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 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 parallel, depending on the energy required), 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 or IXBH40N160 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 36-18N08 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 Cf (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 capacitor to 1000 V. A carefully designed high frequency choke controls rate of in-rush current into the capacitors and also filters the rectified power.

Two or more IXBH 40N160 BIMOSFETs operating in parallel, to match the current requirements of the pulse load, can handle the capacitor’s abrupt discharge functions.

**HIGH FREQUENCY 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. Unlike Ferrites, Amorphous Metal Cores are quite rugged and requires no special care. They are available as “Toroids” 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).
BIMOSFET DRIVER CIRCUITS

BIMOSFETs are new improved devices, which fulfill 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.

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 occurrence 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 occurrence 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 propylene 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 500 VDC will work. However, for those applications demanding higher D.C. Bus voltages, up to, say, 1200 VDC another Driver IC is suggested in Fig(3).

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, ideally 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-off 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 is fully charged, the pulsed load can be turned on by one or more BIMOSFETs, depending on the load current. This can be controlled by sensing the voltage across the CL and turning On S5. As soon as the CL is discharged the control circuit, starts its soft charging cycle, with designed in charging time. Note that lXBH 40N160 can easily handle 1000 VDC as final voltage on the CL and in a transient voltage free environment, this can be extended up to, say, 1200 or even 1300 VDC, which will give greater energy storage capability.

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.

If capacity doubling is called for, two BIMOSFETs can be paralleled in the “H” Bridge as well as 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. 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 i2 t 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.
**NOMENCLATURE:**

1. R, Y, B or R, S, T are names of three phases – 0°, 120° & 240°
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 3Φ Rectifier : VCO 3Φ – 14N08
7. S1, S2, S3, S4 – IXYS make IXBH 40N140 H-MOSFETS
8. LR : Resonating Choke
9. CR : Resonating Capacitor
10. T : Step up High Frequency Transformer
11. D7, D8, D9, D10 – IXYS make 1Φ bridge rectifier with FRED Diodes Type no : VBE 20 – 20N01
12. S5 : Two IXYS make H-MOSFETS in parallel Type no : IXBH 40N160
13. Rs & Cs are non-inductive Resistors and capacitors forming Snubber networks across H-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 requiring quick discharge of Capacitors.
17. LF : Line Filter inductor wound on 3Φ core.
18. CF : Non-polarised Filter Capacitors

*Fig. 2 Elaborate Power Schematic of Capacitor Charging Power Supply*
Fig.(3) H-Bridge Driver Circuit using Bootstrapping techniques, without opto-isolation.
1. (10,12,15,16,17) - IRF140N (Apex Technology) & pin 10
   Power MOSFETs/R-MOSFETs/GBT Gate Drive
   opto-coupler

2. D1/G3, D5, 2D1/G3, D5 - 2N4401 NPN BJT for driving small to medium power
   IGTS/3-MOSFETs/WOSTFTs.
3. 2U4/6, 6U4/6 - 2N4401 NPN BJT for driving small to medium power
   IGTS/3-MOSFETs/WOSTFTs.

2. D1/G3, D5 - 2N4401 NPN BJT for driving medium power
   IGTS/3-MOSFETs/WOSTFTs.
3. 2U4/6, 6U4/6 - 2N4401 NPN BJT for driving medium power
   IGTS/3-MOSFETs/WOSTFTs.

2. D1/G3, D5 - 2N4401 NPN BJT for driving high power
   IGTS/3-MOSFETs/WOSTFTs.
3. 2U4/6, 6U4/6 - 2N4401 NPN BJT for driving high power
   IGTS/3-MOSFETs/WOSTFTs.

4. D1 - IRF140N - 18 VDC, 400 mA sink diode.
5. 4B - 2N2222A.
6. Rs ON - Depends on the MOSFET/3-MOSFETs/GBT being driven.
   The resistor determines "turn on" times of MOSFET/3-
   MOSFETs/GBT.
7. Rs OFF - Depends on the MOSFET/3-MOSFETs/GBT being driven.
   The resistor determines "turn off" time. Rs OFF can be kept
   much smaller than Rs ON to improve turn-off characteristics.

Note: Some applications use switching diodes (say IN4148 or IN4014) in
place of Rs OFF or use Rs OFF in series with switching diode.
8. C3 to C9 - 22.0nF, 25VDC Tantalum Capacitors
9. 0.015µF/150V 35VDC
10. 0.015µF/250V 35VDC
11. 0.015µF/250V 35VDC
12. 0.015µF/250V 35VDC
13. 0.015µF/250V 35VDC
14. 0.015µF/250V 35VDC

Fig.6: MOSFET/3-MOSFET/GBT Driver Circuit with opto-isolation for 3L Inverter Bridge
Fig.6 MOSFET/IGBT Driver Circuit with opto-isolator for 3-phase Inverter Bridge
Fig. (7) ZCS Resonant Mode Inverter Controller Circuit
Fig. 8. Schematic, showing use of IXBD4410/4411 for driving Bi-Mosfets, connected in phase-leg configuration.