CAPACITOR CHARGE/DISCHARGE CIRCUITS, UTILIZING HIGH VOLTAGE IGBTS AND ZCS RESONANT MODE TECHNIQUES

By:ABHIJIT D.PATHAK

There are many applications which require pulse power. The needed burst of energy is derived by rapidly discharging a previously charged capacitor. As the energy stored in a capacitor is equal to $1/2CV^2$, higher voltage gives considerably greater pulse power.

There are many applications of pulse power, such as pulse lasers, which may be used for cutting or welding or flashlamps, which may be used to generate flashes of high intensity light. All these and many more applications require bursts of energy that can be derived from fast discharge of a previously charged capacitor. The applications and need for pulse power has seen exponential growth in the last decade and is likely to continue.

The capacitors used in these types of equipments are high voltage energy storage capacitors that need to be carefully charged by a specially designed "Capacitor-Charging Power Supply" CCPS. Fig(1) depicts charge and discharge cycle of the capacitor (or banks of capacitors in Series/parallel, depending on the energy required and Voltage rating of Capacitors), in which one can easily see the soft and slow charging cycle and the abrupt discharge. Notice also the trickle charge or refresh mode, which immediately follows the charge mode.

In order that these capacitors be charged in the shortest possible time, without causing undue stresses on semiconductors or wound components, it is advisable to use high frequency resonant mode ZCS inverter operating between 20 to 30 KHz. IXYS Corporation's BIMOSFETs can perform creditably as switches for this resonant mode inverter.The chosen devices: IXBH40N140 , IXBH40N160 or the new IXBF40N140 and IXBF40N160 in isolated i4 -PAC, depending on Mains Voltage. For calculating the inductance of the resonating choke, leakage inductance of the step-up transformer (as reflected on the primary side) has to be taken into account.

The incoming mains are first rectified by a 3-phase rectifier bridge, e.g. VUO 36-14N08,assuming mains input voltage is 440 VAC, 50Hz/60 Hz. If 550 VAC, 3 phase is available, one can use VUO 36-16N08 and likewise for 575 VAC, choose VUO 36-18N08.The current rating also depends on the number of capacitors connected in parallel and, therefore, their total capacitance. The rectified power is filtered by a D.C.Choke, made up of four "C" cores (manufactured from annealed 0.23mm strips of CRGO grade silicon iron), arranged in such a way that with the specified air gap, and copper strip wound on a bobbin, it gives just adequate inductance at the operating D.C. current without saturating.

An electrolytic capacitor filters the D.C. bus. Please note the fast acting fuses placed strategically to protect semiconductors. A shunt placed just between the common return path of the inverter and 3-phase bridge rectifier can enable one to pick the voltage off the shunt and, after proper conditioning, use it to shut off the inverter in case of overload or short circuit. Likewise, one can also put Current transformers on each incoming mains and use that to monitor the load and also to use it to trip the shunt operated circuit breaker in case of malfunction or overload. Notice the line filter inductors (LF) placed in series with each phase. This is generally constructed out of E+I cores (with identical three limbs, and three identical bobbins) wound with required gauge polyester insulated copper winding wire, and a required air gap between stack of "E" and stack of "I". The geometry, number of turns and air gap determine the inductance and saturation flux density of this filter inductor, whose purpose it is to reduce the di/dt

and, in conjunction with three C$_F$(filter capacitors), to filter out the unwanted noise, spikes from mains.

As the resonant inverter operates at a frequency in the range of 20 to 30 khz, the step-up transformer is quite small. The inverter can be operated with variable frequency and a predefined duty cycle for ON and OFF, so as to satisfy the capacitor charging requirement.

Please note the high speed bridge rectifier, VBE 20-20N01, made up of FRED Diodes and having PIV of 2000 Volts, just right for charging The series parallel combination of four capacitors to 2000 VDC. A carefully designed high frequency choke controls rate of in-rush current into the capacitors and also filters the rectified power.If still higher D.C.Bus Voltage upto 3500VDC or even 3750 VDC is desired, one can use two VBE 20-20NO1 in series.

Two High Voltage IGBTs IXLF19N250A or IXEL40N400 operating in parallel, to match the current requirements of the pulse load, can handle the capacitor's abrupt discharge functions. A driver circuit that can turn ON or OFF this High Voltage IGBT is shown in Fig.(9). Notice that an isolation transformer is used to generate isolated Vcc for this driver circuit. This circuit can easily drive two of these IXLF19N250A or IXEL40N400 connected in parallel.

HIGH FEQUENCY TRANSFORMER, RESONANT INDUCTOR AND HIGH FREQUENCY FILTER CHOKE

It is proposed to use Amorphous Metal Cores for building the above three wound components. Several advantages ensue all at once, when Amorphous Metal Cores are chosen, instead of Ferrite, Powdered iron or CRGO cores. These are listed below, as benefits over conventional cores:

1. Temperature rise: Reduced
2. Energy Efficiency: Increased
3. Compactness :   Increased
4. Reliability: Increased
5. Application Freq. Range:Higher
6. Cost :   Reduced

The above advantages accrue, because of certain intrinsic properties of Amorphous Materials, which offer lower core losses, even while operating at relatively higher flux densities, exhibiting excellent permeability and high frequency performance. Ferrites are brittle, requiring extreme care in handling. Besides ferrites can't be operated at high flux densities. Unlike Ferrites, Amorphous Metal Cores are quite rugged and require no special care. They are available as "Torroids" and/or "C" Cores in various shapes & sizes to meet particular requirement of power.

Classical design procedures can be followed for designing resonant inductor, high frequency transformer and high frequency filter inductor.

THE CONTROL CIRCUIT

D.C. to A.C. Inverters operating at High Voltage and High Frequency tend to gain significant advantages when using resonant mode and zero current switching technique due to reduced switching losses.

The Control Circuit consists of UC 3865, resonant mode controller in ZCS (Zero Current Switched) mode. This circuit is shown in Fig.(7).

Rmin together with Rrange and Cvco determine the operating frequency. For the application of capacitor charging, using BIMOSFETs , one can choose frequency in the range of 20 to 30 khz, wherein optimization is obtainable. Rmin sets the minimum frequency, while Rrange in conjunction with P5 can set the operating frequency. Output voltage is sensed using Rs and Ps as shown in Fig.(2).This sensed voltage can range from 0 Volts to 2 Volts, that can be fed into the Op Amp U1 in Fig.(7) . U1, U2 and U3 form a linear Amplifier with opo-isolation using, LOC110 or LOC111 or LOC 112 from Clare,inc(An IXYS Company). Using this arrangement 0-2 Volts feedback sensed from across the Charged Capacitor banks, is converted into isolated 0-8 VDC for feeding into UC3865 through lead/lag network. Ps in Fig.(2) can help decide level of this feed-

back (proportional value); R5, P3, and C5 in Fig.(7) determine lead (or velocity or derivative) compensation, while P4, C2 and R6 determine level of lag (or Integral) compensation. Optimum adjustments can yield stable value of output voltage, within preset value(with minimum error) and with desired level of stability. Please note that the circuit has soft start feature, which comes into effect, every time inverter is restarted.

Resonant current in the inverter bridge is sensed by Hall effect transducer which is inserted in the resonant primary loop. For rectification, use either Schottky Diodes or FREDs (Fast Recovery Epitaxial Diodes, forming a bridge rectifier). After filtering, it is sensed as a voltage across R3 . This is fed into "zero" input directly. R1 and P1 help adjust the fault level of this current before feeding this signal into "Fault" pin of UC3865. Hin and Lin are the outputs of this ZCS resonant mode controller. Hin and Lin are fed into the Driver Circuit, which, in-turn, can drive four BIMOSFETs in the "H" Bridge forming high frequency inverter.

BIMOSFET DRIVER CIRCUITS

BIMOSFETs are new improved devices, which fulfil the special requirements of high voltage MOSFETs having lower conduction losses. Until the arrival of IXYS CORPORATION's 1600V BIMOSFETs, one had to connect two (say, 800V) MOSFETs in series to get a high voltage MOSFET, with its attendant driving complexity. The available IGBTs were too slow for some applications. The technical specifications of the entire range of BIMOSFETs are available from IXYS CORPORATION.

Their internal construction is different from both MOSFETs and IGBTs; however, they can be driven easily, using any MOSFET/IGBT driver.

IXBD4410 AND IXBD4411 HALF BRIDGE MOSFET/IGBT DRIVER CHIPSET

This chipset is best suited to applications in Half Bridge, Full Bridge and 3 Phase Bridge topologies. Here the IXBD4410 is wired as a full-featured Low-Side Driver, while IXBD4411 is wired as a full-featured High-Side Driver. Together, they make up a stand alone Driver System for Phase leg of any of the above mentioned Bridge Configurations. The suggested wiring diagram is shown in Fig.(8). Likewise, the wiring diagram is to be repeated for each phase leg and hence one needs two such cards for "H" Bridge and three such cards for 3-Phase Bridge.

As can be seen in this schematic, to obtain galvanic isolation, it uses one ferrite core transformer for sending drive signals to IXBD4411 and another ferrite core transformer for receiving fault and status signals from IXBD4411. T1 represents both these transformers housed in one IC type package. To avoid saturation, capacitors are placed in series with each primary winding to which AC (time-varying signals) are transmitted. 1200 Volts of isolation barrier is built in.

Both IXBD4410 and IXBD4411 are feature-rich Drivers. These include:
1. Undervoltage and overvoltage lockout protection for Vcc;
2. dV/dt immunity of greater than $\pm$ 50 V/ns;
3. Galvanic isolation of 1200 Volts (or greater) between   low side and high side;
4. On-chip negative gate-drive supply to ensure MOSFET/IGBT turn-off even in electrically noisy environment;
5. 5 volt logic compatible HCMOS inputs with hysteresis;
6. 20ns rise and fall times with 1000 pF load and 100 ns rise and fall times with 10000 pF load;
7. 100 ns of propagation delay;
8. 2 Ampere peak output Drive Capability;
9. Automatic shutdown of output in response to overcurrent and/or short-circuit;
10. Protection against cross conduction between upper and lower MOSFET/IGBT;
11. Logic compatible fault indication from both low and high-side drivers.

H-BRIDGE DRIVER CIRCUIT, USING BOOTSTRAPPING TECHNIQUE, WITHOUT OPTO-ISOLATION

Fig(3) shows this circuit with all the necessary details required to build it for driving BIMOSFETs. It is necessary first to understand the driving requirements for BIMOSFETs, connected in "H" Bridge configuration. Note that the primary requirement of any driver is to be able to charge the gate-source or gate-emitter capacitance, with required speed. Another requirement is to have minimum propagation delay, guaranteeing very quick response time between occurence of overload /short circuit and switching off of the BIMOSFETs. In fact, the Control Circuit described above will just do that. A TWO-INPUT-AND gate continuously monitors gate signals Hin and Lin (for upper and lower BIMOSFETs in the "H" Bridge), and in the unexpected event of simultaneous occurence of the two, the AND gate generates a LOGIC HIGH and the Driver IC will stop the output for that much duration. This way, catastrophic punch through between upper and lower BIMOSFETs can never ever occur.

"H" Bridge configuration has another unique requirement, that is the upper BIMOSFET 's emitter is not at the ground potential, but is floating, making it necessary to either employ bootstrapping technique or use galvanic isolation (using opto-coupler or transformer) to drive the upper BIMOSFETs. Bootstrapping technique is used in Fig(3). It is always wise to use negative bias on the gate of non-conducting BIMOSFET in the "H" Bridge. Fig(3) depicts how -ve bias is generated for upper and lower BIMOSFETs. Please note that for the Driver IC chosen, one can't exceed a total power supply voltage of 20 volts; hence we have chosen -3.9 volts. Note that a low current sensitive zener with sharp knee and 1% tolerance should be chosen.

In order to protect the gate-emitter junction of the BIMOSFETs, two 18V Zeners, connected back-to-back are put across the junction. Here again choose low current sensitive zeners with sharp knee and 1% tolerance of Vz. Rb provides a bleed off path for stray charge, that might have accumulated between gate and emitter junction of the BIMOSFETs, to facilitate faster switch-off.

Rg sits in between the output pin of Driver IC and gate of BIMOSFET. Selection of proper value of this resistor depends on various factors; primary among them is speed, with which to turn on the BIMOSFET. Another effect is that of dv/dt (of the Collector-to-Emitter voltage, during switching), which could, by charging the Collector-Gate-Capacitance, force a large current out of the gate, which may damage the output stage of the Driver IC. Presence of sufficient value resistance, between output of the Driver IC and Gate of BIMOSFET, prevents this from happening. It is appropriate at this juncture to talk of the importance of properly selected snubber circuit, consisting of non-inductive low value power resistor connected in series with optimally chosen prolypropelene capacitor.This snubber is highly recommended and by using it, one is lowering the dependence of Rg on dv/dt related compulsions. If by any chance one is trying to connect two BIMOSFETs in parallel to increase current carrying capacity, then presence of Rg in series with gate of each BIMOSFET helps in ensuring simultaneous Turn-On and Turn-Off of the two BIMOSFETs connected in parallel. An optimal value of Rg ,say, 22 ohms can thus be chosen.

A fast switching diode (such as 1N4148) connected inversely across Rg helps very fast turn-off of the BIMOSFETs. If necessary, a low value resistor can be connected in series with this switching diode to obtain soft turn-off.

For most applications, Driver ICs, which have D.C. Bus specification of 600 VDC will work.

For the sake of completeness, Fig(4), depicts suggested circuit diagram for BIMOSFETs connected in 3 phase bridge configuration. All the above comments apply to this Driver circuit as well.

MOSFET/ BIMOSFET/ IGBT DRIVER CIRCUIT WITH OPTO-ISOLATION FOR "H" BRIDGE INVERTER

Fig(5) depicts complete circuit utilizing opto-isolators, identically for each switching device in the "H" Bridge. Needless to say, the lower switches in the bridge actually do not require opto-

isolation, as they are referenced to common ground. The logic behind making identical chains of opto-isolators and push-pull matched transistor pairs is to guarantee same propagation delays for the gate signals for all switches in the "H" Bridge, so when they arrive at the gate of the switches, they bear the same phase relationships, as when they were fed into the driver circuit.

Note that the input signals are individually fed into darlington transistor arrays so as to boost their current capacity. These, in turn, are fed into high speed opto-couplers. The output of the opto-coupler is fed into matched transistor pairs of PNP & NPN through a resistor. Note the elaborate bypassing of isolated power supplies, near the transistor pairs with high quality capacitors (having minimum ESR & ESL).

For both upper BIMOSFETs in the "H" Bridge, isolated power supplies are used to power the PNP-NPN matched transistor pairs. A complete power supply circuit is shown as one of the ways of generating isolated + & - 15 VDC power supplies. Alternatively, D.C. to D.C. converter (or A.C. to D.C. PFC switcher) can be used with multiple isolated + & - 15 VDC supplies.

Rb helps provide a bleed of path for any accumulated stray charge on gate-emitter capacitance of the BIMOSFETs, while the 18 V zeners connected back to back ensures that the gate never ever receives any signal higher than 18.7 volts of either polarity. Note the simple technique used to provide designer with independent choices for selecting Rg ON and Rg off. This enables one to design in the turn-on and turn-off speed of the BIMOSFETs. A properly designed snubber network of Rc and Cc across each BIMOSFET ensures that BIMOSFETs do not turn- On inadvertently due to dv/dt . For the sake of completeness, Fig(6) depicts similar circuit for driving BIMOSFETs in a 3 phase bridge inverter configuration.

PULSED LOAD

Once the energy storage capacitor bank is fully charged, the pulsed load can be turned on by one or more High Voltage IGBTs.(IXYS Corporation's

IXLF19N250A has a V_{CES} rating of 2500 Volts and Max. I_C rating of 32 Amps), depending on the load current. This can be controlled by sensing the voltage across the series-parallel bank of four capacitors and turning on S5 and S6 simultaneously. A series-parallel combination of four C_L along with stabilizing power resistors is what is shown in Fig.(2). This kind of an arrangement allows use of,say, four 1000 Volts rated capacitors to be used on a 2000 Volts charging circuit and thus get four times the energy output from the same capacitors. As soon as C_L is discharged the control circuit, starts its soft charging cycle, with designed-in charging time. Note that IXLF19N250A can easily handle 2000 VDC as final voltage on the capacitor bank and in a transient voltage free environment, this can be extended upto,say,2200 or even 2300 VDC, which will give greater energy storage capability. For still higher Voltage, IXEL40N400 is recommended. This very high Voltage IGBT from IXYS is rated at Vces=4000 Volts and Ic=40 Amps. Here the Bus Voltage can go up to 3500 V or even 3750 V.

If a higher D.C.Bus voltage is available, high frequency high voltage transformer can be done away with and the CL can be directly charged by the same circuits described above.

The versatility of this system lies in its ability to charge a variety of energy storage capacitors for many different types of pulsed loads. The resonant frequency of the Full Bridge Inverter is determined by value of total inductance and capacitance (both distributed and lumped) in series. The capacitance of the energy storage capacitor, being charged, is reflected to primary by multiplying its value by square of the transformer turns ratio(i.e.Crefl= $Cx(Ns/Np)^2$ By changing the rate of charging, one can keep the same current through resonant circuit, for some variations in capacitance values. As this high value capacitance, when reflected to primary, is effectively connected in series with Cr and Lr, the net series effective value of capacitance, which determines the resonant frequency, is nearly same as Cr. This

is, because when one very small value capacitor and one very large value capacitor are connected in series, the net effective value is approximately equal to the smallest value(1/Ceff=1/Cr+1/Crefl where Ceff stands for effective value of net capacitance which determines resonant frequency, Crefl=value of energy storage capacitance reflected to primary, Cr=lumped value of capacitor connected in series with Lr). This is the virtue of the chosen series resonant inverter, which unlike parallel inverter, operates at the same frequency, even though different value energy storage capacitors are being charged.

If capacity doubling is called for, two BIMOSFETs can be paralalled in the "H" Bridge.Likewise more IXLF19N250A can be paralleled in series with the pulsed load. $Vce_{(sat)}$ and Vf of BIMOSFET have a positive temperature co-efficient. This makes it very easy for them to be paralleled. Even the forward voltage drop of the Anti-Parallel diode, having same current rating as the BIMOSFET, has a positive temp. co-efficient, enabling it also to share currents equally, when connected in parallel.

Similarly IXLF19N250A also have positive temp.co-efficient and hence they will tend to share discharge current equally amongst themselves.

It is, of course, understood that similar doubling of capacity will entail choosing appropriately rated higher capacity 3-phase rectifier from a number of available units from IXYS CORPORATION. One can then choose fuses and MCBs (with proper i^2t rating) and bigger filters. For output single phase high speed rectifier, a full range of FRED diodes are available from IXYS CORPORATION. A full bridge rectifier can easily be constructed, using these FRED diodes.

DISCLAIMER:
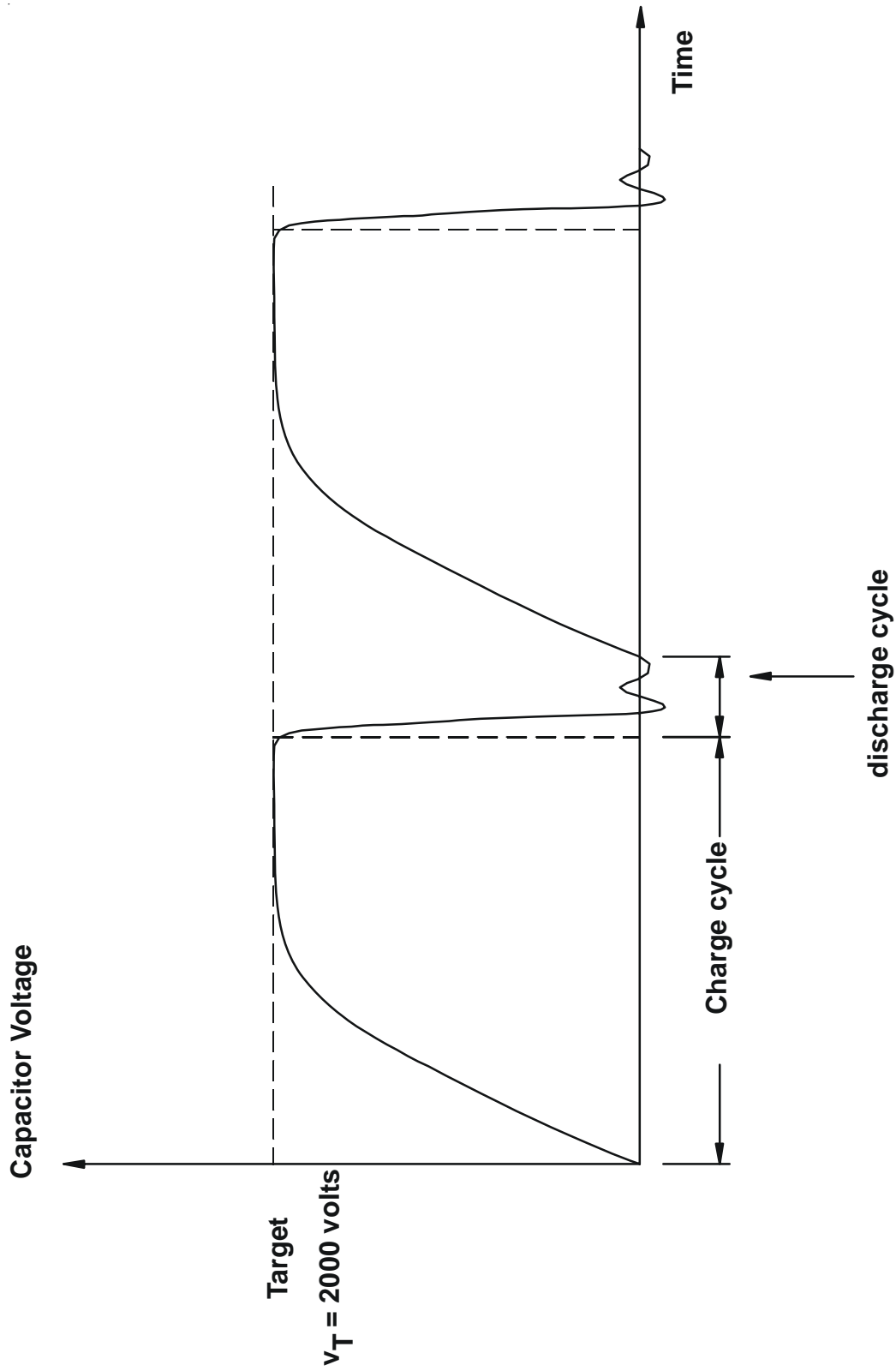
Fig. 1   Charge/Discharge Cycle of Energy Storage Capacitors

Fig. 2 Elaborate Power Schematic of Capacitor Charging Power Supply
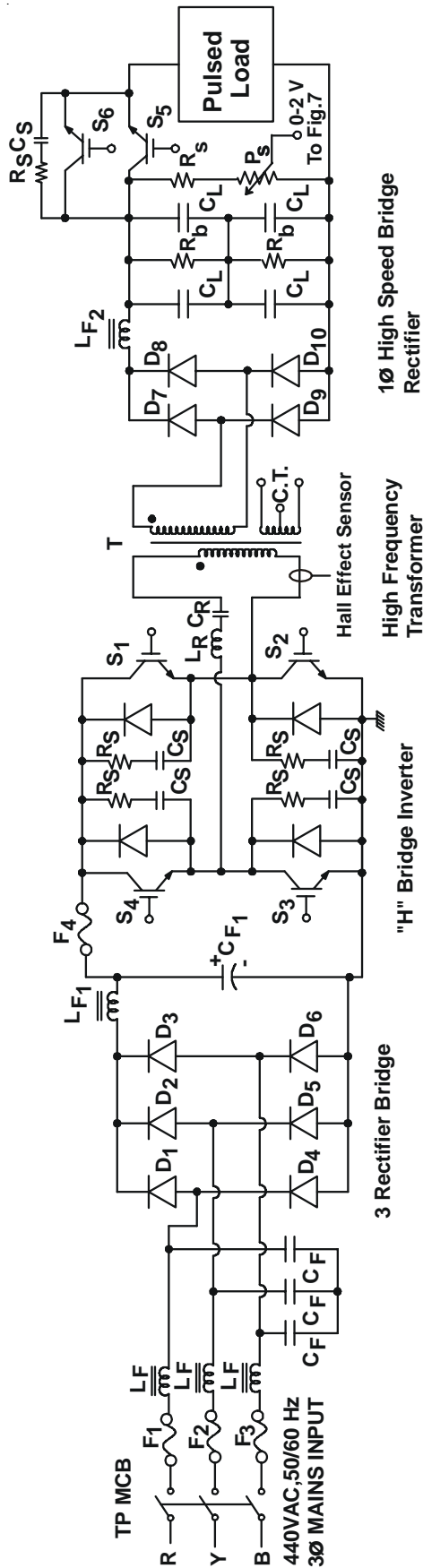
NOMENCLATURE :

1. R, Y, B or R, S, T are names of three phases
2. TP MCB : Three phase Miniature Circuit Breaker.
3. F1, F2, F3, F4 are fast acting fuses - appropriately rated.
4. LF1 : Rectifier Choke (D. C. choke)
5. CF1 : Electrolytic Capacitor for filtering rectified voltage.
6. D1, D2, D3, D4, D5, D6 - IXYS make 3 Phase Rectifier Bridge : VUO 36-14N08
7. S1, S2, S3, S4 - IXYS make IXBH 40N140 or IXBF 40N140 BIMOSFETS
8. LR : Resonating Choke
9. CR : Resonating Capacitor
10. T : Step up High Frequency Transformer
11. D7, D8, D9, D10 - IXYS make Single Phase Bridge Rectifier with FRED Diodes Type
    No : VBE 20-20N01
12. S5, S6 : Two IXYS make IGBTs in parallel Type no : IXLF19N250A
13. Rs & Cs are non-inductive Resistors and capacitors forming Snubber
    networks across BI-MOSFETS.
14. LF2 : Filter choke
15. CL : Capacitor (single or multiple identical Capacitors in Parallel), Which
    are under testing or are to be qualified.
16. Pulsed load could be Flash lamps or pulsed laser or any other load requring
    quick discharge of Capacitors.
17. LF : Line Filter inductor wound on 3 Phase core.
18. CF : Non-polarised Filter Capacitors.
19. Rb : Balancing power resistors to ensure all CL Capacitors are charged to the same Voltage
20. Rs : Value and power rating depends upon final D. C. Voltage
21. Ps : 1K multi turn trimpot. Its center wiper should give 0-2 VDC for highest variation of O/P Voltage.
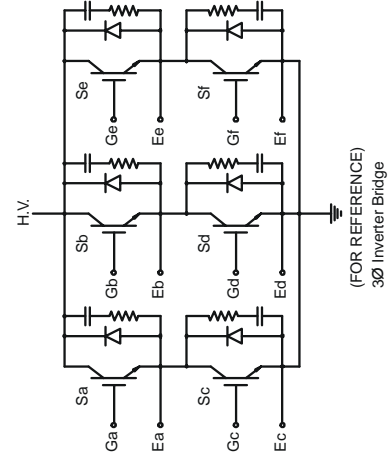   This Voltage is fed into U1 as feedback Voltage for controlling operation of Uc3865.

IC1,IC2= IX2R11P7 For D. C. Bus Voltages up to 600 VDC
IC4=CD4081 Two input AND Gate
D1,D9=DSEP 8-12A HiPerFRED Diodes
D3,D4,D11,D12=IN5822
D5,D6,D7,D8,D13,D14,D15,D16=18V,400mw sensitive Zener with sharpe knee
D2,D10=3.9V,400mw sensitive Zener diode
C1,C4=47MFD,25VDC. Tantalum Capacitors
C2,C3,C5,C6=0.1MFD,1000V polyester or polypropylene capacitors
R1= 33 K,2 W (Value and wattage depends on D.C. Bus voltage; its value determined based on Zener current & D.C. Bus voltage)
Rb=10k,1/4w
Rg = 4.7 Ohms to 33 Ohms (Value depends on the MOSFET / BIMOSFET / IGBT being driven; it determines turn on speed of device)

Fig.(3) H-Bridge Driver Circuit using Bootstrapping techniques, without opto-isolation.
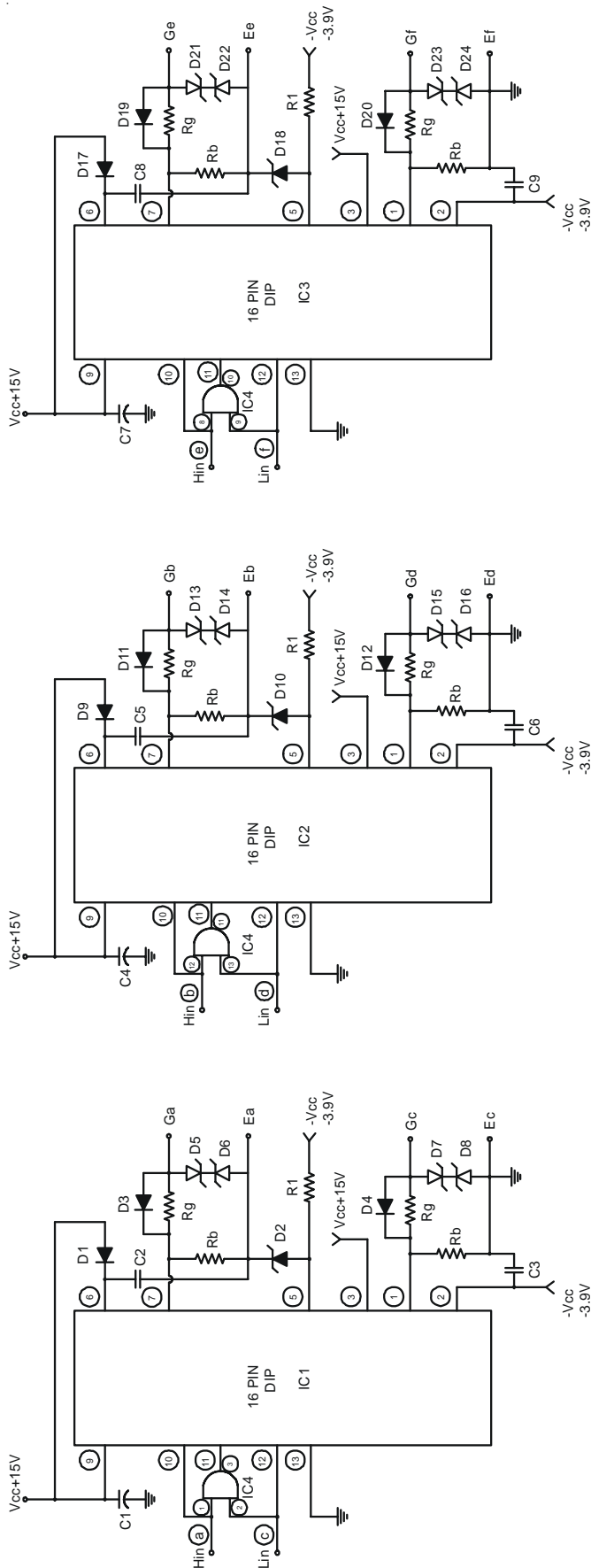
IC1,IC2,IC3=IX2R11P7 For DC Bus Voltages up to 600 VDC
IC4=CD4081 Two input AND gate
D1,D9,D17=DSEP 8-12A
D3,D4,D11,D12,D19,D20=1N5822
D5,D6,D7,D8,D13,D14,D15,D16,D21,D22,D23,D24=18V,400mwSensitive Zener with sharp Knee
D2,D10,D18=3.9V,400mw sensitive Zener diodes with sharp knee
C1,C4,C7=47MFD,25VDC Tantalum Capacitors
C2,C3,C5,C6,C8,C9=0.1MFD,1000 volts polyester or Polypropylene Capacitors
R1=33K, 2 W (Value and wattage depends on D.C. Bus voltage; value calculated by considering Zener current)
Rb=10k,1/4w
Rg= 4.7 Ohms to 33 Ohms (Depends on MOSFET / IGBT being driven in determines turn on speed of device)

Fig.(4) 3 Ø Bridge Driver circuit using Bootstrapping techniques, without Opto-isolation

IXYS

1. U1,U2,U3,U4- HCPL-3120 (Agilent Technologies) 8 pin DIP Power MOSFET / BIMOSFETS / IGBT Gate Drive Opto-coupler

2. Q1,Q3,Q5,Q7- 2N4401 NPN BJT for driving small to medium power IGBTS/BI-MOSFETS/MOSFETS.

3. Q2,Q4,Q6,Q8- 2N4402 PNP BJT for driving small to medium power IGBTS/BI-MOSFETS/MOSFETS.

or

2. Q1,Q3,Q5,Q7- ZTX450 NPN BJT for driving medium power IGBTS/BI-MOSFETS/MOSFETS.

3. Q2,Q4,Q6,Q8- ZTX550 PNP BJT for driving medium power IGBTS/BI-MOSFETS/MOSFETS.

or

2. Q1,Q3,Q5,Q7- TIP41C NPN BJT for driving high power IGBTS/BI-MOSFETS/MOSFETS.

3. Q2,Q4,Q6,Q8- TIP42C PNP BJT for driving high power IGBTS/BI-MOSFETS/MOSFETS.

or

2. Q1,Q3,Q5,Q7- BD743C for driving very high power IGBTS/BI-MOSFETS/MOSFETS.

3. Q2,Q4,Q6,Q8- BD744C for driving very high power IGBTS/BI-MOSFETS/MOSFETS.

4. D1 to D8- 18 Volt,400 mW zener diodes.

5. Rb- 2K2,2W

6. Rg ON- Depends on the MOSFET/BI-MOSFETS/IGBT being driven. This resistor determines "turn on" speed of MOSFET/BI-MOSFETS/IGBT.

7. Rg OFF- Depends on the MOSFET/BI-MOSFETS/IGBT being driven.

This resistor determines "turn off" time. Rg OFF can be kept much smaller then Rg ON to improve turn off characteristics.

Note : Some applications use Schottky Rectifiers (say 1N5822) in place of Rg OFF or use Rg OFF in series with Schottky Rectifier

8. C1 to C8- 22MFD, 25VDC Tantalum Capacitors
9. C9,C15,C21- 1000MFD, 35VDC
10. C10,C16,C22- 470MFD, 35VDC
11. C11,C17,C23- 22MFD, 35VDC
12. C12, C18,C24- 1000MFD, 35VDC
13. C13,C14,C19,C20,C25,C26,- 22MFD, 35VDC
14. D9 to D21- DSEP 8-12A

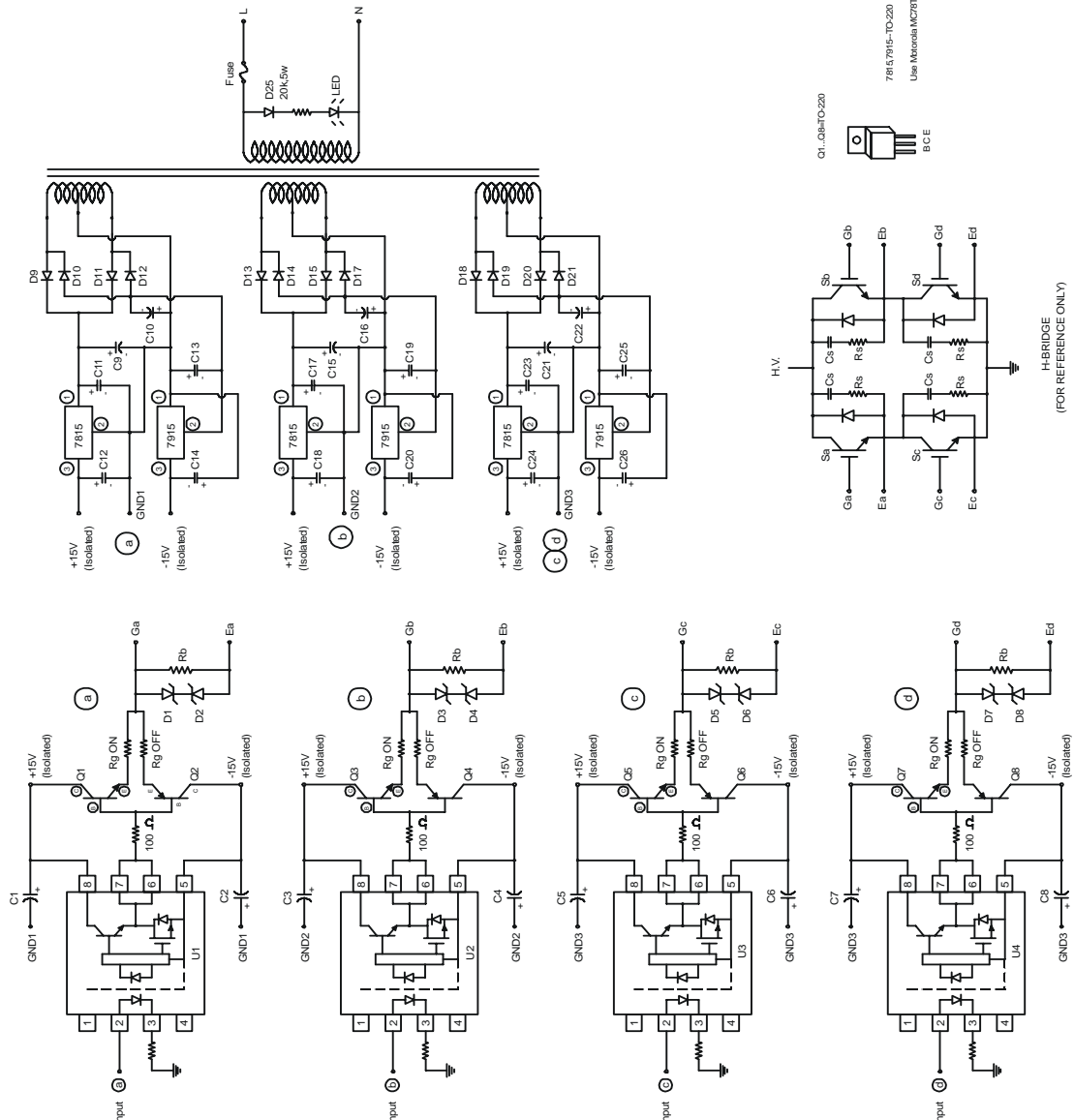7815,7915-TO-220
Use Motorola MC78T15CT

Fig.(5) MOSFET/BI-MOSFET/IGBT Driver Circuit with Opto-isolation for 'H' Bridge Inverter

1. U1,U2,U3,U4,U5,U6- HCPL-3120 (Agilent Technologies) 8 pin DIP
   Power MOSFET/BI-MOSFETS/IGBT Gate Drive opto-coupler
2. Q1,Q3,Q5,Q7,Q9,Q11- 2N4401 NPN BJT for driving small to medium power
   IGBTS/BI-MOSFETS/MOSFETS.
3. Q2,Q4,Q6,Q8,Q10,Q12- 2N4402 PNP BJT for driving small to medium power
   IGBTS/BI-MOSFETS/MOSFETS.

   or

2. Q1,Q3,Q5,Q7,Q9,Q11- ZTX450 NPN BJT for driving medium power
   IGBTS/BI-MOSFETS/MOSFETS.
3. Q2,Q4,Q6,Q8,Q10,Q12- ZTX550 PNP BJT for driving medium power
   IGBTS/BI-MOSFETS/MOSFETS.

   or

2. Q1,Q3,Q5,Q7,Q9,Q11- TIP41C NPN BJT for driving high power
   IGBTS/BI-MOSFETS/MOSFETS.
3. Q2,Q4,Q6,Q8,Q10,Q12- TIP42C PNP BJT for driving high power
   IGBTS/BI-MOSFETS/MOSFETS.

   or

2. Q1,Q3,Q5,Q7,Q9,Q11- BD743C for driving very high power IGBTS/BI-MOSFETS/MOSFETS.
3. Q2,Q4,Q6,Q8,Q10,Q12- BD744C for driving very high power
   IGBTS/BI-MOSFETS/MOSFETS.

4. D1 to D12- 18 Volt,400 mW zener diodes.
5. Rb- 2K2,2W
6. Rg ON- Depends on the MOSFET/BI-MOSFETS/IGBT being driven.
   This resistor determines "turn on" speed of MOSFET/BI-MOSFETS/IGBT.
7. Rg OFF- Depends on the MOSFET/BI-MOSFETS/IGBT being driven.
   This resistor determines "turn off" time. Rg OFF can be kept much smaller then
   Rg ON to improve turn off characteristics.

   Note : Some applications use switching diode (say IN4148 or IN914) in place of
   Rg OFF or use Rg OFF in series with switching diode.

8. C1 to C12- 22MFD, 25VDC Tantalum Capacitors
9. C13,C19,C25,C31- 1000MFD, 35VDC
10. C14,C20,C26,C32- 470MFD, 35VDC
11. C15,C21,C27,C33- 22MFD, 35VDC
12. C16,C22,C28,C34- 1000MFD, 35VDC
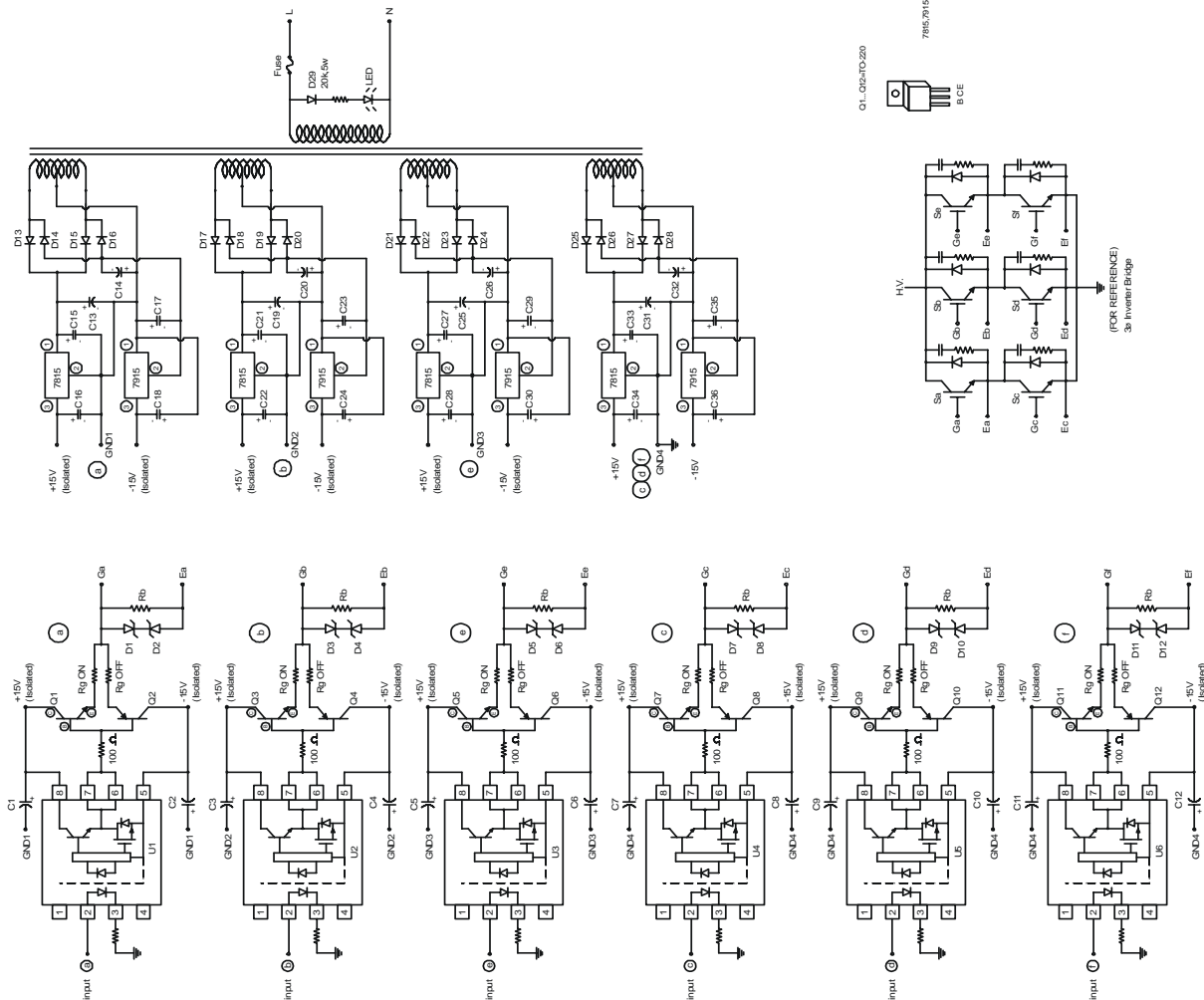13. C17,C18,C23,C24,C29,C30,C35,C36- 22MFD, 35VDC
14. D13 to D29- BA159

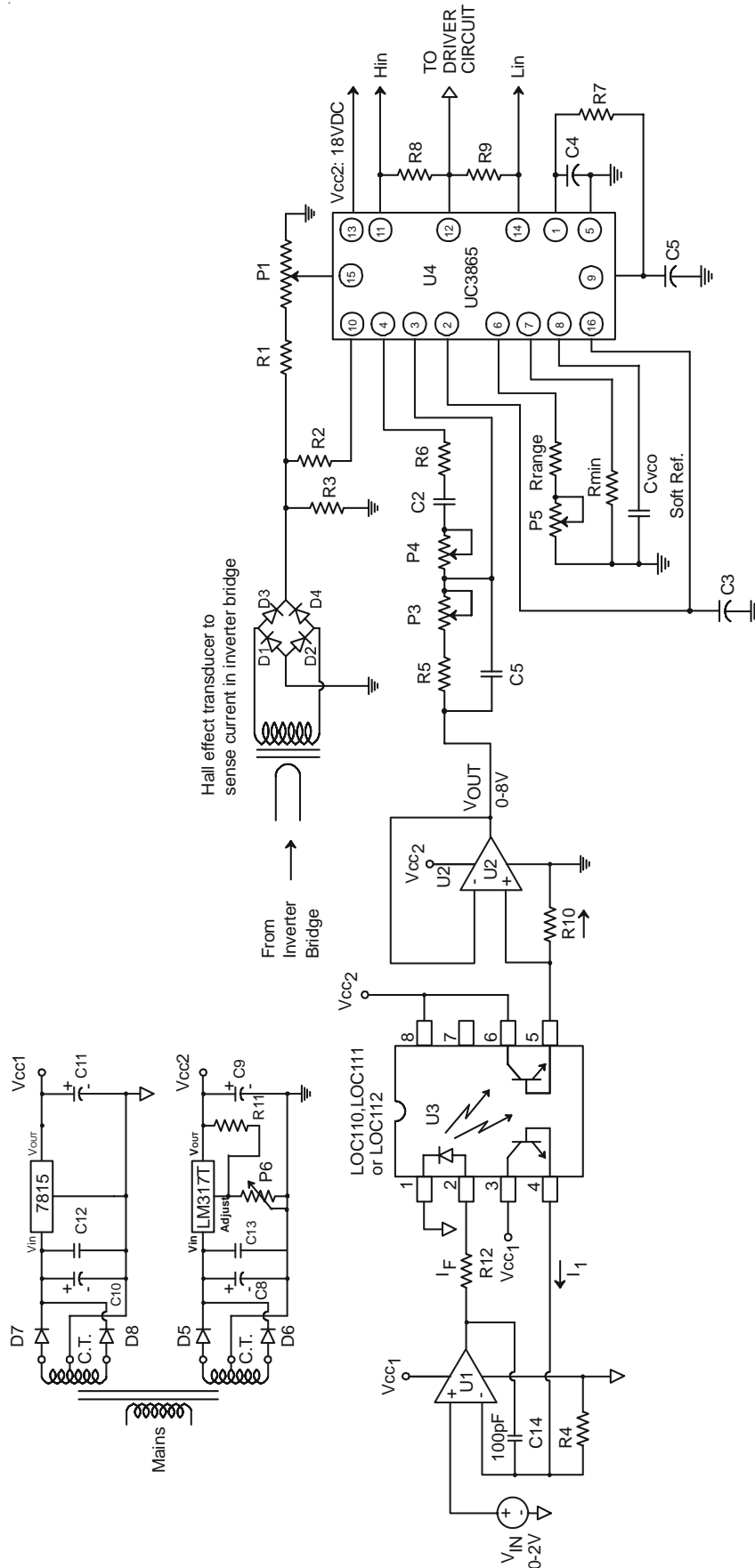**Fig.(6) MOSFET/BI-MOSFET/IGBT Driver Circuit with opto-isolation for 3 ø Inverter Bridge**

Fig.(7) ZCS Resonant Mode Inverter Controller Circuit

Bill of Materials and testing procedure for Fig.(7)

1	U1	OP177FP	
2	U2	OP177FP	
3	U3	LOC110 or LOC111 or LOC 112 are Linear Opto-Couplers from Clare,inc (An IXYS Company)	
4	U4	UC3865	
5	P1,P2,P3,P4	20K TRIMPOT	Multi Turn BOURNS
6	P5	10K TRIMPOT	Multi Turn BOURNS
7	D1,D2,D3,D4	1N5819	
8	D5,D6,D7,D8	1N4002	
9	R1,R2,R5,R6	1K Ohm	All resistors are 1% metal Film,1/4 W
10	R3,R8,R9	10K Ohm	
11	R4	33K Ohm	
12	R7*	4.16K Ohm	
13	R10	133K Ohm	
14	Rmin**	6.8K Ohm	
15	R11	270 Ohms	
16	C1,C4	1uf/35v	Tantalum
17	C2,Cosc	10nf	Multilayer Ceramic
18	C5	1nf	Multilayer Ceramic
19	C6	2nf	Multilayer Ceramic
20	C3	0.1uf/35V	Tantalum
21	C7	22uf/35V	Tantalum
22	C8,C10	2200uf/35V	Electrolytic
23	C9,C11	220uf/35V	Electrolytic
24	C12,C13	0.1uf/35V	Multilayer Ceramic
26	C14	100pf	Silver Dipped Mica or Polystyrene

1. Supply Voltage for Design

   $Vcc = 18Vdc$ for UC3865

2. For given value of "Rmin & Cosc"
   Maximum Output frequency = 38.3 kHz when feedback is not given and when Reference Voltage = 5Vdc.
   Minimum output frequency = 18.65kHz when feedback is greater than reference Voltage = 5Vdc.

3. Value of "R7 & C6" Decides Ton(max) and Ton(min)

   $Ton(max) = 1.2 * R7 * C6$
   For given design it is 8.28 us
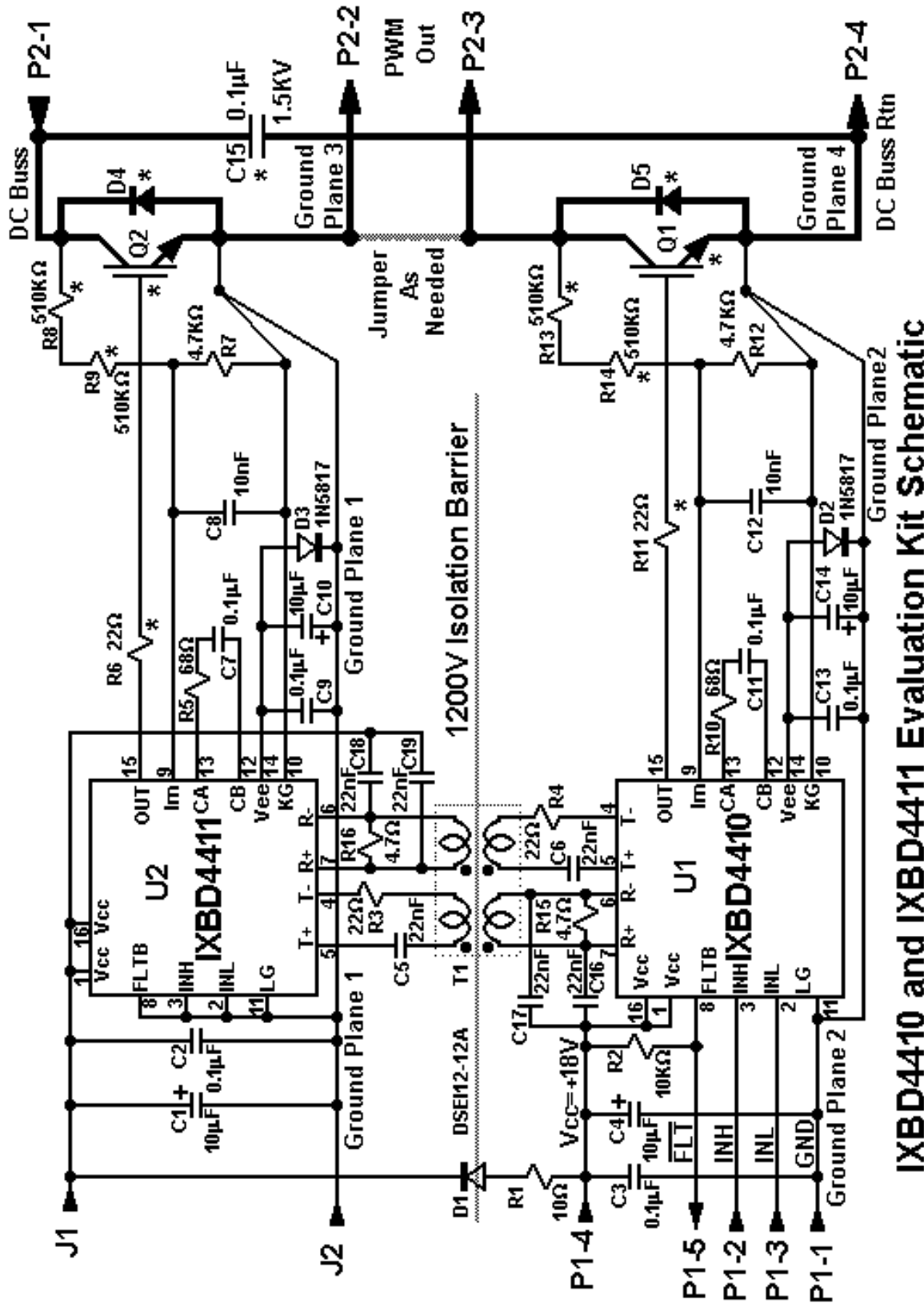 $Ton(min) = 0.3 * R7 * C6$
   For a given design it is 800 ns
   For this design Ton(max) is limited to 13us With C6 = 4 nf ; greater value of C7 causes no effect on Ton maximum.

4. In output, Ton Depends upon the current sensing.
   Output overload/short-circuit is set by setting the value P1 (Multiturn trim-pot) .

5. In output, Frequency depends upon feedback Voltage.

6. R5, R6, C2, C5, P3 & P5 form Lead-Lag network for stability in output. They
   have to be trimmed, depending upon many parameters that can't all be predetermined.
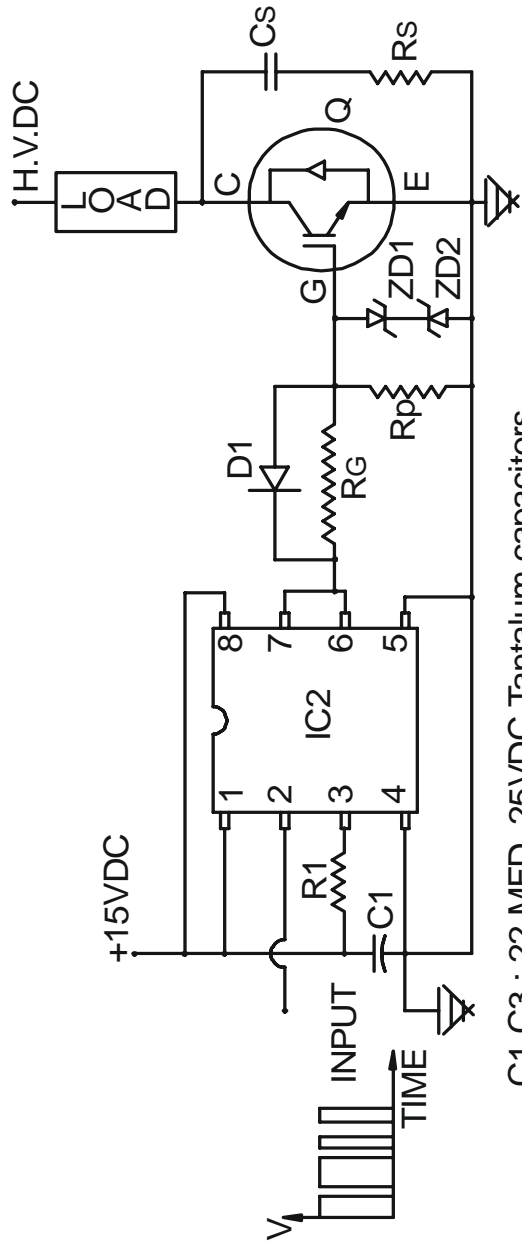
Fig. 8. Schematic, showing use of IXBD4410/4411 for driving Bi-Mosfets, connected in phase-leg configuration.

IXBD4410 and IXBD4411 Evaluation Kit Schematic

* Note: R6, R11, R8, R9, R13, R14, Q1, Q2, D5, D4, and C15 will vary in value and type depending on application.

C1,C3 : 22 MFD, 25VDC Tantalum capacitors

C2 : 2200 MFD, 35VDC Electrolytic capacitors

T1 : 220 VAC to 15-0-15 VAC, 15VA control transformer

110VAC TO 15-0-15

Q : IXLF19N250A   or   IXEL40N400

IC1 : 7815 Regulator

IC2 : IXDD408 or IXDD414

D1 : IN5817

D2,D3 : IN4002

ZD1,ZD2 : 18V, 400MW ZENERS

RG1 : 3.3 ohms to 27 ohms
depending on Turn-ON speed

Rp : 2K2, ¼ W, 5%

Cs,Rs : Snubber network to reduce IGBT switching
losses. Value depends upon fsw. Suggest:
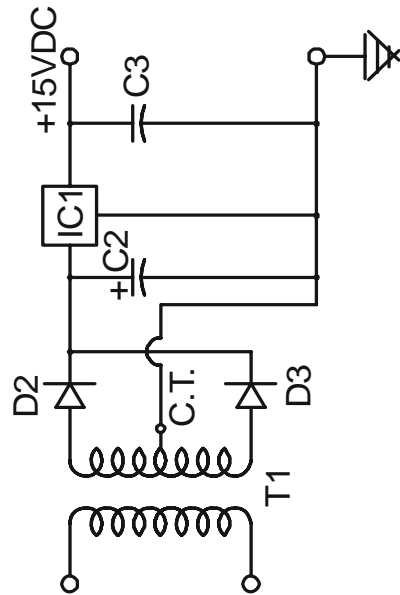Cs=0.1 MFD, Rs=10 to 33 ohms

R1 : 10K, ¼ w

Fig. (9) Circuit schematic showing how to use IXDD408 or IXDD414 to drive IXLF19N250A