APPLICATIONS GUIDELINES FOR GLUE POWER WHEN USING MULTIPLE, DC/DC CONVERTER MODULES

Bert Ashdown, Predrag Ostojic and Tony Scott,

Astec Power
495 March Road
Ottawa, Ontario,
CANADA, K1Y 4H7

bert.ashdown@astecaps.com; predrag.ostojic@astecaps.com; tony.scott@astecaps.com

1. INTRODUCTION

This paper proposes a systematic and practical approach to the problem of coordinating the many voltage rails at high power required by modern communications Printed Circuit Packs (PCPs) when using multiple DC/DC Power Converters.

It is not enough to select single or dual output DC/DC Converters to convert from a nominal input (such as –60Vdc, -48Vdc or +24Vdc) to each desired voltage rail, because each power converter will have its own characteristics. In such circumstances, additional circuitry is required to ensure that the multiple, dc-dc converters operate in unison and in compliance with the demands of the circuits that they are powering (ASIC's, etc.). In other words, extra control circuits must be added to bring all the converters into a single, coordinated, On-board Power System (OPS).

As an example of the need to do this, consider that a converter from one manufacturer may shut down when its input voltage reaches –36V and one from another manufacturer may shut down at -35V. If no coordination is provided, the result may be to potentially leave ASICs and other integrated circuits with insufficient voltage rails when the battery voltage is falling, leading perhaps to costly damage. For the example cited, some circuitry needs to be added to ensure that when the dc input falls to a pre-determined point above all the converters' shut down voltages, they **all** turn off together, thus avoiding potential accidental damage.

The function of the additional circuitry is to 'bind' disparate dc-dc converters into a cohesive power system. The circuitry that provides this 'binding' is called "Glue Power" in this paper in that it describes the 'overhead' that is required to ensure that the overall power supply circuitry is firmly integrated with the circuit that it is powering.

Section 2 provides an overview of the elements of the on-board power system while Section 3 goes into the technicalities of each element. It includes advice on what to look for when determining the design criteria, selecting the converters, the design of the required Glue Power control sub-system, power feeding, protection and EMI filtering. Section 4 provides some general guidelines that we have found to be useful in designing the OPS. Section 5 concludes and summarizes the paper.

1.1 Definitions

In this paper, 'Primary' refers to the input dc side of the power system and 'Secondary' to the low voltage output. Top and Bottom will refer to the sides of the printed circuit board (PCB). DC/DC Converters in this context, are off-the-shelf modules that convert power from one dc voltage to another lower one (for example, -48Vdc to +1.8Vdc). They may have isolation between the input and output voltages, or they may not.

2. OPS OVERVIEW

The basic elements of a complete, on-board power system are shown in Figure 1.

2.1 Input Power Feed Block

Because the OPS fits into a PCP, input dc power will usually be brought onto the PCP via a backplane connector or equivalent; this is shown at the left side of Figure 1. The input power feed will most likely be two independent dc rails, each of which must be protected against noise and transients and then ORed together to form a common input power dc rail. The OR function may apply to just the GO ('hot') bus or to both the GO and RETURN busses.

2.2 Primary Side block

This refers to all the control functions needed on the Primary side. This will typically include an inrush current limiter, a low input shut-down circuit, hot swap circuits and EMI filters.

2.3 DC/DC Converter block

This block typically contains all the converters necessary for the PCP on-board electronics to operate. The converters may be all from one manufacturer or from several sources. They may have I/O isolation, be non-isolated or may be a mix of both technologies (for example; a main dc-dc converter device that has I/O isolation followed by several non-isolated devices). Additional filtering capacitors and inductors may be needed as may trim resistors. Note that the manufacturers' application notes and Field Application Engineers can be a valuable source of information.

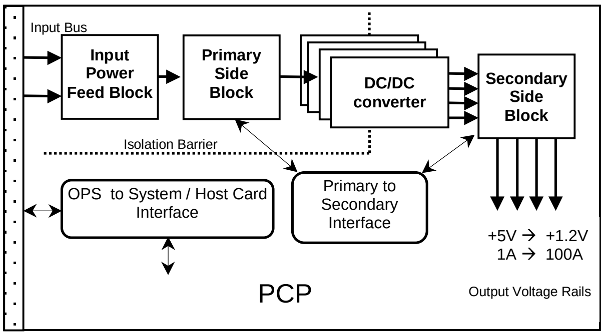

Figure 1: On-Board Power System (OPS)

2.4 Secondary Side Block

It is often necessary in expensive, high reliability communications equipment, to monitor the output voltages so that any converter fault resulting in an out of tolerance voltage turns all the converters off immediately, thus preventing damage to sensitive on board modules. Accordingly, the Secondary Side block may contain over voltage and under voltage detection for each voltage rail. It may also include sequencing FETs with gate control to ensure any desired start up and shut down sequencing can be achieved. Also, because shut down sequencing depends somewhat on load and stored energy, crow bar circuits may be necessary. It should be noted that sequencing depends very much on the ASICs being used in the PCP, and may change during a project if the ASIC manufacturer is changed.

2.5 OPS – System / Host Card Interface

Alarms may have to be generated by the OPS if desired by the customer. For example, if one of the dual dc input feeds is interrupted, it can be useful to detect this in the OPS and report it to the Host system controller. Also, if the OPS is forced to shut down for any reason, the PCP becomes useless to the Host system and should be replaced, and so an alarm indicating this to the central control facility may be useful. In any case, whenever alarms are required, they must interface correctly with the customer's alarm sub-system.

3. OPS DESIGN CRITERIA

Each of the OPS blocks identified in Figure 1 and Section 2 and the associated design constraints encountered in creating them, will be discussed in this section.

3.1 Input Power Feed Block

When creating the Input Power Feed Block (Figure 2), several important goals must be accomplished:

- maximize input power availability
- input overload/short-circuit protection
- reverse voltage protection
- EMI filtering and transient voltage suppression
- safety standard requirements

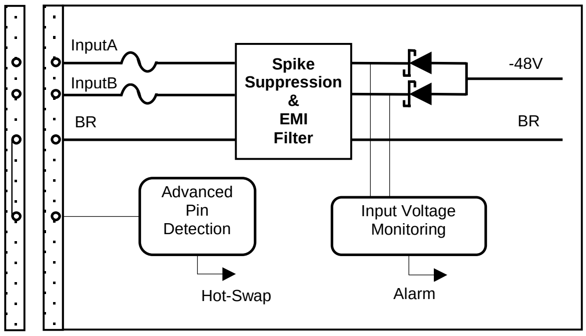

Figure 2: Input Power Feed Block

If high system availability is required, then two input feed lines, preferably supplied from two independent battery sets, are necessary. Each of the input lines has to have its own fuse and filter on the host PCP card. A common input voltage rail for the converter modules is diode-ORed from the redundant input feed lines. For typical input currents ranging from 1A to 5A, off-the-shelf high-voltage (HV) power Schottky diodes are available for the ORing function.

Ideally, the card power connector should be carefully positioned away from high-speed logic signals and have minimum track length between the connector and the OPS. However, the tracking and routing are often dictated by card component placement and the physical path between power connector and converters might be long and densely covered with digital circuits. In such circumstances a good layout design is critical. Some of the things to consider would be:

the number of layers and copper thickness, track shape & width, tracks' impedance balance and primary to secondary isolation (typically requiring 0.055 inches/1.4 mm spacing between Primary and Secondary tracks).

Besides power pins, there may be a need for a signal advanced pin. The role of this pin is to avoid connector deterioration resulting from arcing during card hot-extraction. It may also help prevent latching and possible damage to the digital circuitry by establishing a reference to the circuitry before power is applied to the OPS and the converter start-up sequences are initiated.

Ferrite beads placed close to the power connector help to protect the PCP against HV spikes (e.g. resulting from breaker or fuse operation or other power system disturbances). A capacitive EMI filter is a two-way device designed to suppress high-frequency noise injected from the input power bus lines as well as pick-up noise from long PCB tracks and switching noise from the converter modules.

To improve system fault-tracking capability, a monitoring circuit for each power input line may be required to detect interruption of an input feed and reporting of this event to the Host system controller.

3.2 Primary Side Block

The major design features that this glue power building block provide are:

- low input voltage shut-down control (LISD)
- input current inrush limiting and hot-swap
- input over-voltage (OV) protection
- over-temperature shutdown

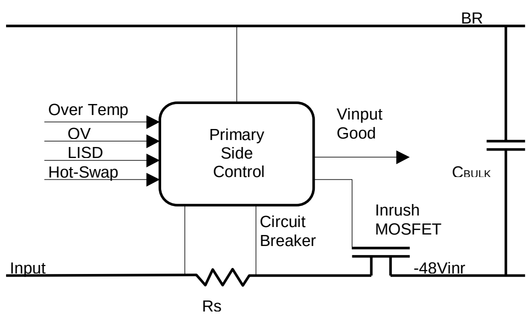

Figure 3: Primary Side Block

Selection of the inrush power MOSFET switch is a trade-off between low dissipation and HV transient protection. The usual OV trip point is set to 80V. A power MOSFET rated for 150V enables a good OV protection margin, while maintaining low dissipation.

C_{BULK} represents equivalent input capacitance of the multiple converter modules and their associated input filters. In the event of a primary side fault, the energy stored in C_{BULK} will provide hold-up time of approximately 1ms. This may have to be increased as necessary to ensure that any software backup, triggered by the event, has sufficient time to complete its task.

The primary side control block can be easily constructed by using discrete and analog logic components, and this may be advantageous if space is available and component "second sourcing" is one of the design goals. However, as an alternative, state-of-the-art IC hot swap or negative voltage controllers (monitors) have some of the required system features and may be used. To create a primary side control block that can be easily applied ("glued") on all system cards, a mixed IC and discrete solution appears to be a good design compromise.

When designing the primary side control block, attention should be paid to the following points:

- "action if fault" strategy (latch-off or hiccup)
- controller HV transient sensitivity and protection
- LISD trip level, recovery level and hysteresis
- OV and OC trip levels and sensitivity
- programmable trip levels and delays

3.3 DC/DC conversion block

Selection of DC/DC converters is an important design step in developing/designing the OPS. Mechanical, thermal and electrical constraints, which play a major role in determining the final choice of converter modules, are:

- PCP power/board space requirements vs. power density of commercial DC/DC converters
- PCP card top and bottom clearances and component height restrictions
- ambient temperature and available cooling
- open frame converters versus closed frame
- standardized footprint versus unique footprint
- the number of output levels
- load dynamics and load noise sensitivity
- primary to secondary isolation (safety)
- MTBF

A typical DC/DC conversion building block is shown in Figure 4.

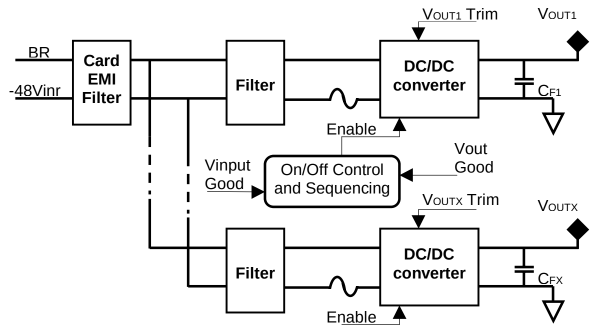

Figure 4: DC/DC Conversion Block

Commercial DC/DC converters have power densities in the range from 1W to over 10W per cm^3. Their nominal output characteristics are usually given at 20°C and at good cooling conditions (e.g. 3m/s cooling air rate). However, for many applications, the expected working (or worst-case) conditions are in the 60°C - 80°C range and with reduced cooling airflow (densely packed cards). Usually, output power derates rapidly at higher temperatures so the manufacturer's data sheet must be consulted to determine if the chosen converter will still be able to serve the PCP electronics at elevated temperatures and de-rated performance. In the extreme, a sample thermal test may be needed to prove advertised characteristics of the device, particularly if it is new to the market.
There are several converter packages, from different producers, which have the same or similar footprint (e.g. 1/4Brick, 1/2Brick, etc.). Standardized footprint converters are obviously the preferred choice, more so when component second-sourcing is a design goal. Open frame converters bring good performances at higher temperature and severe ambient conditions. Closed-frame converters also can perform well if there is sufficient room or cooling conditions on the PCP.

Power supply loads are usually resistive with several hundred µF of decoupling capacitance. If the current transients are expected to be high (1A/µs and over), load currents of several tens of Amperes could cause spikes and unacceptable ringing. Therefore, a reduced parasitic trace inductance and converter placement close to the high current loads are important design goals.

Converters are negative impedance devices and an input filter is needed to compensate the converter module characteristic. Also an input fuse is required per converter by safety agencies.

Multiple switching frequencies from multiple converter modules produce a broad noise spectrum which is reflected to the input power lines. In such cases an enhanced EMI filter is needed as well as good layout design. The EMI filter has to be placed as close as possible to the common input of the converters.

On/Off logic and sequencing circuits can be made by using either discrete and analog logic parts or by using dedicated IC controllers. When designing this glue power building block, some of the following questions have to be resolved:

- action if fault strategy (latch-off or hiccup)
- response time on fault detection
- converter shutdown/enable response time
- sequencing order and sequencing delays
- converters' turn-on delays and output response
- required power-down sequence

Primary side On/Off control and sequencing will be further discussed in section 3.6.

3.4 Secondary side block

Commercial DC/DC converters often have output under/over-voltage protection and output current limiting protection. However, these protection circuits are usually not accessible/adjustable and, if some overall coordination is required for the total OPS, then the need for an independent monitoring and protection circuit exists. Figure 5 illustrates the elements that will usually be necessary for this function. Output voltage protection threshold levels have to be adjustable or programmable to meet host card protection requirements.

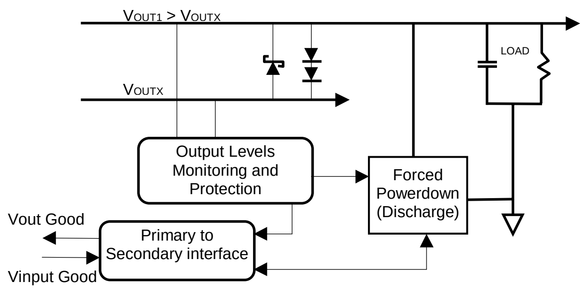

Figure 5: Secondary Side Glue Logic Block

For sensitive digital circuits a power-up and/or power down sequence is often required. Diode clamping to control the voltage difference between outputs is a common solution. However, this simple solution may not cover all power-up/power-down situations especially where high load current and capacitance are involved. In such cases a forced shutdown discharge circuit may be helpful (typically a standard crowbar or power MOSFET short-circuit switch). Several outputs can be discharged through power Schottky diodes using the same Forced shutdown.

Monitoring and protection of output voltage levels usually includes over-voltage, under-voltage and over-current sensing and alarm generating. Additionally, the monitoring and alarm outputs can be used to generate Reset or Interrupt Request signals for the host card digital circuits which normally need an external voltage Monitor/Reset circuit.

Alarm signals, divided hierarchically, are ORed into a few main alarm outputs. If a fault happens, the secondary side control logic generates a Reset pulse and passes an alarm signal to the primary side controller. For example, an OV fault triggers the power-down sequence and initiates turn-off of the OPS.

Secondary side control logic is more complex than the primary side logic. Multiple output voltage levels have to be monitored and controlled. This control circuit has to be the first one to be active on the secondary side during the power-up sequence. In cases where negative voltage levels or very low positive levels (1.2V→ 2.5V) come first, a charge pump is needed to power-up protection circuitry.

3.5 Power Module Status Interface

OPS alarm and status signals may be transferred to the host card digital circuitry through a direct (secondary side) or through an opto-isolated (primary side) interface. For more demanding applications, additional control and monitoring of the OPS is needed. In such cases the interface may transfer alarms, status signals, control signals, measured values (voltage, current, temperature). To fulfil this function, the OPS may have to include a serial or parallel communication device/ link.

Additionally, in some hierarchically organized communication systems, a master card may require more status information or control over system slave cards. For example slave card power supply On/Off control when the system crosses an over-temperature limit.

3.6 Primary vs. Secondary side On/Off control and sequencing

As has already been highlighted, systems with multiple DC/DC converter modules will usually require specific power-up and power-down control of the individual output voltage levels. However, converter modules from different manufacturers and their characteristics (such as start-up delay, reset delay, output voltage response etc.) will vary from one manufacturer to another. For example, start-up delay may be anywhere in the range from 1ms to 300ms. Even converters from the same manufacturer and within the same family will not perform exactly the same way.

In the preceding sections the primary side On/Off control and sequencing circuit was described (Fig. 4, 5). This type of control is used when it is desired to modify the inherent characteristics of the converter modules by controlling the way and sequence in which the converters are started up. The control circuits must be “synchronized” with the converter modules and “flexible” enough to accommodate possible requirement changes (sequence order, sequence delay, etc.) and even converter type change at some time in the development or during production. It also relies on some control of the converter outputs by techniques such as combining power diodes that may not be as precise as possible in addressing start-up and sequencing behavior demanded by the electronic circuits.

An alternative solution to the primary approach is to incorporate the desired On/Off control and sequencing circuitry into the secondary side control circuitry (Fig 6).

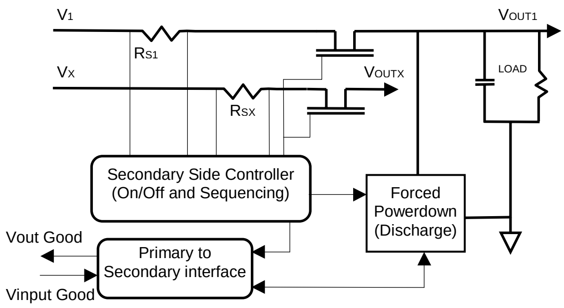

Figure 6: Secondary Side On/Off Control and Sequencing

This control approach does not depend on inherent features of the DC/DC converter modules but seeks to control the application of the outputs to the electronics after they have been established. Output voltage start-up ramps, seen by loads, are controlled and can be easily adjusted. However, high load capacitance may impact certain power-down transitions. In such cases a forced power down circuit is needed.

Power MOSFET switches and resistor shunts are placed in series with loads and replace the function of diodes (Fig. 6). MOSFET switches are constantly on and therefore, increase the internal power dissipation of of the OPS, especially at high output currents. Fortunately, low voltage/low R_{DSon} (5mΩ and below) power MOSFET-s are now available “Off-the-shelf” and allow high current control at low power dissipation.

Secondary side On/Off control and sequencing demands more sophisticated control circuitry. This demand may be offset by using dedicated IC’s or universal micro-controller units (MCU). The On/Off control and sequencing can be combined with output level monitoring and protection circuitry. The same controller might also serve to provide an interface to the host or system card (see 3.5).
In summary, the main advantages and disadvantages of both design approaches are:

Primary side On/Off and sequencing control:

- design depends on DC/DC module features
- control circuitry on primary side (-75Vmax)
- non-accurate diode control of voltage levels
- no additional resistance in series with load
- simple analog control circuit

Secondary side On/Off and sequencing control:

- design independent of DC/DC module features
- control circuitry on low voltage side
- accurate digitally controlled voltage levels
- additional resistance in series with load
- digital control circuit (IC or MCU) with a large number of additional monitor/control features

4. GENERAL GUIDELINES

A series of check lists have been developed to ensure that as many aspects as possible that may affect the design of the OPS are reviewed. They are general guidelines that can be applied to almost any application.

Spend sufficient time at the start of the project in assessing the overall requirements of each element of the OPS and then capture them in a detailed Product Specification that will serve as the ‘contract’ for the required design.

It is difficult to write a Product Specification without knowing all the technical background around the design; any piece of information may turn out to be important. Note that it is also important to become and stay familiar with the system design as it evolves, so that the impact of change on the OPS (or vice versa) can readily be assessed.

4.1 General Requirements

Questions which are beneficial to establishing the overall OPS environment are:

- How much PCP area is allocated for the OPS?
- What are the height restrictions for components on the PCP?
- What is the maximum operating temperature and what is the air flow around the OPS?
- How much heat can the OPS be allowed to dissipate?
- What is the expected input voltage range?
- Should all the DC/DC Converters be latched off when shutting down?
- What is the required overall OPS efficiency?
- Are second sources required for the OPS components
- Will the OPS be generally all together in a compact layout or spread about the PCP or spread over multiple PCP’s?

4.2 Primary Side Technical Information

Become familiar with all the regulatory standards that may apply. The customer will usually appreciate circuits that are very small, without heat sinks, if possible, and “guaranteed” to pass the final safety and EMI testing.

Check and determine:

- How many PCPs will operate at the same time?
- Do the ORing diodes need heat sinks and is it necessary to use them in the Battery Return?
- Does any Inrush FET need heat sinking?
- Is the OPS input fuse value correctly set with margin for temperature?
- Are filter capacitors correctly rated for voltage?
- Are input ferrite beads correctly rated for current?
- Is there a correctly rated fuse at the input of each DC/DC Converter?
- Is the connector rating and pin isolation correctly specified?
- Is there a need for advanced pin(s)?
- Are the low input shutdown circuits coordinated?

4.3 Secondary Side Technical Information

The Secondary side is the “working side”; about which the customer may have the least information. Don’t lose contact with the PCP design team - keep them up to date on choices, consequences and risks. Circuit design and layout can be fairly straight forward, until the sequencing has to be changed.

Useful information to know is:

- What are the output rail voltages and currents?
- What are the expected load changes, rapidity and slew-rate of the changes?
- Are the over and under-voltage shut-down circuits coordinated with the loads and the DC/DC Converters' expected output tolerances?
- How much output capacitance will be present?
- What is the required start-up sequencing of the output rails?
- What is the required shutdown sequencing of the output rails?
- How much voltage drop can be tolerated between the DC/DC converters and the loads?

4.4 DC/DC Converters Technical Information

The heart of the system. Make sure you choose devices from a manufacturer that can deliver what you need when you need it; who has detailed technical information on all aspects of the product, and who is willing to share such information. Check out the company size and facilities if they are not known to you. Don't use 'typical' data sheet performance figures, use 'worst case'; confirm thermal operation by actual measurement if necessary.

It's important that you address:

- Does the specified output regulation, ripple and noise match the load requirements?
- Is there sufficient input stability capacitance?
- Is the output voltage change versus sudden load change acceptable?
- Is there sufficient power available at the specified temperature and air flow? Are heat sinks needed?
- Is a trim resistor needed?
- Will the sense PCP traces need to be terminated at a connector to another board?
- How long do the Converters take to start up from time of input application or enabling?
- What are the maximum low shutdown voltages and will they be coordinated through the OPS?
- What are the minimum, high shutdown voltages and will they be coordinated through the OPS?
- What is MTBF forecast for the DC/DC Converters under operational conditions?
- Are second sources available for the selected Converters?

4.5 Primary to Secondary Interface

The key is to maintain the required isolation, across DC/DC Converters and on every layer of the board(s). Opto-couplers are inexpensive devices and reliable enough if used so that they meet the requirements under all conditions including aging.

- What are the Isolation requirements based on regulatory standards?
- How many links across the interface are needed?

4.6 OPS to System Interface

Don't forget that there may be a need for an interface and to determine the extent of the requirements:

- What alarms are required from the OPS?
- What is the required interface? (e.g. TTL logic? Digital serial or parallel link? etc.)
- Are input detection circuits required?

4.7 Layout

This is of course, critical to the success of the design and will usually require that the OPS designer will spend much time in design and review because the layout designer may not be experienced in analog and power circuit design. Try to have all the OPS together in one area to simplify layout design and review.

- Is sufficient spacing maintained between Primary and Secondary components and traces on the PCP boards? (0.055 inches/1.4 mm on outer layers and 0.020 inches/0.5 mm inner)
- What is the copper weight on each layer? Is it sufficient for the maximum current on the traces?
- Do high current traces appear as planes on more than one layer?
- Do any high current traces have constrictions that will compromise the ampacity?
- If a trace has many vias passing through it causing holes, is the remaining copper sufficient for the required ampacity?
- Are there long signal traces and have they been properly decoupled?
- Are long secondary traces running close to or under the DC/DC Converters and/or near input power traces?
- If current carrying traces appear on multiple planes, are there sufficient vias for the current transfer?

5. CONCLUSIONS

In this paper we have attempted to share our experience in Glue Power design which has been obtained over the course of many communications systems projects.

The key is that unlike designs using a single DC/DC Converter module, the use of multiple converters, coupled with the operational requirements of modern communications ASICs, requires a total system approach. This system approach will increase the probability of success, both for the OPS designers and the communication customer.

The importance of the OPS Product Specification, which is basically the agreement between OPS provider and customer as to what is to be built, cannot be over emphasized.

System descriptions of, and the need for, Glue Power have been presented. Each system block has been described in some detail, and check lists are given that will hopefully be helpful in ensuring that “nothing falls though the cracks”.

Finally, a paper such as this cannot supply answers to all the problems and the different circumstances that can arise, but it is hoped it is a sound basis which can be built on by those with OPS experience and will help those new to the discipline to avoid pitfalls.