RELIABILITY ANALYSIS ON REDUNDENCY UPS SYSTEMS

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ABSTRACT - In regard to the very stringent-going requirements applied to power supply systems in nowadays applications, the reliability of typical UPS redundency systems are investigated Several resonable assumptions are made to build up the probability models. The reliabilities of the typical UPS redundency systems are analysed. Their relating Relaibility and MTTF(Mean Time To Faults) are evaluated It is resulted in that the MTTF of today's UPS redundency systems is unlikely to be beyond 1,000,000 hours

INTRODUCTION

In recent years the information industry grows swiftly based on the great progress on technologies in semiconductors, micro-electronics and computer science, various plans of NII(National Infromation Infrastructures) are bringing into action in many countries, many financial banking or stocking lans and wans and huge databases built up All these cause the rigorous requirements on stability, interference-free and reliability to power supplies. The UPS's(Uninterruptible Power Supply), as the basic power suppplies to information equipement, has faced to the challenge of supplying power in high reliabbility. Since then diverse paralleled redundency UPS systems instead of single UPS have supplied by manufacturers and their dealers to meet the information technology market demands

The reliability analysis has been made to several typical redundency UPS systems currently available in the market to get the MTTF(Mean Time To Faults) and P_S(the working or survival probabilitry after worked a specific period of time) as a quantitative measurement to the reliability of the redundency UPS systems so that comparison can be applied to various redundency systems to distinguish them from each other by merit of reliability.

REDUNDENCY MODES AND THEIR PROBABILISTIC MODELS

Terms

For the convenience of discussion, it is preferred to introduce, at first, several terms that are used through in this paper:

a) Bypass. The UPS or the redundency UPS system switches its output from built-in inverter to the AC line input and thus the load draws energy directly from the electrical net.

b) System Failure. It is considered to be failed(system failure) if the output of the redundency UPS system is beyond its specified range or if the system is permanently transferred to Bypass.

c) Reliability. The working or survival probability of a UPS or a redundency UPS system after worked a period of 100,000 hours.

d) Module. A functioning block of circuitry that performs specific functions in a UPS or in a redundency UPS system.

e) Mode The way of wiring that connects more than one UPS to form a redundency UPS system.

f) Model. The probabilistic Model being built up corresponding to a specific redundency system, serves the reliability analysis to redundency UPS systems.

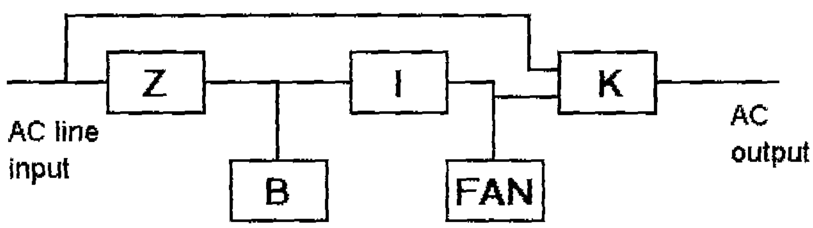

Fig. 1 Functioning Diagram of UPS

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UPS's Modules

Although Nowadays UPS products available are in vast diversity in their performances, types and circuitries, a UPS basically contains the following (functioning) modules as shown in Fig. 1:

Rectifier. Here the name 'Rectifier' actually means the rectifying module in a UPS, which converts the AC line input into DC output to feed energy to battery and its following inverting circuit. This module is described by a block marked with a 'Z' in Fig. 1.

Inverter. It means the inverting module in a UPS, which inverts the input DC energy into AC output to supply various loads(equipement). This module is indicated by a block marked with an 'I' in Fig. 1.

Battery. Battery is the energy storage in a UPS which is indicated by a block marked with a 'B' in Fig. 1. In normal case, i.e., energy supplied by AC line input, the battery is charged to store some energy while in power failure, it discharges to supply DC energy for inverter to continue outputing AC energy to loads and thus keeps the UPS's output energy uninterruptible.

Power Switch. The switching module with active power devices, that swiftly switches the energy flowing path in a UPS and is represented by a block marked with a 'K' as shown in Fig. 1. Most commonly it is used as a Bypass switch in a UPS or a redundency UPS system so as to guarantee power supplying continually to load from AC line input in case of that the UPS system itself failed.

Fan. The module for forced cooling in a UPS and is indicated as a block marked with a 'FAN' in the Figure.

Power Distributor. This is a Module used in one Mode of redundency UPS systems. Please refer to Fig. 2(b), it is the block marked 'PD', which functions to control equal power distribution among UPS's of the redundency system

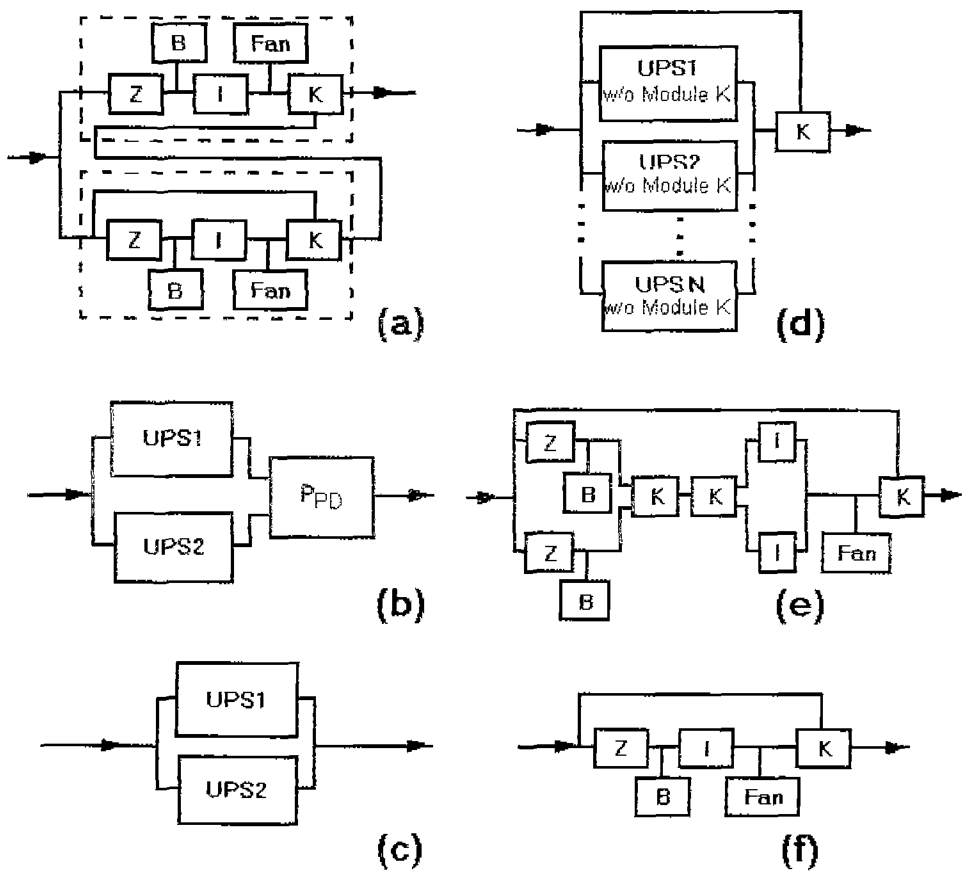

Fig. 2 (a) ~ (f) Typical Modes of redundency UPS systems

Redundency Modes

In regard to the redundency UPS systems, there are various Modes available. Listed below are the most common ones that be taken into investigation(please refer to Fig. 2):

a) Smart Mode. Refering to Fig. 2(a) it is a simplified parallel connection of two UPS's but looks very much like the ones in serial connection and is thus sometimes called 'Serial Mode'. In this Mode, one of the input terminals of Module K of the main UPS(the one in upper dashed line block in Fig. 2) is no longer connected to AC line input as usually does but instead connected to the output of backup UPS, the one within the lower dashed line block. In normal state, the main UPS supplies full energy to load and the backup one is idle, while in case of failure Module K of main UPS switches and the backup UPS supplies full energy through Module K of the main UPS to load.

b) Power Distribution Mode. As indicated in Fig. 2(b), a power distributor Module is set to accept power from two UPS's output and supplies power to load. The power distributor controls that the two UPS's equally supply power to load. In case of one UPS being failure, the other UPS supplies full power to load. This Mode is mainly adopted by some manufacturers in their earlier redundency system products and is not widely accepted by now because the power distributor is an active Module with complicated structure and is rather difficult to be well adjusted for good working status.

c) Parallel Mode. In Fig. 2(c), both the input and output terminals of the two UPS's are connected together respectively. The output power to load is well balanced among the two UPS's by exchanging control signals among them. This is the most widely used redundency Mode today.

d) N + 1 mode. As shown in Fig. 2(d), this Mode is an extension of Parallel Mode, in which N units(generally N > 2) of UPS's are paralleled as does in parallel Mode but with only one separate power switch Module K instead of each one contained in one UPS to provid a Bypass channel for the redundency system.

e) Special Mode. This Mode is actually a special kind of UPS's(Fig. 2(e)), of which one UPS contains two identical Rectifiers and two identical Inverters with anyone rectifier being able to connect to anyone Inverter through internal power switches. Only in case of both Rectifiers or both Inverters failed, the UPS fails and switches to Bypass through the power switch Module.

Probabilistic Models

In order to simplify to some extent the building up of probabilistic Models for corresponding redundency UPS systems, the folowing assumptions are made:

a) Same kind of Modules, e.g., the rectifiers, in different UPS's that form the redundency system have the same failure rates and Reliabilities.

b) Failure rate of each Module is determined by classes and quantities of power devices(MOSFETs, IGBTs, etc) the Module contains. This implies that the failure rates from small-signal circuit and passive components are considered insignificant than those of power devices(active devices).

c) Battery's influence to reliability of redundency systems are not taken into account because they are replaceable and will be replaced before they run failed under normal maintennance condition.

d) UPS's under different load levels have the same Reliabilities. This assumption is set because of that under either light-load or heavy-load condition there are several possible failure mechanisms in switching-mode power supplies.

In addition, it should be stated that those UPS's under investigation are assumed to be in good quality, i.e., there is no faults/mistakes occurred during products' design, development, manufacturing and QC procedures of UPS's so that those UPS's will well perform under their specified enviroment. Therefore the reliability of them is meaningful.

Following is a concise notation to symbols used in reliability analysis:

λ: failure rate.

P: reliability.

MTTF: mean time to faults.

All those symbols are further distinguished by their subscripts, i.e., subscript '$_S$' indicates those quantities related to redundency UPS systems while subscript '$_{S,\,a}$' indicates quantities related to redundency system with the redundency Mode as shown in Fig. 2(a), subscript '$_0$'(zero) relating those to a single UPS while proper characters as '$_Z$', '$_I$', '$_K$', etc relating those quantities to Modules rectifier, inverter and power switch respectively. For example, λ_Z is the failure rate of Module rectifier, P_0 be the reliability of a single UPS and $MTTF_{S,\,c}$ denoting the mean time to faults of a redundency UPS system with the Mode shown in Fig. 2(c), and so forth.

Based on the recommanded methods[1], the probabilistic Models corresponding to those redundency UPS system Modes as shown in Fig. 2(a) ~ (f) are built up and are indicated in Fig. 3(a) ~ (f) respectively, in which (f) is the Model for a single UPS. The reliabilities for various Modules are determined according to the failure rate data from manufacturer's datasheet manuals[3][4].

RELIABILITY ANALYSIS TO VARIOUS REDUNDENCY UPS SYSTEMS

Modules

For a functioning Module, when anyone power device in the Module failed, the Module becomes failed. This situation results in that the probabilistic Model for the Module is a serial connection of all power devices. In order to make the results comparable to each other, we suppose that the rectifier Module is composed of one rectifying bridge, four IGBTs and four Ultra-fast Diodes; the inverter Module adopts IGBT full bridge; the power switch Module uses one triac and the FAN Module contains a fan. Considering that the failure rate values for the same power devices have apparent discrepancies due to different failure mechanisms and conditions, we use the values averaged

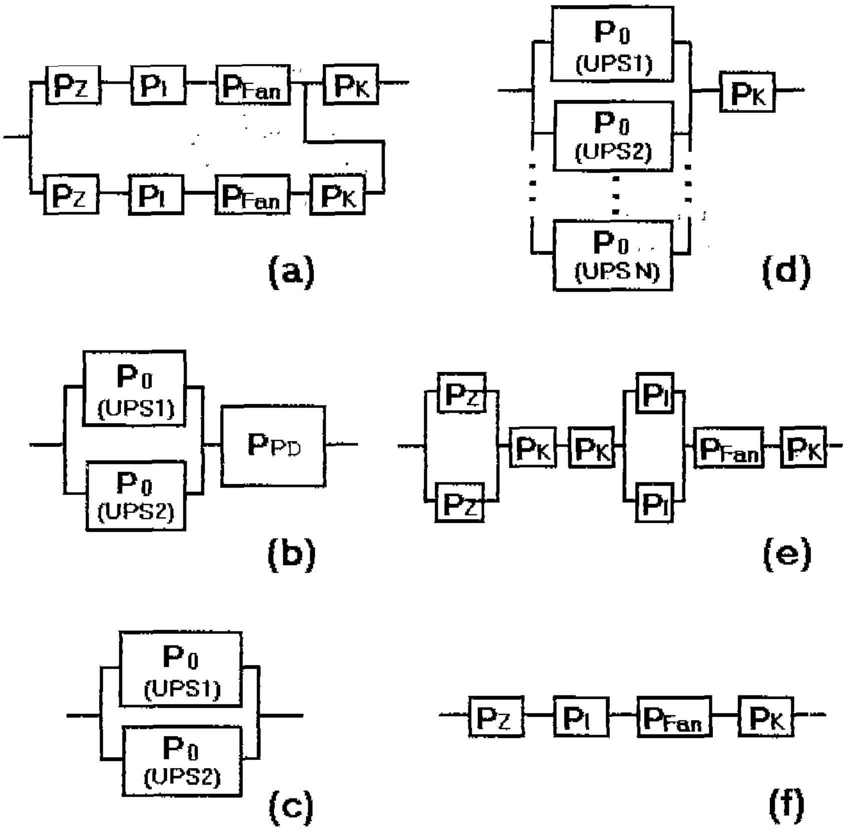

Fig. 3 Probabilistical Models corresponding to redundency Modes in Fig. 2

from the available datasheet manuals[2]-[4]. The averaged failure rates of power devices are as follows:

$\lambda_{IGBT} = 0.5358 \times 10^{-6}$ /hrs

$\lambda_{DIODE} = 0.1786 \times 10^{-6}$ / hrs

$\lambda_{BRIDGE} = 0.1826 \times 10^{-6}$ /hrs

$\lambda_{TRIAC} = 0.5193 \times 10^{-6}$ /hrs

The failure rates for various Modules are computed as:

$\lambda_Z = 3.0362 \times 10^{-6}$ /hrs

$\lambda_I = 2.8576 \times 10^{-6}$ /hrs

$\lambda_K = 0.5756 \times 10^{-6}$ /hrs

$\lambda_{FAN} = 0.8930 \times 10^{-6}$ /hrs

$\lambda_{PD} = 1.4288 \times 10^{-6}$ /hrs

Listed below are Reliabilities for each Module of a UPS after worked 100,000 hours:

$P_Z = 0.7332$

$P_I = 0.7514$

$P_K = 0.9441$

$P_{FAN} = 0.9146$

$P_{PD} = 0.8669$.

Redundency UPS Systems

According to the probabilistic Models shown in Fig. 3(a) ~ (f) corresponding to their redundency Modes in Fig. 2, it can be derived the following reliability expressions(in parentheses are those Reliability values of 100,000 hours worktime) and be evaluated the MTTF's results.

For single UPS(Fig. 3(f)):

$$P_0 = P_Z P_I P_K P_{FAN} \quad (0.4757) \tag{1}$$

and $$MTTF_0 = 135{,}825 \text{ hrs.} \tag{2}$$

For smart Mode(Fig. 3(a)) they are:

$$P_{S,a} = P_0(1 + P_K - P_0) \quad (0.6985) \tag{3}$$

and $$MTTF_{S,a} = 189{,}337 \text{ hrs.} \tag{4}$$

For the parallel Mode(Fig. 3(c)) it comes that

$$P_{S,c} = (2P_0 - P_0^2) \quad (0.7251) \tag{5}$$

and $$MTTF_{S,c} = 203{,}738 \text{ hrs.} \tag{6}$$

For the power distributor Mode(Fig. 3(b)), it could easily result in that

$$P_{S,b} = P_{S,c}P_{PD} = (2P_0 - P_0^2)P_{PD} \tag{7}$$

(0.6286)

and $MTTF_{S,b} = 157{,}802$ hrs (8)

For the N + 1 Mode(Fig. 3(d)):

$$P_{S,d} = P_K \sum_{i=0}^{N-m} \sum_{j=0}^{i} (-1)^j C_N^i C_i^j P_0^{N-i+j} \quad (9)$$

where m is the number of UPSs needed to be in working status for the N + 1 Mode redundancy system.
If N = 5 and only one UPS is needed to be in working status, then

$$P_{S,d} = 0.9157 \quad (10)$$

and $MTTF_{S,d} = 281{,}855$ hrs (11)

If N = 10 and also one UPS is needed to be in working status, it comes that

$$P_{S,d} = 0.9433 \quad (12)$$

and $MTTF_{S,d} = 345{,}693$ hrs (13)

Finally for the special Mode(Fig. 3(e)), it results in.

$$P_{S,e} = P_K^2 P_0[4 - 2(P_Z + P_1) - P_Z P_1] \quad (0.6706) \quad (14)$$

and $MTTF_{S,e} = 152{,}695$ hrs (15)

DISCUSSION AND CONCLUSION

Single UPS

Its MTTF($MTTF_0$, see (2)) is evaluated to 135,825 hours. As some factors are omitted in analysis, the real value should be less than it shown. The specified MTTF of 100,000 hours for several quality UPS products from the world famous manufacturers are thus believed to be reasonable and acceptable.

Smart Mode

By comparing the performances, the smart Mode is practically equivalent to the parallel Mode as its MTTF and Reliability are less than those of parallel Mode by only 7.1% and 3.7% respectively(refering to (3), (4), (5) and (6)). However the smart Mode system is constructed by very simple wiring to two completely independent UPS's and thus gets low cost in system configuration. So it is such a redundency mode that has higher Performance / Price Ratio and that is worth adopting in common enviroment.

Parallel Mode

It is the typical means used today to enhance the reliability of power supply systems. In comparison with a single UPS, it increases the system's MTTF and Reliability by 50.0% and 52.4% respectively(see (5), (6), (1) and (2)). However each such UPS for the redundency system should have a hardware interface to exchange control information with each other so that the redundency system can be constructed and worked properly. This leads to higher configuration cost for the redundency system and thus should be well compromised among the system's reliability requirements and expenses budgets for optimization.

Power distribution Mode

Although this Mode provides a kind of parallel redundency system, its power distributor is a rather complicated circuits with power devices and is difficult to be well adjusted for good performance. Above all, its MTTF and Reliability are deteriorated, in contrast to parallel Mode, by 22.5% and 13.3% respectively(refer to (7), (8), (5) and (6)) and furthermore it performs even worse than does the smart Mode but bears apparently higher cost due to the added power distributor and the manpower for adjustment. Therefore such a redundency Mode could hardly be used satisfactorily in applications.

N + 1 Mode

Increasing the number of UPS's(N > 2) in the N + 1 Mode certainly increases the MTTF and Reliability of the redundency system. For example when N increased from 2 to 5, the MTTF and Reliability are raised by 38.3% and 26.3% respectively(refering (10), (11), (5) and (6)). However as the more the UPS's are added into the redundency system, the less the contribution to the MTTF and Reliability results. For instance when another 5 units of UPS's is further added onto the N = 5 system(thus N = 10 now), the MTTF and Reliability can be further increased by only 31.4% and 3.8% respectively(see (12), (13), (5) and (6)) while the system cost for UPS's has been doubled. Therefore it can be seen that the MTTF is unlikely to approach or beyond 1,000,000 hours from a practical redundency system configured with reasonable number of UPS's in the state-of-the-art.

Based on this argument, it might be seen that using a large number of UPS's to construct the N + 1 Mode redundency system is not a good idea unless the system is constructed to be expandable in its power capacity or to try to use a number of small UPS's instead of huge UPS's to take advantage of favorable prices of small UPS's. Nevertheless in such a situation it generally demands more than one UPS's in working status to guarantee the system running smoothly and this requirement results in apparent deterioration in system's MTTF and Reliability, e.g., if six UPS's are requested in working status in a N = 10 system, its MTTF and Reliability are lowered down to 90,193 hours and 0.3649 respectively, which are only 44.3% and 50.3% of those for a two UPS's parallel Mode system. Practically this performance is even worse than be a single UPS!

Special Mode

The Reliability and MTTF of Special Mode are 0.6706 and 152,695 hours respectively, which are significantly worse than those of Parallel Mode and also are not as good as those of the Smart Mode but the UPS in Special Mode costed much more than those used in other redundency Modes due to its complex circuitry inside. Even though such kind of UPS's, in case of failure, could not be maintained online unless two such UPS's are adopted to form a redundency system. Therefore this Mode doesn't offer a reasonable Performance / Price Ratio and is not significant in applications.

REFERENCES

[1] MIL-STD -721, MIL-STD-750 and MIL-STD-280

[2] MIL-HDBK-217

[3] Power Devices Manual, Motorola Inc., 1994

[4] Power Semiconductors Data Book, International Rectifier, 1994