Understanding more about rectifiers in DC power systems

Alan Gobbi
Director of Communications
APC, DC Networks
Wetherby Road, Boroughbridge
YO51 9UY, UK.
Tel. +44 1423 320000, Fax +44 1423 320073

Abstract.
Many factors affect the choice of a rectifier in a DC power system. The need to optimize power solutions has become a necessity to satisfy the increasingly competitive converging ICT markets. Careful assessment of all operating requirements can have a very significant effect on the choice of rectifier. This paper explores the significance of many different factors including, cooling regime, input voltage range, output current limit characteristic and operating temperature range.

1) Introduction:
Many factors need to be considered when selecting Rectifiers for telecom power systems. Historic trends of large monopolistic PTTs over engineering solutions will not be tolerated in the future as the global market becomes increasingly competitive. To optimise a power solution it is necessary to carefully assess many interrelated factors trading off performance and cost issues so that end users requirements are met in a cost effective manner.

The situation has also been made more critical by the additional requirements placed on power solutions to meet increasingly onerous regulatory requirements for safety and EMC. It has become essential to offer optimized solutions for each application, however it is not practical to design and build from scratch every element of a new power system, it is necessary to be able to confidently configure systems from standard building blocks.

Clearly rectifiers form the heart of a power system, without the right rectifier there is little chance of configuring an optimum system. This paper explores the many interrelated parameters associated with rectifiers and their operating environment offering a means of logically selecting rectifiers to power telecom systems.

The scope of this article is limited to single phase rectifiers in the power range of 200W to 6kW, although many of the ideas may be applicable to a broader range of power.

2) Cooling regime - Fans or Convection:
The cooling regime deployed in a system has a very significant impact on the choice of rectifiers. Some systems necessarily have to have convection cooled rectifiers but some applications can accept fan cooled rectifiers. The most obvious differences between fan cooled products and convection cooled products are the size and cost for a given power output, assuming all other factors remain constant. Traditionally large PTTs opted for convection cooling, offering a long product life, apparent low maintenance costs and the actual initial cost of the power was not as significant as it now is. It was acceptable to over engineer the solution, to "play safe".

Fan cooled units offer a cost and size advantages relative to convection cooling. These advantages are partially offset by some disadvantages including acoustic noise, dust, limited fan life and reliability but in practice these issues may not be as significant as first thought. A poorly
unreliable than a system using fan cooled rectifiers where the rectifiers cooling is less dependant on the enclosure design. Hot spots in convection cooled systems can be difficult to avoid. Moreover, actual critical semiconductors in fan cooled product can be more reliable because of lower temperature rises than in comparable convection cooled systems. Rectifiers using temperature dependant fan speeds offer longer fan life whilst maintaining adequately low device temperatures. Additionally, good fan monitoring can provide advanced warning of imminent fan failure, allowing a user to methodically replace the fan in a unit before a total failure occurs. Overall cost effective design lives of 20 years or more are viable with fan cooled products.

In addition to the fan cooled and convection cooled techniques mentioned above, two other techniques are sometimes deployed, externally system cooled and assisted convection.

2.1) External system cooled

A rectifiers convection cooling is supplemented by forced air flow provided by the system enclosure. This approach enables higher power densities to be achieved without some of the disadvantages of fan cooling within the rectifier box. This technique is particularly beneficial in OEM applications where the power system is integrated into the full telecommunications system. Some of the benefits of this approach are:-

- The cooling within the system enclosure can be multi functional providing airflow for other parts of a telecom system, not just the power system.
- Only one central cooling system to maintain, no fans in each individual component part of a system to replace.
- Useful convection rating (approximately 60% of full rating) if system cooling fails.

2.2) Assisted convection

When rectifier conditions require part time fans supplement the rectifiers convection cooling. If temperatures are high or if high output currents are sustained fans are turned on. High system integrity can be maintained by exercising the fans and monitoring the fans performance on a routine basis. If fans fail to perform adequately alarm signals can be raised so that the system can be effectively maintained without disrupting normal operation. Benefits of this approach are:-

- Part time fans allow systems to have design lives greater than the life of individual fans within rectifiers without the need for planned fan replacement.
- Good use of redundancy and battery recharge reserve can be used such that under normal conditions fans within rectifiers do not operate.
- Dust and noise problems are reduced substantially because of the part time nature of the fan operation.

The following example shows how a system may be configured:-

Rectifier
Convection rating 30A
Fan assisted rating 50A

Load:
Maximum real load 110A
Battery charge current 30A
Total current 140A

N + 1 redundancy required.

To support the total current of 140A three rectifiers will be required with a forth needed to provide the redundancy. If however all four units are operating, as normally will be the case, and the batteries are fully charged, the maximum load current demand will require only 110/4 = 27.5A per rectifier, less than the convection rating of the rectifier. Under these conditions no fans will operate. If the system has to recover the charge into the battery after a mains fail period or if one of the rectifiers fails the system will still operate satisfactorily but the fans within the rectifiers will operate. For typical systems the actual proportion of operating time that fans will operate is very low.
resulting in long product lives. Also note that, for the example given above, if a fan in one of the rectifiers fails the total current capability of the system will only reduce by 10% (4 x 50A to 3 x 50A plus 30A), whereas if the system used continuous fan cooled rectifiers the power capability would reduce by 25% if one fan failed.

The following table show typical relative power densities for the cooling regimes defined above.

<table>
<thead>
<tr>
<th>Cooling regime</th>
<th>Relative density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection</td>
<td>1.00</td>
</tr>
<tr>
<td>Fan cooled</td>
<td>2 to 2.5</td>
</tr>
<tr>
<td>System cooled</td>
<td>1.5 to 2</td>
</tr>
<tr>
<td>Assisted convection</td>
<td>1.3 to 1.7</td>
</tr>
</tbody>
</table>

Note: Assuming that all operating conditions are comparable.

3) **Input Voltage range:**

Selecting the right input voltage range for a particular application is becoming more critical. For historic applications within Great Britain it was normal to specify on input range of 216V to 264V i.e. 240V +/- 10%. The trend now in some market areas is to specify input ranges to suit world voltage ranges - 85V to 264V (or more). In practice for most applications neither extreme is optimum.

The advent of 110v input Power Factor Corrected rectifier input stages to meet the emerging international regulatory requirement pertaining to input current harmonics has led to products with universal input voltage capability.

For portable equipment marketed or used throughout the world the choice of universal input with power factor correction is obviously right, whereas for permanent installations careful selection of input range can be advantageous. Providing full parametric performance over a wide input voltage range has a significant impact on the cost and size of a rectifier. This also interrelates to the cooling within the system. In practice a rectifier operating at 85V input can have twice the loss that it would have operating at 230V.

Clearly it is sometimes necessary for rectifiers to operate fully over wide voltage ranges but in some applications it is acceptable to only offer short term capability for voltages below a threshold level, eliminating the need to manage the heat loss on a continuous basis resulting in substantial cost and size savings.

If a system is required to operate from a nominal 115V supply the percentage difference in maximum power loss in the rectifiers between operating at 103.5V (115 - 10%) and 85V can be up to 15%. Systems specified to operate continuously from 85V need to reliably dissipate approximately 15% more power than a system specified to operate continuously at 103.5V. Having a continuous thermal rating for 103.5V does not imply that the system can not reliably support short term operation at substantially lower voltages. The precise limitations being dependant upon the thermal management within the rectifier.

The following graph shows the power loss in Watts against input voltage for a typical rectifier.

4) **Current Limit Characteristic:**

It is usual to provide a constant current limit characteristic over the output operating voltage range of a power system, with either a fold back characteristic or constant current limit down to a short circuit. This traditional approach may not be as ideal. Taking into consideration the true nature of all the loads will allow a system to be optimized.

The total load placed on a telecoms power system is the sum of many smaller loads. Some load element are resistive, some are constant current, some are constant power and batteries will take varying currents dependant upon their charge status. If the maximum total load...
current, including battery charge current allowance, is used to size a power system at the maximum battery float voltage more power capacity than needed may be provided.

In modern telecommunications systems increasingly large proportions of the equipment utilises local DC/DC converters providing fixed output voltages independent of the power system bus voltage. This constant power demand results in an increasing input current as the bus voltage falls. If a constant power load consumes 1 amp at 55V it will consume 1.3A at 40V. In contrast a constant resistance load of 1A at 55V will consume only 0.7A at 40V. Carefully assessing the true nature of all the loads across the full operating voltage range will reveal if it is possible to optimize a system by providing an output current limit characteristic other than the traditional constant current characteristic.

The following method allows the optimum characteristic to be determined.

If: 
- \( I_d = \) Maximum DC/DC input current at 40V 
- \( I_r = \) Maximum resistive current at 55V 
- \( I_b = \) Constant battery charge allowance 
- \( I_t = \) Total load current

Then at 55V:
- \( I_t = I_d \times 40/55 + I_r + I_b \)

And at 40V:
- \( I_t = I_d + I_r \times 40/55 + I_b \)

Assuming that the normal float voltage is 55V and the minimum battery voltage is 40V.

The following two examples illustrate the possible outcomes.

**Example 1**

If: 
- \( I_d = 100A \), \( I_r = 20A \) and \( I_b = 10A \)

At 55V:
- \( I_t = (100 \times 40/55) + 20 + 10 = 102.7A \)

Equivalent to 5.64kW power capability.

And at 40V:
- \( I_t = 100 + (20 \times 40/55) + 10 = 124.5A \)

Equivalent to 4.98kW power capability.

**Example 2**

If: 
- \( I_d = 50A \), \( I_r = 70A \) and \( I_b = 10A \)

At 55V:
- \( I_t = (50 \times 40/55) + 70 + 10 = 116.4A \)

Equivalent to 6.4kW power capability.

And at 40V:
- \( I_t = 50 + (70 \times 40/55) + 10 = 110.9A \)

Equivalent to 4.44kW power capability.

In example (1) if a partial constant power characteristic is employed within rectifiers the maximum power capability can be reduced from 6.85kW (124.5 x 55) to 5.64kW, a saving of more than 17%.

In example (2) the current demand across the operating voltage range reduces slightly as the voltage falls, hence it is appropriate to have a constant current output characteristic within rectifiers. The output characteristic of modern switched mode topologies can easily be tailored to suit total load requirements minimising the total installed power requirements to satisfy a particular load combination.

The following diagram shows an output current limit characteristic of a unit optimized to suit example (1) above.

![Output current limit characteristic diagram](image)

A - shows the conventional constant current limit characteristic.
B - shows the partial constant power current limit characteristic.
C - shows a constant power load.

The triangular area between A and B equates approximately to a 17% reduction in power requirements.

5) **Temperature range:**

The operating temperature range for telecommunications equipment is of vital importance. Some equipment is required to operate in normal room temperatures whereas some equipment needs to operate over a wide temperature range, (e.g., -40°C to +65°C) As already implied in section 1, careful consideration of temperature and cooling is vital for a systems to operate reliably and effectively.
If applications require power systems to operate over wide temperature ranges clearly it necessary to ensure that all component parts of the system will operate reliably, but to minimise cost and maximise a power systems capability it is worth while looking closely at the extremes of temperature and assessing if full performance is required.

- Is it necessary to meet fully all aspects of a systems normal temperature specification at very low temperatures?

- Is it necessary to provide the full power rating at very high temperatures?

In effect the more constraints that can be removed from the extremes of the temperature range the more cost effective a system can be.

**Low temperature.**

Some equipment will be required to continuously operate at very low temperature without any compromises to the performance, in which case the power system will have to be fully rated meeting all parametric requirements. If some compromises can be accommodated significant cost savings can be realised. The most common reason why a power system needs to operate at very low temperatures is to ensure that a system can start up reliably if it has been left dormant for a substantial period of time in a cold climate. In practice a power system will soon warm up with self heating once it has started. Relaxation of non critical parameters at low temperatures, such as output noise, ancillary features etc. is advantageous in terms of rectifier cost. In effect it is beneficial if rectifiers can be specified to start up at the lowest required temperature and meet fully all parametric requirements at a higher temperature.

**High temperature.**

Normal power supplies, if required to operate at high ambient temperatures, sometimes have deratings applied above certain temperatures. This can equate to as much as 30% reduction in power for an ambient temperature increase of 20°C. This restriction in output capability can be accounted for with a conventional power supply at the system design stage where the load requires the power supply to operate in voltage control. Current limit only being required to operate in fault conditions

With rectifiers the output is required to operate in voltage control when batteries are in a high state of charge but when batteries are recovering from a discharge rectifiers are required to operate in current limit for sustained periods of time. If a temperature derating is applied to a rectifier, for safe operation in current limit it is necessary for the rectifiers current limit to be reduced to ensure that the power capability of the rectifier in the worst case ambient temperate is not exceeded. In effect to operate at high temperature a conventional rectifier will have to have a lower current limit than if its maximum temperature of operation is lower.

It is usual in many real applications for the local rectifier ambient temperature to vary with climate and operating conditions of the system. It is not usual for the local ambient to remain at its maximum specified level for sustained periods of time. It is possible with the right thermal control of a rectifiers current limit to maximise a power systems capability for most operating conditions, limiting only its capability in maximum ambient conditions, in particular when the input voltage to the rectifier is towards the lower end of the specified range. Instead of restricting a rectifiers output capability to the safe power level that can be sustained at the maximum ambient temperature for all operating temperatures it is possible, with the right thermal management and monitoring within a rectifier to automatically offer more power at lower temperatures.

It may not be possible to accept any dynamic temperature derating in a particular application, but careful assessment of the minimum requirements at the maximum ambient temperature may allow this feature to be exploited. For instance:

- Does the system need to be able to provide battery recharge current at its maximum operating temperature or is it acceptable to have a longer recharge time?

- Can some of a systems features be inhibited at maximum ambient
so reducing the maximum current demand?

¥ Can the redundancy in the system be sacrificed at maximum ambient?

The benefits that can be exploited if rectifiers have temperature dependant current limits are significant. This feature can also be combined with the above mentioned partial constant power characteristic so that as many as possible of the benefits proposed can be exploited. Also note that the varying rectifier power loss with input voltage will allow a rectifier with a temperature regulated current limit to offer more current capability at high ambient temperature if the system operates normally close to the nominal mains voltage than if the system operates close to the minimum specified voltage.

6) Connectivity:

The way that a rectifier is connected to a system has a significant effect on the cost of ownership of a system. The three ports that need to be connected are, AC input, DC output, and alarm signals. Simple rectifiers can have screw terminal for the power connections and a simple multi pin signals connector but these are becoming unpopular because of the relative difficulty of installing or replacing them. The popular trend is to have "Hot plug" rectifiers that allow a rectifier to be automatically connected to the AC supply, the DC bus and alarms monitoring circuits as the product is slid on to its support shelf. This process has to fault tolerant and idiot proof. The process of installation or removal does not need any real skill to carry out. Rectifiers that have "hot plug" connections cost more to produce than more basic products with screw terminal connections, but if the cost of installation and maintenance is taken into account they can be more cost effective. Other rectifiers are available that fall in between the above two types. A unit with input connector, output connector and signal connector that does not automatically make connections as it is installed on a shelf can still be "Hot Swapped", although the process requires a higher level of skill to ensure that the system integrity is maintained during the process of changing or installing a rectifier. The right choice of connectivity for a rectifier is very dependant upon the application and location. If the location is somewhat remote and the installation or maintenance process has to be carried out without a skilled workforce it is probably more optimum to choose Hot Plug units, where as if the applications is in an area where skilled technicians are to hand then a unit with lower connector costs may be more optimum.

7) Conclusion:

Many interrelated factors can affect the choice of a rectifier for a telecom application. If the default worst case conditions are used to specify a rectifier the system may have substantially more capability than really needed. Choice of the cooling regime can affect the physical size of the rectifier by a factor of up to 2.5. Fan cooling of some form may be viable for applications that at first sight would appear to need to be convection cooled. The power loss in a rectifier increases significantly as input voltage falls. Careful specification of input voltage requirements is important for optimizing a system. The maximum power capability of a rectifier can vary by up to 20% if partial constant power current limit characteristics are employed for certain types of load. Flexible use of temperature dependant current limit characteristics can offer adequate capability at high ambient temperature. Hot plug rectifiers may at first seem to be more expensive, but if total cost of ownership is considered they can be cheaper.

Overall there are many factors, more than covered in this paper, affecting the optimum choice of a rectifier to power a telecommunications system. A full understanding of all aspects of a system is a prerequisite if an optimum power solution is to be configured.