A White Paper from the experts in *Business-Critical Continuity™*

UPS functioning modes: *a new algorithm for unprecedented efficiency*

EMERSON™
Network Power

Abstract
The standard UPS technology most widely accepted by the industry as the ideal solution for large installations to date is double conversion and the variations of its configuration. In double conversion mode the UPS provides reliable insulation against power quality problems. It allows control of output voltage and frequency regardless of the voltage and frequency input conditions.

But we must pose the question, is double conversion the only possible solution for resolving these types of disturbances?

Although double conversion technology has proved to be reliable in protecting installations against almost any and every type of disturbance it has one notable drawback – efficiency. In providing such high protection, double conversion UPS constantly work in Maximum Protection mode, causing them to use a large amount of surplus energy.

So, is there a more efficient solution for providing protection to mission critical installations?

The paradigm solution is a UPS which is able to differentiate between different types of electrical disturbances and respond using the most efficient and effective functioning mode for compensating each particular disturbance. This has been made possible with the development of the revolutionary Trinergy™.

1. Introduction

In large mission critical power installations, such as data centers, the use of double conversion UPS has always been considered the best choice for providing loads with a high level of protection against virtually all types of electrical network disturbances.
The use of a double conversion UPS continues to be the commanding solution for protecting against specific electrical supply conditions. Over time both digital signal processing (DSP) and the patented Vector Control technology developed by Emerson Network Power's Chloride business, made it possible to introduce specific higher efficiency solutions. One such solution is intelligent double conversion which was introduced to the UPS market by Chloride in 1998.
Intelligent double conversion was designed to continuously examine the mains supply and identify in which instance it is able to supply the load directly through the bypass line. This technology is now widely used in three phase products ranging from 10 kVA to 800 kVA.
While intelligent double conversion allows for the significant reduction of UPS energy loss, in some cases the line conditions are not sufficient enough to allow the system to work consistently in high efficiency mode. This can be due both to mains disturbances and/or load characteristics (particularly current distortion and displacement). This sometimes results in the UPS having to work permanently in the double conversion Maximum Protection mode.

Following the extended adoption of these configurations it became evident that there was nonetheless the need for an even more intelligent solution. Such a system would be able to discriminate between different types of disturbances and provide conditioning according to the level and type of disturbance, rather than always using a single solution (double conversion or intelligent double conversion) for all types of disturbances.

There are a certain number of disturbances (such as sags, voltage fluctuations, harmonics and so on) that can be compensated with filters, particularly active filters, avoiding the need for the energy to flow through the double conversion line.

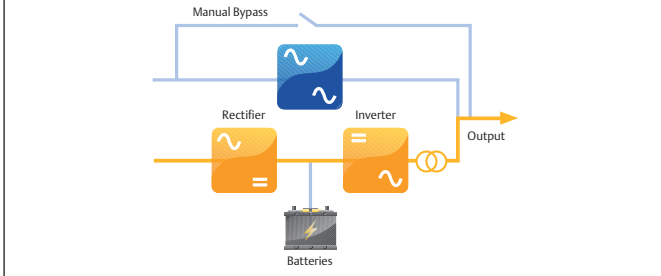


Figure 1 *- Typical single line diagram of a double conversion UPS (VFI) with output transformer.*

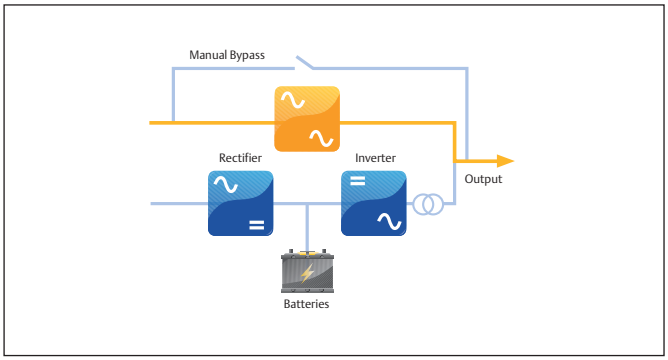


Figure 2 *- Single line diagram working with priority on the bypass line. The inverter is continuously synchronized with the bypass line and ready to seamlessly take the load whenever needed.*

2. What if the standard UPS already had an active filter?

It does. When the UPS is in line interactive mode the inverter is idle and is always ready to deliver immediate power to the load. Therefore, the inverter can be used to compensate disturbances from the mains to the load or vice versa, hence once again being able to completely isolate the load from the mains without having to use the double conversion solution. It is possible that mains failures may still occur or that the compensation requested is higher than what the inverter is able to provide, in which case the UPS will immediately and seamlessly activate the double conversion line.

Today, these solutions have been further enhanced by the adoption of the latest technology in double conversion three phase products: Transformer-free UPS (see Fig. 3).

This UPS topology can now reach up to 1600 kW of power in a single unit that, together with the latest control technology, is able to deliver the ultimate level of power protection while achieving the highest efficiency level in the market.

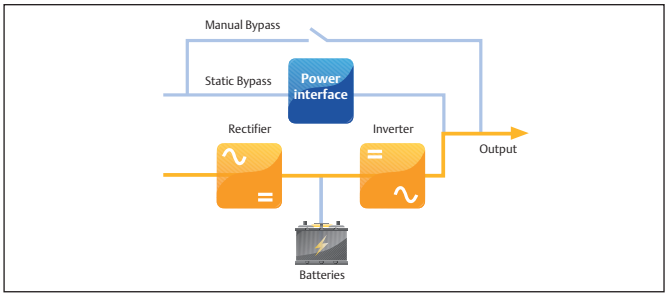
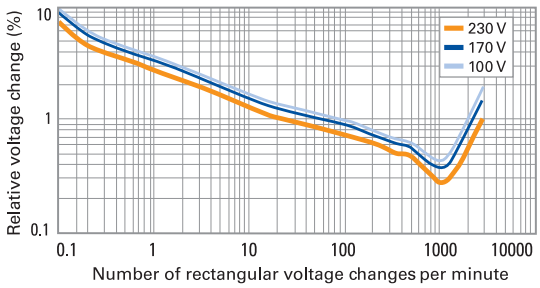


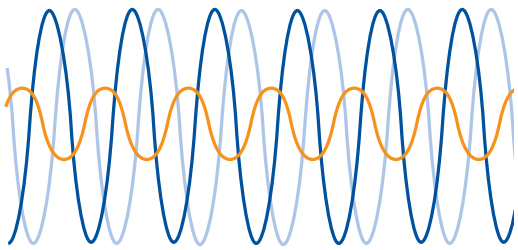
Figure 3 *- New transformer-free UPS with Trinergy™ technology working in double conversion.*

2.1 Typical electrical disturbances

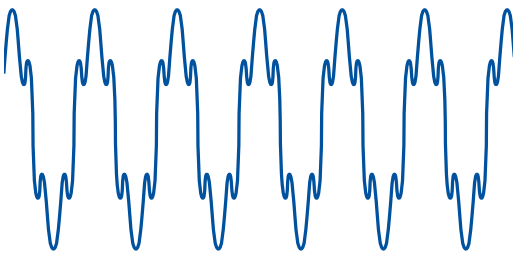
The electrical supply quality depends on several types of disturbances that can be briefly summarized in the following categories:[1]



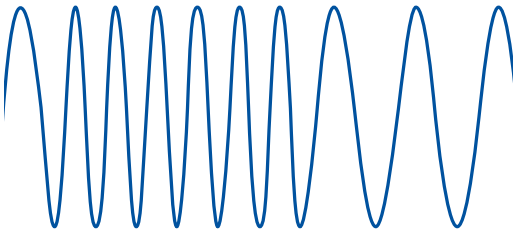
Voltage fluctuations and flickers



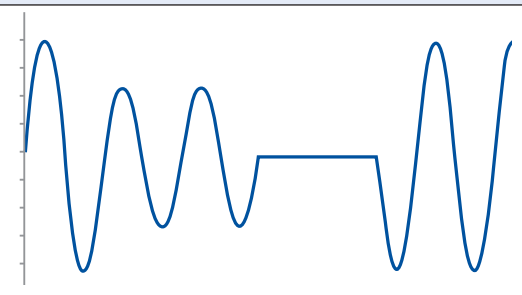
Voltage imbalance



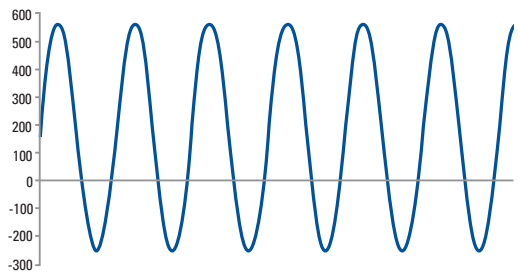
Harmonics and inter-harmonics



Power frequency variations



Voltage dip (sag) and interruptions



DC components, notching and electric noise

Other disturbances include inducted low frequency voltage and oscillatory transients.

2.2 Available solutions

There are several solutions presently available in the market to condition and improve the energy supply quality to the load:

- UPS
- Transient Voltage Surge Suppressor (TVSS)
- Static transfer switches
- Series active filters
- Parallel active filters
- Hybrid active filters (series and parallel)

The latter three solutions based on active filters are typically used to compensate all of the disturbance categories, except voltage interruptions and frequency variations, within certain limits and with high efficiency.
When considering the common electrical disturbances seen earlier in section 2.1, the UPS in its double conversion configuration, is the only one to date capable of compensating all of the possible electrical disturbances. The UPS is indeed capable of supplying high quality voltage to the load both during the presence of large voltage amplitude fluctuations and also during total power supply interruptions. The latter can be achieved with local energy storage devices, such as batteries or flywheels.
The double conversion UPS is certainly a leading solution, its only drawback is that it consumes a significant amount of surplus energy in continuously converting input AC power to DC power and then DC to output AC.

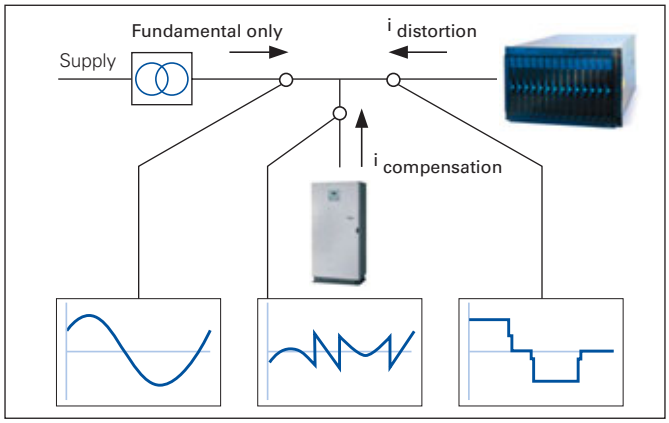


Figure 4 *- Parallel active filter for harmonics, PF and transient compensation.*

2.3 Intelligent double conversion for high efficiency

In many cases the high level of power conditioning achieved with a double conversion UPS is greater than what is actually needed for the disturbance present. An ideal solution would therefore be a solution capable of working in double conversion mode only when and if required. Hence, only when there is an out of tolerance input voltage fluctuation.

The intelligent double conversion UPS, is therefore a UPS which works on the automatic bypass line as a primary load source while having:

1. the inverter continuously synchronized to the bypass line in order to allow a fast, reliable switch to double conversion or battery supply if needed;

2. the input continuously monitored to check for possible fluctuations that deviate from a normal condition.

This solution allows double conversion to be used only when needed and supplies the load by dissipating only a very small amount of energy through the bypass line.

- Typical efficiency of the latest transformer UPS in double conversion is 93%.
- Typical efficiency of a transformer UPS on bypass line is 97%.

To avoid switches between the two lines occurring too frequently, (after a mains out of tolerance or failure) there is a specific algorithm which, depending on the frequency and duration of the mains problems, will allow the load to be monitored for a longer period of time before returning to the bypass line. Therefore, depending on the electrical environment, the UPS will remain for a certain period of time on the bypass line and the remaining period of time on the double conversion line. For a detailed explanation of the efficiency implications that result from this type of solution please refer to *"New Control Techniques for UPS Dynamic Efficiency Optimization "* (Zanei, 2009).[2]

This is the standard solution adopted by all Emerson Network Power three phase high power UPS (above 10 kVA) to achieve a higher efficiency. While this is certainly a good solution for improving the overall efficiency of the UPS there are ways it can be further improved while continuing to maintain the highest level of protection against power disturbances.

- What happens when the electrical environment experiences concentrated mains out of tolerances too frequently?
- Why does the UPS need to go into double conversion mode even for small out of tolerances when it could alternatively use a smaller filter?
- What can be done to limit the effects of undesirable loads (distorting or displacing) when connected directly to the mains in Digital Interactive Mode?

In the three cases mentioned above the UPS will spend a significant amount of time in the double conversion mode even if it is not always necessary. This is due to the approach, correctly taken by these types of high efficiency solutions, to completely decouple the mains from the load (see Fig. 1).

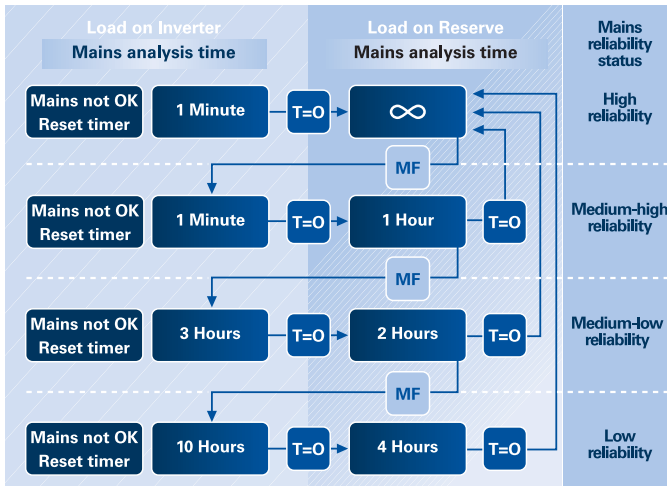


Figure 5 *- The algorithm used to control the UPS status depending on the mains quality. This algorithm is fundamental in avoiding switches between double conversion mode and digital interactive mode occurring too frequently when the mains quality deteriorates.*

2.4 Using the inverter as an active filter

A solution would therefore be to use both a parallel and a series active filter during the functioning on the bypass line.
This allows compensation of most of the disturbance categories seen in section 2.1, except voltage interruptions and frequency variations, within certain limits while continuing to maintain a high efficiency. This can be achieved given that the active filter uses less power than double conversion to compensate disturbances.

Inverter as a parallel active filter: the inverter will work as a current controlled generator, generating a current that compensates the reactive and harmonic content of the load.

Inverter as a series active filter: the current of the active filter will have a shape intended to compensate the bypass line voltage in order to be able to remain inside the tolerance limits. This is possible by adding a series inductance that will serve one main purpose; that of adding a small line impedance for the active voltage compensation by interacting with the current of the active filter generated by the inverter.
Proportional to the current generated for the compensation of disturbances, power losses will be greater than those experienced on the high efficiency bypass line, but in any case will be less than those which occur in the double conversion mode.

If this is then incorporated with the use of the latest transformer-free technology in the same UPS, it becomes evident that this UPS with the Trinergy™ technology really does have the highest efficiency in the industry.

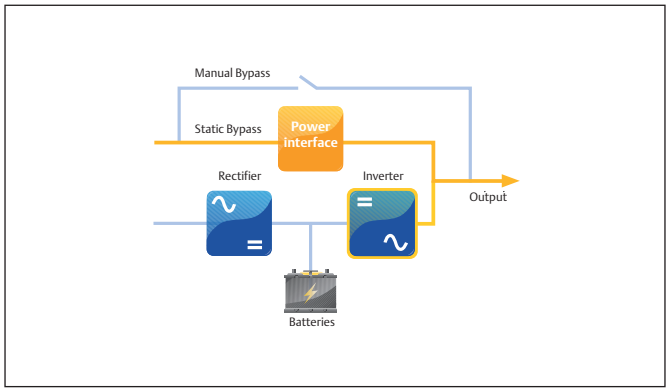


***Figure 6** - Trinergy™ technology. The UPS is configured to automatically compensate load reactive power by using the IGBT inverter as an active filter that can be both configured as a parallel or series active filter, while the load is supplied through the static bypass line.*

3. Trinergy™ control description

Trinergy™ is the revolutionary new solution that incorporates the three existing standard topologies in one transformer-free UPS:

- **Maximum Power Control mode** (IEC 62040-3 VFI): is the double conversion mode which provides the highest level of power conditioning. It protects the load from all types of electrical network disturbances using a greater amount of energy. Efficiency at full load with the latest transformer-free technology is over 95%.

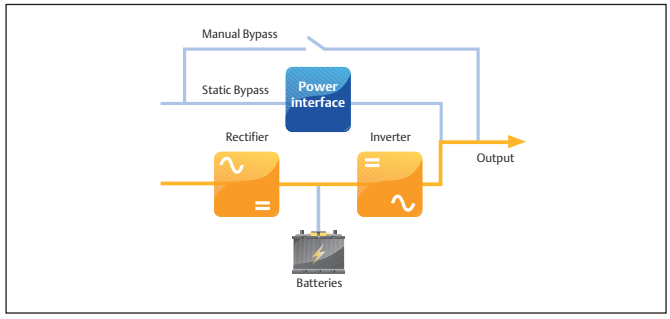


***Figure 7** - Transformer-free UPS with Trinergy™ technology working in double conversion.*

- **Maximum Energy Saving mode** (IEC 62040-3 VFD): this mode detects when the need for conditioning is non-existent and allows energy flow to pass through the bypass line. In this case efficiency reaches 99%.

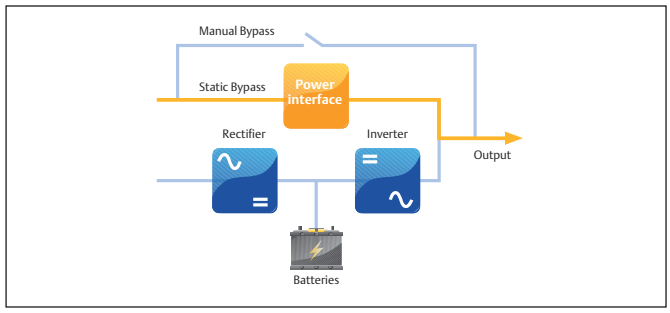


***Figure 8** - New transformer-free UPS with Trinergy™ technology working in digital interactive mode.*

- **High Efficiency & Power Conditioning mode** (IEC 62040-3 VI): compensates only the main disturbances such as the load THDi, the load PF and main sags and swells. The energy used is derived from the use of the inverter as an active filter giving all the necessary reactive power. In a typical condition this mode will have an efficiency of between 97 and 98.5%, depending on the load type (e.g. non linear, linear etc.) and the input mains conditions.

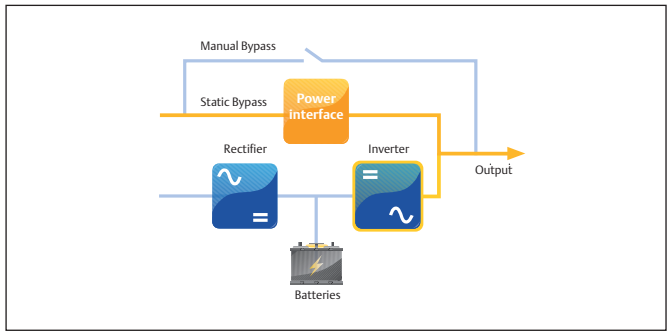


***Figure 9** - New transformer-free UPS with Trinergy™ technology working in line interactive mode with active filter providing power conditioning to the load.*

The precise control of Trinergy™ allows it to quickly and seamlessly activate one of the three different functioning modes of the UPS in order to accomplish the efficiency and effectiveness of each of the standard configurations. At the same time, Trinergy™ is able to provide the performance and power protection of a Class 1 (IEC 62040-3) UPS for the load and perfect input power conditioning (THDi < 3% and input PF > 0.99) for the upstream distribution.

Conclusion

In concluding we can confirm that double conversion technology in UPS is highly effective for resolving virtually all network disturbances. Nonetheless the fact remains that a highly efficient UPS with an eco mode has little sense if the time in which the UPS can work at high efficiency is reduced, and it is limited in protecting the mains and load from unwanted fluctuations.

Incorporating all of the standard configurations and making them available in one single unit allows the UPS to function in high efficiency mode for a significantly extended period of time. Trinergy™ accomplishes this goal by being able to instantly and seamlessly provide the correct level of power compensation, both to protect the load and to avoid the disturbances deriving from the load propagating in the entire installation.
This has been made possible by adopting patented Vector Control technology to regulate the inverter as an active filter in series and parallel when the UPS is working on the bypass line.

Therefore it is possible to achieve, in typical installation situations (as recorded by LIFE™.net, remote monitoring and diagnostic service), an average efficiency of 97.9% very close to the ideal one of 99%[3] making Trinergy™ able to reach the efficiency and effectiveness of each of the standard configurations while continuing to maintain the performance and power protection of a Class 1 (IEC 62040-3) UPS.

Bibliography

(1) IEEE 1159-1995, *"IEEE Recommended Practice for Monitoring Electric Power Quality"*, June 1995
(2) *Zanei G., Cevenini E., Ferro A. & Rossi C.: "New Control Techniques for UPS Dynamic Efficiency Optimization"*, INTELEC Korea 2009
(3) The Quest for Energy Efficiency

Appendix

	Controlled variables (Electrical conditions controlled by the UPS)					Observed variables within UPS specifications (UPS use these to decide the functioning mode)					Efficiency	
	INPUT		OUTPUT (LOAD)			INPUT RANGE		LOAD RANGE				
Mode	THDi	PF	V	THDv	f(Hz)	V(v)	f(Hz)	THDi	PF	THDv		
Double conversion VFI	<3%	>0.99	400	<2% (<3%)	50	250V - 460V	45-65	THDi >30%, C.F. <3	Any PF leading or lagging	<2% (<3%)	>95%	SET1
Interactive VI	<5%	>0.99	400 +/- 10%	<3% (<5%)	Same as input	400 +/- 15%	50 +/- 3%	THDi >5%, THDi <30%	0.7 <PF< 0.95	<3% (<5%)	97-98.5%	SET2
Digital Interactive VFD	<5%	≥0.95	400 +/- 10%	<3% (<5%)	Same as input	400 +/- 10%	50 +/- 3%	THDi <5%	PF≥ 0.95	<3% (<5%)	99%	SET3

Table A *- Trinergy™ Functioning Modes control variables**

The activation of Trinergy™'s three different functioning modes is based on the real time power tracking of the main parameters related to the input network conditions and to the output load quality.
The parameters set out in the table below show the method used by Trinergy™ to determine which of the three functioning modes to activate in response to the various input and output characteristics.

The electrical conditions related to the load and the network are constantly monitored, thus allowing the best power protection to be supplied to the load at all times with the highest level of efficiency.

If the observed variables listed above are outside the ranges described, the UPS will activate a different functioning mode in accordance with the algorithm reported in Figure B.

The variables indicated in the table above can be customized by the service engineer on request.

*The conditions in the table refer to full output load.

The Trinergy™ State Diagram (Fig. B) shows how Trinergy™ makes the choice between the three different functioning modes. The UPS begins operating in double conversion mode and switches to the the VI or VFD mode only after the monitoring of the network conditions indicates that the quality of the observed variables is sufficient and stable enough.

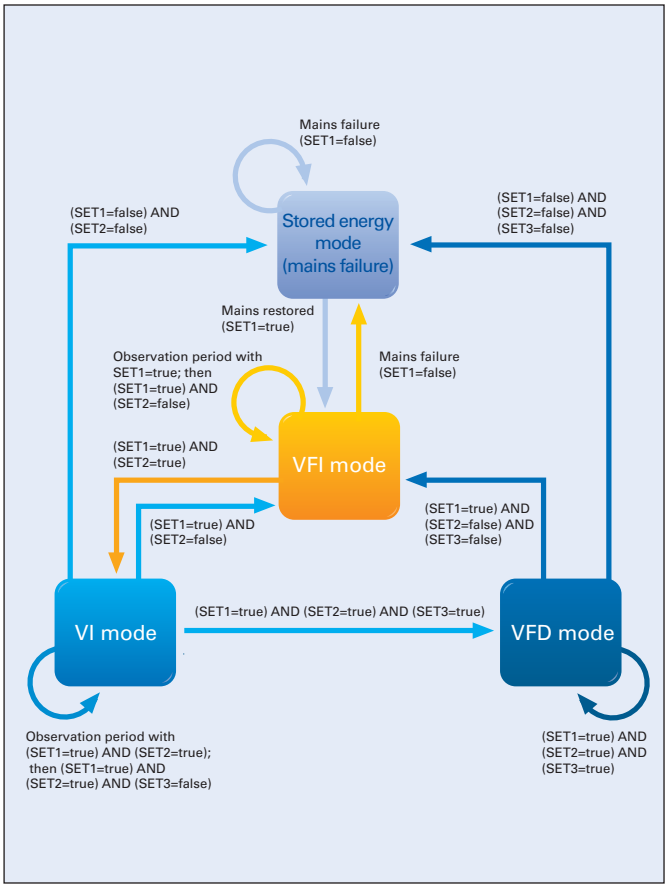


Figure B *- Trinergy™ State Diagram.*

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