REGULATION SCHEME FOR PRECISION MAGNET POWER SUPPLY

Samit Bandyopadhyay, Manoranjan Das
Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata – 700064, India

Abstract

Accelerators require extremely precise high-current magnet power supplies to drive its magneto-optic devices for proper beam dynamics. The dc precision of the power supply, which generally defines the absolute tolerance of its current, can be split up into three distinct parts - ripple, short-term and long-term stability. To ensure that the output current is within an error-band of 10ppm or less, a three-loop regulation topology has been developed and implemented in a high current magnet power supply (750A/12V) that uses transistor bank as the series pass element.

INTRODUCTION

The component of the dc precision, which also defines the stability of the magnet power supply, is divided into three major parts- a. Long-term stability, b. Short-term stability and c. Output ripple. The major components /modules of the magnet power supply that needs to function simultaneously to meet its required stability components by taking necessary action in terms of power supply output is shown in Figure 1.

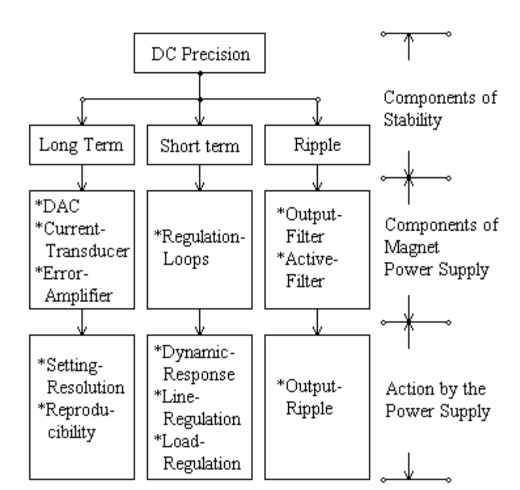

Figure 1: Components of stability of Magnet Power Supply

The factors that are responsible to affect the power supply stability are:

a. The input three-phase ac utility line, which may change in ramp or step.
b. The 12-pulse rectification of the ac signal gives an unregulated voltage, which contains an ac component of 600Hz and its harmonics.
c. Temperature, which affects semiconductor devices the most.
d. Load variation (Resistance of the load) with respect to temperature - a slow process.

REGULATION SCHEME

The implementations of close regulation highly stable low ripple magnet current require a special regulation scheme / topology [1]. The regulation scheme adopted for a high current 750A/12V, 10ppm magnet power supply using a series pass transistor bank is shown in Figure2.

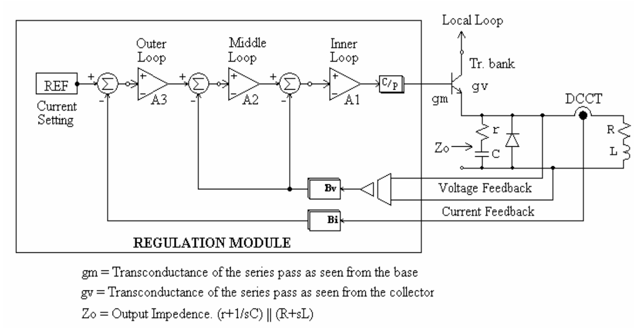

Figure 2: Regulation Scheme

The equivalent model of the designed regulation module along with the transfer function is shown in Figure 3.

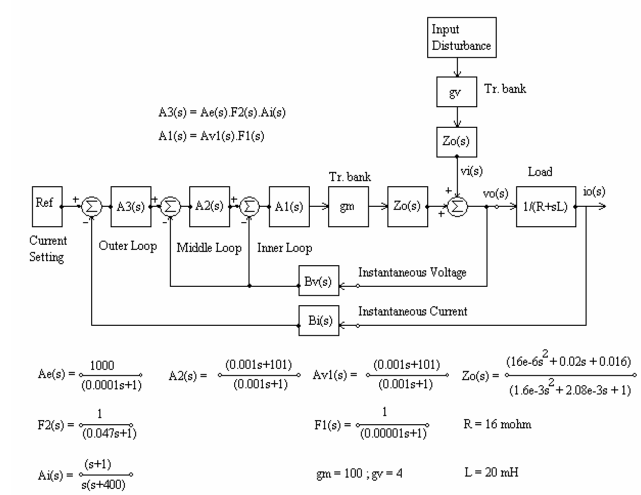

Figure 3 Equivalent model with transfer function

The underlying facts about this regulation topology are:

a. Precision low noise voltage reference source of very low drift and long-term stability for current setting.
b. Highly precise operational amplifiers with low offset voltage, exceptionally low TCV_{os}, high CMRR and PSRR used in the regulation module, increases the system accuracy over temperature.
c. Ultra-stable current sensor in the feedback loop. The current sensing for current regulation loop is done using DCCT [2] based on the zero flux principle. The

DCCT along with its associated electronics is made to give 10V output for primary current of 750A.

d. The regulation module consists of two fast inner voltage feedback loops ensuring short-term stability and an outer slow current loop for ppm stabilization that ensures the overall stability of the power supply.

e. The inner voltage feedback loop acts as an active filter [3] to reject the output voltage ripple. It also rejects the output voltage fluctuations due to float of input mains. The series–pass transistor bank, present as an element of this active filter, has the advantage of large control bandwidth that is considered to be infinity in the model. The output voltage change due to the change in the input voltage is given by the expression (1)

$$\frac{\Delta vo}{\Delta vi} = \frac{1}{1 + (A1 \cdot gm \cdot Zo \cdot Bv)} \quad (1)$$

For $A1 \cdot gm \cdot Zo \cdot Bv >> 1$, the equation (1) reduces to

$$\frac{\Delta vo}{\Delta vi} \approx \frac{1}{(A1 \cdot gm \cdot Zo \cdot Bv)} \quad (2)$$

Thus to achieve $\frac{\Delta vo}{\Delta vi} \to 0$, for all disturbances (ripple and fluctuations) from the input, the gain and bandwidth of the denominator of equation (2) has to be made as large as possible. The trans-conductance gm is fixed for Darlington configuration used for the transistor bank. Hence large gain and compensation is done using $A1(s)$ to make the loop stable. The inner voltage loop is closed with respect to input at a frequency of 12.7KHz, and thus a 28db rejection is achieved at input ripple frequency of 600Hz.

f. Considering both the inner and middle loop, the output voltage fluctuation or ripple suppression with respect to the input is given by

$$\frac{\Delta vo}{\Delta vi} = \frac{1}{1 + \{(A2+1) \cdot A1 \cdot gm \cdot Zo \cdot Bv\}} \quad (3)$$

For $\{(A2+1).\ A1.gm.Zo.Bv\} >> 1$, the equation (3) reduces to

$$\frac{\Delta vo}{\Delta vi} \approx \frac{1}{\{(A2+1) \cdot A1 \cdot gm \cdot Zo \cdot Bv\}} \quad (4)$$

The combined voltage loops (inner and middle) with proper compensation are closed with respect to the input at a frequency of 23kHz and thus a 52db rejection of 600Hz input ripple.

g. The magnet load with a large time constant (L/R) comes into the outer current control loop. Hence the loop is closed at a low frequency of 0.3Hz so that the pole introduced by the load is above the bandwidth of the circuit and does not affect the current loop stability. This slow outer type–1 (integrating type) current loop helps in getting a zero steady state error, which means that the output magnet current should perfectly obey the command that is the reference signal. This outer loop meets the required load regulation and tracks the reference for long-term current stability.

TEST RESULTS

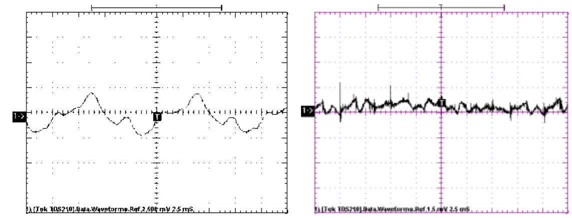

Figure 4. Input Voltage Ripple (left) = 1V_{p-p} and Output Voltage Ripple (right) < 5mV_{p-p}

The input and output voltage ripples at full load current of 750A is shown Figure 4. The output current of the power supply is measured using standard test-bench [4] consisting of a precise ultra-stable DCCT with its associated electronics and 6-1/2-digit data logger for real time monitoring of the output current for obtaining its long-term stability.

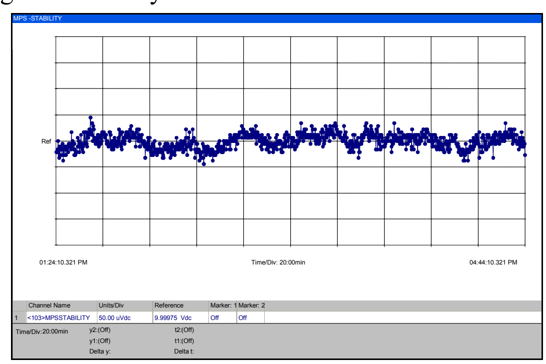

Figure 5. The current Stability Curve (Scale: y-axis: 1div=5ppm; x-axis: 1div=20min)

CONCLUSION

The design and the model of the regulation scheme adopted for the development of precision magnet power supply of 750A/12V comply well with its high stability specification of 10ppm.

ACKNOWLEDGEMENT

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