Resonant switching in IGBT converters

High blocking voltage and soft switching is useful

Better utilisation of silicon by reaching higher switching frequencies at constant overall losses, and the elimination of the passive output filter, will repay the cost of components to realise resonant switching

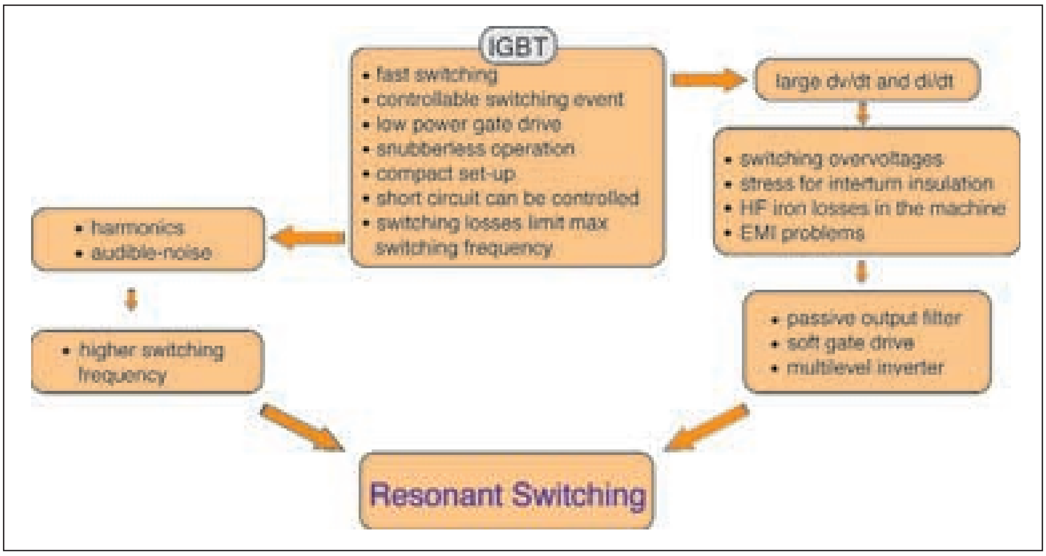

Figure 1: *Motivation for resonant switching*

■ The resonant switching technique which is widely spread in DC/DC converters and converters for induction heating is not yet applied in 3-phase AC/AC converters. Looking at modern semiconductors, especially IGBT or IGCT which are designed for snubberless operation, the resonant technique, as a successor of the turn-off circuits for thyristors, carries the stigma of being old-fashioned and complex. This article gives some arguments for using resonant switching instead of, or as an alternative to, hard switching.

Figure 1 gives an overview of the properties of an IGBT and the resulting behaviour. First, especially with devices with a high blocking voltage, the switching frequency is limited to rather low frequencies, second due to the high switching speed, the voltage and current rates of change, dv/dt and di/dt, are very high. Resonant switching topologies claim to mitigate both effects. Compared to the snubber circuits where the switching losses are dissipated in external resistors or, for very high power converters, fed back into the DC-link via DC/DC converters, the resonant switching topologies already avoid the generation of switching losses. The switching losses are not moved out of the semiconductors into passive components. This is realised by forcing either voltage (ZVS) or current (ZCS) or both (ZVCS) to zero during the switching event. In principle there are two possibilities to realise this. Either one resonant circuit for each inverter leg (e.g. Resonant Pole *figure 2a*) or one for the complete inverter bridge (e.g. Resonant DC Link *figure 2b*).

The latter possibility represents an optimum concerning the count of additional components. All the resonant topologies have in common that the utilised resonant circuits have a very low damping to minimise the additional losses in the passive components which are not avoidable. *Figure 2* depicts a representative for each mentioned group. Both topologies depicted in *figure 2* have in common that the resonant operation is triggered by using additional switches; so there is no free oscillating resonant circuit with the drawback of time-restricted switching

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events and a poor current spectrum. The resonant operation takes place only when a change in switching state in the bridge is desired. This provides a PWM capability for the proposed topologies; in this context they are called quasi resonant converters.

The sum of both is limited by the modules capability to transmit the resulting heat away from the chip area. It is not possible to minimise both by improvements in semiconductor technology, because the physical effects giving rise to this limit are opposed. In an application the dynamic

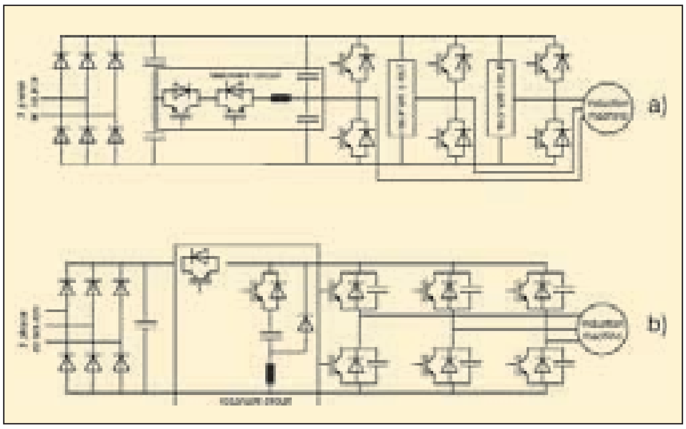

Figure 2: *a) resonant pole inverter*
b) resonant DC link inverter

In both proposals the passive components need not carry the load current, this results in low voluminous components in the resonant circuit. They are used to enable a non-dissipative switching event and not to carry the power from source to load as in resonant DC-DC converters. They are also not part of the load as in induction heating converters.

Corresponding to their task, to prepare the voltage and/or current shapes before and after the switching event, the time-constants of the resonant circuit are chosen much smaller than the load time-constant. So the load current is assumed to be constant during the resonant cycle. Because of the load-side current injection during a resonant cycle the load current spectrum is not altered by the resonant operation. The resonant current is not fed into the load.

The losses of an IGBT module consist mainly of static (conduction) and dynamic (switching) losses. The driving and blocking losses are neglected in this examination. The static losses are caused by the forward voltage drop during conduction V_{CE}, while the dynamic losses are a result of the switching events.

losses can be influenced by employing snubber networks or soft switching topologies but the static losses cannot.

Especially with IGBTs (or IGCTs) with very high blocking voltage it is reasonable to think about using soft switching, because in these applications the switching frequency is typically below 1 kHz and can be increased up to 3 kHz when soft switching is used, resulting in a better load current spectrum.

Due to the possibility of defining the voltage rate of change at the output terminals by choosing appropriate values for the passive components an additional output filter to protect the insulation of the connected interface cables and motor windings from the large dv/dt values can be avoided. The better utilisation of silicon by reaching higher switching frequencies at constant overall module losses, and the elimination of the passive output filter, will compensate the additional costs of the equipment realising resonant switching.

Today the standard IGBT is designed and optimised for hard switching and snubberless operation. But the sensitivity against switching overvoltages caused by the large di/dt and the unavoidable set-up stray inductance require small protecting snubber networks, especially when single IGBT modules instead of integrated half-bridges or six-packs are used. Resonant switching topologies make such snubbers unnecessary. As mentioned above the passive components of the resonant circuit are used to define the voltage and/or current shapes during a resonant cycle. Due to the softened slopes of the output voltage the reliability of the whole converter can be improved because the components are stressed less.

The semiconductor structure, of course, influences the gain of resonant switching topologies too. Above blocking voltages of 1000 V only NPT-type IGBTs are on the market. This means that during turn-off a low tail current with a long duration occurs. Under soft switching conditions this tail current is lengthened. Especially at high switching frequencies it is possible to switch the IGBT on when the switch-off transient has not yet finished; resulting in increasing switching losses. Although these IGBTs can be

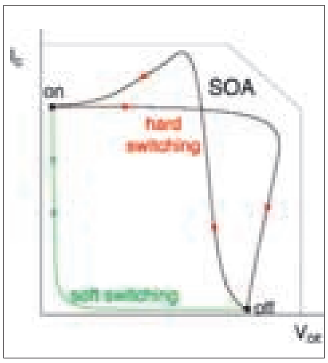

Figure 3: *SOA trajectories*

used in resonant switched inverters it is desirable to have modified IGBTs particularly designed for soft switching. Recently more and more semiconductor manufacturers offer such specialised IGBTs. PT-type IGBTs which were promising for resonant switching due to their short tail duration are not to be found in the high power range because of their NTC-behaviour and complex production.

So far, many positive aspects of resonant switched converters have been pointed out, but there are some drawbacks in this technique too. First, irrespective of the topology used, there is, caused by the resonant function, a certain increase in voltage and/or current stress for the semiconductors used. Looking at QRDCL-Inverters there is a demand for additional measurement and evaluation equipment to control the switching sequence of the IGBTs in the resonant circuit. Although the proposed QRDCLI are PWM-capable there are some restrictions because for each switching event in the bridge the switches of the resonant circuit have to be switched. So employing a sine-triangle-PWM the switching frequency in the resonant circuit is six times the inverter switching frequency. This, of course, can be mitigated by choosing another control scheme. Such a restriction does not exist for the Resonant Pole Inverter, but the count of additional parts is clearly higher compared to the RDCLI. To guarantee a proper resonant function even under low load conditions measures like boosting the current by short-circuiting the DC-link are necessary. Some topologies need a certain amount of energy stored in the resonant tank to perform the resonant operation; so at the end of a resonant cycle this energy has to be restored. Both cases increase the expenditure in controlling a resonant switched converter.

Although today there is no commercial use of resonant switched three-phase AC/AC converters it can be seen in the literature that there is a rising interest in this technology. New semiconductor devices, EMI problems, the stress of windings due to large dv/dt values and a lack in utilisation of the silicon area always bring the resonant technique into discussion. The advantages promise to compensate the additional expenditure in components both from technical and financial aspects. ■

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