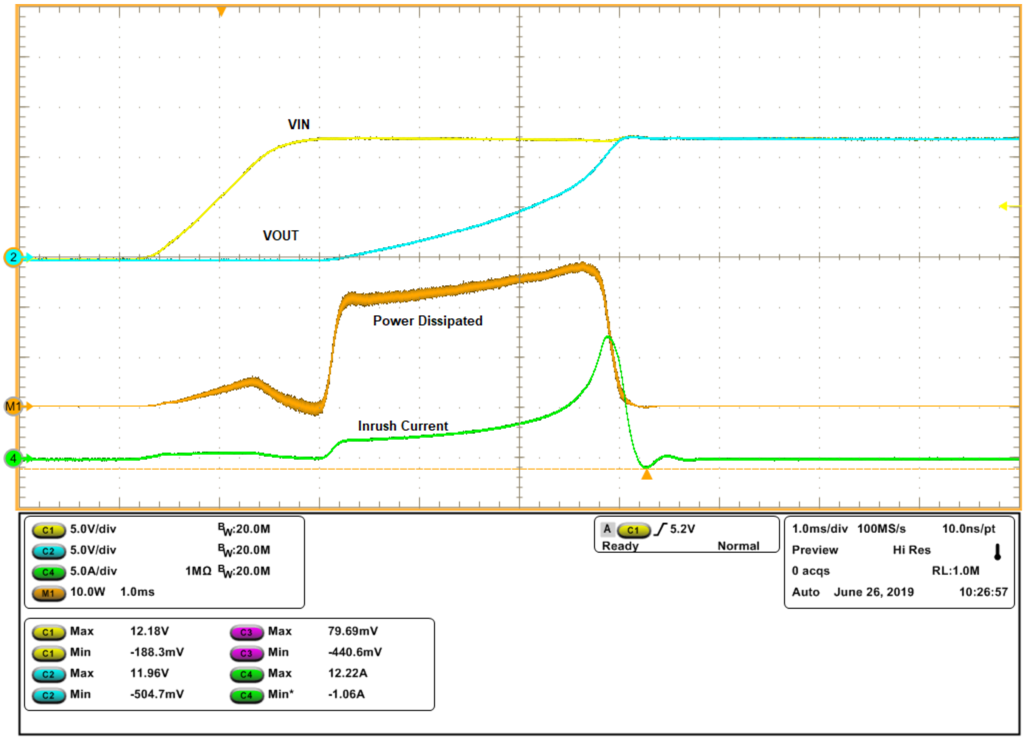

Figure 3-2. Clean Start-up with Constant Power Dissipation in Power Switch

With increased input voltage and load capacitance, the power dissipation in the power switch can go beyond SOA limits of the power switch and can lead to hiccups in start-up. Figure 3-3 shows the hiccup in start-up with the TPS24710 device for V_{IN} of 15 V and C_{OUT} of 2.2 mF. The device tries to charge load capacitance up to a time of 8 ms and output reaches up to 7.5 V.

See *TPS24710 Design Calculator* to design with the TPS24710 device.

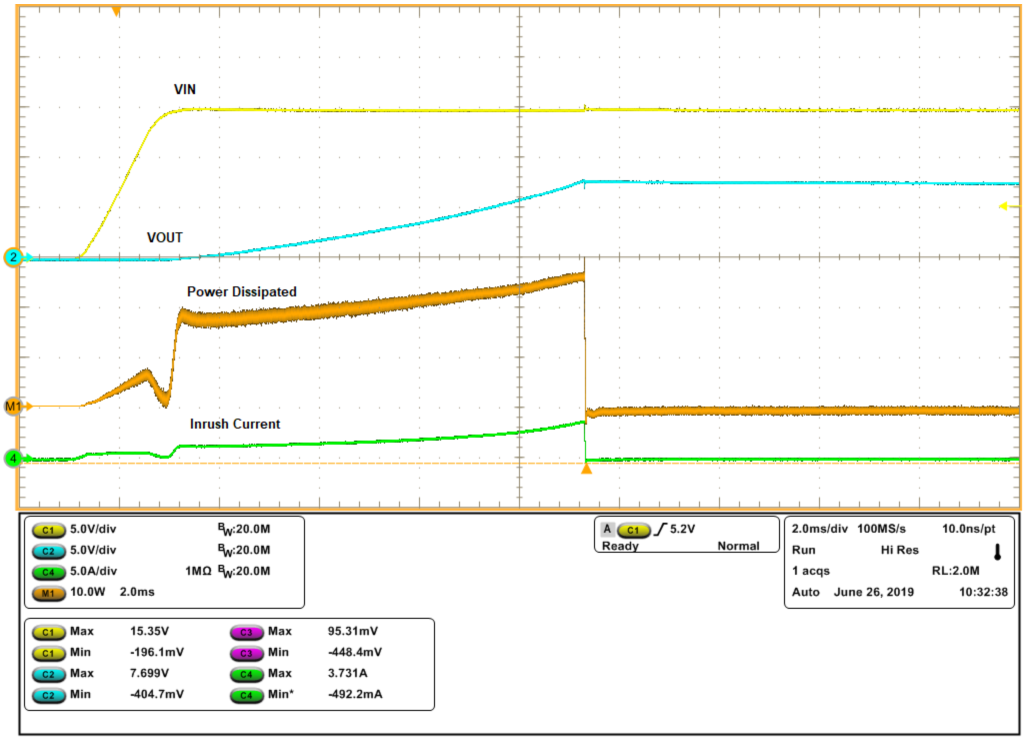

Figure 3-3. Hiccup in Start-up with Constant Power Dissipation in Power Switch

4 Powering Capacitive Loads with Thermal Regulation at Start up

To power large capacitive loads without hiccups, a thermal regulation is required at start-up to prevent the shutdown of the power switch. With thermal regulation at start-up, the power switch regulates the junction temperature less than the thermal shutdown temperature and allows clean start-up with large capacitive loads. The TPS2663 and TPS1663 devices include the thermal regulation at start-up to provide clean start-up with large capacitive loads. Figure 4-1 shows the application circuit with the TPS2663x device.

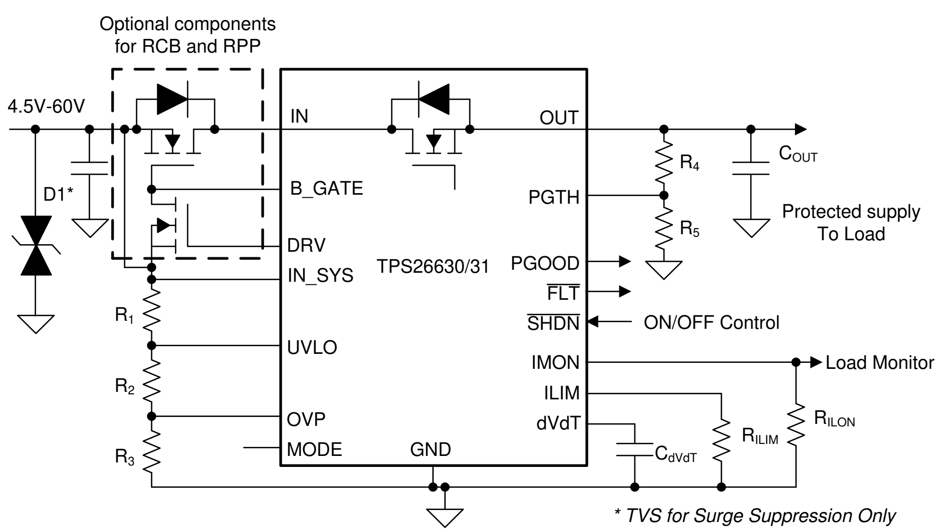

Figure 4-1. TPS2663x Application Circuit

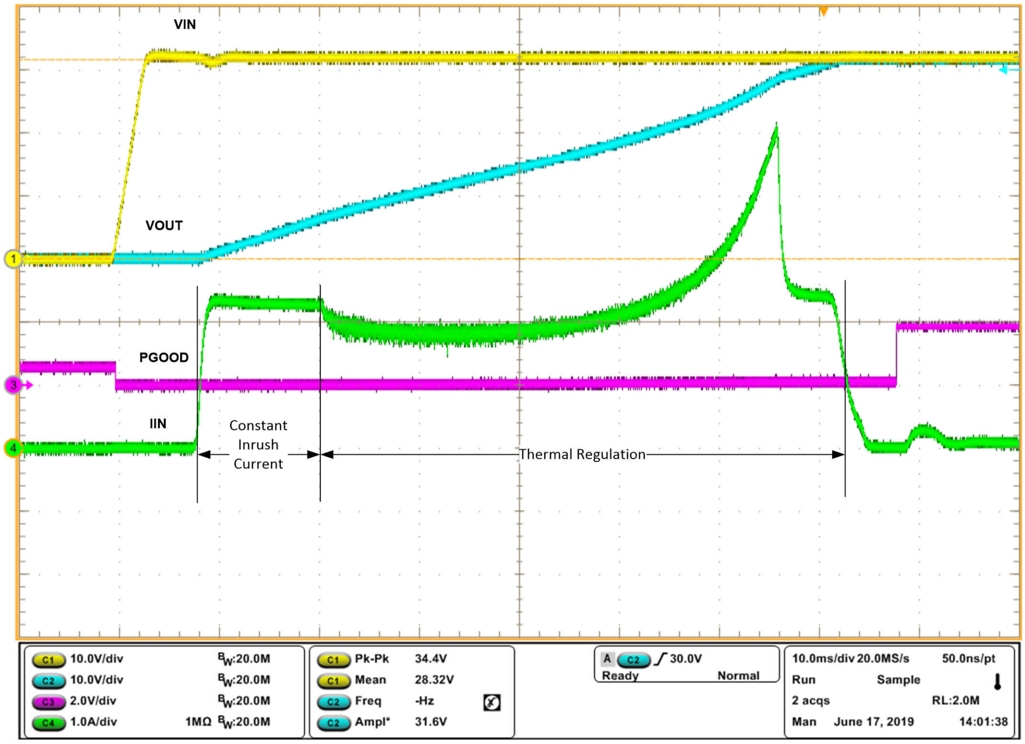

Figure 4-2. Clean Start-up with Thermal Regulation with C_{OUT} = 4.7 mF

Figure 4-2 shows the clean start-up with 4.7-mF capacitive load for V_{IN} of 32 V. The device starts with constant inrush current and then goes into thermal regulation to prevent thermal shutdown and powers up in 65 ms. Without thermal regulation, the start-up time increases even in the order of minutes for charging large capacitive loads. In case of unknown capacitive loads, it becomes difficult to select the appropriate value of inrush current and slew rate for charging output capacitors. With thermal regulation, the designers can achieve fast and reliable startup without selecting the appropriate value of inrush current and output slew rate.
With higher capacitive load, the power switch heats up even faster and thermal regulation is initiated earlier. Figure 4-3 illustrates clean start-up with a capacitive load of 20 mF and V_{IN} of 32 V.

See *TPS2663 Design Calculator* to design with the TPS2663 and TPS1663 devices.

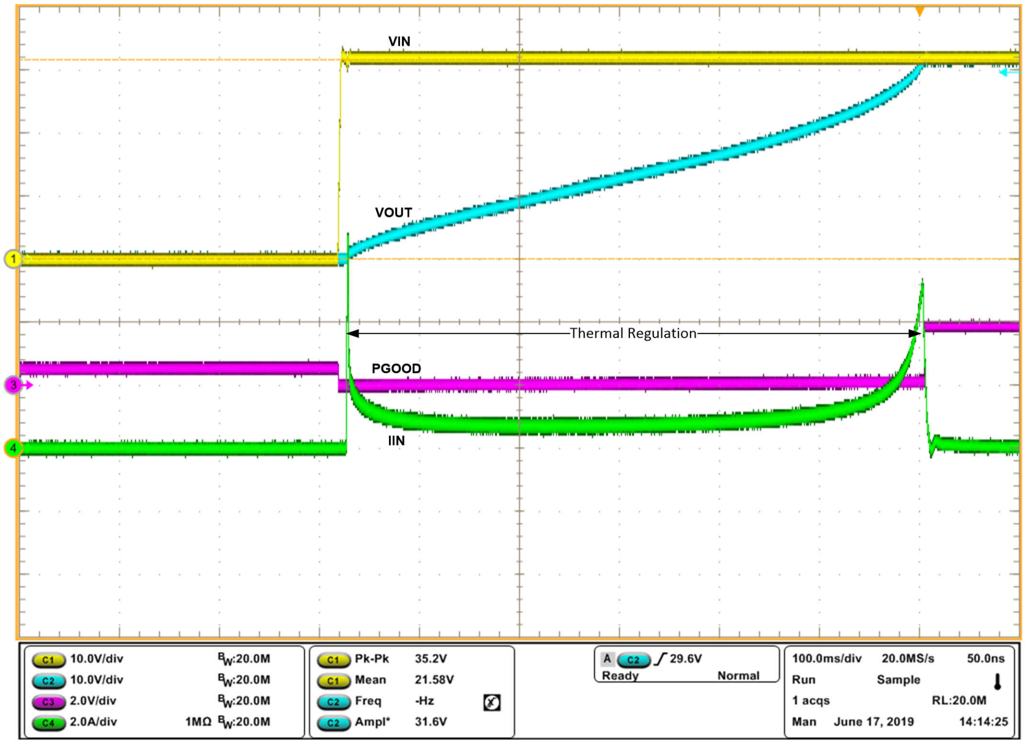

Figure 4-3. Clean Start-up with C_{OUT} of 20 mF

Table 4-1 lists the charging time with different capacitive loads and ambient temperatures for the TPS2663 and TPS1663 devices.

Table 4-1. Charging Time and Capacitance with Temperature

		TEMPERATURE			
VIN		–40°C	0°C	25°C	105°C
4.5 V	Charging time	20.5 ms	19.9 ms	20.9 ms	21 ms
	Capacitance value	32 mF	32 mF	32 mF	32 mF
18 V	Charging time	287.9 ms	312.2 ms	408 ms	1390 ms
	Capacitance value	32 mF	32 mF	32 mF	32 mF
32 V	Charging time	1625 ms	1757 ms	2144 ms	2622 ms
	Capacitance value	32 mF	32 mF	32 mF	16 mF

5 Conclusion

Powering large capacitive loads through constant inrush current can lead to hiccups in start-up due to thermal shutdown whereas powering large capacitive load with constant power dissipation in power switch need an external MOSFET to withstand the power dissipation during start-up. The TPS2663 and TPS1663 devices with integrated thermal regulation and MOSFET provide an optimized solution for achieving fast and reliable start-up with large and unknown capacitive loads.

6 References

- Texas Instruments, *Compact, Efficient, 24-V Input Auxiliary Power Supply Reference Design for Servo Drives*
- Texas Instruments, *TPS2663 Design Calculator*
- Texas Instruments, *TPS26600 Design Calculator*
- Texas Instruments, *TPS24710 Design Calculator*

7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (May 2019) to Revision A (February 2022)	Page
• Updated title from *Reliable Startup with Large and Unknown Capactive Loads* to *Reliable Startup with Large and Unknown Capacitive Loads*	1

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