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AN6481

RC Snubber Design for Dynex Thyristors and Diodes

Application Note

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***Abstract*—Thyristors and diodes are widely used in power electronics for their high current and voltage capabilities, but switching them can cause damaging transients due to parasitic effects. RC snubbers protect these devices by suppressing oscillations. This application note outlines the design of an RC snubber circuit for thyristors and diodes, focusing on mitigating transient voltage spikes during switching. Key factors such as resistor and capacitor sizing, device ratings, and parasitic effects are discussed. Practical design guidelines and a simulation tool are provided to help engineers optimise the snubber circuit.**

1 Introduction

Thyristors and diodes are widely used in power electronics for controlling and rectifying high-voltage and high-current applications. However, during switching events, these semiconductor devices are prone to voltage transients and oscillations due to the inductive components in the circuit. These transients can lead to voltage spike across the device, increased electromagnetic interference (EMI), and in some cases, permanent damage.

Although semiconductor devices have an inherent junction capacitance, this capacitance is often insufficient to control the voltage spike that occurs when a reverse voltage begins to rise during the turn-off phase. To mitigate the transient effects and ensure reliable operation, an RC snubber circuit is commonly employed [1].

An RC snubber circuit consists of a resistor and capacitor in series, connected across the thyristor, as shown in **Figure 1**. This simple yet effective circuit serves multiple purposes: it suppresses voltage spikes, dampens high-frequency oscillations, and aids in commutation processes. By absorbing the energy from transients and dissipating it safely, the RC snubber enhances the overall performance and longevity of the semiconductor device.

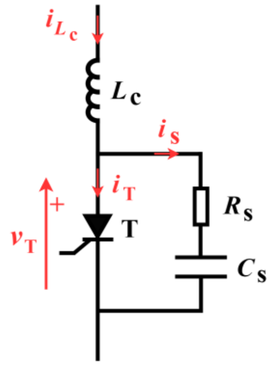


Figure 1. A thyristor with RC snubber and commutation inductance, L_C.

This application note provides a detailed examination of the turn-off process and reverse recovery in thyristors, followed by an exploration of methodologies for modelling reverse recovery. It then delves into the design approach for selecting the R and C components in the snubber circuit and introduces the Dynex simulation PLECS model for optimising these component values.

It is important to note that, while this application note primarily focuses on thyristors, the fundamental principles of RC snubber design also apply to diodes.

2 Turn-off Process of a Thyristor

This section discusses thyristors reverse recovery and presents the most well-known methods for modelling it.

2.1 Thyristor reverse recovery

The thyristor waveforms during reverse recovery are shown in **Figure 2.** When a thyristor is forward biased, the current flow is determined by both majority and minority carriers. If the forward current is reduced to zero by applying a reverse voltage, the thyristor briefly continues to conduct due to stored minority carriers in the PN junction and bulk material. This process, called reverse recovery, occurs as the minority carriers gradually recombine.

During the reverse recovery process, initially, after applying the reverse voltage, the voltage remains near zero because the minority carriers continue conducting. As these carriers dissipate, the thyristor's ability to conduct decreases, allowing the reverse voltage to rise. Once the stored charge is cleared, the device becomes non-conducting. In circuits with inductance, the sudden stop in current can induce a voltage spike due to the rapid release of energy from the inductive components.

In **Figure 2**, I_{RR} (also referred to as I_{rrm} in the literature) is the peak reverse recovery current. V_R (also referred to as V_{RM} in Dynex datasheets and application notes) is the applied reverse voltage and $V_{R(peak)}$ is the peak transient reverse voltage.

The reverse recovery time (t_{rr}) is measured from the point where the current through the thyristor drops to zero. It continues until a straight line, drawn after the current reaches I_{RR} and heads toward zero, passes through the points corresponding to $0.9I_{RR}$ and $0.25I_{RR}$ intersects the zero current axis.

The reverse recovery period consists of two components: t_A and t_B.

- t_A: The time interval from the current crossing zero to reaching the peak reverse recovery current, I_{RR}. t_A results from charge storage in the depletion region of the junction.
- t_B: The time interval from I_{RR} to when the reverse recovery current returns to zero. t_B results from charge storage in the bulk semiconductor material.

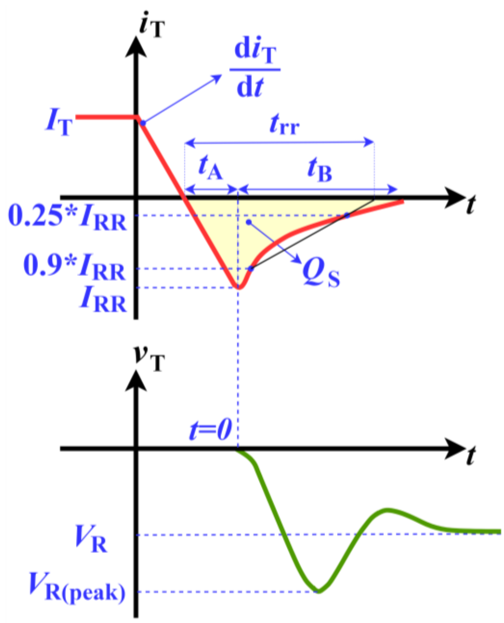


Figure 2. Thyristor Turn-off Waveforms

The type of reverse recovery can be described by a softness factor, s, defined as $s = (t_{rr} - t_A)/t_A$. A larger softness factor indicates a "softer" reverse recovery, meaning the reverse current decreases more gradually, which can reduce noise and stress on the circuit. Additionally, I_{RR} is related to t_A by the expression $I_{RR} = t_A.(di_T/dt)$, where di_T/dt is the rate of change of thyristor current.

I_{RR} and reverse recovery charge, Q_S (which is also referred to as Q_{rr} and Q_r in the literature), depends on factors such as the junction temperature, the rate of fall of the forward current (di_T/dt), and the magnitude of the forward current before commutation (turn-off), I_T. It should be noted that the dependence of the I_{RR} and Q_S on I_T, becomes negligible if the rate of current change (di_T/dt) is slow enough to create a quasi-stationary decay of the forward current. This condition is met when the ratio $I_T/(di_T/dt)$ is at least several times greater than the carrier lifetime, which is typically in the range of a few hundred microseconds. In such cases, the forward current decays gradually, reducing the impact of the initial current magnitude on the reverse recovery process.

2.2 Thyristor reverse recovery modelling

In general, there are four well-known approaches for modelling the reverse recovery process of a thyristor/diode. These models can be used to estimate the peak reverse voltage during reverse recovery process. As shown in **Figure 2**, the reverse voltage remains zero until the reverse recovery current reaches its peak value, I_{RR}. Therefore, to simplify the analysis in the reverse voltage calculation, it is assumed that the initial time (t=0) begins when the reverse current reaches I_{RR} and the initial snubber capacitor voltage (at t=0) is zero.

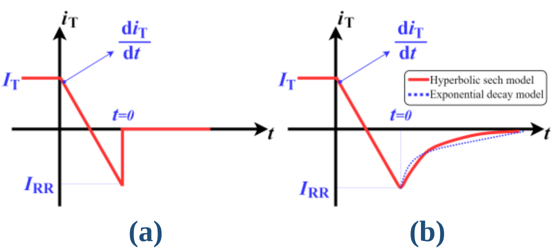


Figure 3. Reverse recovery models. (a) Snap-off model. (b) Exponential decay and hyperbolic secant models.

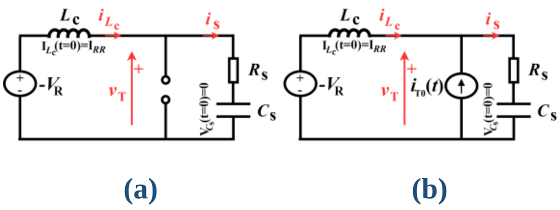


Figure 4. Equivalent circuit of a thyristor with snubber protection at t=0. (a) Snap-off model. (b) Exponential decay model.

2.2.1 Snap-off reverse recovery current model

For the ease of analysis, the diode reverse recovery current can be assumed to snap off instantaneously at I_{RR} as shown in **Figure 3(a)**. Therefore, in this approach, when analysing the circuit with a thyristor/diode during reverse recovery, it is assumed that at t=0, the thyristor behaves as an open circuit, and the initial current in the commutation (stray) inductance is equal to I_{RR}. An exemplary circuit for calculating the peak reverse voltage across a thyristor with snubber protection is shown **Figure 4(a)**.

2.2.2 Exponential reverse recovery current model

In practice, the thyristor current recovers as showed in **Figure 2**, where the post-recovery current waveform is assumed to decay exponentially. Therefore, when analysing the circuit with a thyristor/diode during reverse recovery, it is assumed that at time t=0, the thyristor acts as a current source, with the current decaying exponentially according to function (1). An exemplary circuit for calculating the peak reverse voltage across a thyristor with snubber protection is shown **Figure 4(b)**.

$$i_{T0}(t) = -I_{RR}e^{-\frac{t}{\tau}} \qquad (1)$$

where τ is the decay time constant and can be obtained as (2).

$$\tau = \frac{Q_S}{I_{RR}} - \frac{I_{RR}}{2\, di_T/dt} \qquad (2)$$

2.2.3 Hyperbolic secant reverse recovery current model

In exponential recovery current model, as shown in **Figure 3(b)**, the reverse recovery current transitions sharply from its peak value to an exponential decay. This sharp change can lead to inaccuracies in modelling the real behaviour of the current waveform. To address this, the hyperbolic secant recovery current model was introduced. While similar to the exponential decay approach, the key difference lies in how the recovery current is represented. Instead of a sharp transition, this model creates a smoothly rounded reverse recovery current peak, which closely resembles measured transient recovery currents, as seen in **Figure 3(b)**.

In the circuit analysis approach using this model, the current source representing the reverse recovery behaviour of the thyristors/diodes follows a hyperbolic secant function, providing a smoother and more accurate depiction of the recovery process. This approach requires more complicated mathematical calculations and current source functions which are thoroughly discussed in [2].

For semiconductor devices with typical soft recovery, the exponential model is highly effective and well-suited for calculating turn-off overvoltage. While the hyperbolic secant model offers greater accuracy, the exponential decay model remains the preferred choice due to its simplicity and ease of use, avoiding the need for complicated mathematical calculations.

2.2.4 Circuit-based reverse recovery model

In many practical applications, accurately modelling the reverse recovery behaviour of diodes and thyristors is crucial for understanding their performance under switching conditions. Traditional models, such as the exponential decay or hyperbolic secant recovery models, rely on mathematical approximations to represent this behaviour. However, they often fall short of capturing the detailed physical effects present in real-world circuits and require computer coding, making them less convenient to implement.

To address this limitation, the circuit-based reverse recovery model is introduced in [3]. As shown in **Figure 5**, this model incorporates actual circuit components, such as resistors, inductors, and controlled current sources, to simulate the reverse recovery process accurately. By including physical components, this model offers a representation of device behaviour during switching transients.

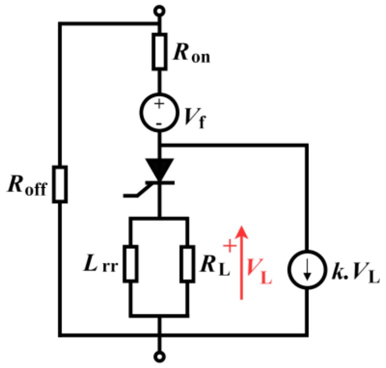


Figure 5. Thyristor reverse recovery circuit-based model.

This model is also preferred because it provides a better balance between accuracy and usability. It not only reflects the physical phenomena occurring during reverse recovery but also simplifies parameter extraction by directly linking device characteristics to measurable quantities. Moreover, the circuit-based reverse recovery model is seamlessly integrated with simulation tools like PLECS, where it is already incorporated into the built-in diode and thyristor models. This makes it easy for engineers to use this model in their simulations, without the need for complicated manual setup, ensuring reliable results with minimal effort.

This model is fully discussed in [3]. The values of all the components can be calculated directly from the datasheet using the equations provided in [3]. When using PLECS, no manual mathematical calculations are required, as PLECS performs these internally. The users simply need to input a few constants from the datasheet, along with the specific requirements of their design.

In the next section, we will explain how to use PLECS to perform snubber circuit analysis and estimate the reverse voltage during the reverse recovery process.

3 Design of RC Snubber Circuit

This section outlines a methodology for designing snubber circuits for thyristors and diodes. The approach utilises PLECS simulations with the circuit-based reverse recovery current model. First, the use of PLECS to estimate the

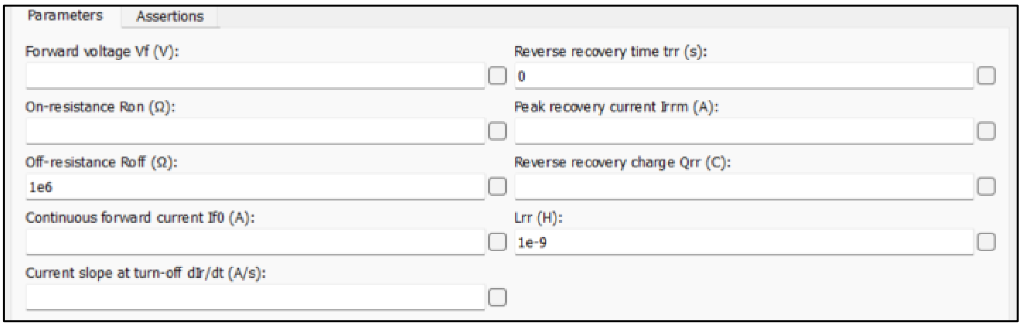


Figure 6. The required data for reverse recovery current modelling in PLECS.

reverse recovery behaviour of thyristors and diodes is explained. The simulation model developed by Dynex using PLECS is then introduced. This simulation model is instrumental in optimising the resistance and capacitance of the snubber circuit, ensuring the desired voltage limitation during transients while minimising losses and capacitance.

3.1 Thyristor/diode reverse recovery analysis in PLECS

In PLECS, thyristors and diodes with reverse recovery capability can be selected. The model includes an internal circuit similar to the one shown in **Figure 5**. There is no need for the user to manually calculate the parameters in **Figure 5**. Instead, the user simply enters the necessary input parameters required for those calculations as shown in **Figure 6**.

Generally, the following parameters are needed:

I_{f0} in A and $\mathrm{d}I_{\mathrm{r}}/\mathrm{d}t$ in A/s, which represent the continuous forward current before thyristor turn-off (same as I_{T}) and the rated turn-off current slope under test conditions (same as $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$), respectively. Based on the $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$ and using the datasheet, values of Q_{rr} in C (Q_{S} value in datasheet) and I_{rrm} in A (I_{RR} value in datasheet) can be obtained. For t_{rr} in s, set to 0s, as its value is calculated based on Q_{rr} and I_{rrm}. For L_{rr} in H, set to 1nH. V_{f} in V and R_{on} in Ω corresponds to $V_{\mathrm{T(T0)}}$ and r_{T} from the datasheet, respectively. R_{off} in Ω is set to infinity or to the datasheet value.

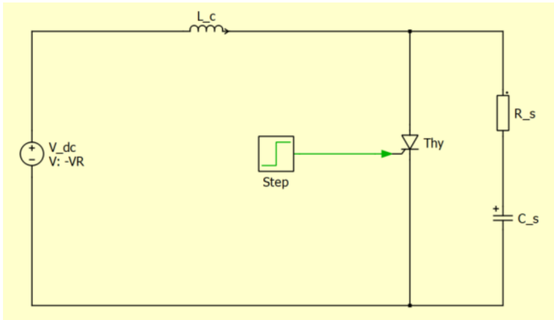
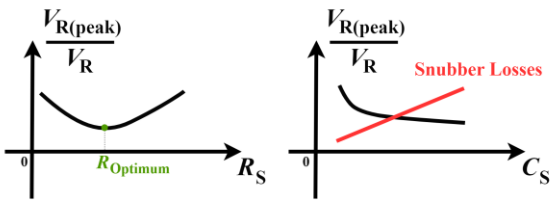


Figure 7. An exemplar circuit for estimating $V_{\mathrm{R(peak)}}$ of a thyristor with snubber protection during reverse recovery.

In PLECS, the thyristor/diode with reverse recovery capability can be utilised in various circuit topologies to analyse its performance and impact on the circuit. For instance, as shown in **Figure 7**, a simple circuit can be used to investigate the peak reverse voltage of a thyristor during turn-off process, $V_{\mathrm{R(peak)}}$, when using a snubber circuit. This analysis is conducted under a specific applied reverse voltage, V_{R}, and $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$, determined by the applied reverse voltage and commutation inductance ($V_{\mathrm{R}}/L_{\mathrm{C}} = \mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$).

3.2 RC snubber circuit design using PLECS

The design of an RC snubber has two main objectives. The first is to suppress the peak reverse voltage to a value safely within the device's maximum capability, including an appropriate safety margin. The second objective is to minimise snubber power losses and capacitance, thereby reducing the size and cost of the additional snubber circuit.



(a) (b)

Figure 8. Snubber components optimisation trends. (a) Typical variation of $V_{R(peak)}$ with R_S at a fixed capacitance (b) Typical variation of $V_{R(peak)}$ and power losses with capacitance at the optimal R_S.

Literature has demonstrated that, for each capacitance value, there is an optimal resistance point, $R_{Optimum}$; deviations from this resistance result in an increase in the peak reverse voltage. Additionally, increasing the capacitance generally reduces the peak reverse voltage but leads to higher snubber losses. Beyond a certain capacitance value, the reduction in peak reverse voltage becomes minimal compared to the increase in snubber losses. **Figure 8(a)** and **(b)** effectively show these trends [1].

As mentioned, PLECS can be used to estimate the peak reverse voltage during reverse recovery. Additionally, PLECS offers several other benefits, such as estimating power losses in the snubber circuit. Therefore, the circuit shown in **Figure 7** can be enhanced with additional blocks for these estimations. Furthermore, by utilising PLECS simulation scripting, an optimisation algorithm can be developed in conjunction with the simulation circuit to find the optimal solution based on specific requirements.

Dynex has developed a PLECS simulation model (*.plecs) that can be conveniently used for this optimisation. The model is available for download on the Dynex website, with separate versions for thyristors and another for diodes. This simulation model, which requires only data available on the Dynex datasheet along with the converter's reverse applied voltage and commutation inductance, can be easily utilised. Once the necessary data is provided, the model determines the optimal resistance value for each capacitance that minimises the peak reverse voltage. The simulation model also shows how the peak reverse voltage and snubber losses vary with changes in the capacitance (at its corresponding optimal resistance). With this information, the users can make informed decisions to select the best option based on their specific requirements.

4 Design Examples Using Dynex PLECS Snubber Design Model

This section provides two design examples—one for a single-phase system and another for a three-phase system—to demonstrate how to use the Dynex PLECS simulation model for designing an RC snubber. These examples guide the user through the design process, demonstrating how to optimise the RC snubber parameters to achieve effective circuit protection and performance enhancement.

4.1 Single-phase example

In this section, an RC snubber is designed for the DCR4000M52 in a single-phase rectifier ensuring a voltage margin of at least 1000V. The maximum applied reverse voltage is 2600 V, the commutation inductance is 500 µH, the maximum possible current prior to thyristor turn-off is 1000 A and gird frequency is 50 Hz.

In the first step, $\mathrm{d}i_T/\mathrm{d}t$ is calculated from (3), resulting in a value of 5 A/µs.

$$\frac{\mathrm{d}i_T}{\mathrm{d}t} = \frac{V_R}{L_C} \tag{3}$$

According to the DCR4000M52 datasheet, maximum values of Q_s and I_{RR} are 9250 µC and 170 A, respectively, at $\mathrm{d}i_T/\mathrm{d}t$ of 5 A/ µs. In addition, $V_{T(T0)}$ and r_T are 0.95 V and 0.24 mΩ, respectively. Assume I_T 10000 A, ensuring that $\mathrm{I_T}/(\mathrm{d}i_T/\mathrm{d}t)$ is at least several times greater than the carrier lifetime.

Open the Dynex PLECS Snubber Design Model, then navigate to Simulation > Simulation Scripts. Enter the data as presented in **Figure 9.** All the parameters apparat from f which is the switching frequency are defined in **Section 3.1**.

Once the data is entered, click "Accept" and then "Run".

```
Scripts | Description: Script
Script

%Dynex PLECS Snubber Design Model

%Please enter the below parameters
Ron=0.00024 ;
Vf=0.95     ;
If0=10000   ;
V_R=2600    ;
didt=5e6    ;
Qrr=9250e-6 ;
Irrm=170    ;
f=50;
```

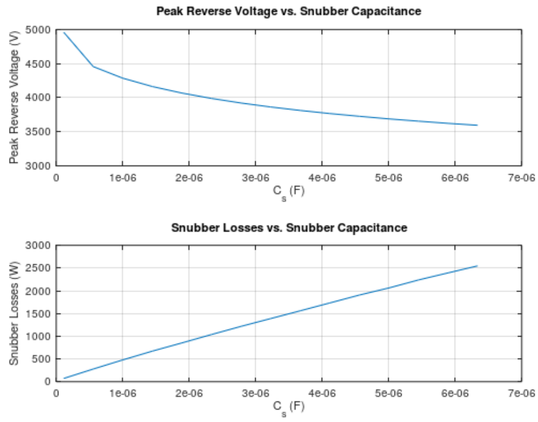
Figure 9. The required data for optimisation in Dynex PLECS Snubber Design Model.

After a few minutes, the optimisation results are displayed in graphs or can be accessed through the console by navigating to Window > Show Console, as presented in **Figure 10(a)** and **(b)**, respectively. As shown, to account for a 1000 V margin, the optimal configuration includes a capacitor with a capacitance of 1.5 μF and a resistor with a resistance of 51 ohms. The values are rounded up/down based on the available standard resistance and capacitance in the market. Additionally, the resistor must have a power loss capability of more than 700 W.

This approach can also be extended to other topologies, such as pulse power converters, AC switches, and various power electronics converters incorporating thyristors and diodes. However, it is vital to ensure precise modelling and representation of the snubber circuit, applied reverse voltage, and di/dt experienced by the thyristors and diodes, especially when dealing with more complex converter topologies. The following example, based on a 6-pulse converter, shows how to achieve this effectively.

4.2 Three-phase example

In the common 6-pulse bridge configuration shown in **Figure 11(a)**, in contrast to single-phase rectifiers and AC switches, the RC snubbers interact with each other during turn-off process. For instance, when thyristor A turns off, thyristors B and C are conducting, effectively short-circuiting their RC snubbers, while thyristors D, E, and F are in the blocking state, allowing their RC snubbers to influence the turn-off behaviour of thyristor A. This results in an equivalent circuit, as showed in **Figure 11(b)**, for this phase of the turn-off.



(a)

Octave Console

List of optimised resistance for each capacitance

C_s (F)	R_s (ohm)	V_RM (V)	Loss (W)
0.000000111	152.18	-4960.9	70.8
0.000000556	104.00	-4455.9	278.2
0.000001000	67.29	-4285.9	479.3
0.000001445	51.24	-4163.4	672.3
0.000001890	44.35	-4067.8	853.2
0.000002334	37.47	-3988.7	1037.4
0.000002779	32.88	-3921.8	1217.2
0.000003223	30.59	-3863.8	1388.1
0.000003668	28.29	-3812.7	1559.4
0.000004113	26.00	-3767.2	1731.9
0.000004557	23.71	-3726.8	1906.0
0.000005002	23.71	-3688.9	2062.2
0.000005447	21.41	-3655.5	2238.1
0.000005891	21.41	-3623.4	2393.4
0.000006336	21.41	-3595.2	2548.1

(b)

Figure 10. The output results of Dynex PLECS Snubber Design Model for the single-phase rectifier. (a) Graphs. (b) Data.

Using standard formulas for the parallel and series connection of resistors and capacitors, the RC snubber seen by thyristor A during turn-off has an equivalent resistance and capacitance given by equations (4) and (5), respectively.

$$R_{\mathrm{Eq}} = \frac{3}{5} R_{\mathrm{S}} \tag{4}$$

$$C_{\mathrm{Eq}} = \frac{5}{3} C_{\mathrm{S}} \tag{5}$$

An RC snubber needs to be designed for the DCR3370M65 thyristor in a three-phase rectifier, ensuring a voltage margin of at least 1000V. The thyristor is subject to a maximum applied reverse voltage of up to 3500V, a maximum current of up to 1500A before turn-off, and operates at a grid frequency of 50 Hz.

In the first step, $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$ needs to be calculated. However, commutation inductance is not provided. When commutation inductance is not provided for a 6-pulse converter, a worst-case line impedance of 5% can be used as (6) [1].

$$L_{\mathrm{C}} = 0.05\frac{V_{\mathrm{LL}}}{\sqrt{3}I_{\mathrm{L}}}\frac{1}{2\pi f} \tag{6}$$

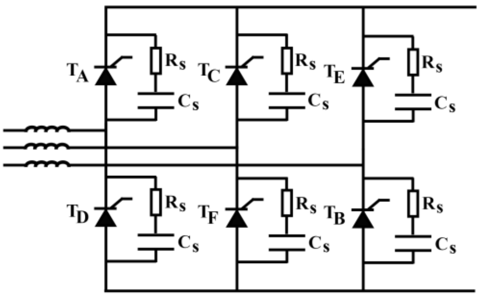
where V_{LL} is line-to-line voltage, which is 3500 V, I_L is fundamental component of rated current which is 1500 A here.

From (6), L_{C} is 214 µH. $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$ is calculated from (7), resulting in a value of 8 A/µs.

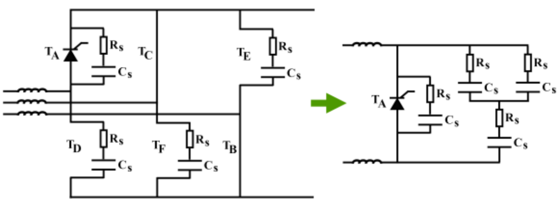
$$\frac{\mathrm{d}i_{\mathrm{T}}}{\mathrm{d}t} = \frac{V_{\mathrm{R}}}{2L_{\mathrm{C}}} \tag{7}$$

In (7), the double inductance is due to the resultant inductance in the commutating circuit for a three-phase rectifier.

According to the DCR3370M65 datasheet, maximum of Q_{s} and I_{RR} are 14000 µC and 260 A, respectively, at $\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t$ of 8 A/ µs. In addition, $V_{\mathrm{T(T0)}}$ and r_{T} are 1.04 V and 0.33 mΩ, respectively. Assume I_{T} 12000 A, ensuring that $\mathrm{I_T}/(\mathrm{d}i_{\mathrm{T}}/\mathrm{d}t)$ is at least several times greater than the carrier lifetime.

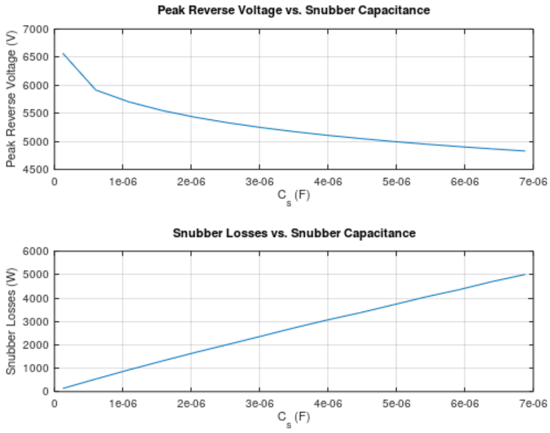


(a)



(b)

Figure 11. 6-pulse thyristor converter. (a) Schematic. (b) equivalent circuit when thyristor A turns off.



(a)

List of optimised resistance for each capacitance

C_s (F)	R_s (ohm)	V_RM (V)	Loss (W)
0.000000121	133.94	-6567.8	136.3
0.000000604	95.58	-5913.3	538.0
0.000001086	61.25	-5702.8	930.9
0.000001569	47.12	-5550.0	1306.3
0.000002052	39.04	-5429.7	1670.4
0.000002535	35.00	-5330.5	2016.9
0.000003018	30.96	-5245.9	2367.0
0.000003501	26.92	-5172.9	2723.3
0.000003984	24.90	-5107.6	3060.9
0.000004466	24.90	-5050.1	3370.8
0.000004949	22.88	-4996.8	3709.6
0.000005432	20.87	-4949.3	4051.6
0.000005915	20.87	-4905.9	4358.0
0.000006398	18.85	-4865.5	4704.3
0.000006881	18.85	-4827.8	5009.2

(b)

Figure 12. The output results of Dynex PLECS Snubber Design Model for three-phase rectifier. (a) Graphs. (b) Data.

Following the same procedures as single-phase rectifier example, the optimisation results are displayed in **Figure 12(a)** and **(b)**, respectively. As shown, to account for a 1000 V margin, the optimal configuration includes a capacitor with a capacitance of 2 µF and a resistor with a resistance of 39 ohms.

However, 39 ohms and 2 µF are values of R_{Eq} and C_{Eq}, respectively. Therefore, from (4) and (5), the required snubber resistance, R_{S}, and capacitance, C_{S}, for each thyristor's snubber are 68 ohms and 1.2 µF, respectively. The values are rounded up/down based on the available standard resistance and capacitance in the market. Additionally, the resistor must have a power loss capability of more than 1700 W.

4.3 Reverse recovery waveforms

After, selecting the customised optimum RC values, the reverse recovery waveforms can be observed from the same simulation model.

```
Model initialization commands
%Please enter the below parameters
Ron=0.00024 ;
Vf=0.95     ;
If0=10000   ;
V_R=2600    ;
didt=5e6    ;
Qrr=9250e-6 ;
Irrm=170    ;
f=50        ;
R_s_=51     ;
C_s_=1.5e-6 ;
```

(a)

```
Model initialization commands
%Please enter the below parameters
Ron=0.00033     ;
Vf=1.04         ;
If0=12000       ;
V_R=3500        ;
didt=8e6        ;
Qrr=14000e-6    ;
Irrm=260        ;
f=50            ;
R_s_=40         ;
C_s_=2e-6       ;
```

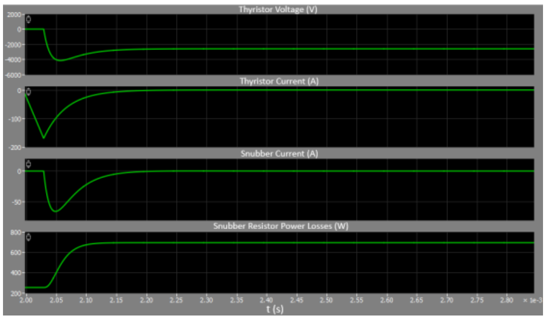
(b)

Figure 13. The required data for waveforms observation. (a) Single-phase rectifier. (b) Three-phase rectifier.

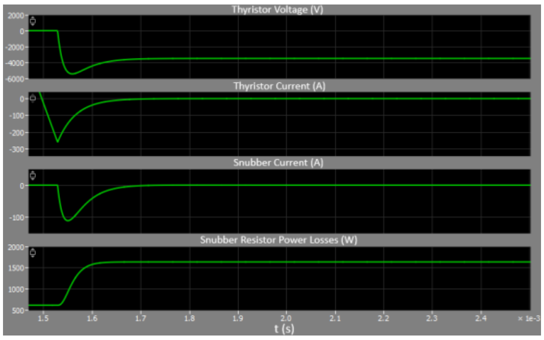
To see the waveforms for the provided examples, navigate to Simulation > Simulation parameters > Initialization and enter the parameters as shown in **Figure 13(a)** and **(b)**. As shown, the only new parameters that are needed to be entered are the optimised snubber capacitor and resistor. For three-phase rectifiers, please use (4) and (5) to calculate the new equivalent resistance and capacitance based on the standard rounded values for the snubber components.

Once the data is entered, click "Ok", and then "Simulation>Start". To observe the waveforms, click "Waveforms".

In **Figure 14(a)** and **(b)**, the waveforms including thyristor voltage, thyristor current, snubber current and snubber losses are presented for single-phase and three-phase examples. As shown, the snubber circuits provide the required voltage margin. In **Figure 14(a)** and **(b)**, the power losses graph represents the steady-state power losses in the snubber resistor, and the initial transient is ignored as this graph does not accurately represent the power losses over time; only the steady-state value is relevant for assessing the true power dissipation.



(a)



(b)

Figure 14. Reverse recovery waveforms. (a) Single-phase rectifier. (b) Three-phase rectifier.

4.4 Extra design considerations

Other considerations when designing a snubber circuit include the following:

- To reduce costs, standard resistance and capacitance values are typically used. The capacitance is chosen as the supplier's standard value closest to the calculated need. A higher capacitance provides a greater safety margin but increases resistor losses, while a lower value can result in higher voltage peaks.
- Estimation errors can arise from factors like datasheet inaccuracies, simulation errors, and component tolerances. It is advisable to include a reasonable margin for the thyristor/diode voltage blocking capability and the power losses in the components. It is typically advisable that the estimated peak reverse voltage does not exceed 80% of the device's maximum voltage blocking [4].
- When selecting a snubber capacitor, key factors include rms and repetitive voltage ratings. Capacitor reliability is affected

by voltage utilisation, ambient temperature, and self-heating. Generally, capacitors should not exceed 70% of their rated voltage to ensure a long life. Critical parameters like peak and rms current ratings must also be considered to prevent overheating. Proper mechanical design is essential to minimise heating from nearby components, as ambient temperature significantly impacts reliability.

- Reliability literature recommends using resistors at no more than 60% of their power rating for a reasonable lifespan. For ambient temperatures above 60°C, further power reduction is advised. However, in applications where the worst-case scenario duration for snubbers is brief, power loss margins can be optimised to exceed 60%.
- Resistors with low inductance and a layout that minimises stray inductance in the snubber circuit should be chosen. High inductance leads to increased oscillations, reducing the snubber circuit's efficiency.
- A small snubber resistance could result from the calculation. However, this can lead to an excessive initial discharge current when the thyristor is triggered at high voltage. This happens because the snubber capacitor's discharge current adds to the load current during the thyristor's turn-on process. If the $\mathrm{d}i_T/\mathrm{d}t$ becomes too large, it may cause thyristor failure. Therefore, it's important to thoroughly evaluate the $\mathrm{d}i_T/\mathrm{d}t$ rating of the thyristors in these situations, especially when the snubber needs to discharge quickly and frequently. In practical terms, this implies that the snubber resistor should not be too small.
- The RC snubber circuit reduces d*v*/d*t* during the off-state, preventing unintended triggering of the thyristor when d*v*/d*t* is too high. Furthermore, when thyristors are used in series, the snubber helps maintain uniform voltage changes across the devices, ensuring the thyristors turn on simultaneously.

5 Final Remarks

This application note outlined the design of an RC snubber circuit for thyristors and diodes in rectifier applications. It discussed key factors like resistor and capacitor sizing, device ratings, and parasitic effects. Theoretical design guidelines and simulation tools were introduced, including the Dynex PLECS simulation model, which can be used to optimise the R and C components and evaluate their performance. Two practical examples, including single-phase and three-phase rectifiers, are provided to demonstrate the use of the Dynex PLECS simulation model and to highlight additional considerations necessary for effective design.

The circuit simulation model presented in this application note is an original creation by Dynex, developed using the PLECS simulation platform. Dynex is neither affiliated with nor endorsed by Plexim GmbH. Users without a valid PLECS license can install the software and run simulations in demo mode. While this mode allows for simulation execution, it does not permit data export or model saving, so it is advised to run the simulations with a valid license for full functionality.

6 References

[1] T. M. Undeland, A. Petterteig, G. Hauknes, A. K. Adnanes, and S. Garberg, ‘Diode and thyristor turn-off snubbers simulation by KREAN and an easy to use design algorithm’, in *Conference Record of the 1988 IEEE Industry Applications Society Annual Meeting*, Oct. 1988, pp. 647–654 vol.1.

[2] R. S. Chokhawala and E. I. Carroll, ‘A snubber design tool for P-N junction reverse recovery using a more accurate simulation of the reverse recovery waveform’, I*EEE Trans. Ind. Appl.*, vol. 27, no. 1, pp. 74–84, Jan. 1991, doi: 10.1109/28.67534.

[3] A. Courtay, ‘MAST power diode and thyristor models including automatic parameter extraction’, in *SABER User Group Meeting*, 1995.

[4] J. Przybilla, R. Keller, C. Schneider, H.-J. Schulze, and F.-J. Niedernostheide, ‘Advantages in Application-Design by using Direct-Light-Triggered Thyristors’, in *PCIM Conference*, 2004.

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