

-48 V DC Computer Equipment Topology - an Emerging Technology

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This paper was prepared by an INTELEC adhoc-group of interested persons from telecommunications operators and equipment suppliers, who see a strong need for the improvement of the powersupply for Internet, and for an option to power computers and similar equipment from the telecommunications DC power plant. The following is a short version of the whitepaper that the group was commissioned to produce by the INTELEC Advisory Committee at its meeting in Melbourne 1997.

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Our Vision

We expect every vendor of equipment used by telecom network operators to offer an option of four to eight hours operation during AC mains outages.

We believe that the most reliable, safest and cost-effective way to accomplish this is to power all equipment from the telecom DC power plant, particularly the 48-volt versions.

We urge all end user and specifiers of Internet and data products to purchase and install DC fed equipment as a first choice. Such an approach will significantly increase the overall reliability.

We seek the more efficient and less complex solution that replaces the switch-mode rectifier in AC-powered equipment with a DC-DC converter rather than one that replaces the UPSs with inverters powered from the telecom DC power plant.

Abstract

This paper describes the escalating Internet development, which is characterised by the integration of telecommunications and data communications. An obvious example is Internet telephony through packet switching. Carrying voice traffic means intensified demands on power

supplies of the Internet equipment, to meet public demand for an ever-functioning service. With data traffic, a small number of power outages and service interruptions are tolerated, in accordance with the more limited requirements on power supplies for data communications. When it comes to voice, demands on power supplies are more stringent. With the snowballing expansion of the Internet and, at the same time, the growing needs of society

for well-functioning telecommunications, power supplies play a key role. We should take this opportunity to invest in the right power supply at the right time, to use the advantages offered by the Internet, to avoid the disadvantages of the power supplies of today's Internet equipment, and to benefit from what telecommunications power supplies have to offer.

1. Introduction - Presentation of problem.

The telecommunications and computer industries are merging. The telecom network is in the midst of a large and rapid transformation, boosted by the Internet. The telecom network is and will continue to be used for a great many more services than plain old telephony. What is new is that the services of the Internet, including telephony, are transferred as data, which means a dramatic expansion of data traffic. In most cases, the ordinary telecom network lines are used for connections to individual users. Large computer centres use optical fibre lines or other broadband facilities.

The Internet is an innovation that uses parts of the original infrastructure of the telecom network: its interoffice trunks, access lines and switches augmented with standard and new specialised computers. Both are relatively inexpensive and based on standard computer technology. They are connected to the telecom infrastructure capable of transmitting data traffic most effectively. The telephone set may for instance be replaced by a personal computer, which is a much more advanced terminal. This will open up the implementation and use of new services for a variety of purposes such as work, entertainment, information, marketing, financial transactions and the like.

Two different technologies and industries meet, and now merge in the Internet. The two have by tradition, however, a fundamentally different approach to service disruptions that can result from external events or from maintenance, repairs or additions.

The telecommunications industry is essentially public; it serves society and is expected by the general public to operate at all times. One responsibility is to provide vital "lifeline" emergency services such as 112 (EU) and 911 (US). The computer industry was originally batch-oriented. There was no requirement for real time operation, or for serving the public at large. And so there was no demand for no-break, long-lasting operation. As a consequence, a special transmission method emerged: "packet switching", the transfer mode used for the Internet. During major service interruptions, it has been both possible and allowable to put off repair, deliver results at a later stage, or try alternate routing. On the other hand, much effort has been spent on protection against brief

interruptions within batch runs. These differences are important for understanding the following discussion of power supplies for telecom and computer installations.

2 Background - different traditions, different answers.

The computer and telecommunications industries have chosen different standard solutions for the power supplies of their respective systems, and the reason is the two major differences in requirements described above. The requirements differ regarding general reliability and availability performance, and reserve time in case of AC mains outages. In the computer industry, the standard solution is the use of uninterruptible power supply (UPS) systems to supply no-break 120/230 V AC, whereas the telecommunications industry uses 48 V DC battery plants. UPS systems typically provide 10 - 30 minutes battery reserve time, which is insufficient for telecommunications systems. With longer outages, diesel engine-alternator sets may be used, but they are economically justified only for large or important installations. The telecommunications battery plants typically provide several to many hours of battery reserve time, and prove to be a healthy investment in both large and small installations.

In the early days of the Internet, its network elements were placed at large computer centres and telecom exchanges, and from there connected to the transmission systems of the telecom networks. The exchanges were nearly all equipped with UPS systems and diesel alternator backup sets, so the computer industry's standard AC solution for power supplies was acceptable to the telecommunications industry. The present Internet expansion will push the integration of equipment deep into the telecom system, with computer-based equipment located at small telephone exchanges, private branch exchanges (PBXs) and local area networks (LANs), most devoid of UPS systems or diesel alternator sets. In the existing infrastructure of the telecommunications industry, there are hundreds of thousands of highly dependable 48 V DC installations already in use by the operators. Economically and technically it would be an absolute mistake to rebuild these installations to equip them with a new system for no-break AC power. There are now strong arguments that favour a 48 V DC power interface for Internet equipment. Other factors that favour this solution include harmonic distortion in the power distribution from UPSs, availability performance and maintenance.

Telecom and computer equipment is often collocated. Not only does electronic equipment need power supplies, but it has special environmental requirements for electrical safety, earthing, transient protection, electromagnetic compatibility (EMC), fire protection, cooling and ventilation. In these respects, there is little difference

between telecom and computer equipment. The computer and telecommunications industries, however, use different designs for power supplies and their products differ in reliability and availability performance

3 Technical solutions - a comparative study

3.1 48 V DC System

A 48 V DC power supply system is characterised by its technical simplicity, see Fig. 3-1. It consists of a number of paralleled rectifiers that connect to one or more battery strings that are also connected in parallel. In the event of a mains outage or rectifier failure, the load continues to operate from the batteries without switching or interruption. The distribution of power to the loads originates at the point where the battery strings are paralleled, with only fuses or circuit breakers interposed. The electronic equipment in the load has built-in DC-DC converters that interface to the battery.

It is technically quite simple to connect both rectifiers and batteries in parallel to obtain reliable load sharing. This paves the way for power supply systems with a modular design of the rectifiers, batteries and the conductors that interconnect them. Modular systems are imperative for

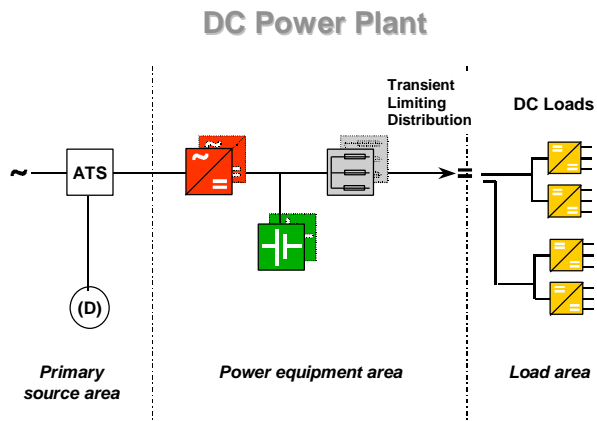


Fig. 3-1. Block diagram of a DC installation

simple and inexpensive maintenance of installations by persons with limited training on power systems, a need shared by telecom operators with other companies and organisations.

During operating conditions, the parallel rectifiers provide the current consumed by the load, the float current for the batteries and the additional current for recharging the batteries after a mains outage. Redundant rectifiers fill two needs: battery recharging after a mains outage and continued operation if one rectifier fails.

The battery voltage of most telecom switching equipment is 48 V. This voltage is a universal standard for telecommunications equipment, and is well defined both by

the European Telecommunications Standards Institute (ETSI) and the American National Standards Institute (ANSI). For AC power, there are 14 different voltage and distribution systems defined across the world. One of the motives behind the universal 48 V DC standard is that it allows work on a live conductor with minimum risk for personal injury and without special safety measures. This is a practical advantage when craftspersons work at a distance from the voltage source and therefore can not disconnect it.

3.2 UPS Systems

A UPS system is technically more complicated than a DC battery plant, see Fig. 3-2. To achieve a reliable and economical system, you need a rectifier, batteries, an inverter, a static switch and a service by-pass switch. The battery voltage is a variable, since the battery is located inside the UPS. The battery voltage is selected to yield the most economical system components and the lowest possible power dissipation. The voltage may reach 400 V DC or more in a medium-size UPS. Compared to a 48 V DC system, this voltage requires a larger number of series-connected battery cells, up to 10 times as many, which in turn means a failure frequency in the battery circuit 10 times as high. The longer string also results in more cells being over- or undercharged at the constant-voltage float operation of the string.

To maintain power to the load in the presence of faults in the battery or inverter circuits, a static switch automatically switches the entire load to the AC mains in one or two milliseconds or vice versa. Often there is also a manual service by-pass switch to perform the same function when maintenance or repair of the UPS is required.

Parallel connection of AC-generating equipment is a complex procedure, and parallel connection of the inverters in a UPS or of entire UPSs is rare because of the costs. Parallel connection requires synchronisation of the units involved with special circuits for this purpose alone.

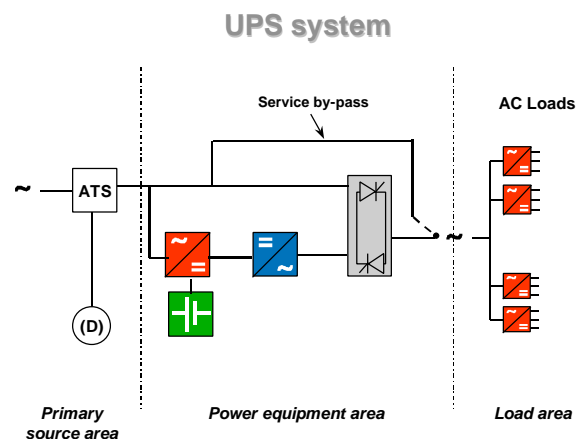


Fig.3-2. Block diagram of a UPS installation
There are two different applications of UPSs:

- One where the UPS is used to protect a load sensitive to disturbances such as voltage transients and power outages on inferior or "foul" mains. Here the entire load current must be converted twice with the resulting power losses.
- One where the mains have good quality and protection is needed only against the occasional interruption. Here the load can be fed from the mains via a by-pass switch, and in case of a mains outage the UPS is connected via a static switch. This way a healthy operating economy is obtained with little power loss for most of the operating time.

The rectifier feeds the inverter and floats the battery in normal operation. In the event of a power outage it must recharge the battery when mains power returns. A UPS is typically dimensioned for brief reserve times with deep discharge of the batteries. The rectifier's capacity for recharging batteries in a short time is usually limited. A solution where more batteries are connected to extend reserve times is therefore both difficult and inappropriate.

3.3 Distribution and harmonics

Comparisons of DC and AC systems should consider their capabilities of protecting the connected telecom or computer equipment from disturbances on the mains. Examples of such disturbances are high switching voltages, transients, lightning strikes, harmonic distortion and interference from other equipment. With the 48 V DC system, the telecom and computer equipments are always galvanically isolated from the mains. The large system battery also works as a filter against possible transients or harmonics passing through the rectifier. This means an almost total elimination of problems with disturbances passing from the mains to the DC distribution system.

Short-circuits in a distribution system cause transient voltages with great variations, depending on the resistances and inductances in the distribution system. In a 48 V DC installation, a well-defined and predictable distribution system may be arranged, with control of both resistance and inductance. It is achieved either with a specially arranged cable system or with a capacitor backup at load point. In such a system, voltage transients caused by short-circuits and fuse clearing are under control, and do not spill over to loads served by other feeders. The battery is capable of providing enough current to clear the fuses quickly. Such distribution systems have been standard for telecom installations ever since the introduction of electronics 25 years ago, under the name of transient limiting distribution.

In by-pass operation with a UPS, the telecom and computer equipment is directly exposed to the mains, without any protection against disturbances. Obviously the by-pass can be fitted with various kinds of protectors and filters, but doing so adds cost. In operation, with all the power passing through the rectifier and the inverter, it may be necessary to shift to by-pass operation to clear the fuse associated with a short-circuit in the secondary distribution system. The short-circuit current available from the UPS inverter is normally not sufficient to clear a fuse. For secondary distribution, normal AC distribution practices are followed. With this type of distribution, it is hard to say how other parallel loads will be affected. One way of circumventing this problem is to use decentralised UPSs, one for each object of importance. This approach, however, can give problems with harmonisation of the battery reserve time and cause higher maintenance costs. There are evidently several factors of uncertainty in the UPS systems architecture that must be taken into account if it is to be used in telecom or computer installations with high availability performance requirements.

Another very problematic phenomenon in all AC distribution systems is the occurrence of harmonic distortion. This is a very tangible problem with UPSs since they are not stiff power sources. For these problems to be mastered, the UPS and its load must be well known and preferably matched at the planning stage. There is limited room for uncontrolled upgrading and connection of new computers. The action usually taken to manage fuse clearing and harmonics-related problems is to over-dimension the UPS. This approach entails high costs, both for the UPS and for the mains power distribution system, which will have to be dimensioned accordingly. Another measure is to add new equipment, such as active harmonic filters. This will also cost more money, lead to a higher frequency of failure and in turn to a lower availability performance.

Harmonics are the result of loads that are non-linear. The common computer load consists of a number of parallel-connected switch-mode rectifiers that have capacitors at the input stage. When they are connected to a sinusoidal voltage source, they do not draw a sinusoidal current. The voltage crest factor remains near unity, but the current crest factor can exceed 2,5. In three-phase systems the most powerful harmonics are the 3rd and the 5th. The 3rd harmonic can cause a serious problem, since these currents do not cancel in the neutral conductor and may therefore overload it. This conductor is normally not dimensioned for high currents, since the fundamental currents cancel in the neutral. If it comes to the worst, the overload may cause a fire. But what usually happens is that circuit breakers trip or fuses clear for no apparent reason.

4 Availability performance

The point was made earlier that it is increasingly important to keep up the operation of telecom and data services. Telecom and computer installations are expected to function even though the surrounding geographical area, building or part of a building may be affected for hours by a power outage. Telecom operators have policies governing the battery reserve times required at various installations for uninterrupted telecom services.

During a mains outage, the battery reserve time is the primary resource. At certain installations, standby engine-alternator sets are available. It should be noted, however, that the standby set does not replace the batteries, but only reduces their sizes.

When comparing the possibilities of a 48 V DC system and a UPS system to keep up telecom and data services, it appears from the above that the possibility of long battery reserve times is a decisive factor. It is a function amply provided for in a 48 V DC system, whereas UPS systems are optimised for short reserve times.

5. Reliability analysis

5.1. System Configurations

DC power supply systems and an AC power supply system are shown in Figures 5-1, 5-2 and 5-3. In the DC system 1, the batteries and the boost converter back up the rectifier.. The reserve time is 3 hours. The DC-system 2 has 8 hours reserve time. The rectifiers and the boost converters are composed of $(n+1)$ units, in which the extra unit provides redundancy.

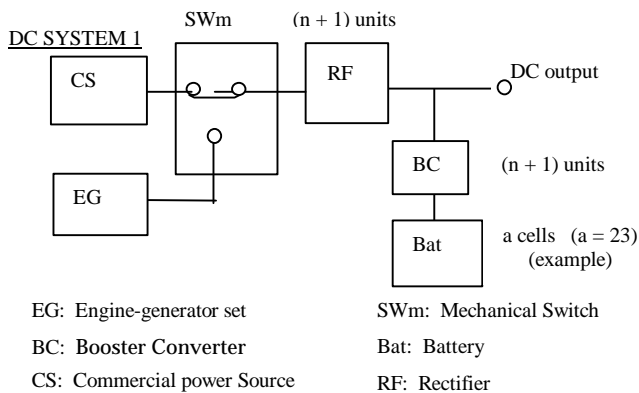


Fig.5-1 System Configuration for DC Power Supply

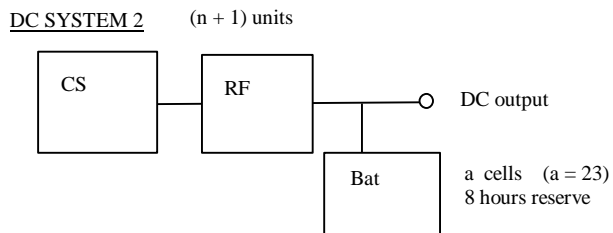


Fig. 5-2 System Configuration for DC Power Supply without Engine-Generator Set

The AC system omits the boost converters and adds an inverter and an AC bypass circuit. The switch S_{We} connects the output to the inverter or to the bypass circuit. The control circuit $CONT$ controls the operation of the switch S_{We} . The number of cells in the battery string depends on the output power and supplier's design, in NTT it ranges from 54 cells (10 kVA output) to 206 cells (300 kVA output), with a maximum reserve time of 3 hours.

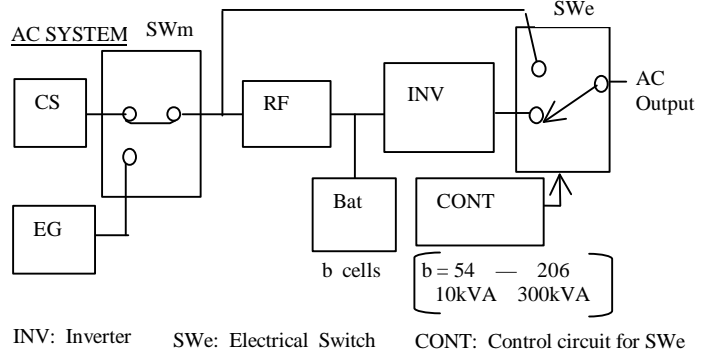


Fig. 5-3 System Configuration for AC Power Supply

5.2. Models for Unavailability Analysis

Models for unavailability analysis are shown in Figures 5-4, 5-5 and 5-6. The model for the DC system comprises two blocks, Block 1 and Block 2, connected in parallel. The model for AC system comprises two series connected blocks, Block 3 and Block 4. Block 4, which contains the power path of the switch and the controller for the switch, is the common component in the AC system reliability model, because failures in these components cause system failures.

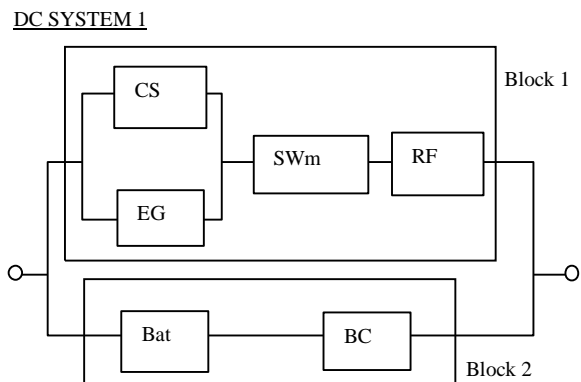


Fig. 5-4 Reliability Model for DC System 1

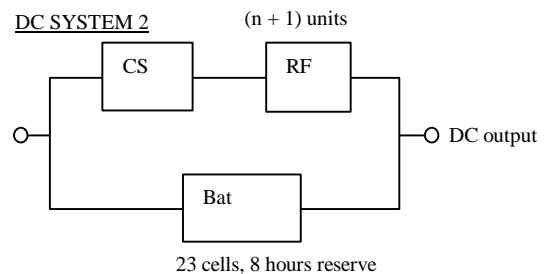


Fig. 5-5 Reliability Model for DC Power Supply without Engine-Generator Set

| Component | Unavailability W | Repair rateμ (1/hour) | Failure rateλ (1/hour) | Reference |
|-----------------|-----------------------|-----------------------|------------------------|---------------------------|
| CS/EG | 6.8×10^{-8} | 2.2 | 15×10^{-8} | Field data |
| SWm | 1.5×10^{-6} | 0.5 | 0.75×10^{-6} | Design data |
| RF | 4.6×10^{-8} | 0.5 | 2.3×10^{-8} | Field data (N+1 units) |
| Bat (23 cells) | 3.9×10^{-6} | 4.2×10^{-2} | 1.64×10^{-7} | Field data ^[1] |
| BC | 4.6×10^{-8} | 0.5 | 2.3×10^{-8} | Field data (N+1 units) |
| INV | 6.3×10^{-5} | 0.5 | 3.13×10^{-5} | Design data |
| Swe/Cont incl | 7.4×10^{-6} | 0.5 | 3.7×10^{-6} | Design data |
| Bat (100 cells) | 1.70×10^{-5} | 4.2×10^{-2} | 7.13×10^{-7} | Field data ^[1] |

Figure 5-7 Table of reliability data. Battery reserve time T is 3 hours.

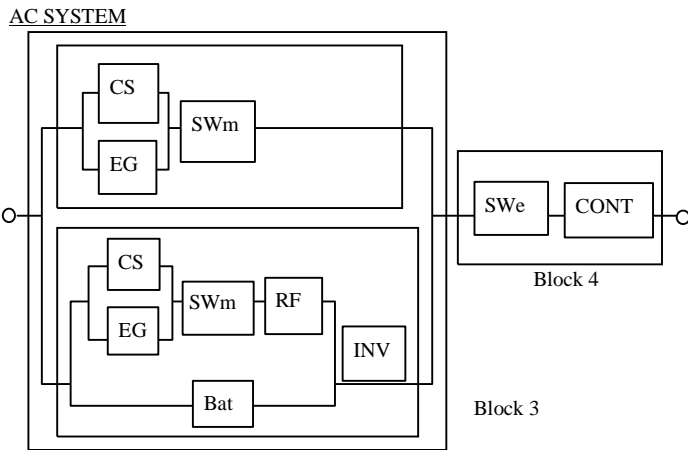


Fig. 5-6 Reliability Model for AC Power Supply

5.3. Unavailability Calculations

5.3.1. DC System 1

Unavailability for the DC System (W_{DC}) can be calculated by adding the following two components of unavailability, W_1 and W_2 . W_1 , in which the battery and the boost converter BC are operating but the failure of Block 1 persists longer than the battery reserve time. W_2 , in which the battery and the boost converter BC fail during failure of Block 1. Reliability values for this calculation are shown in table in Figure 5-7.

$$W_{DC1} = W_1 + W_2$$

$$W_{DC1} = [W_{CS/EG} \times \exp(-\mu_{CS/EG} \times T) + W_{SWm} \times \exp(-\mu_{SWm} \times T) + W_{RF} \times \exp(-\mu_{RF} \times T)] + [(W_{CS/EG} + W_{SWm} + W_{RF}) \times (W_{Bat} + W_{BC})]$$

$$W_{DC1} = 3.45 \times 10^{-7} + 6.37 \times 10^{-12}$$

$$W_{DC1} = 3.45 \times 10^{-7} \quad (\text{for } T = 3 \text{ hours})$$

5.3.2 DC System 2

The unavailability for DC System 2 is calculated as:

$$W_{DC2} = W_1 + W_2$$

$$W_{DC2} = [W_{CS} \times \exp(-\mu_{CS} \times T) + W_{RF} \times \exp(-\mu_{RF} \times T)] + [(W_{CS} + W_{RF}) \times (W_{Bat})].$$

$$W_{DC2} = 9 \times 10^{-10} \quad (\text{for } T = 8 \text{ hours})$$

From this result, we can understand why battery failures in DC systems have little effect on the availability of DC-power because the probability of simultaneous battery and rectifier failures is very small.

5.3.2. AC System

The unavailability of Block 3 (W_3) is much lower than the unavailability of Block 4 (W_4) since the AC bypass backs up the inverter sub-system. The unavailability of the AC system (W_{AC}) is therefore:

$$W_{AC} = W_4 = W_{CONT+Swe}$$

$$W_{AC} = 7.4 \times 10^{-6}$$

5.4. Conclusions

The calculated unavailability of the DC system is less than one-twentieth that of the AC system. In the AC system the failure of a single component, the control circuit for the electrical (bypass) switch, can cause loss of power to the loads. Loss of power results in loss of service to customers, which is intolerable for telecom systems.

6 Costs

There are many costs to be considered in the dimensioning of power supplies for safe operation of telecom and computer plants. What is the cost of a failure in terms of life and limb? What is the cost to be borne by an operator once it is known that a telecom service could not be maintained in a common power outage. These are the kinds of questions to be asked by telecom and data operators, and customers alike. Just comparing the price for a computer with a 48 V DC interface with the equivalent AC version does not give the right comparison. Just looking at the costs of a 48 V DC system and a UPS system will not take you very far, as they are optimised for different applications. All cost comparisons should be made with equal

consideration of reliability and availability for a complete system including battery reserv time.

7 Market estimates

By the turn of the century, the global market for data communications equipment is expected to exceed \$100B per annum. This market consists of several categories of products intended for LANs, WANs, remote access and network support and services. Figure 7-1 illustrates the relative size of each equipment category.

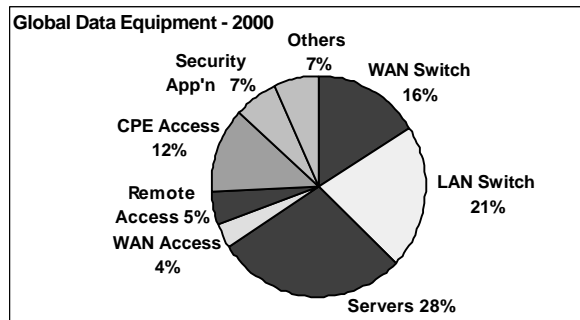


Fig 7-1. Global Data Communications Equipment Segments

While the majority of sales have historically been for private network application, a growing portion is now deployed into public networks. This deployment comes about because the Public Network Operators (mainly the Local Exchange Carriers, the Competitive Access Providers or Newly Licensed Operators, the Long Distance Carriers and the Internet Service Providers) must modernise and expand their network capacity to handle the fast-growing demand for data communications traffic. As a result, by the turn of the century, sales to these operators are expected to represent close to 35% of the total demand for data communications equipment. The major applications for Public Network Operators will be for WAN switching and access (ATM, frame relay and router) and for network servers and data security solutions.

To preserve the Quality of Service (QoS) and level of reliability that their customers expect, the Public Network Operators will demand "telecom-grade" solutions from the data communications equipment vendors. These levels differ markedly from those historically found in private networks, where price has often been the key driving factor. One can also conceive that in many critical applications where the traffic originates and terminates in a private network (LAN or other CPE terminal), the same higher level of performance and reliability will be required. One such requirement is to have the reliable source of DC power developed in voice telephony networks today.

Most vendors who are already involved in the WAN switching business, or who have a strong base in voice telephony, already offer telecom-grade data communications products. Other vendors, who have historically been more involved in the LAN, CPE and server segments, still tend to design for AC powering. They will need to make the transition to DC powering if they intend to sell to Public Network Operators.

8 Conclusion

The major finding of this study is that AC-systems with electronic switches does not comply with telecommunications reliability standards. Also sales of data communications equipment to operators are expected to represent close to 35% of the total demand for data communications equipment

Developments in the telecommunications industry are snowballing. New services and equipment are implemented at a rapid rate, new operators turn up all the time, and all this is for our benefit as consumers. We expect the new services to function just as well as voice telephony always did. This is why controlled and reliable power supplies are important for equipment that furnishes telecom and data services. Apart from telecommunications, the electric power industry and other manufacturing and processing industries are becoming increasingly interdependent. The computers and systems used in these industrial contexts are subject to the same stringent demands for availability performance and reliability as in the telecommunications industry. It should therefore be of interest to these other industries to use DC power supplies based on a single industrial standard in all process computer systems. Taking the long view, all office and residential premises with information technology (IT) equipment may soon be compared with telecom and computer installations, and here DC is a powerful argument in favour of electrical safety and availability performance.

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