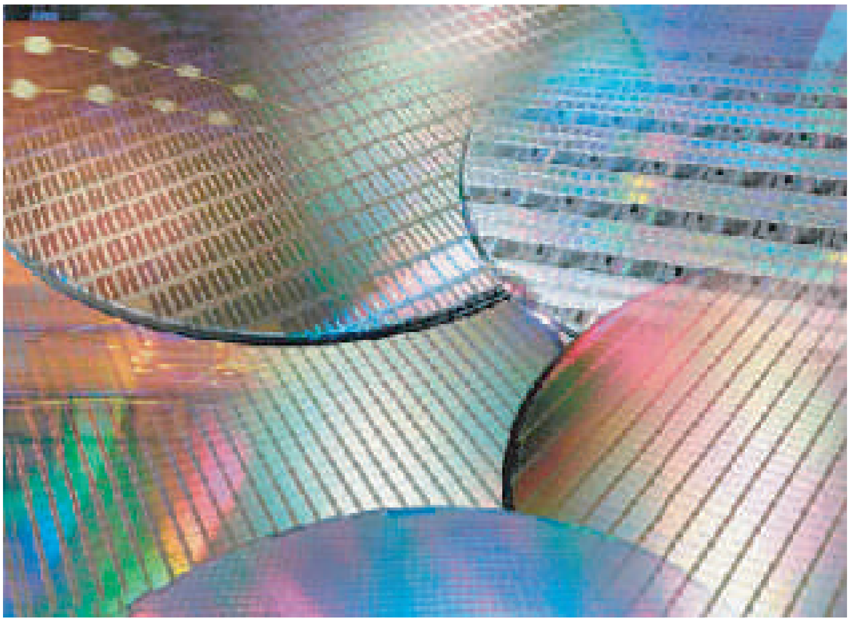
ROCK STEADY

The importance of reliable power distribution in microprocessor manufacturing plants



Paolo Perani, Richard E. Brown

The impact of power supply disturbances on production processes is nowhere more keenly felt than in the microprocessor manufacturing industry. Here, interruptions of any kind have the potential to be economically disastrous, so much so in fact that power quality and a reliable power supply have become critical to business success. Solutions *are* available, but finding the best one can be a haphazard affair. Help is now at hand in the form of a predictive reliability model, developed by ABB, that simulates expected plant behavior and quantifies the impact of improvement options. Using this model, ABB identifies the combination of measures that will yield the highest level of reliability for the lowest possible cost.

Microprocessors are part of the fabric of modern life, controlling and supervising the things around us in innumerable ways. Although still mainly associated with personal computers, they are found everywhere – in automobiles, cellular phones, coffeemakers, and in countless other everyday products. Given this popularity, it can surprise no one to learn that demand for microprocessors is growing exponentially, forcing industry to build new manufacturing facilities at an ever-increasing rate.

Building a microprocessor manufacturing facility is an expensive business, however, with even a mid-sized plant typically costing more than one billion US dollars. To recover this cost, the plant must be kept working at full stretch. Each day of operation is crucial, and any factor that could affect production, especially the reliability of the electricity supply, has to be taken seriously. As implied, disturbances in the power distribution system can severely reduce a plant's profitability, and microprocessor manufacturers give the highest priority to avoiding the circumstances in which they can occur.

Manufacturing microprocessors

The microprocessor production process consists of a *front end*, in which a large silicon wafer containing hundreds of identical microprocessors is produced, and a *back end* that deals with the individual microprocessors after they are separated from the wafer. Generally, it is the front end that is vulnerable to power system reliability problems.

The front-end process is highly automated and may involve hundreds of steps over a period of 10 to 30 days. A reliability problem that arises during this time can ruin the entire batch. As microprocessors become more sophisticated, more manufacturing steps are required, so that the cycle time is tending to increase. Also, the shift from 8-inch to 12-inch wafers is more than doubling the number of microprocessors in each batch. This reduces by 40% the power consumption per die, but the power needed for the production process increases by 30%. Together, these factors greatly increase the losses that could be incurred by a power quality disturbance.

The economic impact of a power interruption depends upon where the wafer is in the front-end process. If the process has just begun, economic losses will be relatively small, but if the process is nearly complete weeks of plant operation may be wasted. As such, the value of the wafer can be thought of as increasing as it moves to each new step. The economic impact of a power interruption can therefore be modeled as the *moves lost* of a front-end process.

The monetary value of a single move lost depends on the type of microprocessor in production at the time of the interruption and its market value, which is also a function of time. For the cases considered here, a typical value of 2.4 USD per move lost is assumed.

Impact of power quality

Voltage sags are temporary reductions in voltage, being typically caused by faults or by large motors starting. An interruption is defined as a voltage sag to 10% (eg, a decrease from 220 V to 22 V) or less.

The impact of voltage sags and interruptions depends upon their magnitude and duration as well as on the sensitivity of the manufacturing equipment. For example:

- A 20-ms voltage sag to 65% will cause electronic controllers to crash. The manufacturing process has to be restarted, resulting in a large number of moves being lost.
- A 200-ms voltage sag to 50% will cause the entire process to crash, so that all the process equipment parameters have to be restored. This can take anything up to 12 hours.
- An interruption lasting several minutes will result in even more moves lost than a deep sag. Wafers are processed in Class 1 clean rooms, which are ten thousand times cleaner than a hospital operating room. If the air filtration system shuts down, specks of dust will contaminate the wafer and render it unusable. Interruptions of this length can also shut down UV filters, resulting in bacteria and organic particles contaminating the ultra-pure water used to wash the wafer.
- Even longer interruptions can result in environmental conditions capable of

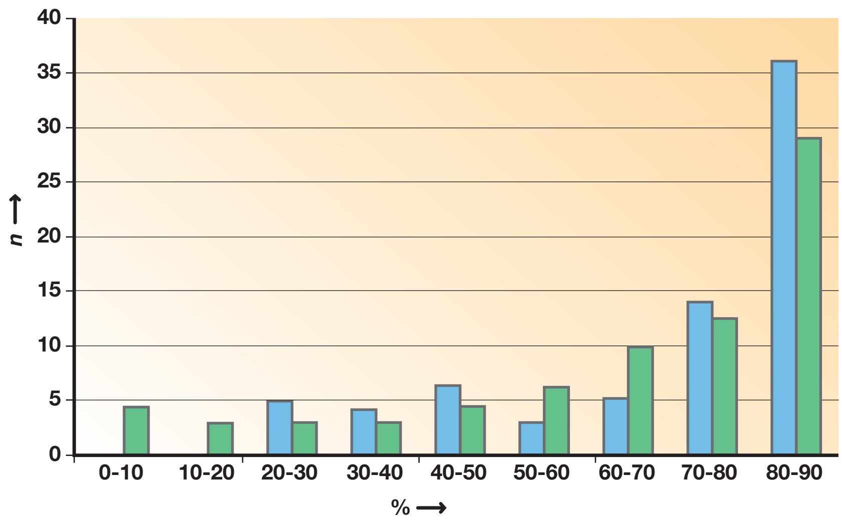
ruining the front-end process. For example, the temperature and humidity tolerances for the lenses used in lithography – the process by which the integrated circuit design is transferred to the silicon wafer – are ±2°C and ±2%, respectively. If air-handling units are shut down due to an extended interruption, these tolerances will be exceeded and the lenses will have to be taken out of service and sent back to the manufacturer for re-calibration, causing production to be stopped for weeks.

Because of the high economic cost of power quality disturbances, many sensitive facilities are beginning to ask electric utilities to guarantee levels of reliability in their energy contracts. Although not widespread at this time, such guarantees are already in effect for several US car-manufacturing facilities in the state of Michigan; if a factory experiences a power quality disturbance that disturbs the production process, it receives a large credit on its energy bill.

1 Predicted (green) and measured (blue) voltage sag distribution

n *Events per year*

% *Percentage voltage sag (0 = no voltage)*



Economic impact

The economic impact of power supply disturbances is illustrated by a recent study of a microprocessor manufacturing facility conducted by ABB. When it was first built its electrical power was supplied by a single 130-kV overhead line. Inside the plant, critical loads (about 10% of the total) were served by uninterruptible power supplies (UPS) which, besides mitigating voltage sags, could keep the loads supplied with power for about 10 minutes after an interruption occurred. However, interruptions on the 130-kV line frequently exceeded the maximum UPS backup time and caused total plant shutdowns.

A few years ago, a second 130-kV overhead line was added to the plant. This new line provides full redundancy, and a total plant shutdown has not occurred since its installation.

Unfortunately, though, the second line doubles the exposure of the plant to voltage sags that occur when lightning strikes the utility power lines. If the voltage sag is severe enough, equipment not protected by power quality devices will fail in some way, possibly causing hundreds of thousands of dollars in moves lost. Such an event could be repeated dozens of times every year.

To examine the magnitude of the problem, ABB created a predictive reliability assessment model that allowed the benefits of different means of reliability improvement to be examined.

Predictive reliability model

A reliability model of this kind is able to predict power quality disturbances based on system connectivity information and component reliability data. For each load point in the system, it computes the expected number of momentary interruptions, the expected number of sustained interruptions, and the expected number of voltage sags of varying severity. A good model is able to simulate expected plant behavior, identify reliability problems, quantify the benefit of solutions, and identify the best way to achieve maximum reliability for the lowest possible cost.

The microprocessor manufacturing plant was modeled in ABB's Power Delivery Optimizer software, an Internet-based application developed by the Utility Partner Group. This model contains both the utility transmission system and the plant distribution system. Characteristics of the model include:

- 250 km of surrounding overhead utility power line and 16 associated utility substations
- Site main substation, including two 130-kV primary supplies and a 15-kV emergency supply
- 11 site substations serving 29 MVA of peak load and containing 12 MVA of UPS devices

The software uses an analytical simulation to determine the expected reliability of the plant. For each contingency (such as a fault) the program simulates the protection system response, identifies loads that are adversely impacted, and weights this impact by the contingency probability. This procedure is performed for all possible contingencies in order to obtain the expected annual reliability characteristics of the plant.

To perform a reliability analysis, component reliability data such as failure rates and repair times are required. For this model, generic data based on published literature was initially assigned and then calibrated based on the plant's historical failure information.

The reliability model predicts that the 15-kV bus of the main plant substation will experience, on average, one 4-hour interruption every 25 years (this number takes no account of the effects of UPS devices). Due to this low figure, it is expected that the main economic losses will be caused by voltage sags rather than interruptions. A profile of the actual voltage sags and the predicted number is shown in 1.

In 2001 alone three voltage sags, in a part of the plant not protected by power quality devices, resulted in a loss of more than 1.1 MUSD:

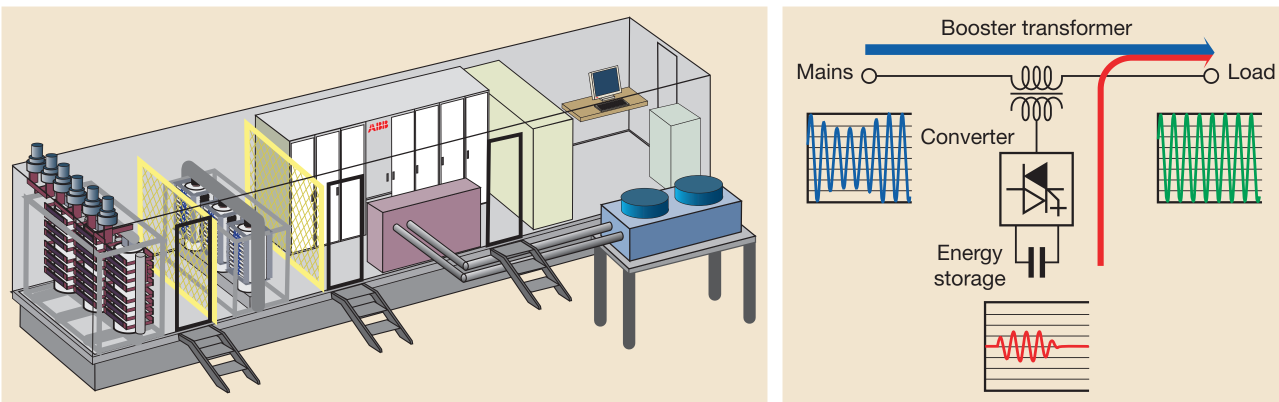
- A sag to 36% of the nominal voltage that lasted 320 ms caused 116 thousand moves lost in the test department and 52 thousand moves lost in production (a total of nearly 400 KUSD).
- A sag to 24% of the nominal voltage that lasted 220 ms caused 100 thousand moves lost (nearly 240 KUSD).
- A sag to 24% of the nominal voltage that lasted 400 ms caused 220 thousand moves lost (nearly 500 KUSD).

Since this level of reliability is not acceptable, mitigation projects were explored. Using the new model, the reliability impact of each project was quantified in order to determine the highest levels of reliability for the lowest possible cost.

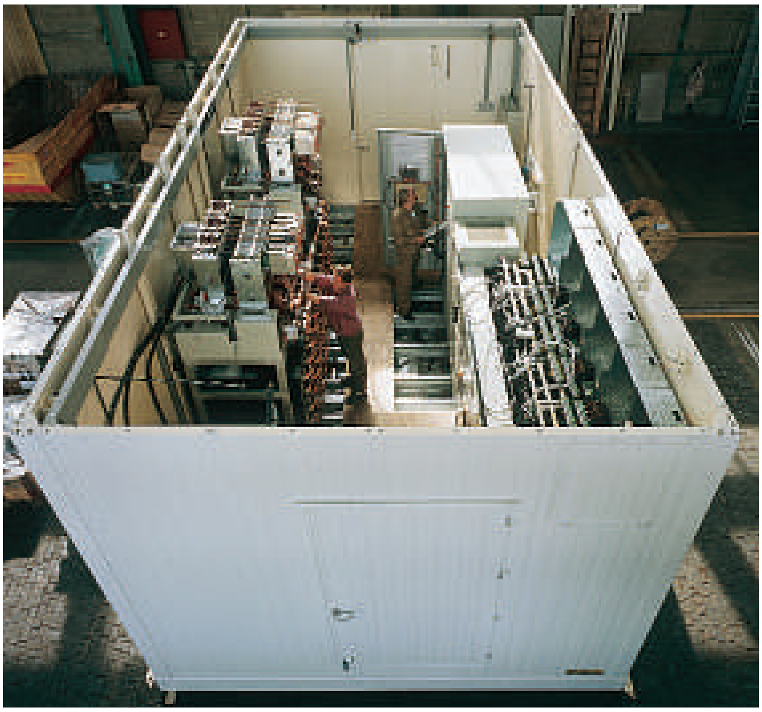
Improving reliability

After exploring several possibilities, it was seen that the installation of a dynamic voltage restorer (DVR) 2, 3 would be the most effective way to improve reliability. Basically, a DVR is a transformer connected in series with the transmission line. When a voltage sag is detected, the DVR instantaneously injects a compensating voltage. If sized large enough, a DVR is able to inject the full nominal voltage and essentially becomes a UPS. In practice, however, a DVR is

2 Dynamic Voltage Restorer, with (from left to right) converter unit, short-circuit device, switchpanel, control panel, monitoring system and UPS (both in the compartment on the right).



3 Dynamic Voltage Restorer



sized to compensate for sags that may reasonably be expected to occur, and cannot compensate for complete interruptions or long-term reductions in rms voltage.

Installation of the DVR increases the reliability to a level where it is difficult to achieve further improvement in a cost-effective way. One way in which sags due to direct lightning strikes could be mitigated would be to improve the transmission tower grounding and install surge arresters on each phase of each tower. The model indicated, for example, that increasing lightning protection on 63 km of line surrounding the facility would reduce the number of unmitigated voltage sag events to one in 20 years. However, the cost of doing this would far exceed the economic benefit gained by the plant.

More reliable ... more profit

The example looked at above highlights the importance of power distribution reliability and power quality as economic factors in microprocessor manufacturing. Although most facilities are equipped today with redundant supplies that enable them to withstand short power failures, they still remain vulnerable to certain kinds of interruptions and voltage sags. Microprocessor production relies so much on very high power quality that even modest sags can result in a large number of moves lost, with enormous economic repercussions for the plant.

Two key strategies exist for minimizing moves lost in a microprocessor manufacturing plant; one based on uninterruptible power supplies and the other on dynamic voltage restorers. UPS devices can protect selected equipment from virtually any power quality disturbance, but are expensive and can only be economically justified for a small part of the load. Properly sized DVRs protect the remainder of the plant from voltage sags and can pay for themselves in avoided costs within a year if voltage sags are a common occurrence.

The same strategy can be used for new plant projects, too. It is usually most cost-effective to provide dedicated UPS protection for the most sensitive equipment and to protect the remainder of the new plant with a properly sized DVR.

The key to a cost-effective solution is predictive reliability modeling. Computing the expected reliability of existing systems and quantifying the impact of improvement options helps the user identify the measures that will yield the highest level of reliability for the lowest possible cost.

Authors

Paolo Perani
ABB Industries
IT-24044 Dalmine
Italy
paolo.perani@it.abb.com

Richard E. Brown
ABB Inc
Raleigh NC 27606
USA
richard.e.brown@us.abb.com