Eaton Energy Saver System: Facts and Principles

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Executive summary

While reliability and resilience are always the top priorities for data centre power sources, energy efficiency is invariably the third item on the list. After all, maximising energy efficiency not only cuts operating costs, it also reduces environmental impact. Over the years, the drive for data centre energy efficiency has led to the development of uninterruptible power supplies (UPSs) with lower and lower losses. These days, UPSs can, for example, typically reach around 94 to 95 per cent efficiency when operating in double conversion mode at load levels of 40 per cent or more.

Whilst this level of efficiency may initially seem to be good, it's sobering to note that in a modest-sized data centre with a total load of just 100 kW, the losses are an astonishing 6 kW. Over a year of 24/7 operation that amounts to well over 50,000 kWh of electricity paid for, wasted and converted to heat that has to be removed by the data centre cooling system. Many modern large data centres have much larger total loads than this – up to several megawatts is by no means unusual – and in such cases the energy wastage will, of course, increase in proportion with the load.

It's clear that further improving energy efficiency in UPSs is an important concern, and Eaton has addressed this by developing its unique Energy Saver System (ESS). Put simply, ESS uses a static bypass switch to power the UPS loads directly from the mains supply at all times when the mains supply quality is good. However, if the mains supply fails or its quality deteriorates, the UPS switches to double-conversion mode within two milliseconds, which is so fast that even the most sensitive of IT loads are unaffected.

While operating in ESS mode, Eaton's UPSs typically achieve efficiencies of around or above 99 per cent, which means that the amount of energy wasted – and the amount of heat generated – is reduced by over 80 per cent compared with a standard double-conversion UPS. The remaining sections of this paper explore in more detail how ESS technology works, the types of applications for which it is most suitable, how it helps to increase UPS reliability and life, and the benefits it has been proved to deliver in practice.

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Powering Business Worldwide

The technology of ESS

For critical applications, UPSs based on double-conversion topology are almost always used, as this topology provides the best possible protection against the widest range of power quality problems. In essence, the power sections of double-conversion UPSs comprise four main functional elements: a rectifier, an inverter, a static bypass and a battery. The arrangement of these elements is shown in Figure 1.

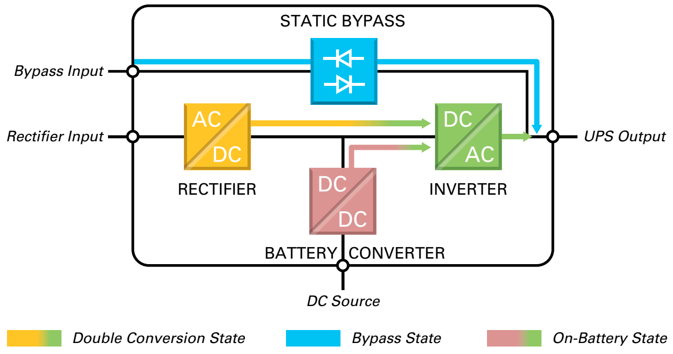

Figure 1. Arrangement of power sections in a double-conversion UPS

A conventional double-conversion UPS has three operating states. It can operate in double-conversion mode, when the rectifier supplies power to the inverter and the loads are powered from the output of the inverter. Typically, it will operate in this mode most of the time. However, if the mains power supply fails, or is of insufficient quality to power the rectifier, the UPS will operate in on-battery mode, where the inverter draws power from the batteries instead of the rectifier.

The final operating mode is bypass mode where the static bypass is closed and the loads are powered directly from the bypass supply. This is usually seen as a fallback operating mode used when there are problems with the UPS or when maintenance needs to be performed.

UPSs with ESS have power sections that are made up of exactly the same four functional elements as conventional UPSs that don't have this feature. This is hugely significant, as it means no new elements, which might add complexity and reduce reliability, are introduced. Instead, the standard functional elements are used in a novel way that takes advantage of their full potential.

The key difference is that UPSs with ESS technology have a fourth operating mode, which unsurprisingly is called ESS mode. In this mode, the static bypass is closed and the UPS loads are fed directly from the mains supply, just as they are in bypass mode with a conventional UPS. The losses in ESS mode are minimal – typically around 1 per cent – because the only devices in the power path between the mains supply and the loads are the static switching elements themselves.

But what is the difference between bypass mode and ESS mode? The answer, as shown on Figure 2, below is that in ESS mode, the rectifier and inverter function elements are held in a state of 'extraordinary preparedness'. This means that their control circuitry is functioning fully and, for example, is continuously ensuring that the inverter is synchronised with the mains power supply. The power semiconductors of these rectifier and inverter are, however, 'gated off'. This means that they receive no drive signals from the control circuitry and, therefore, aren't switching. And, as they are handling no power, they generate no losses.

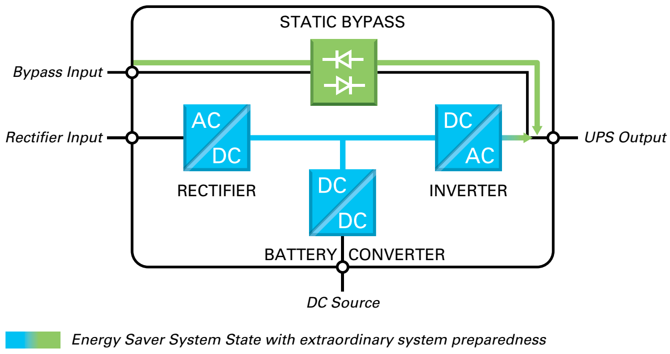

Figure 2. The difference between bypass mode and ESS mode

Because the control circuitry remains fully operational in ESS mode, when the mains power quality deteriorates, all that's needed to switch to double-conversion operation is to turn on the drive signals to the output power semiconductors. This can be done almost instantaneously and, while Eaton guarantees a switching time between ESS mode and double-conversion mode of 2 milliseconds, in practice the transition is usually accomplished in a shorter time. Should the mains supply fail completely or deteriorate to the point where it can no longer be used to power the rectifier, the UPS will, of course, transition instantly to on-battery mode, in exactly the same way as any other double-conversion UPS.

From the above description, it will be noted that the control circuitry of power modules that make up the UPS remains operational in ESS mode, and a perfectly valid question is to ask whether this circuitry itself consumes power that contributes to the ESS mode losses. The answer is that it does, but the contribution is negligible – the control circuitry for each power module can be expected to consume about 200 W when the power semiconductors are not being driven. This is about the same amount of power consumed by a games console and, as such, it has little impact on overall ESS mode efficiency.

Controlling ESS

In the preceding section, we have considered primarily how the power elements of an ESS UPS operate, but we have not yet discussed another essential element of ESS technology – how the UPS decides when to switch from ESS to double-conversion mode and back again. This decision-making process is handled by advanced digital signal processing techniques.

Every modern double-conversion UPS incorporates at least one digital signal processor (DSP). Where a UPS is made up of several uninterruptible power modules (UPMs), an approach that is widely used as it makes it easier to optimise loading and to build in redundancy, each UPM will have its own DSP. In Eaton products, there is a further DSP that forms part of the system bypass module. In Eaton UPSs, all of the DSPs continuously monitor both the mains input to the UPS and the output to the loads, looking for anomalies such as low voltage or frequency out of tolerance.

If any of the DSPs detects an anomaly, the transition between ESS mode and double-conversion mode is triggered instantly. This arrangement provides a high degree of security and, in effect, it has inherent redundancy, as only one of the DSPs needs to detect an anomaly for the transition to be triggered. Further, the UPMs and, indeed, the UPSs incorporate HotSync technology which allows them to load share without the need for any communications link or central controller that could, if it failed, shut down the whole system. In fact during ESS operation, even if a UPM or communication fails, the system recovers to double-conversion mode and continues to supply and protect the loads provided, of course, that the serviceable UPMs have sufficient capacity to meet the load requirements.

The UPSs may also be commanded to switch to double-conversion mode by means of external signals, which may be desirable if, for example, it becomes necessary to power the UPS from a standby generator. The criteria for automatic transitioning between ESS and double conversion modes and back again are highly configurable and can be adjusted to suit conditions on individual sites so that unnecessary transitioning is avoided. A widely used option, for example, is so-called 'storm detection' where, if multiple transitions occur in a preset time period, the UPS will stay in double-conversion mode for, typically, one hour.

ESS and reliability

We have already touched on the inherent redundancy of the control system in an Eaton UPS and noted that ESS technology introduces no major new elements into the UPS which could compromise its reliability. A further factor worthy of note is that, as the simplified reliability state diagrams shown in Figure 3 below make clear, a conventional double-conversion UPS has four possible reliability states, but a UPS using ESS operation has five. This means that a UPS with ESS is less likely to fall into the mission failure state and is, therefore, inherently more reliable.

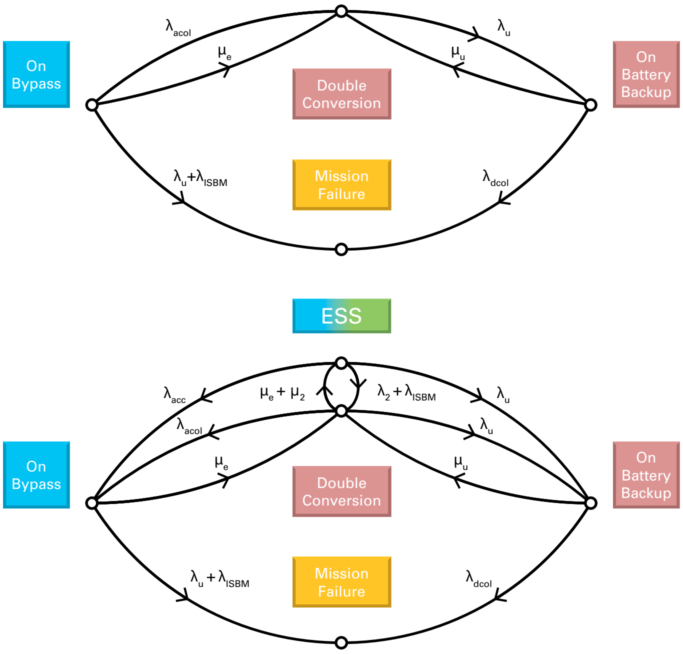

Figure 3. Simplified reliability state diagrams for double conversion and ESS

There is, however, another important factor that has a major influence on the reliability of UPSs: the electromechanical components, which are essential in all types of UPS, are subjected to far less stress than in conventional UPSs. All electromechanical components have moving parts that wear and will eventually fail. Reducing the stress on these components can, therefore, do much to increase the reliability and extend the life of the equipment in which they are used.

Consider cooling fans, for example. These are as necessary in UPSs with ESS as they are in any other type of UPS, because there will be times – if the UPS is operating in double-conversion mode, for example, or if the batteries are being charged – when the fans will need to run to remove heat from the unit. When the UPS is in ESS mode, however – which is likely to be well over 90 per cent of the time – the fans can be switched off. This saves energy and extends their lives.

And it is not only the electromechanical components that benefit from reduced stress. When operating in ESS mode, a UPS supplies the load via the static bypass, and holds the rectifier and inverter in a quiescent state while, of course, maintaining extraordinary system preparedness. In this quiescent state, the rectifier and inverter are under negligible load and stress, which results in significantly enhanced reliability and lifespan.

ESS and surge protection

A detailed consideration of surge protection, which safeguards loads powered by UPSs against the effects of voltage transients ('spikes') injected into the mains supply by lightning strikes and switching operations, is beyond the scope of this white paper.

It is worth noting, however, that even though surge protection is not a primary function of ESS technology, it does make a substantial and useful contribution. This is primarily because UPSs include input, output and DC link capacitors connected in a way that maximises system-wide surge suppression capabilities.

These capacitors help to reduce the amplitude of the transients and making them easier for the metal oxide varistor (MOV) devices that are the primary means of surge suppression to hold them to a level where they can cause no damage. The reduced stress on the MOV devices also means that these have longer service lives.

When to choose ESS

UPSs that incorporate ESS technology can be used to advantage in almost any application where a conventional double-conversion UPS would be used, and they are particularly well suited to data centre applications. Their increased efficiency means reduced running and cooling costs. The two millisecond or faster transition between ESS and double-conversion modes easily meets or exceeds the requirements of Federal Information Processing Standards (FIPS), the Institute of Electrical and Electronic Engineers (IEEE), the International Commission for Information Technology Standards (ITI) and the International Electrotechnical Commission (IEC). Compliance with these requirements confirms that the transition will be invisible to IT loads of all types.

Nevertheless, there is a small number of situations where UPSs may not be able to deliver their full benefits by using ESS. These situations are characterised by having poor quality mains supplies that would result in either frequent switching between ESS and double-conversion modes or long and regular periods of operation entirely in double-conversion mode. These poor quality supplies are most often derived from inadequately maintained generators or from badly overloaded public supply networks.

Problems can also occur in data centres where the cooling loads and IT loads are powered from the same supply transformer as, in such cases, the starting and stopping of the air-conditioning compressors may produce transients that are sufficiently large to trigger the UPSs to transition into double-conversion mode. In most of these cases, however, this situation can be remedied by fine-tuning the mains quality detection parameters for ESS in the UPS.

Finally, it is worth noting that, in the unlikely event that a UPS is installed and ESS operation is not found to be useful, little is lost as the ESS mode can be readily disabled. The UPS will then operate as a conventional double-conversion model with absolutely no loss of features or functions other than those directly related to ESS operation.

ESS pedigree

Many potential users see ESS as new and relatively unproven technology and this makes them wary of adopting it. Their concerns are, however, misplaced; ESS has a long and well-respected pedigree and it has been proving its worth and reliability in numerous applications worldwide for more than half a decade. In Denmark, for example, where very high consumer energy prices together with environmental awareness have acted as a spur to the adoption of innovative energy-saving technologies, more than 90 per cent of data centres that use Eaton three-phase UPSs are equipped with products that incorporate ESS.

In considering the pedigree of UPSs with ESS technology, it is important to remember that they are the latest generation in a long line of Eaton UPS products which have established an enviable reputation for reliability and quality. It is also worth remembering that, as discussed earlier, the power elements used in UPSs are essentially the same well-proven elements as are used in the company's conventional double-conversion UPSs. The HotSync technology used for load sharing is equally well proven.

The DSP sections of the UPSs have, of course, been enhanced to provide the necessary supply monitoring features and to generate the transition control signals, but these enhancements are, once again, incremental changes rather than a radical redesign. In other words, ESS technology, for all its apparent novelty, has as its firm foundation, tried-and-tested elements that IT and other critical power professionals around the world have, for many years, been happy to rely on to support their most critical loads.

The reliability of ESS technology has been confirmed in a wide range of applications in various mains configurations. A recent sample taken from over 100 sites globally recorded over 1500 units operating in ESS mode for over 20 million hours by the beginning of 2015, demonstrating that these UPSs suffer noticeably fewer failures than conventional double-conversion units in similar applications. The energy-saving claims are also well-proven with an average of over 300 MWh of energy saved every day, totaling 180 GWh, since ESS technology was first introduced in 2009. During this period, CO_2 emissions have also been reduced by 80,000,000 kg. Additionally, in Denmark, more than 90 per cent of the data centres using Eaton three-phase UPS systems, rated at 40 kW or more, have successfully cut their energy usage by nearly 10 per cent using ESS technology.

ESS benefits

While the principal benefits of ESS technology have already been discussed in the earlier sections of this white paper, it is useful to summarise them here.

- Energy savings. Achieving energy savings is the primary goal of ESS technology and it does this very effectively in almost all applications. A UPS running in ESS mode will typically operate at 99 per cent efficiency whereas the efficiency of a conventional double-conversion UPS is likely to be nearer 94 per cent, even under optimum operating conditions. In a large UPS installation with a 1 MW load, the savings can amount to as much as €0.10 per minute, which is equivalent to €50,000 per year.
- Reduced CO_2 emissions. Because ESS reduces energy wastage, it reduces CO_2 emissions. Again considering an installation with a 1 MW load where ESS increases efficiency from 94 to 99 per cent, the emission reduction will be around 195 tonnes per year. This is equivalent to the amount of CO_2 that would be produced by driving a car around the world 30 times.
- Reduced cooling costs. As UPSs operating in ESS mode generate less heat than conventional double-conversion UPSs, they require less cooling. Note that this doesn't mean that the cooling plant can necessarily be downscaled, as it must still have the capacity needed to cool the UPSs when it is necessary for them to switch to double-conversion mode. It does mean, however, that the cooling plant will, for most of the time, be operating well below its maximum capacity and provided the plant is properly designed, this will lead to big savings in the energy needed to run the plant.
- Enhanced reliability. ESS technology in UPSs add no major new elements to conventional double-conversion designs, so there is no additional complexity that might degrade reliability. In fact, as the existing elements are used to their full potential, reliability is enhanced. Further reliability enhancements result from the reduced stress ESS mode operation places on key components, such as power semiconductors and electromechanical devices like cooling fans.
- Proven technology. ESS UPSs use the same basic technology and building blocks as are providing reliable service in numerous conventional UPSs around the world. In addition, ESS products have now been available for over five years and are themselves in widespread use. Experience and customer reports confirm that the units deliver outstanding load protection combined with exceptional reliability.

Conclusion

UPSs with ESS provide extensive and valuable benefits for users. Their energy-saving qualities mean that they also help to protect our planet. They deliver these extra benefits while continuing to provide, without any compromise whatsoever, all of the benefits offered by the very best conventional double-conversion UPS. This means that there is a compelling case for those purchasing or specifying new UPS systems to consider and carefully evaluate the advantages that ESS technology would offer in their specific applications.

While still considered by many IT professionals as a new technology that needs to be approached with caution, ESS has in fact already passed the demanding test of user experience and, in the near future, there is every possibility that it will become the de facto UPS technology against which all others are judged.

About Eaton

Eaton is a power management company with 2014 sales of $22.6 billion. Eaton provides energy-efficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power more efficiently, safely and sustainably. Eaton has approximately 102,000 employees and sells products to customers in more than 175 countries. For more information, visit www.eaton.com.

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