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1 Navy Case No. 77,470

PATENTS

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4 **SELECTIVELY CONTROLLED ELECTRICAL POWER  
SWITCHING SYSTEM**

5 This invention relates in general to electrical power switching circuitry, and more  
6 particularly to such circuitry having a selective operational capability so as to accommodate  
7 different types of electrical loads.

8 BACKGROUND OF THE INVENTION

9 Electrical power switching circuits are generally available to respectively provide different  
10 operational modes, including hard-switching and soft-switching. The hard-switching mode  
11 involves a snubbing technique, widely implemented through low or medium power converters  
12 to achieve circuit simplification and obtain low cost effectiveness. However, hard-switching  
13 operation of such circuits becomes less desirable because of high switching loss as power level  
14 and switching frequency increases. Soft-switching or zero voltage switching on the other hand  
15 was developed to reduce switching loss, but involves increased circuit complexity and cost as  
16 well as operational inadequacy under low level load current conditions.

17  
18 Direct current electrical power supply circuitry having selective operational switching  
19 controls are also known as disclosed for example in U.S. Patent Nos. 5,030,844 and 5,391, 928 to  
20 Li et al. and Tomiyori et al., respectively. However, the circuits disclosed in the foregoing  
21 patents do not include or suggest mode control to alternatively provide for both hard-switching  
22 and soft-switching operations.

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24 It is therefore an important object of the present invention to provide a selective switching  
25 control for supply of electrical current alternatively conducted to a load under either a  
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1 hard-switching mode or a soft-switching mode in order to accommodate different load conditions  
2 in a more efficient and less costly manner.

### 3 SUMMARY OF THE INVENTION

4  
5 In accordance with the present invention, the electrical configuration of an electrical power  
6 converter circuit is automatically changed under selective control through a switching converter  
7 between soft-switching and hard-switching operational modes. The power converter circuit  
8 features an auxiliary circuit section in the form of a resonant commutated pole inverter having  
9 auxiliary switches. During start-up, one of two snubber switches of a mode control section may  
10 be actuated after a main power switch in the switching converter is gated on or off to select and  
11 implement different switching modes.  
12

### 13 BRIEF DESCRIPTION OF DRAWING FIGURES

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15 A more complete appreciation of the invention and many of its attendant advantages will be  
16 readily appreciated as the same becomes better understood by reference to the following detailed  
17 description when considered in connection with the accompanying drawings wherein:

18 FIG. 1 is a block diagram of a power supply circuit system in accordance with one  
19 embodiment of the invention;

20  
21 FIG. 2 is a circuit diagram illustrating the switching converter section of the system depicted  
22 in FIG. 1;

23 FIG. 3 is a circuit diagram illustrating the mode control section of the system depicted in  
24 FIG. 1; and

25 FIG. 4 is a circuit diagram illustrating the auxiliary circuit section of the system depicted in  
26 FIG. 1.  
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## DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawing in detail, FIG. 1 diagrams the supply of electrical power from a DC voltage source 10 to an output load 12 through a power switching converter generally referred to by reference numeral 14, which operates either under a soft-switching mode or a hard-switching mode dependent on selective control exercised thereon through a mode control arrangement generally referred to by reference numeral 16. Soft-switching operation of the switching converter 14 is made feasible under low current levels by means of an auxiliary circuit 18 associated therewith. Dependent on mode selection, voltage level and other factors or conditions associated with the type of output load 12 to be powered, a suitable operational sequence is imposed on the switching converter 14 and its auxiliary circuit 18 by means of gating control 20 as hereinafter described.

As diagrammed in FIG. 2, the switching converter 14 includes a pair of main transistor switches 22 and 24 connected in series between positive dc voltage bus 26 and negative dc voltage bus 28 extending from the voltage source 10. A series connection 29 between the main switches 22 and 24 is coupled by inductor winding 30 to the output load 12. Thus, electrical power is alternatively supplied to the load 12 from the dc voltage buses 26 and 28 by turn-on and turn-off of the switches 22 and 24 in accordance with sequence control signals applied to their gate electrodes by the gating control 20 to obtain a desired switching sequence. Current conducted through the main switches 22 and 24 during supply of power is unidirectionally restricted by diodes 32 and 34 respectively connected across the input and output transistor electrodes of the main switches 22 and 24. Also connected across the input and output electrodes of each switch 22 and 24, respectively in series with resonant capacitors 36 and 38, is the mode

1 control 16 through which the switching mode is governed in conjunction with the auxiliary  
2 circuit 18 directly connected to the negative dc voltage bus 28 and coupled through capacitor 40  
3 to the positive dc voltage bus 26. The auxiliary circuit 18 is disabled by closing of by-pass  
4 switch 41 selectively connecting capacitor 40 to the bus 28.  
5

6 FIG. 2 diagrams the mode control 16 directly connected to the positive voltage bus 26 to  
7 which the input electrode of transistor switch 32 is connected. The mode control 16 is also  
8 coupled through capacitor 38 to the input electrode of diode 34 and the negative voltage bus 28.  
9 The diodes 32 and 34 are thereby respectively connected across directionally opposite diodes 42  
10 and 44 of the mode control 16 as shown in FIG. 3. Each of such diodes 42 and 44 is connected  
11 across a snubber circuit, respectively formed by switches 46 and 48 in parallel with resistors 50  
12 and 52. Thus, when both of the snubber switches 46 and 48 of the mode control 16 are opened  
13 and the auxiliary circuit 18 is disabled upon closing of switch 41, the switching converter 14  
14 performs a hard-switching operation under sequence gate control of the main transistor switches  
15 22 and 24 for supply of electrical energy to the load 12 at lower power levels and at lower  
16 frequencies.  
17

18  
19 The auxiliary circuit 18 as diagrammed in FIG. 4 is coupled to the load 12 through  
20 inductance winding 52 in series with the winding 30 of the converter 14. The capacitor 40 of  
21 converter 14 on the other hand is connected across the buses 26 and 28 in series with a capacitor  
22 54 through a junction 56 in the auxiliary circuit 18. Acting as an auxiliary resonant commutated  
23 pole inverter, the circuit 18 includes a pair of auxiliary transistor switches 58 and 60 connected in  
24 series between junction 56 and the inductance 54. Such transistor switches 58 and 60 have  
25 control gate electrodes connected to the gating control 20 for energy storage reset purposes.  
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1 Directionally opposite diodes 62 and 64 are respectively connected across the switches 58 and  
2 60. The diode 62 is also connected in parallel with series connected resistor 66 and capacitor 68,  
3 while the diode 64 is connected in parallel with series connected resistor 70 and capacitor 72.  
4  
5 When one of the transistor switches 22 and 24 of the converter 14 is gated on and the other gated  
6 off pursuant to a sequence imposed by gating control 20, inductive load current is transferred to  
7 both resonant capacitors 36 and 38 which are operative to swing voltage supply from one input  
8 voltage bus to the other under zero voltage soft-switching through the main switches 22 and 24.  
9  
10 At low level load current, such soft-switching is made possible by the auxiliary transistor  
11 switches 58 and 60 of the circuit 18 resetting the charge stored in the resonant capacitors 36 and  
12 38 of the switching converter 14.

13         The snubber resistors 50 and 52 and snubber switches 46 and 48 of the mode control 16  
14 provide for selection between the aforementioned soft and hard switching operations. Soft  
15 switching made possible below a predetermined current level by auxiliary circuit 18 as  
16 aforementioned, requires one of the main switches 22 and 24 of the switching converter 14 to be  
17 gated on by gating control 20 before dc voltage is applied from source 10. During start-up of  
18 such soft-switching operation, one of the snubber switches 46 and 48 may be opened before  
19 turn-on of one of the main switches 22 and 24 so that charging and discharging of the DC  
20 capacitor 40 is not required. When said one of the main transistor switches 22 and 24 is then  
21 gated on, a normal soft-switching control sequence is implemented to especially accommodate  
22 frequent start and stop operations. Operation in a hard-switching mode under low current levels  
23 may also be accommodated by disabling the auxiliary circuit 18 as aforementioned.  
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2 In regard to start up of a power switching converter in a soft-switching mode, additional  
3 circuitry was heretofore required to perform the time consuming functions of slowing charging  
4 the DC bus capacitor to a target voltage level following its complete discharge before one of the  
5 main switches is gated on such operations were performed in order to avoid damage caused by  
6 discharge of the resonant capacitors associated with the power switching circuit, and involved  
7 higher power losses. Such problems are avoided according to the present invention by selection  
8 of a hard-switching mode for the power switching circuit 14 during initial start up by gating off  
9 one of the mode selector switches 46 and 48 of the mode control section 16 and limiting current  
10 discharge form the resonant capacitors 36 and 38 through resistors 50 and 52. When a main  
11 power switch 22 or 24 is gated on, the mode selector switch 46 or 48 may be gated on before  
12 implementing a normal soft-switching mode.  
13

14 Obviously, other modifications and variations of the present invention may be possible in  
15 light of the foregoing teachings. For example, the mode selector switches 46 and 48 may be  
16 mechanical switches with electrical actuator or semiconductor switches. It is therefore to be  
17 understood that the invention may be practiced  
18 otherwise than as specifically described.  
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3 **SELECTIVELY CONTROLLED ELECTRICAL POWER**  
4 **SWITCHING SYSTEM**

5 ABSTRACT OF THE DISCLOSURE

6 Electrical energy from a DC voltage source is supplied through a power switching converter  
7 under operational control, to an electrical load in accordance with a soft-switching mode  
8 implemented by an auxiliary resonant commutated pole inverter. A mode control section having  
9 snubber switches connected to the switching converter selectively changes switching operation to  
10 a hard-switching mode so as to accommodate supply of load current at higher levels to the  
11 electrical load.  
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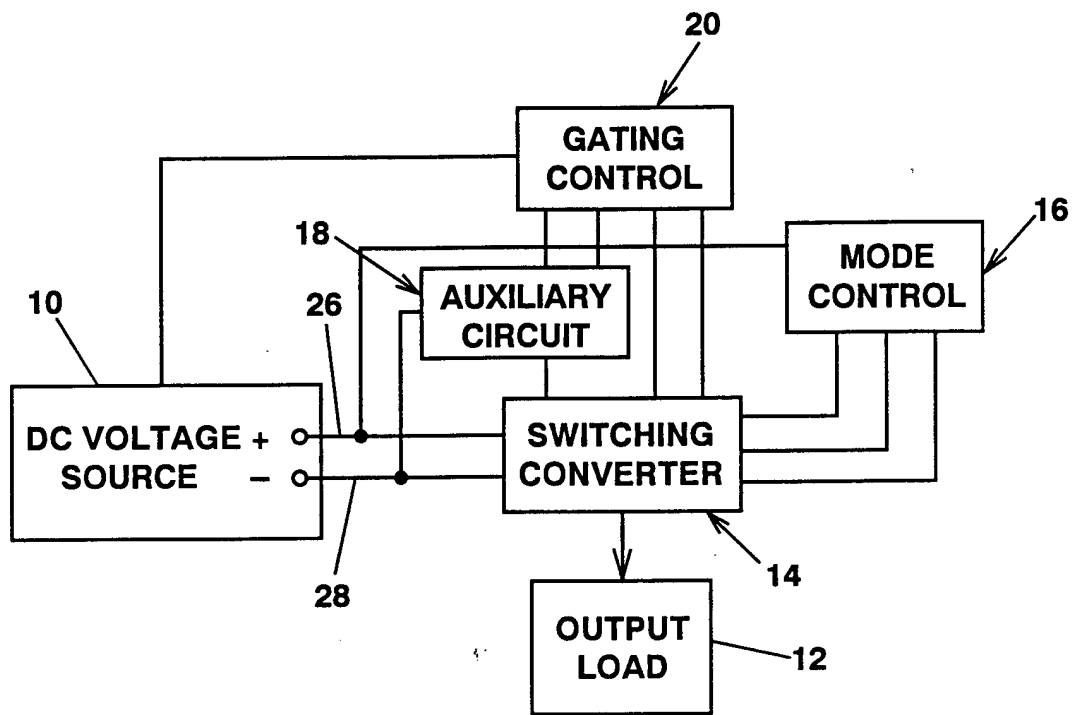


FIG. 1

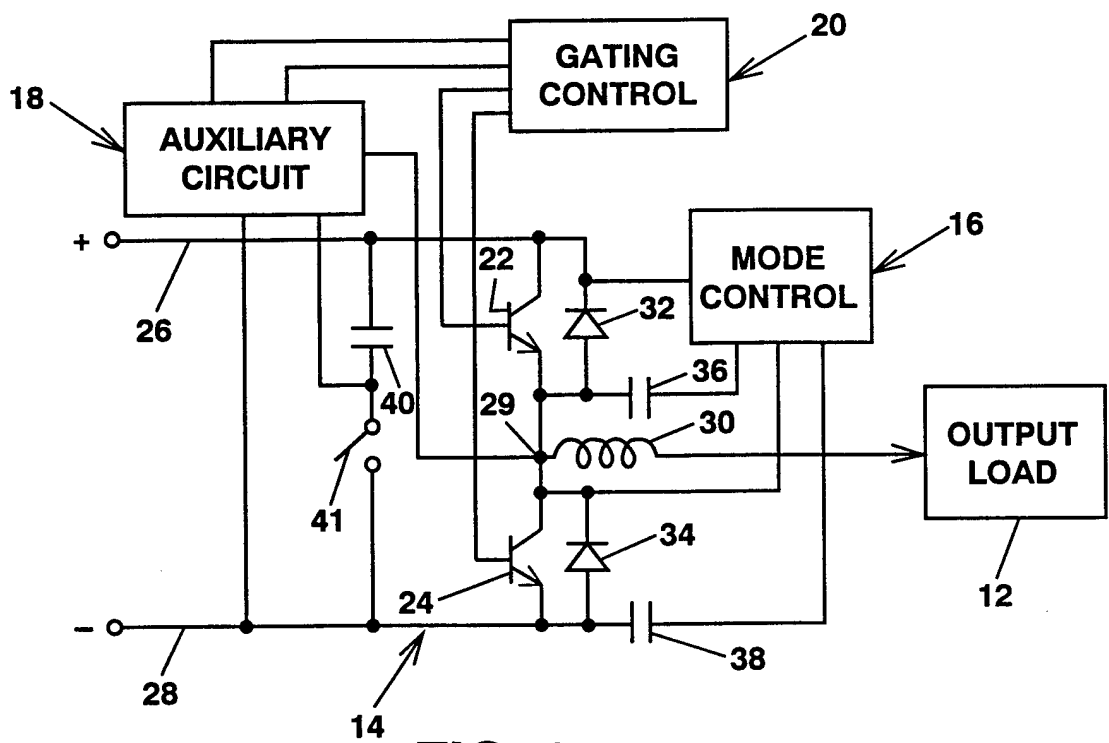


FIG. 2

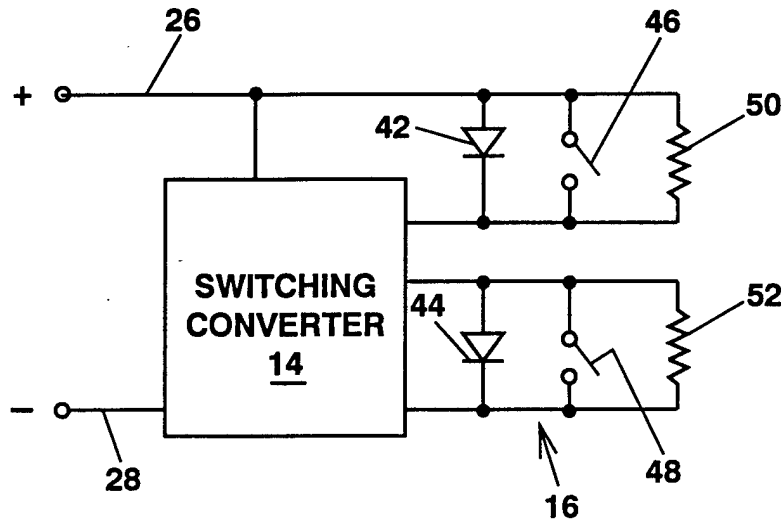


FIG. 3

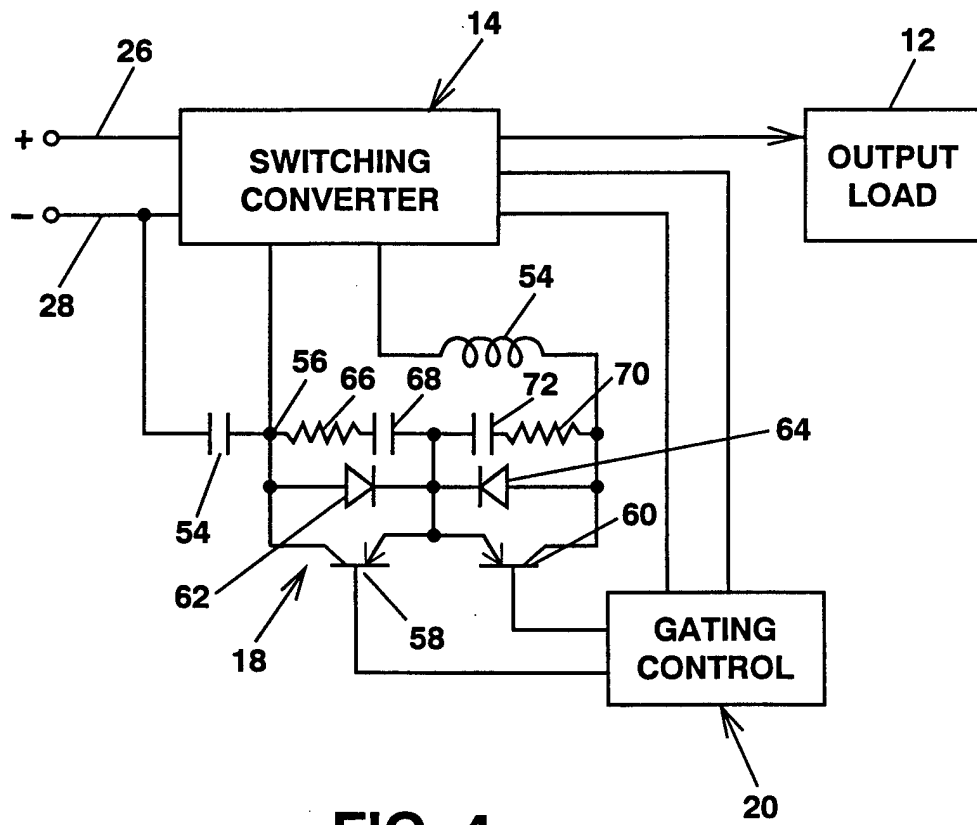


FIG. 4