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ABSTRACT

FAST-RESPONSE FREE-RUNNING FREQUENCY-STABILIZED DC-TO-DC CONVERTER

EMPLOYING A STATE-PLANE-TRAJECTORY CONTROL LAW

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Implementations of a state-plane-trajectory control law for energy-storage dc-to-dc converters are presented. Performance characteristics of experimental voltage step-up converter systems employing these implementations are reported and compared to theoretical predictions.

SUMMARY

FAST-RESPONSE FREE-RUNNING FREQUENCY-STABILIZED DC-TO-DC CONVERTER

EMPLOYING A STATE-PLANE-TRAJECTORY CONTROL LAW

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A recent analysis of one commonly used power conditioning system -- the closed-loop regulated voltage step-up dc-to-dc converter -- led to the postulation of a conceptual state-plane-trajectory control law for it and for related energy-storage converters. Reference 1 describes the development of this control law and presents data from digital computer simulations which enable comparisons of the performance of voltage step-up dc-to-dc converters utilizing the new control law with converters using conventional controllers. In this reference it is shown that, at least conceptually, a voltage step-up dc-to-dc converter may be made to operate in a free-running mode, stabilized at a specified operating frequency, and to achieve performance characteristics approaching the theoretical limits revealed by a comprehensive state-plane analysis of the system. A companion paper submitted to PESC 77 presents detailed derivations of the equations which are needed to design such a controller to meet specific system requirements. The present paper describes several approaches to the implementation of this analytically derived control technique and presents experimentally measured performance data of actual voltage step-up dc-to-dc converters operating under this control law.

The controller discussed in this paper continuously monitors and processes

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four signals from the converter power stage. Two of these signals correspond to the chosen system state variables of inductor current and capacitor voltage; the others correspond to the two externally imposed operating conditions of input supply voltage and output load current. The latter two are used in conjunction with the circuit component values, a designer-specified time parameter, and the desired average output voltage of the regulated converter to compute a two-segment switching line in the system state plane. This switching line, illustrated in Fig. 1, divides the system state plane into an "on region" and an "off region". The command to turn the power switch on or off is determined by comparing the measured state of the system to the computed state-plane switching line. Since the switching line is a function of the input voltage and output current, any changes in these operating conditions are immediately reflected as changes in the switching line and, thus, in the switching sequence of the power transistor. In theory, this control technique can achieve steady-state operation for a step change in input voltage or output current in one on/off cycle of control, and after the new steady-state condition has been attained, enables the converter to operate with zero percent regulation of the average output voltage and at a constant frequency if desired.

The mathematical operations required by this controller are all algebraic and thus do not require increasing the order of the system by introducing additional energy-storage elements or integrators into the system feedback paths. The algebraic operations can be implemented by means of numerous techniques, including digital computation, integrated-circuit analog function modules, and hybrid combinations of these approaches. The behavior of experimental voltage step-up dc-to-dc converters operating under the control of

some of these implementations is presented and discussed with respect to
such performance measures as speed of response to changes in externally
imposed operating conditions and deviations from simulated and theoretically
predicted responses.

The principal purpose of this paper is to demonstrate the physical
realizability of a relatively complex analytically founded control law for
a class of energy-storage dc-to-dc converters. An experimental converter
operating with this control technique approaches the theoretical limits in
static and dynamic performance which are predicted by the state-plane analysis.
As might be expected, the improved system performance is accomplished at the
expense of more complicated control circuitry. However, with the current
rapid advances in electronic component development, it is believed that
control circuitry of this complexity is viable, and it is intended that this
paper demonstrate the technical feasibility of such systems.

REFERENCE

[1] W. W. Burns, III and T. G. Wilson, "State-Plane Trajectories Used to
Observe and Control the Behavior of a Voltage Step-Up DC-to-DC Converter,"
1976 Power Electronics Specialists Conference Record, pp. 212-222, June 1976.

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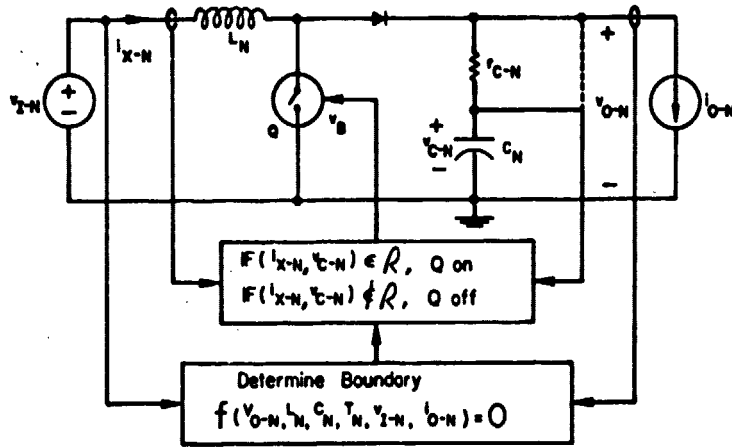
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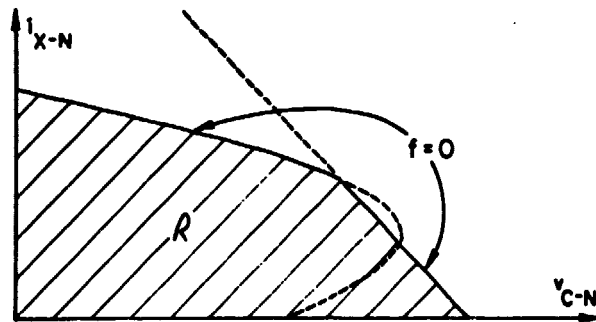
(B)

Fig. 1. (A) Conceptual diagram of free-running controller for the voltage
step-up converter. (B) Switching line f=0 divides the state plane of
inductor current, i_{X-N}, versus capacitor voltage, v_{C-N}, into an "on region",
cross-hatched, and an "off region."