Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2768517 C 2017/06/20

(11)(21) 2 768 517

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2011/02/18
(87) Date publication PCT/PCT Publication Date: 2011/08/25
(45) Date de délivrance/Issue Date: 2017/06/20
(85) Entrée phase nationale/National Entry: 2012/01/18
(86) N° demande PCT/PCT Application No.: CA 2011/000185
(87) N° publication PCT/PCT Publication No.: 2011/100827
(30) Priorité/Priority: 2010/02/18 (US61/305,590)

(51) Cl.Int./Int.Cl. *H02M 3/24* (2006.01), *H02M 3/305* (2006.01), *H02M 3/335* (2006.01)

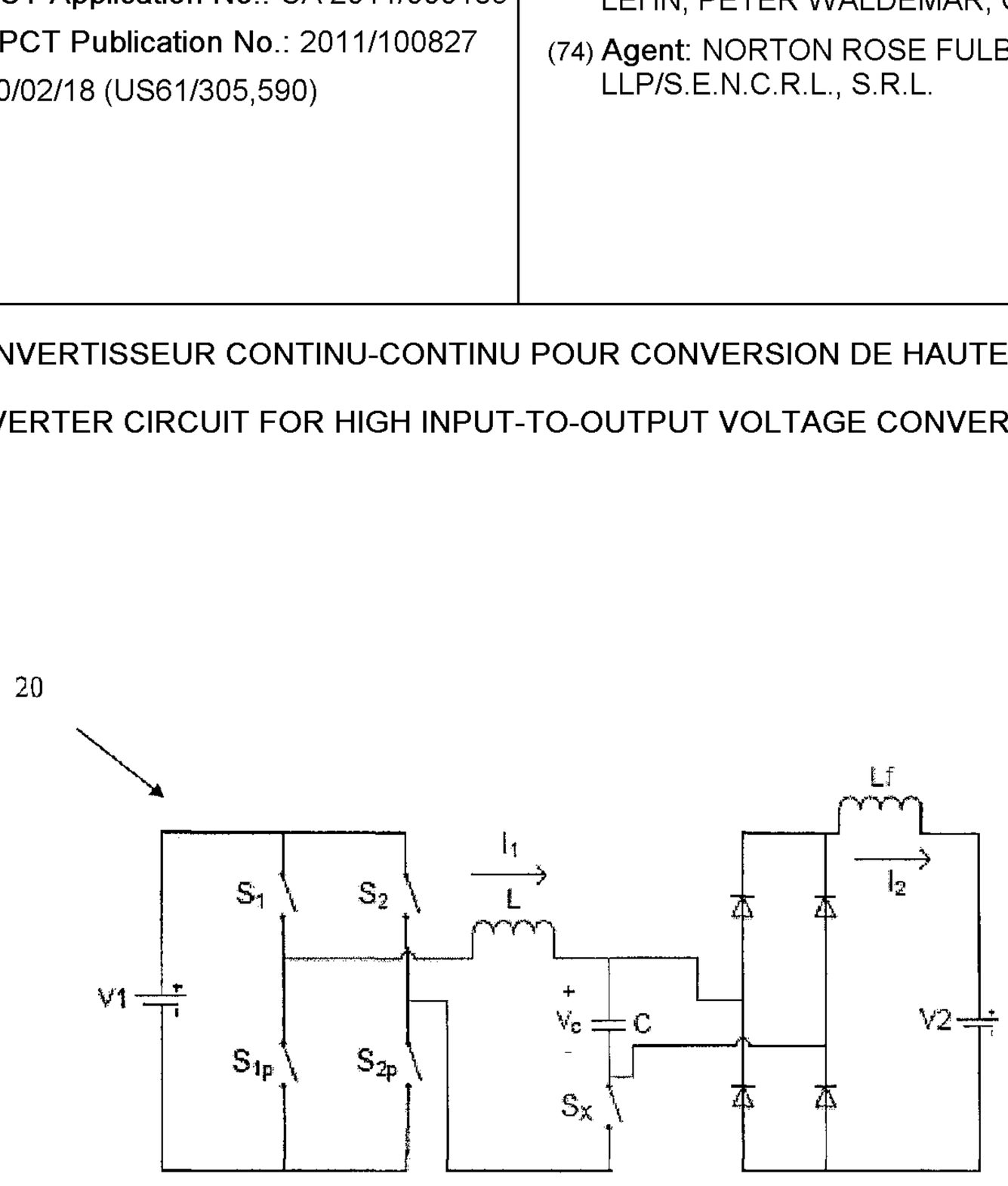
(72) Inventeur/Inventor:
LEHN, PETER WALDEMAR, CA

(73) Propriétaire/Owner:
LEHN, PETER WALDEMAR, CA

(74) Agent: NORTON ROSE FULBRIGHT CANADA LLP/S.E.N.C.R.L., S.R.L.

(54) Titre : CIRCUIT CONVERTISSEUR CONTINU-CONTINU POUR CONVERSION DE HAUTE TENSION ENTREE-SORTIE

(54) Title: DC-DC CONVERTER CIRCUIT FOR HIGH INPUT-TO-OUTPUT VOLTAGE CONVERSION



(57) Abrégé/Abstract:
The present invention provides a series of DC-DC converter circuit designs, and DC-DC converters based on such circuit design, that provide high input-to-output voltage conversion. The converters include a resonant tank and a means for interrupting the tank current to produce a near zero-loss "hold" state wherein zero current and/or zero voltage switching is provided, while providing control over the amount of power transfer. A resonant DC-DC converter for high voltage step-up ratio in accordance with the circuit design includes: (a) a low voltage DC- AC converter, (b) a resonant tank, (c) a high voltage AC-DC converter, (d) a (i) common ground on an input and an output without use of a transformer and/or (ii) a single high voltage controllable switch within the resonant tank.

ABSTRACT

The present invention provides a series of DC-DC converter circuit designs, and DC-DC converters based on such circuit design, that provide high input-to-output voltage conversion. The converters include a resonant tank and a means for interrupting the tank current to produce a near zero-loss "hold" state wherein zero current and/or zero voltage switching is provided, while providing control over the amount of power transfer. A resonant DC-DC converter for high voltage step-up ratio in accordance with the circuit design includes: (a) a low voltage DC-AC converter, (b) a resonant tank, (c) a high voltage AC-DC converter, (d) a (i) common ground on an input and an output without use of a transformer and/or (ii) a single high voltage controllable switch within the resonant tank.

1. A resonant dc-dc converter, comprising:

(a) a low voltage full-bridge or half-bridge dc-ac converter coupled to an input dc voltage at an input terminal of the dc-dc converter;

(b) a resonant tank coupled to the dc-ac converter;

(c) a high voltage ac-dc rectifier coupled to the resonant tank, and having an output terminal of the dc-dc converter; and

(d) a controllable switch within the resonant tank, said controllable switch being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to an output terminal;

wherein the hold state is caused by operating the controllable switch in a non-conducting state.

2. The resonant dc-dc converter of claim 1, wherein the controllable switch only blocks current in one direction.

3. The resonant dc-dc converter of claim 2, wherein the controllable switch has no reverse blocking characteristic.

4. The resonant dc-dc converter of claim 2, wherein a lossless snubber circuit is introduced to the resonant dc-dc converter by connecting a diode from either: (a) a drain of the controllable switch that is a high voltage MOSFET; (b) a collector of the controllable switch that is an IGBT; or (c) an anode of the controllable switch that is a thyristor; to an output terminal of the resonant dc-dc converter.

5. The resonant dc-dc converter of claim 2, wherein the resonant dc-dc converter incorporates a transformer, said transformer being operable to provide electrical isolation between input and output.

6. The resonant dc-dc converter of claim 5, wherein an output rectifier is connected to be operable to provide bi-polar (positive, neutral and negative) dc output.

7. The resonant dc-dc converter of claim 1, wherein a lossless snubber circuit is introduced to the resonant dc-dc converter by connecting a diode of a terminal of the controllable switch to an output

terminal of the resonant dc-dc converter, so that one or more voltage spikes are clamped across the controllable switch.

8. The resonant dc-dc converter of claim 1, wherein the controllable switch is controllable in synchronism with the low-voltage full-bridge or half-bridge dc-ac converter.

9. The resonant dc-dc converter of claim 8, wherein the controllable switch is controllable so that one or more switching events of the controllable switch occur at a zero crossing of current of the controllable switch.

10. The resonant dc-dc converter of claim 1, wherein duration of non-conduction of the controllable switch is variable to regulate power flow from input to output.

11. A resonant dc-dc converter comprising: (a) a low voltage dc-ac converter coupled to an input dc voltage; (b) a resonant tank coupled to the dc-ac converter at an input terminal of the dc-dc converter; (c) a high voltage ac-dc converter coupled to the resonant tank and having an output terminal of the dc-dc converter; and (d) a controllable switch within the resonant tank circuit being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to the output terminal; wherein the resonant dc-dc converter for high voltage step-up ratio is operable to provide one or more of the following: (i) a common ground plane for input and output; and (ii) a transformer between input and output; wherein hold state is caused by operating the controllable switch in a non-conducting state.

12. A resonant dc-dc converter comprising: (a) a low voltage dc-ac converter coupled to an input dc voltage at an input terminal of the dc-dc converter; (b) a resonant tank coupled to the dc-ac converter; (c) a high voltage ac-dc converter coupled to the resonant tank and having an output terminal of the dc-dc converter; (d) a controllable switch within a circuit of the resonant tank being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to the output terminal; and (e) a common ground plane for an input and output that does not require use of a transformer; wherein the hold state is caused by operating the controllable switch in a non-conducting state.

13. A dc-dc converter with a transformer, wherein the dc-dc converter with the transformer comprises: (a) a resonant tank; (b) a switch, controllable with a circuit of the dc-dc converter with a transformer to periodically perform high voltage blocking of resonance by maintaining a high voltage across the switch, thereby periodically alternating between a first state and a second state and periodically discontinuing tank oscillation in the resonant tank by causing the dc-dc converter to enter a hold state while the switch is in the first state, to periodically suspend power transfer by the dc-dc converter to control a rate of power transfer by the from the input dc voltage to an output dc voltage; (c) a converter on a low voltage side; and (d) an output rectifier on a high voltage side; wherein the hold state is caused by operating the switch in a non-conducting state.

14. The resonant dc-dc converter of claim 8 wherein one or more switching events of one or more dc-ac converter switches occur at a zero crossing of currents of the respective one or more dc-ac converter switches.

15. The resonant dc-dc converter of claim 1 wherein the controllable switch periodically discontinues tank oscillation in the resonant tank by alternating between conducting and non-conducting periods.

16. The resonant dc-dc converter of claim 15 wherein the durations of the conducting and the non-conducting periods of the controllable switch are variable to regulate power flow from input to output.

17. A resonant dc-dc converter, comprising:

(a) a low voltage full-bridge or half-bridge dc-ac converter coupled to an input dc voltage;

(b) a resonant tank coupled to the dc-ac converter;

(c) a transformer coupled to the resonant tank;

(d) an output rectifier coupled to the transformer to provide bi-polar (positive, neutral and negative) dc output; and

(e) a controllable switch within the resonant tank, said controllable switch being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank by causing the dc-dc converter to enter a hold state while the controllable switch is in the first state, periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input dc voltage to an output dc voltage; wherein the hold state is caused by operating the controllable switch in a non-conducting state.

18. The resonant dc-dc converter of claim 8, wherein the controllable switch is controllable so that one or more switching events of the controllable switch occur at a zero crossing of voltage of the controllable switch.

19. The resonant dc-dc converter of claim 4, wherein the lossless snubber circuit includes at least a diode connected from a transistor terminal of the controllable switch to a positive terminal of the output terminal of resonant dc-dc converter, the diode permitting energy transfer from the transistor terminal to the positive terminal.

1. A resonant dc-dc converter, comprising:

(a) a low voltage full-bridge or half-bridge dc-ac converter coupled to an input dc voltage at an input terminal of the dc-dc converter;

(b) a resonant tank circuit coupled to the dc-ac converter;

(c) a high voltage ac-dc rectifier coupled to the resonant tank circuit, and having an output terminal of the dc-dc converter; and

(d) a controllable switch within the resonant tank circuit, said controllable switch being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank circuit by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to an output terminal.

2. The resonant dc-dc converter of claim 1, wherein the controllable switch only blocks current in one direction.

3. The resonant dc-dc converter of claim 2, wherein the controllable switch has no reverse blocking characteristic.

4. The resonant dc-dc converter of claim 2, wherein a lossless snubber circuit is introduced to the resonant dc-dc converter by connecting a diode from either: (a) a drain of the controllable switch that is a high voltage MOSFET; (b) a collector of the controllable switch that is an IGBT; or (c) an anode of the controllable switch that is a thyristor; to an output terminal of the resonant dc-dc converter.

5. The resonant dc-dc converter of claim 2, wherein the resonant dc-dc converter incorporates a transformer, said transformer being operable to provide electrical isolation between input and output.

6. The resonant dc-dc converter of claim 5, wherein an output rectifier is connected to be operable to provide bi-polar (positive, neutral and negative) dc output.

7. The resonant dc-dc converter of claim 1, wherein a lossless snubber circuit is introduced to the resonant dc-dc converter by connecting a diode of a terminal of the controllable switch to an output terminal of the resonant dc-dc converter, so that one or more voltage spikes are clamped across the controllable switch.

8. The resonant dc-dc converter of claim 1, wherein the controllable switch is controllable in synchronism with the low-voltage full-bridge or half-bridge dc-ac converter.

9. The resonant dc-dc converter of claim 8, wherein the controllable switch is controllable so that one or more switching events of the controllable switch occur at a zero crossing of current of the controllable switch.

10. The resonant dc-dc converter of claim 1, wherein duration of non-conduction of the controllable switch is variable to regulate power flow from input to output.

11. A resonant dc-dc converter comprising: (a) a low voltage dc-ac converter coupled to an input dc voltage; (b) a resonant tank circuit coupled to the dc-ac converter at an input terminal of the dc-dc converter; (c) a high voltage ac-dc converter coupled to the resonant tank circuit and having an output terminal of the dc-dc converter; and (d) a controllable switch within the resonant tank circuit circuit being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank circuit by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to the output terminal; wherein the resonant dc-dc converter for high voltage step-up ratio is operable to provide one or more of the following: (i) a common ground plane for input and output; and (ii) a transformer between input and output.

12. A resonant dc-dc converter comprising: (a) a low voltage dc-ac converter coupled to an input dc voltage at an input terminal of the dc-dc converter; (b) a resonant tank circuit coupled to the dc-ac converter; (c) a high voltage ac-dc converter coupled to the resonant tank circuit and having an output terminal of the dc-dc converter; (d) a controllable switch within a circuit of the resonant tank circuit being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank circuit by causing the converter to enter a hold state while the controllable switch is in the first state, and thereby periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input terminal to the output terminal; and (e) a common ground plane for an input and output.

13. A dc-dc converter with a transformer, wherein the dc-dc converter with the transformer comprises: (a) a resonant tank circuit; (b) a switch, controllable with a circuit of the dc-dc converter with a transformer to periodically perform high voltage blocking of resonance by maintaining a high voltage across the switch, thereby periodically alternating between a first state and a second state and periodically

discontinuing tank oscillation in the resonant tank circuit by causing the dc-dc converter to enter a hold state while the switch is in the first state, to periodically suspend power transfer by the dc-dc converter to control a rate of power transfer by the from the input dc voltage to an output dc voltage; (c) a converter on a low voltage side; and (d) an output rectifier on a high voltage side.

14. The resonant dc-dc converter of claim 8 wherein one or more switching events of one or more dc-ac converter switches occur at a zero crossing of currents of the respective one or more dc-ac converter switches.

15. The resonant dc-dc converter of claim 1 wherein the controllable switch periodically discontinues tank oscillation in the resonant tank circuit by alternating between conducting and non-conducting periods.

16. The resonant dc-dc converter of claim 21 wherein the durations of the conducting and the non-conducting periods of the controllable switch are variable to regulate power flow from input to output.

17. A resonant dc-dc converter, comprising:

(a) a low voltage full-bridge or half-bridge dc-ac converter coupled to an input dc voltage;

(b) a resonant tank circuit coupled to the dc-ac converter;

(c) a transformer coupled to the resonant tank circuit;

(d) an output rectifier coupled to the transformer to provide bi-polar (positive, neutral and negative) dc output; and

(e) a controllable switch within the resonant tank circuit, said controllable switch being controllable to periodically alternate between a first state and a second state and to periodically discontinue tank oscillation in the resonant tank circuit by causing the dc-dc converter to enter a hold state while the controllable switch is in the first state, periodically suspending power transfer by the dc-dc converter to control a rate of power transfer from the input dc voltage to an output dc voltage.

18. The resonant dc-dc converter of claim 8, wherein the controllable switch is controllable so that one or more switching events of the controllable switch occur at a zero crossing of voltage of the controllable switch.

19. The resonant dc-dc converter of claim 1, wherein hold state is caused by operating the controllable switch in a non-conducting state.

20. The resonant dc-dc converter of claim 4, wherein the lossless snubber circuit includes at least a diode connected from a transistor terminal of the controllable switch to a positive terminal of the output terminal of resonant dc-dc converter, the diode permitting energy transfer from the transistor terminal to the positive terminal.

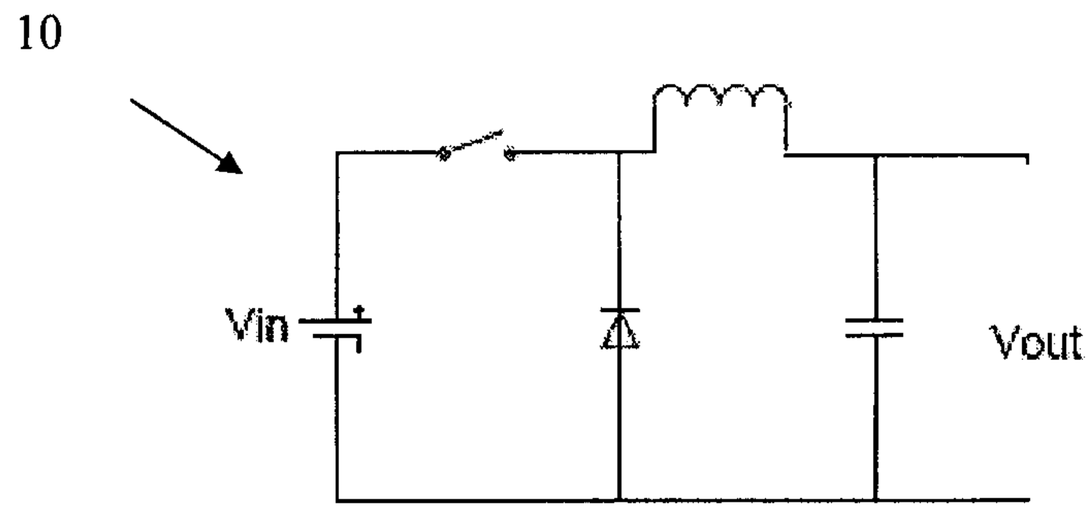


FIG. 1

PRIOR ART

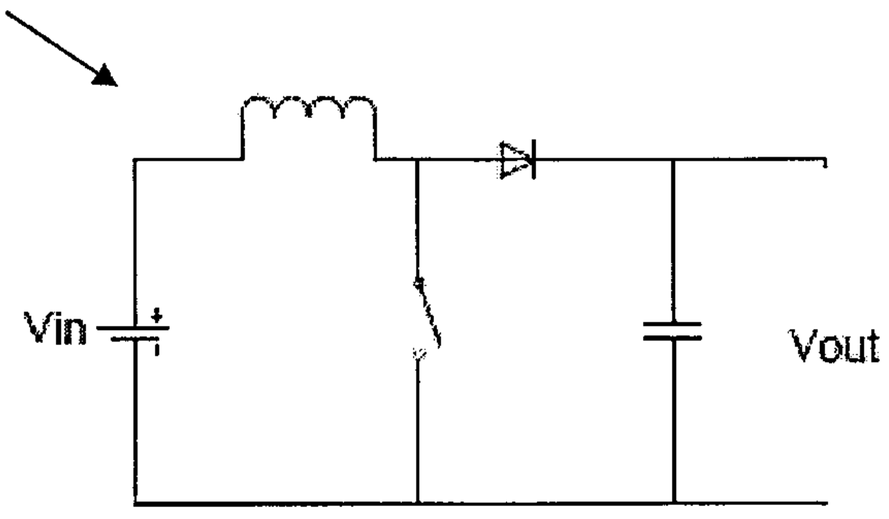


FIG. 2

PRIOR ART

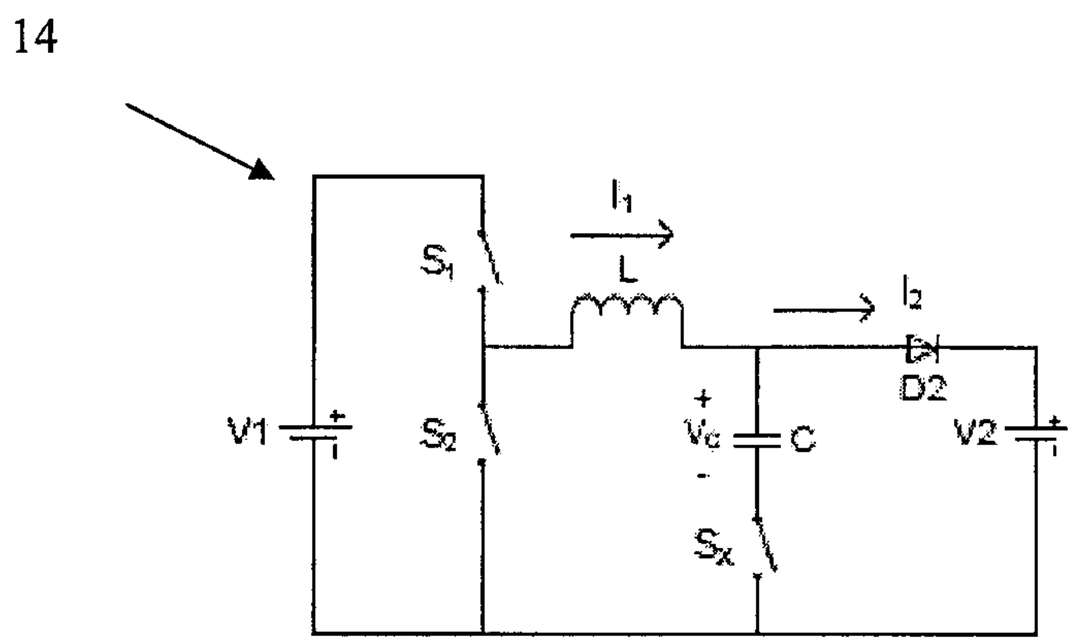


FIG. 3(a)

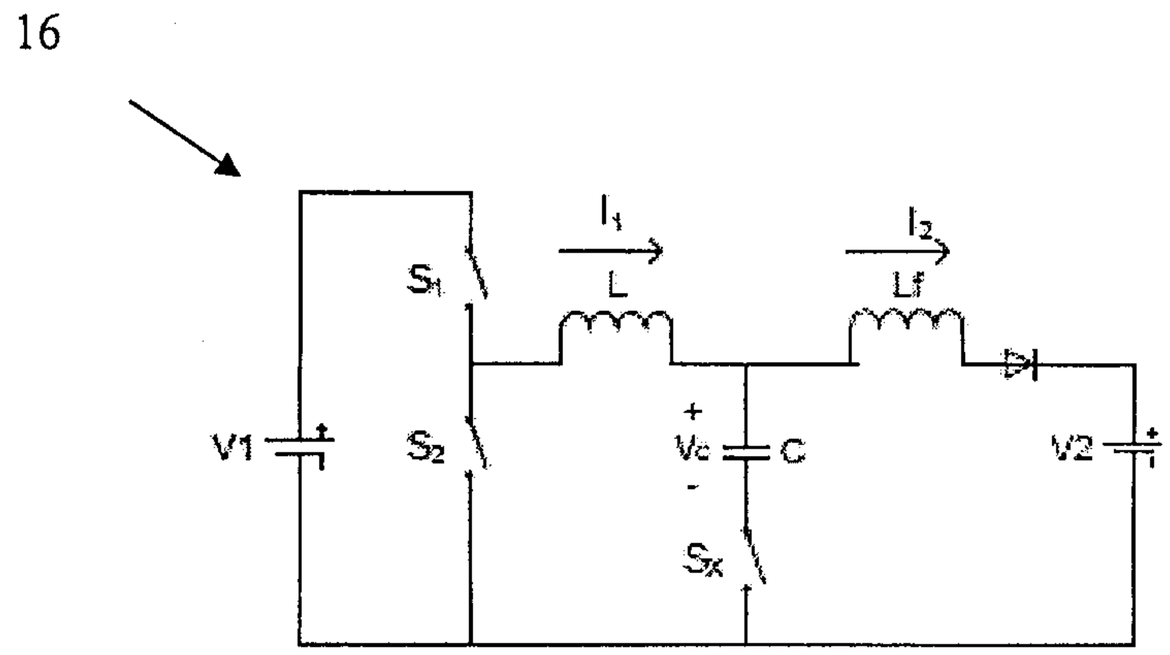


FIG. 3(b)

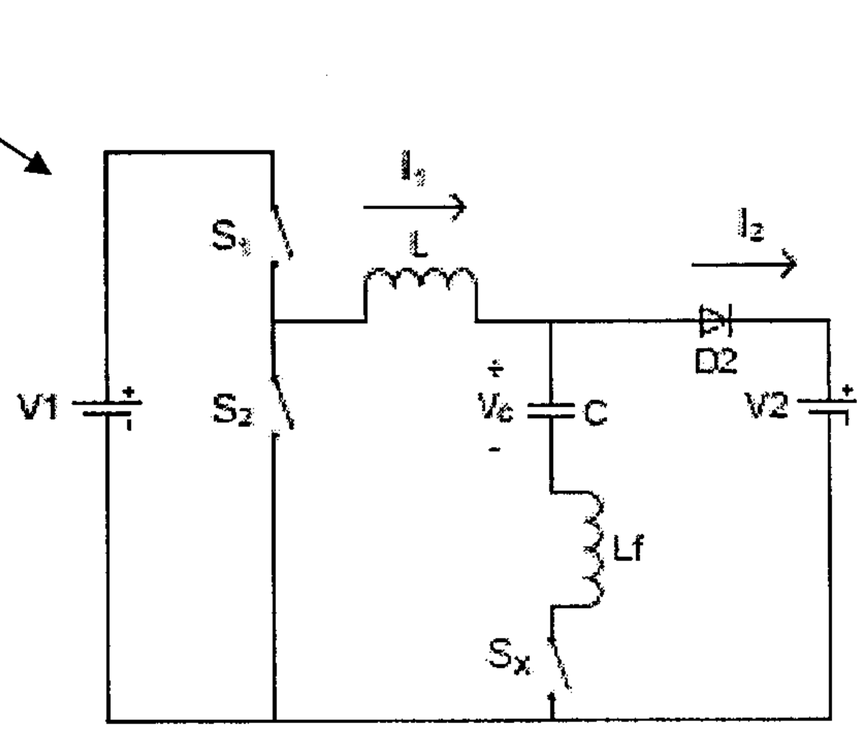


FIG. 3(c)

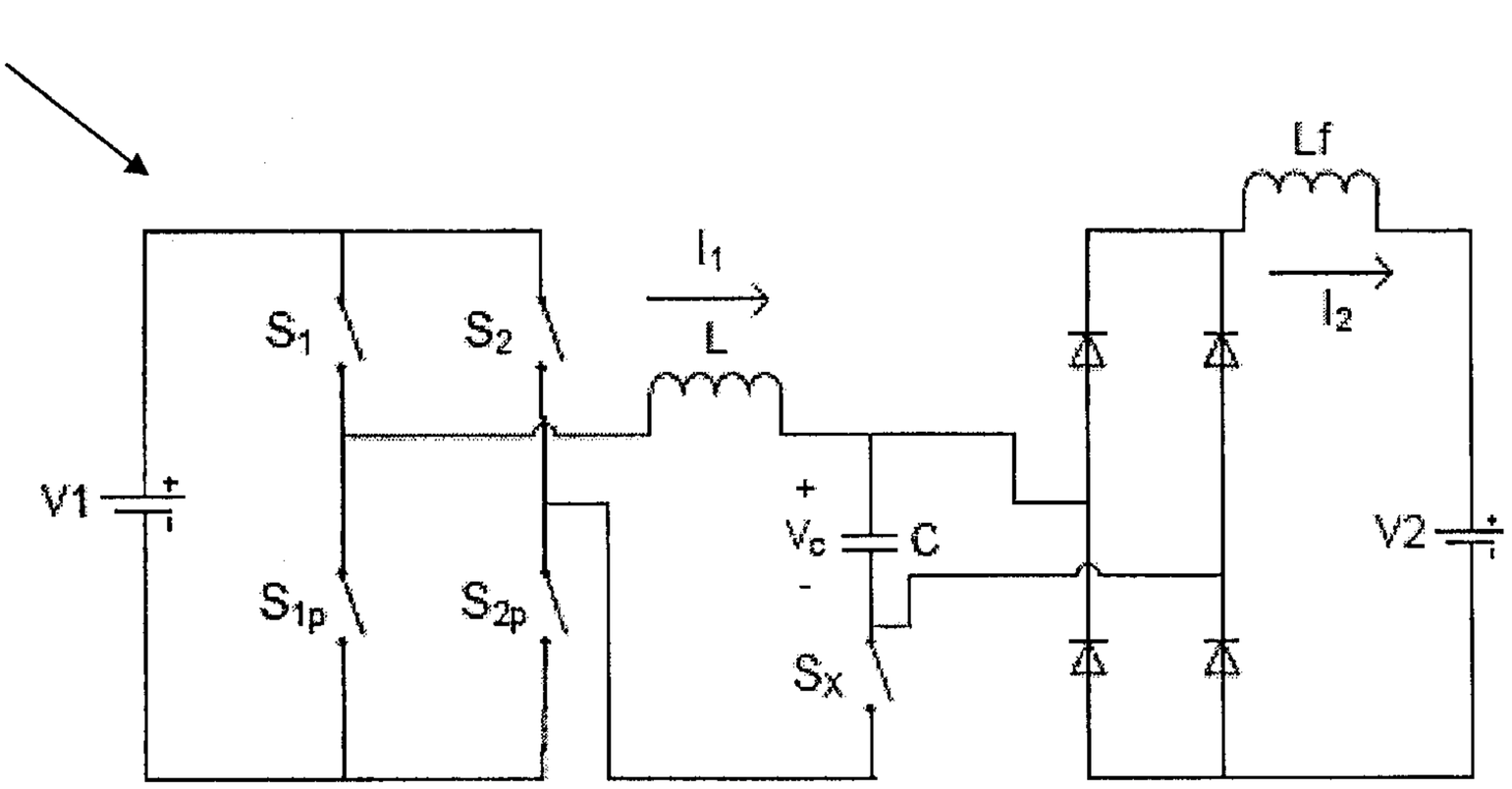


FIG. 4

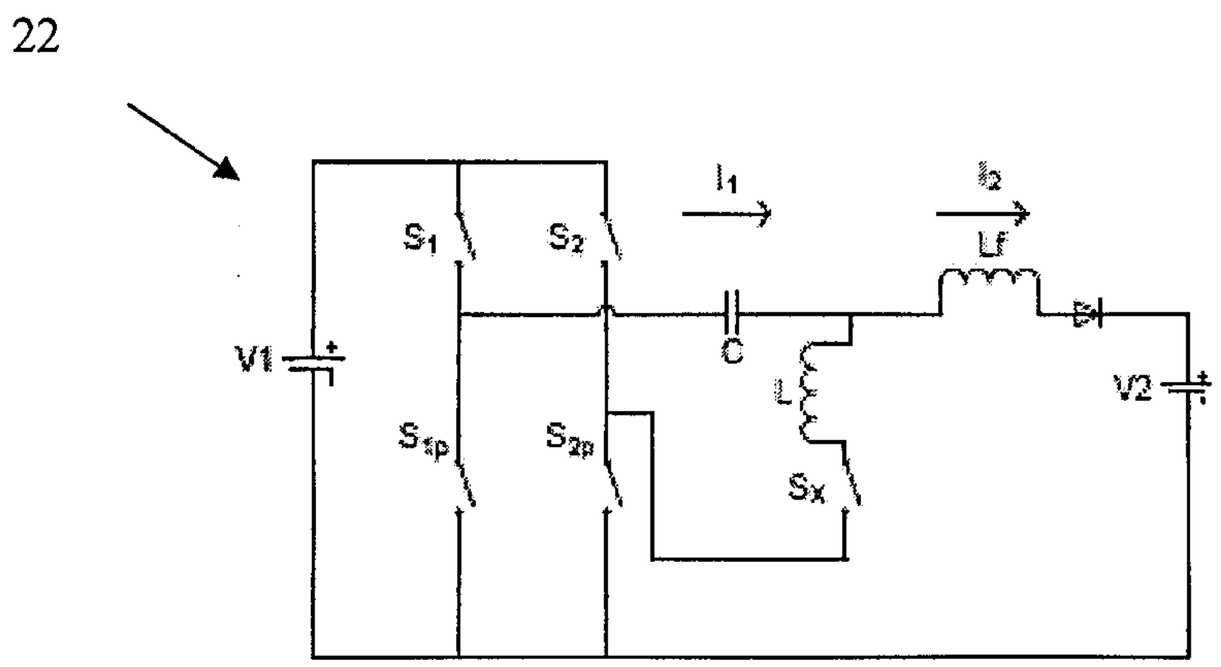


FIG. 5(a)

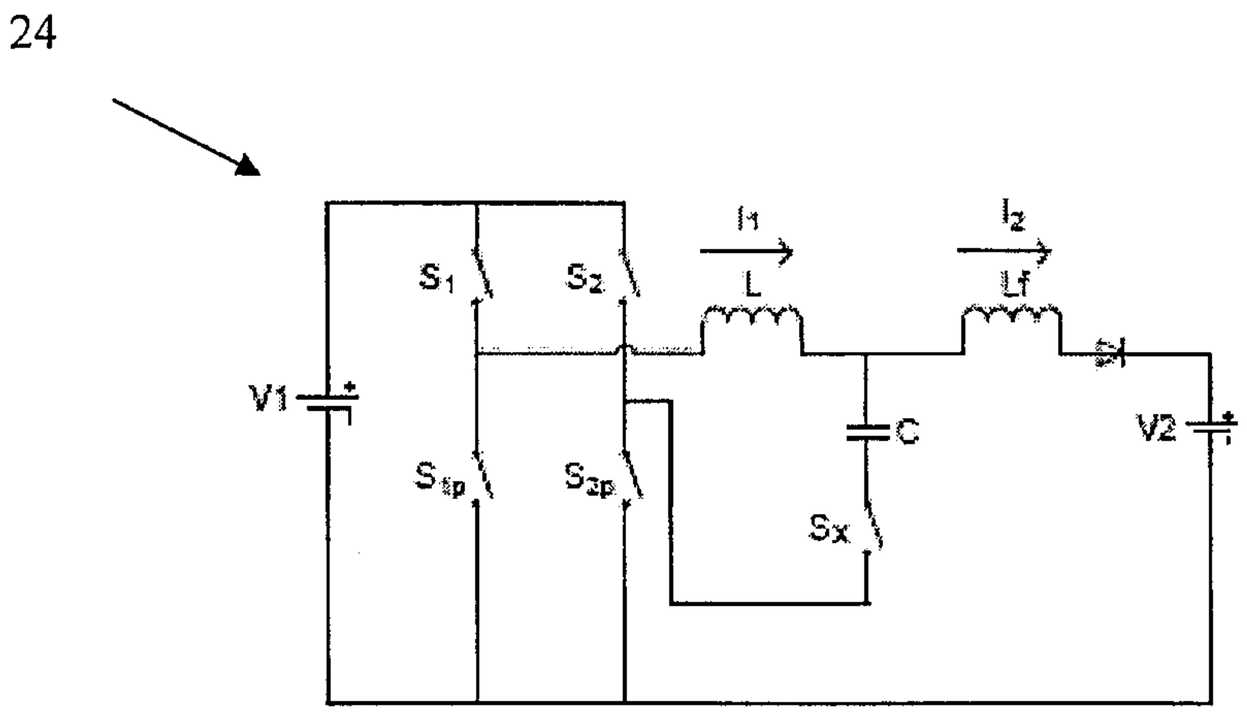


FIG. 5(b)

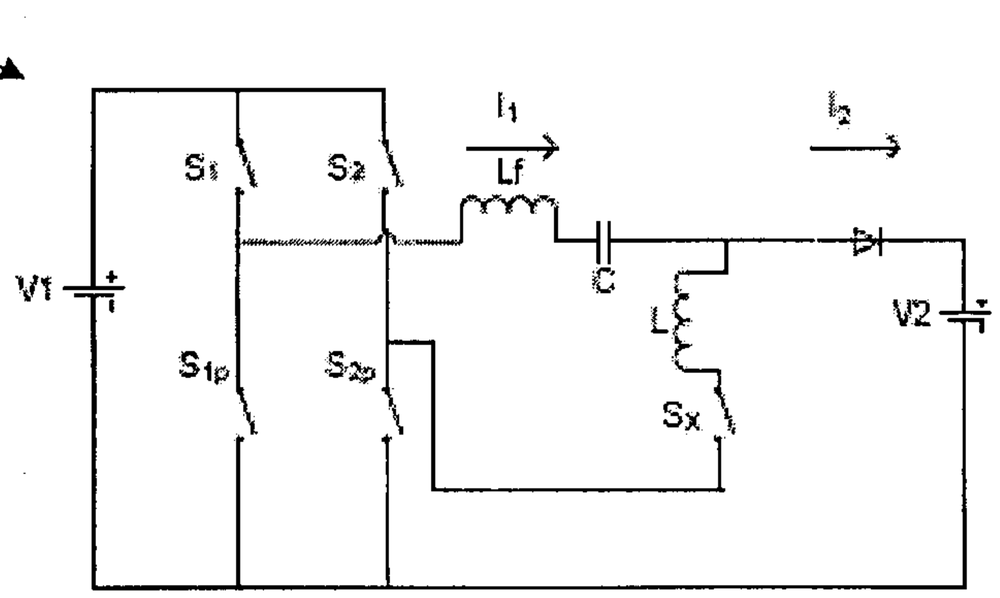


FIG. 5(c)

28

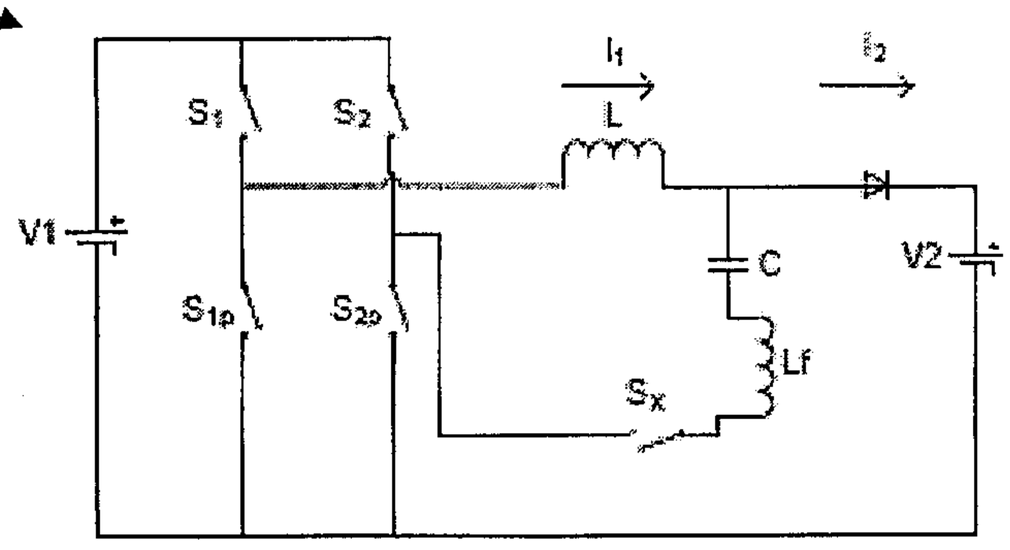


FIG. 5(d)

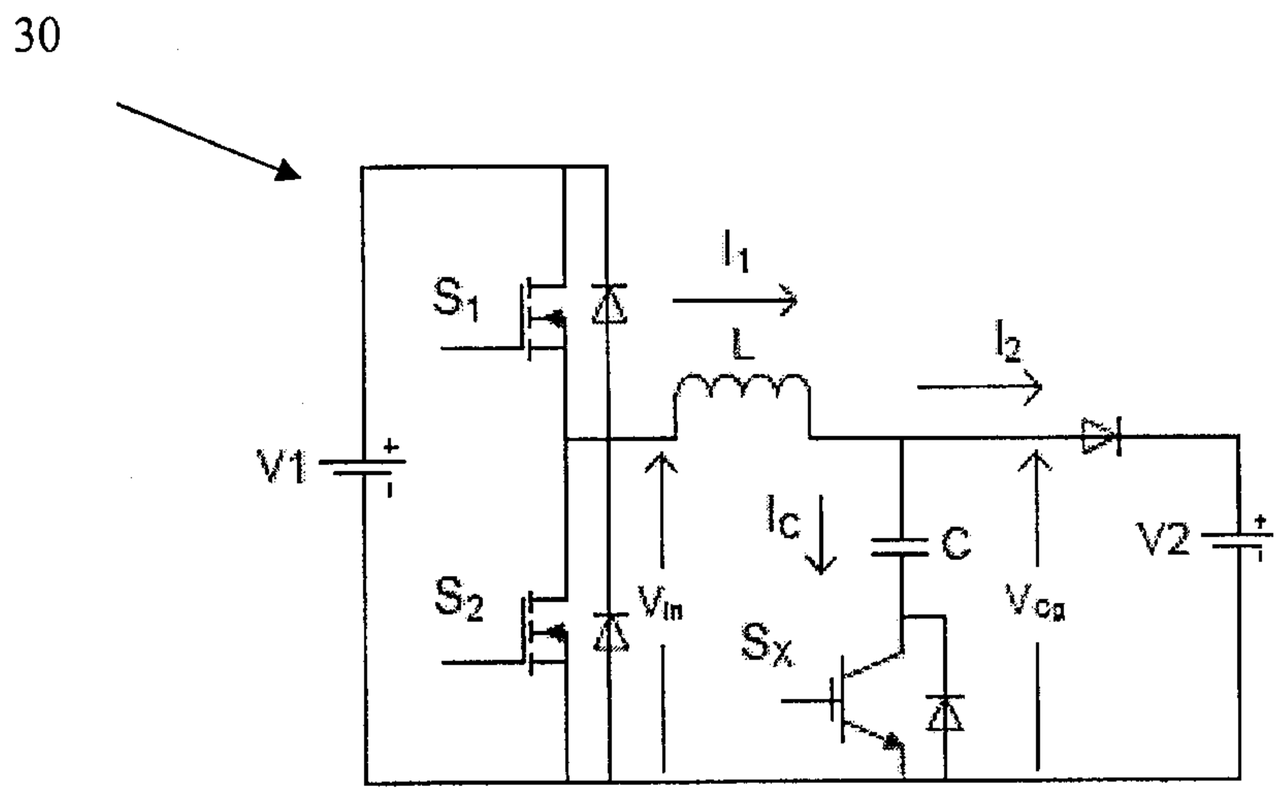


FIG. 6

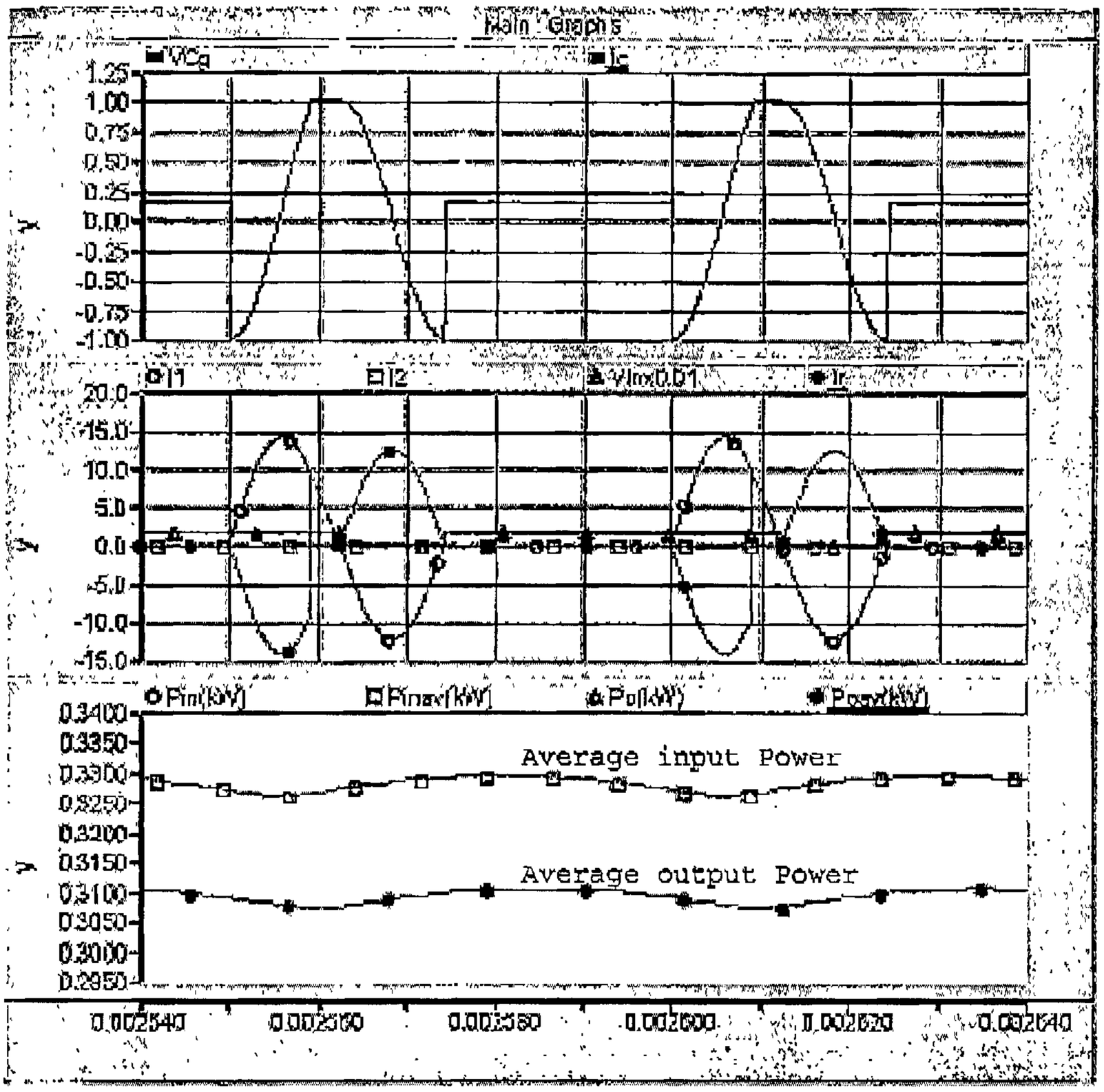

Main Graphs
Vcg
Ic
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
I1
I2
Vinv0.01
Ir
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
Pin(kW)
Pinav(kW)
Po(kW)
Poav(kW)
0.3400
0.3350
0.3300
0.3250
0.3200
0.3150
0.3100
0.3050
0.3000
0.2950
Average input Power
Average output Power
0.002540
0.002560
0.002580
0.002600
0.002620
0.002640

FIGURE 7

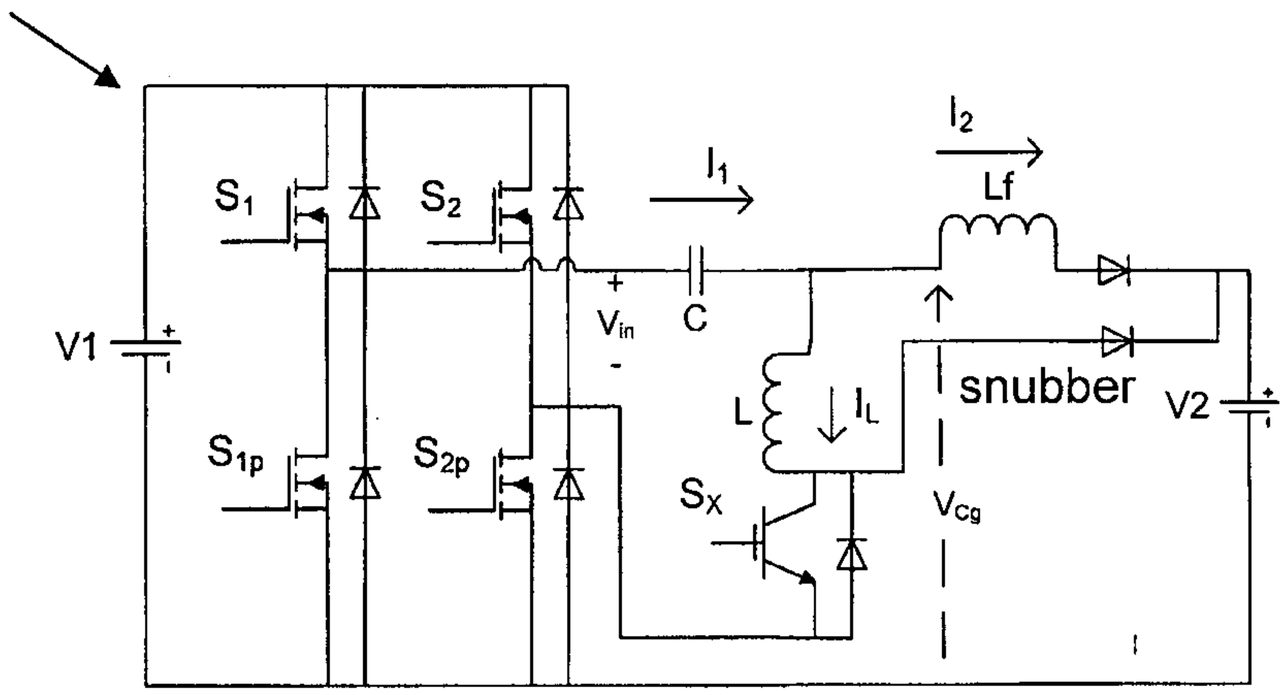


FIG. 8

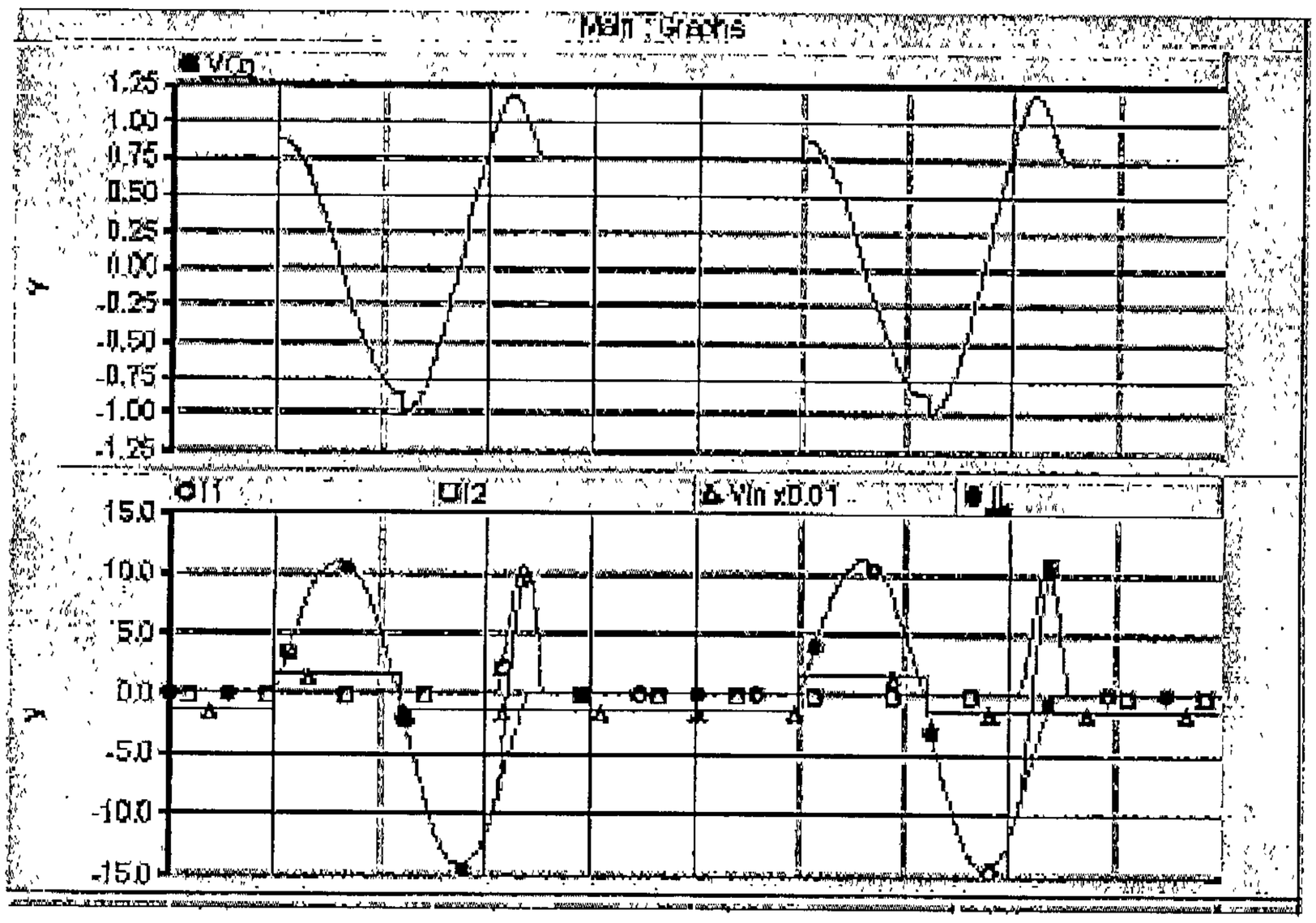

Main Graphs
Vout
1.25
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
-1.25
I1
I2
Vin x0.01
IL
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0

FIGURE 9

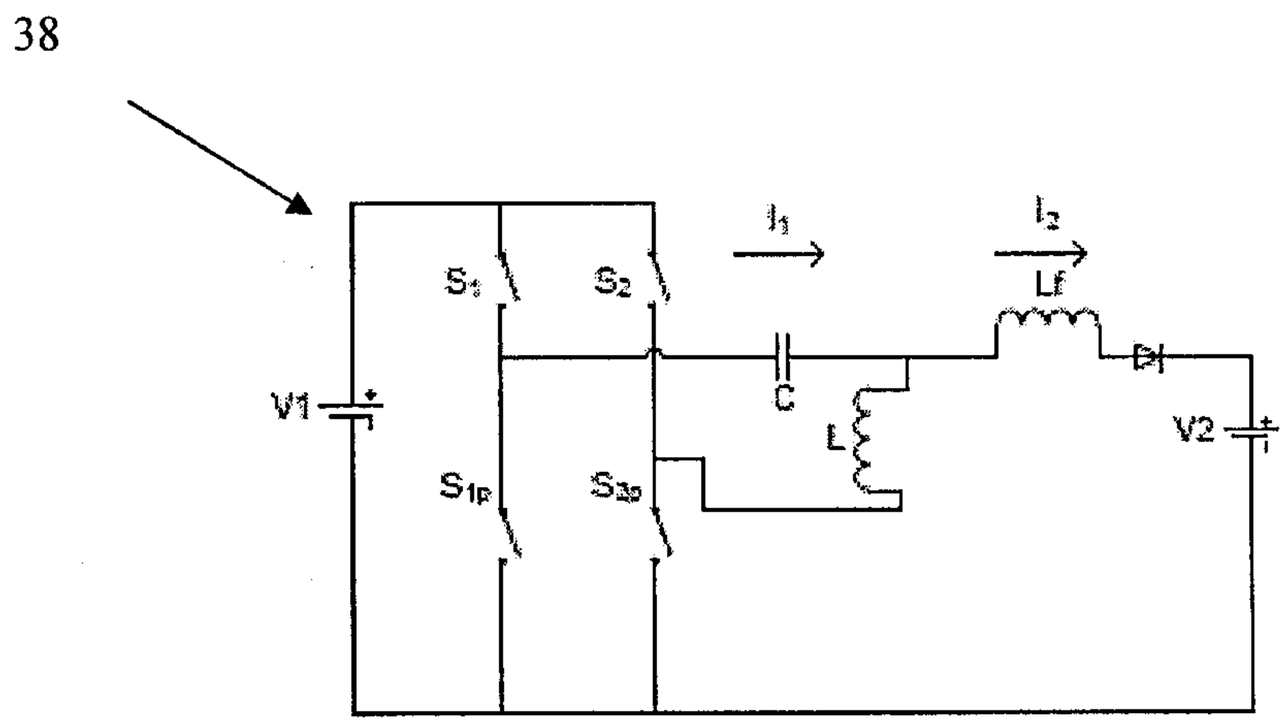


FIG. 10(a)

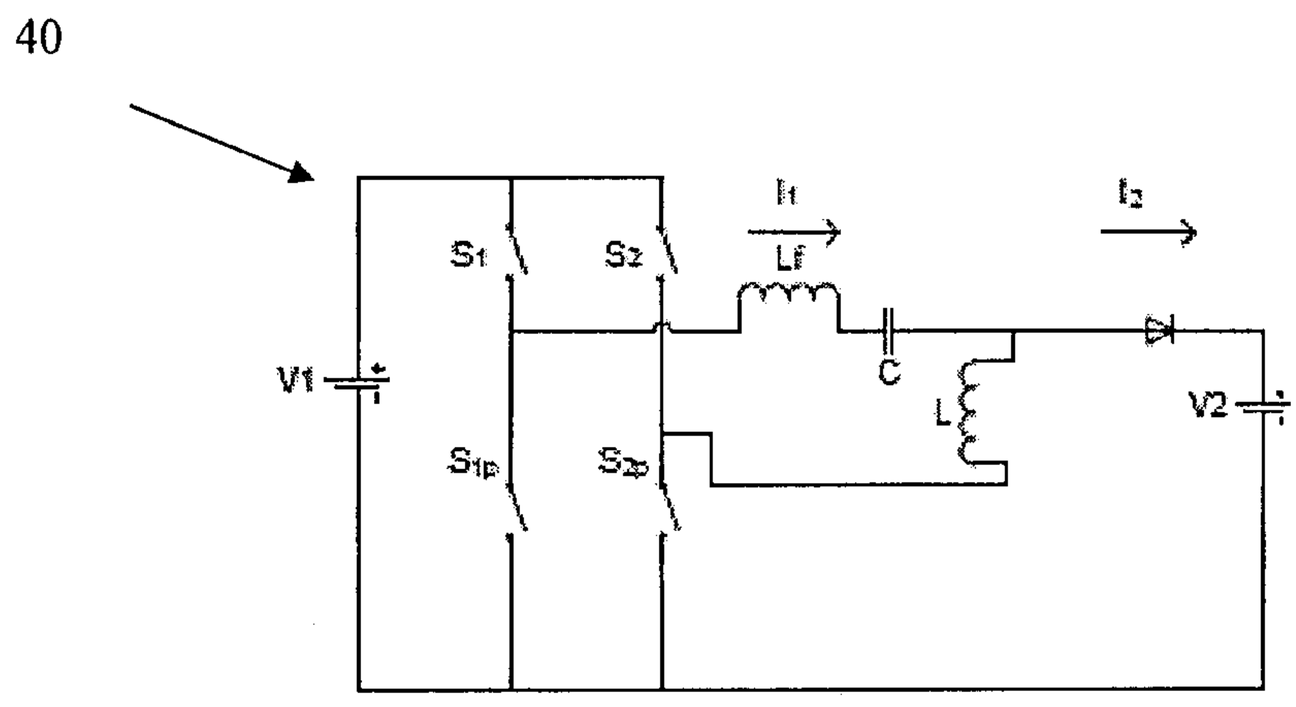


FIG. 10(b)

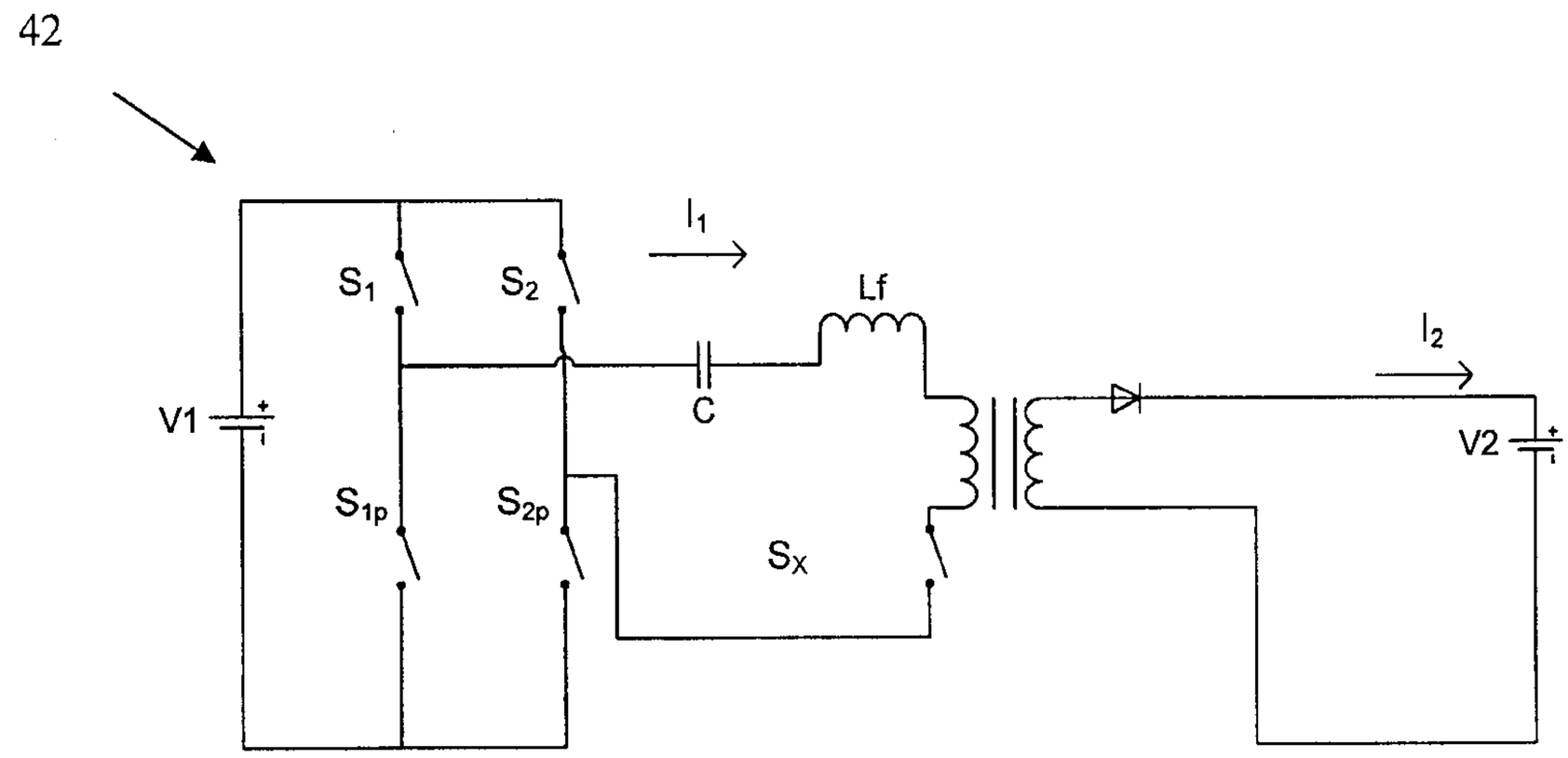


FIG. 11(a)

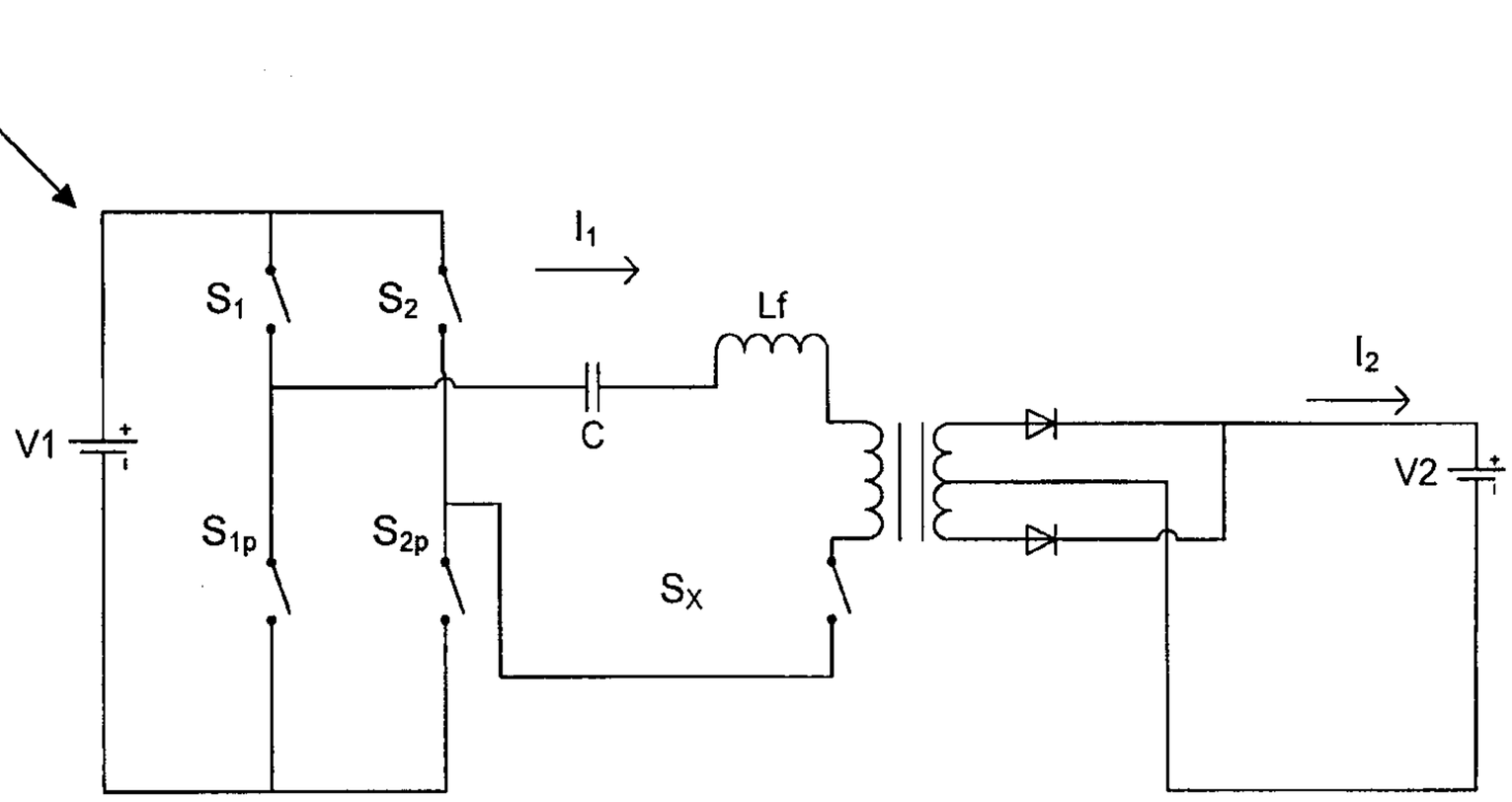


FIG. 11(b)

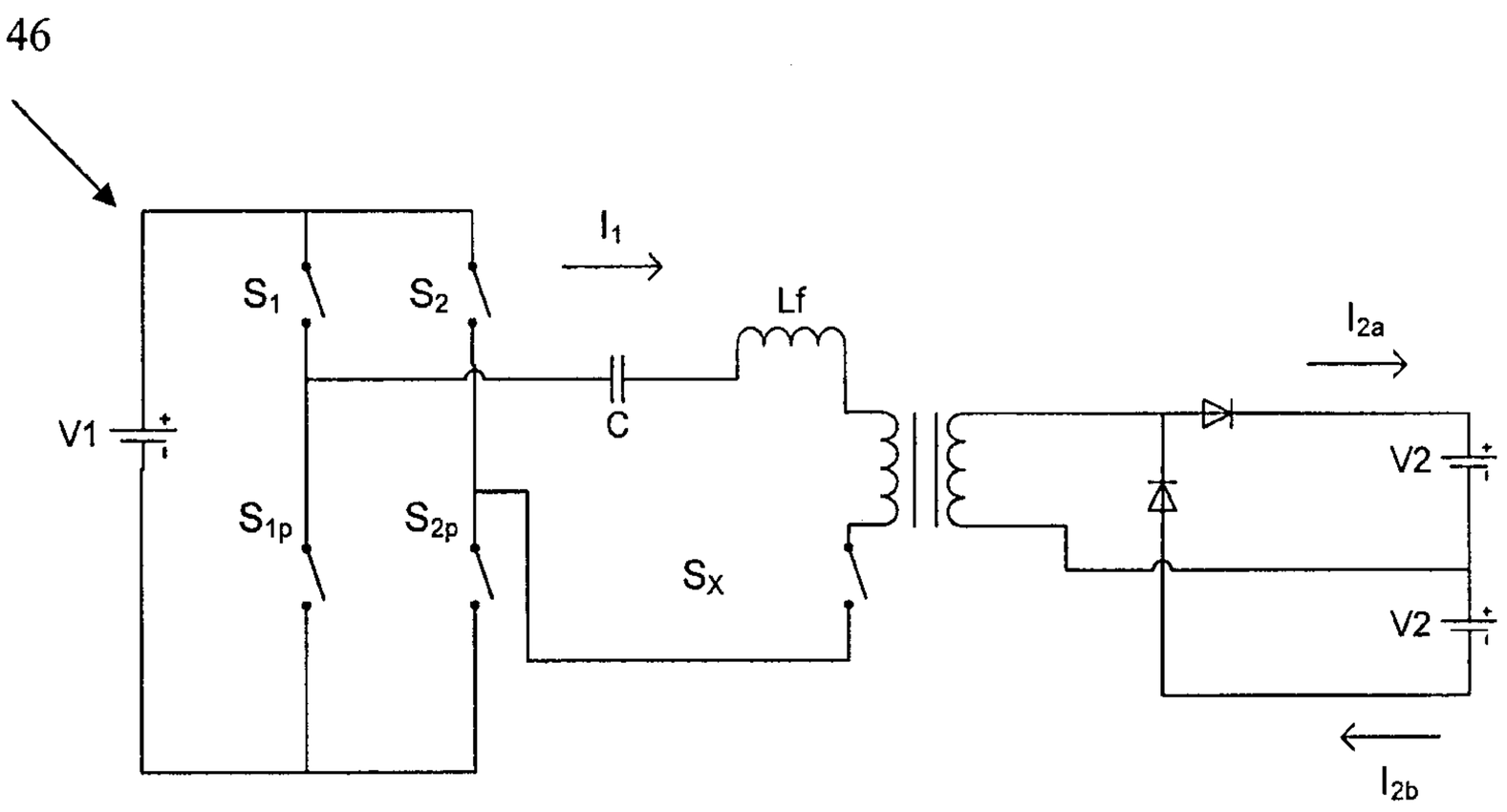


FIG. 11(c)

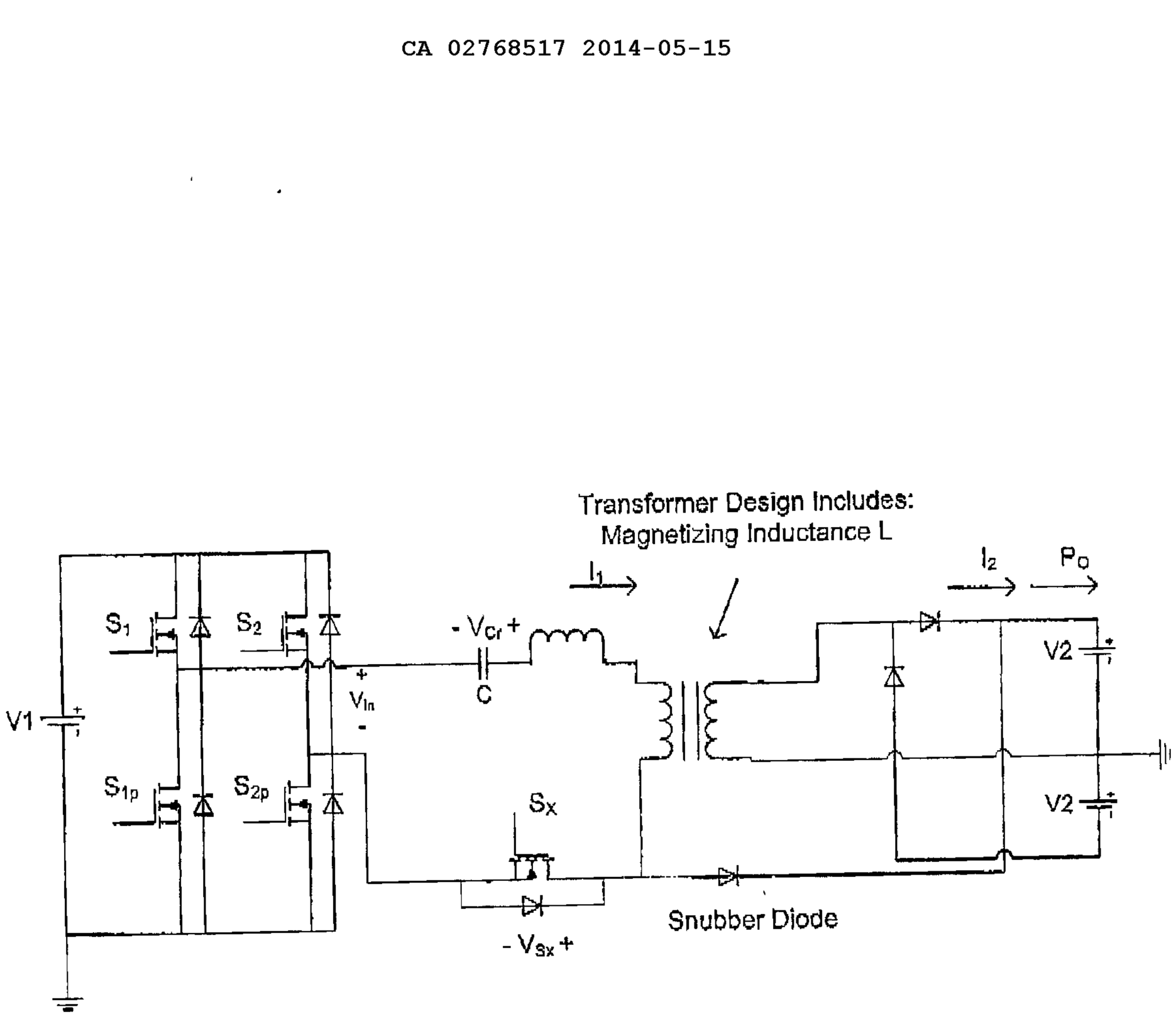

Transformer Design Includes:
Magnetizing Inductance L
I_1
I_2
P_O
S_1
S_2
S_{1p}
S_{2p}
S_X
V1
V_{In}
$-V_{Cr}+$
C
V2
V2
$-V_{Sx}+$
Snubber Diode

FIGURE 12

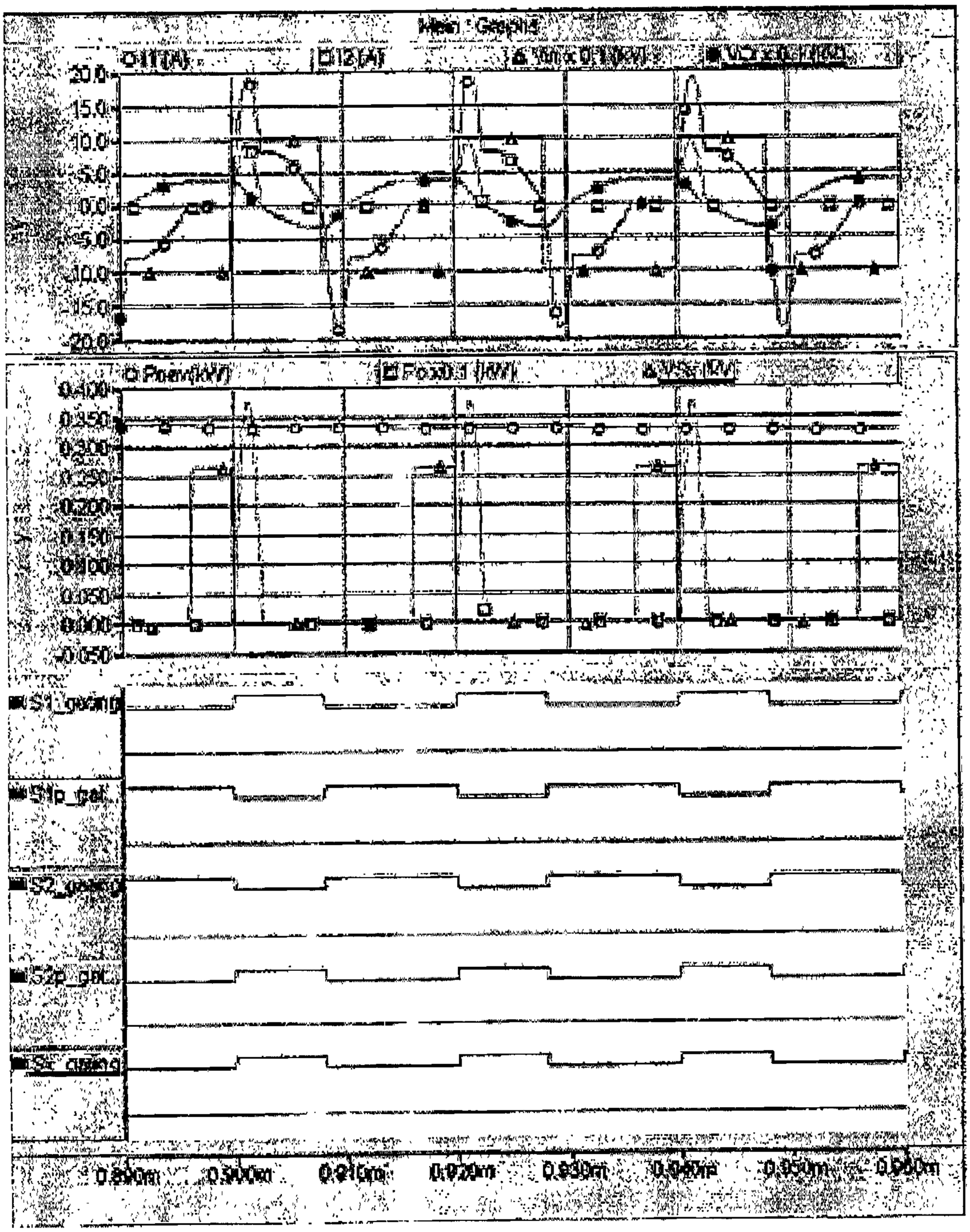
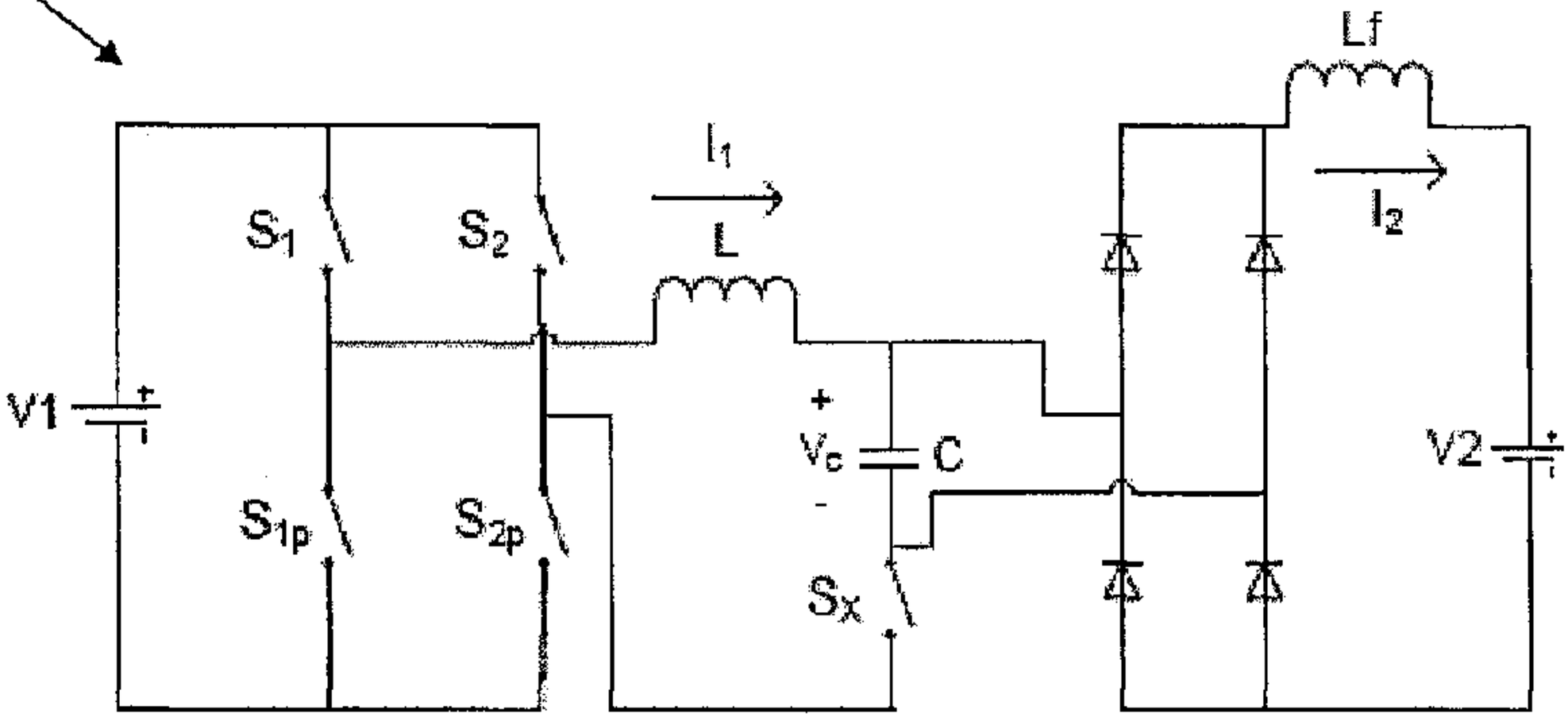


FIGURE 13

20