Understanding Regulation Modes: Constant Voltage (CV), Constant Current (CC), Constant Power (CP) and Constant Resistance (CR)

Introduction. Power supplies can be used in many different fields in real-world applications and a wide variety of behaviours are requested depending on the specific task that needs to be performed. This application note is focused on giving a power supply user a brief overview on the possible scenarios related to the power converters depending on needs and requirements.

A very important first distinction has to be made on the dynamic requirements of the considered application: in principle, all requirements can be classified as for DC (Direct Current) sources or for AC (Alternate Current) sources. Additional distinctions apply - e.g. DC pulsed sources or other types - but this topic will not be covered on this application note. Besides these dynamic requirements of the power supply, a very important distinction has to be made on the type of regulation that should be performed on the power supply output.

Most of the applications require the power supply to work either in **Constant Voltage** (**CV**) mode, where the output voltage needs to be kept at a chosen value, or in **Constant Current** (**CC**) mode, where the value to be kept stable is referring to the output current. In some specific application the requested value to be regulated is depending to a value which is related to both voltage and current: this could be, for example, the output power or the equivalent output resistance, thus requesting the **Constant Power** (**CP**) mode or the **Constant Resistance** (**CR**) one.

Regulation Modes. Taking a closer look at the previously listed regulation modes, the schematic representation of each one of them on the V-I plane can be represented as shown in **Figure 1**.

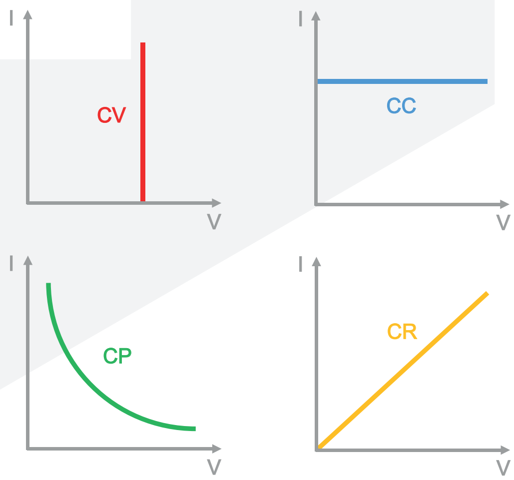

Figure 1: *CV, CC, CP and CR regulation modes*

The **CV** mode is the most common regulation scheme for power supplies and it is often called also *fixed-voltage* mode. The majority of the consumer AC/DC adapters have a CV control scheme at its output so that the output voltage is kept constant: the power supply adapts its output current based on the connected load values. Some other applications require the mirrored situation (**CC**) where the output voltage is adapted in order to maintain the output current at a stable value.

In typical but more uncommon situations, the required value that needs to be held stable by the power supply is the output power (**CP**) or the equivalent output resistance (**CR**).

A mathematical representation of these regulation schemes can be summarized in formulas **(1)** to **(4)**. In these equations *Vo(t)*, *Io(t)*, *Po(t)* and *Ro(t)* are the output voltage, current, power and resistance respectively and *K* is an arbitrary constant (within the allowable range of the power supply). Depending on the model of power supply the behavior of the unit itself is more complex - e.g. a CV power supply usually moves to a CC mode when its maximum rated current is reached - so we will have a practical example of one of our high-performance programmable power supplies capable of running in all these four modes.

CV: $$V_O(t) = K \quad (1)$$

CC: $$I_O(t) = K \quad (2)$$

CP: $$P_O(t) = V_O(t) \cdot I_O(t) = K \quad (3)$$

CR: $$R_O(t) = \frac{V_O(t)}{I_O(t)} = K \quad (4)$$

Example. We will analyze the working principles of one power supply of the **FAST-Bi-1K5** series, in particular the 5040 model which has ratings of ±50 A, ±40 V and a maximum output power of 1.500 W.

The FAST-Bi-1K5 digital power supply (**Figure 3**) is a bipolar, bidirectional and regenerative power unit: this means that it is capable of working in all four (4) quadrants of the V-I plane. In other words, it can act both as a source and as a sink/load and when acting as a load it can put back the excess energy in the AC mains network with only a very small amount of dissipated power.

The operation in the V-I plane of the unit is shown in **Figure 2**. As it can be seen, the operation can take place at any point of the four quadrants of the V-I plane as long as it is within the vertical lines of Vo = 40 V and Vo = -40 V (CV), the horizontal lines of Io = 50 A and Io = -50 A (CC) and the curves of constant power Po = 1.500 W and Po = -1.500 W (CP). Two sample lines are shown

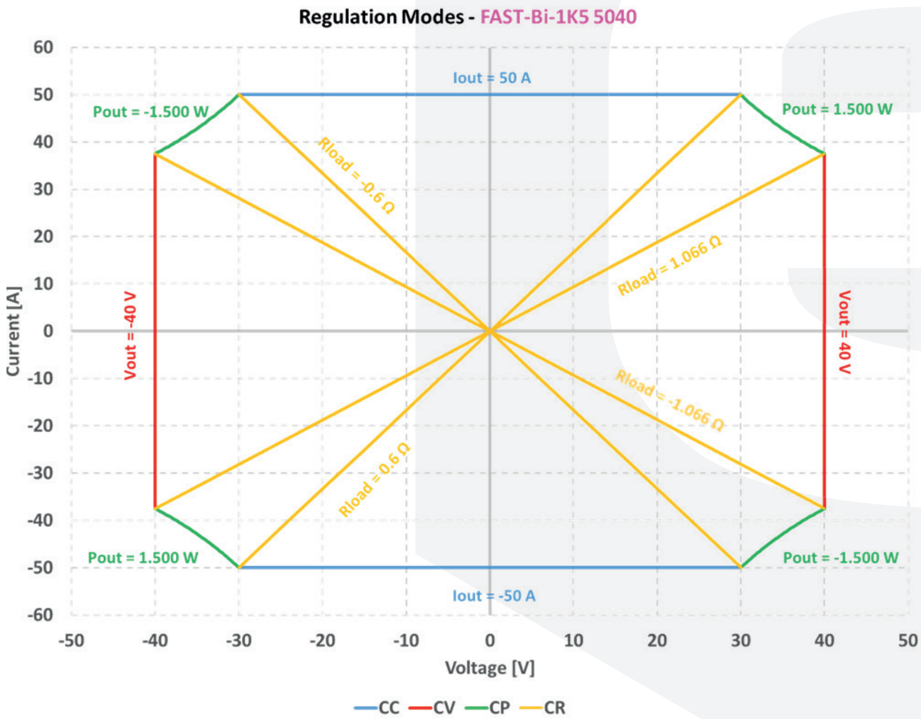

Figure 2: *V-I operation of the FAST-Bi-1K5 5040*

for the Constant Resistance (CR) mode of operation, respectively Ro = 0.6 Ω and Ro = 1.066 Ω (and the corresponding negative ones). The power supplies of the FAST-Bi-1K5 series run a digital control loop on an embedded System-on-Chip (SoC) that is configurable and adaptable to the specific connected load and application at the user's convenience. A list of very important applications that all need a different type of bipolar (or 2-quadrant) operation

Figure 3: *FAST-Bi-1K5 unit*

of the power supply are hereafter listed (and can be graphically seen in **Figure 4**):

- **battery** charging/discharging (Q1 and Q4);
- correcting **electromagnets** (Q1 and Q3);
- **superconducting** magnets (Q1 and Q2).

In **battery** testing it is necessary to work in the first quadrant (as a source) when charging the battery (+V, +I) while the fourth quadrant (as a sink) is needed in order to discharge it (+V, -I). Also, in these applications, most of the times, a different regualtion scheme needs to be applied (in the simplest case rechargeable batteries need to be charged using only CC and CV modes but many other models apply).

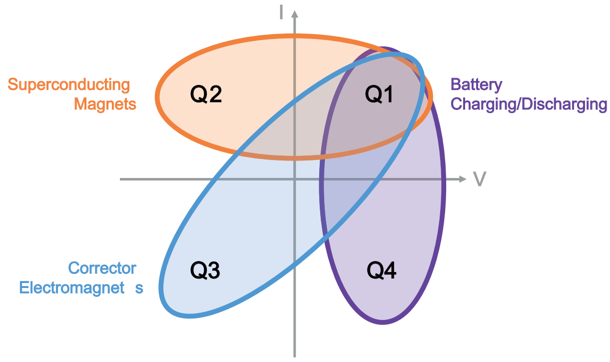

Figure 4: *Application examples requiring bipolar operation*

Power supplies for corrector **electromagnets** need to always work as a source (except for transients when they need to discharge the back-EMF from a largely inductive load) so that the first quadrant (+V, +I) is needed to generate a magnetic field while the third one (-V, -I) needs to be used to invert the field direction.

Superconducting magnets require the power converter to work in a third different bipolar way: they need to be charged operating in the first quadrant (+V, +I) but the huge amount of energy stored in the quasi-purely large magnetic load usually requires the power supply to invert its voltage polarity - i.e. second quadrant (-V, +I) - in order to discharge it. In some superconducting applications all four quadrants are needed.

Summary. Real-world applications are widely heterogenous and different devices may need to have a power supply with the right characteristics connected to them. The main regulation schemes are CV, CC, CP and CR and most of the programmable power supplies on the market can perform only one (or two) of these regulations. Additionally, these available power supplies have a fixed regulation loop (most of the times analog) that is designed to cover a wide range of loads but it is not optimized to a specific condition. The dynamic behavior of these units is thus strongly affected by the characteristics of the load and the application usually is not fulfilled at its best.

The FAST-Bi-1K5 can operate in **all regulation modes** and the control loop together with its parameters can be tuned considering the connected load and the desired performance. All this can be done with the same device.

Beside these aspects the regenerative architecture allows feeding back into the AC network the excess energy when the unit needs to act as a sink / electronic load: this reduces power dissipation, increases reliability and consequently minimizes operation costs.

Battery testing, active loads, superconducting magnets, electromagnets and many other applications may be all performed with the same hardware unit at the state-of-the-art level

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CAEN ELS s.r.l.
SS14 km 163.5 in Area Science Park
34149 - loc. Basovizza - Trieste (TS)
Italy

Registered Office:
via Vetraia 11
55049 - Viareggio (LU)
Italy

info@caenels.com
www.caenels.com

by only configuring the device for the specific need. An example of different Constant Power (CP) curves, corresponding to different power levels (source and sink) on a FAST-Bi-1K5 5040 can be seen in **Figure 5**.

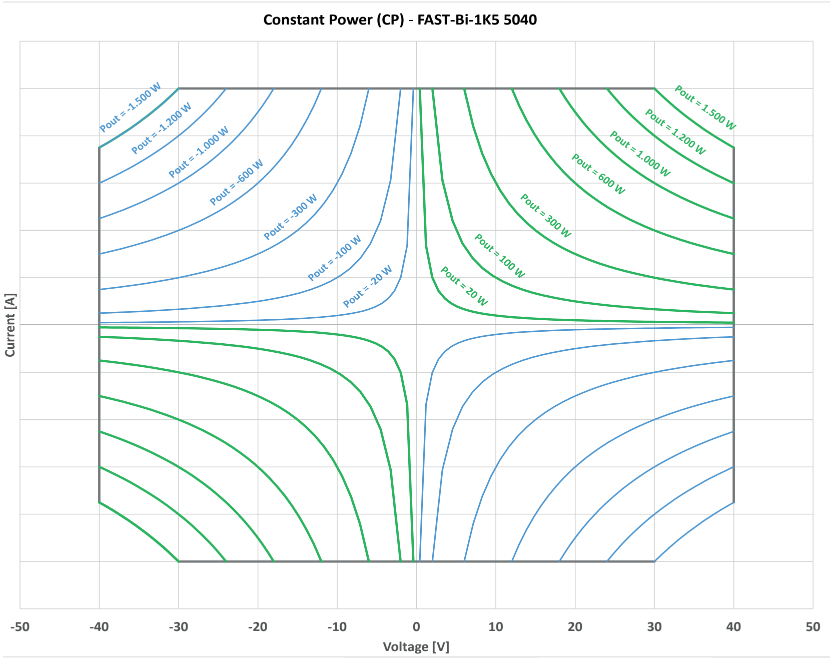

Figure 5: *Constant Power (CP) curves*

The previous curves clearly trace the paths that the power supply needs to follow - at different values - in order to reach the desired power setpoint when configured in the Constant Power (CP) regulation mode.

Conclusions. The embedded **Web-Server**, running on a Linux OS makes the FAST-Bi-1K5 easy to access and platform independent. The regulation parameters can be configured and set remotely for all the regulation modes, any waveform scheme can be reproduced with the embedded high-speed Arbitrary Waveform Generator (**AWG**) and the behavior of the current, voltage, power and equivalent resistance monitored directly on the embedded **4-channel oscilloscope** (with all curve tracing, triggering capabilities, and much more). Different ratings are available for our power supply series and, in this specific case, up to four units of the FAST-Bi-1K5 of identical output ratings can be paralleled to have higher equivalent power ratings. Different waveforms - e.g. custom-defined routines - as well as different regulation schemes can be directly configured by the user. A unique procedure for automatically find and set the best parameters for the specific application is also available for these units as an additional license (called **AUTO-TUNING**). Please check our website www.caenels.com for more information.

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