Power system overviews ‘at a glance’

Knowing precisely where weaknesses and problems exist in the operation of a power system, in its component parts, subsystems or transmission lines and buses, is valuable information. Presented immediately, even rough information, obtained without running a full, complex analysis and simulation, gives operators the advantage of knowing more sooner. To provide such information, ABB has developed PSGuard Tool. This new software tool provides a ‘first view’ of power system ‘quality’, determines weak areas and points out buses and transmission lines that might need special attention before a critical situation can arise.

The outages and operational problems that plagued power systems in the northeastern United States and parts of Europe last year resulted in a rush to identify the causes and find possible solutions. The analyses not only concluded that voltage instability was one of the major reasons for the blackouts, but also established that technologies were available that could have prevented them.

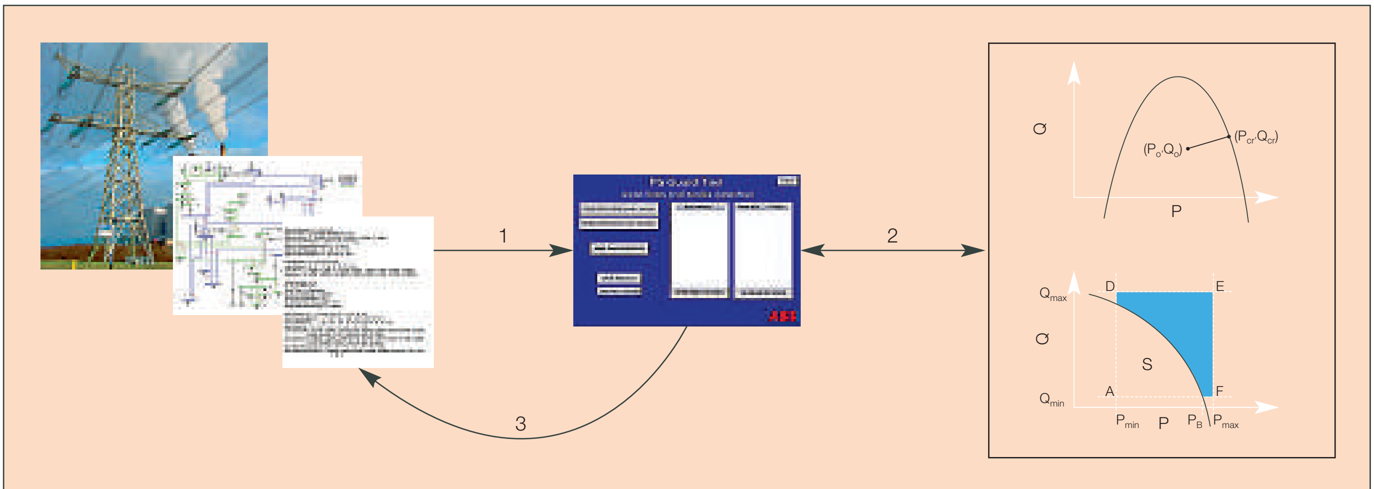
Although the causes of blackouts differ and their scenarios vary, a pattern does exist for many of them. Ignoring the possibility of insufficient generation capability, one major reason for blackouts is voltage instability. By causing lines to trip, this has a ‘knock-on’ effect, ie other lines or parts of the system become heavily overloaded.

Voltage instability

Increased competition in the electrical energy market is forcing utilities in many countries to operate their transmission systems at or close to their limits. Voltage control and voltage stability – always key considerations of the industry – have become even more important as a result.

Voltage instability is defined as the inability of a power system to return the voltage to nominal levels following equipment failure, a human error or environmental event. Such incidents depress the power system voltage. In strong systems, voltages return to their pre-event levels immediately after a fault is cleared. However, in weaker systems with long transmission lines, remote generation, low fault power or large numbers of shunt capacitors, such events can cause the voltage to become unstable or even collapse. The system voltage may then remain at an unacceptably low level for a long time, even indefinitely.

Voltage instability is a typical problem, for example, where there are many small-to-large motor loads (eg, air-conditioning systems). In such areas it is obviously important to be able to plan, and ensure, power system operation in critical situations. This presupposes, however, that a utility has knowledge about all the factors affecting voltage stability and can precisely determine the voltage stability margins that are necessary in the event of possible disturbances. To obtain such complex infor-



Data flow with PSGuard Tool. After the power system has been analyzed for 100 % and 120 % load, P-Q curves are created for each individual element. Coefficients are then calculated and compared with threshold limits to determine the (weak or strong) states of the elements.

mation, utilities have normally had to run a complete dynamic analysis of the power system.

Stability studies and analyses are also used to determine and identify those parts of a power system that are prone to voltage instability and obtain information about how the voltage stability conditions in them can best be improved. Two main purposes are served by such studies:

- Analysis and learning from the past.
- Determination of action that can be taken.

To deal with the first of these, ABB has developed PSGuard Tool. This new software tool provides immediate information on power system conditions and voltage stability vulnerability without having to run a complete analysis with complex calculations and simulations.

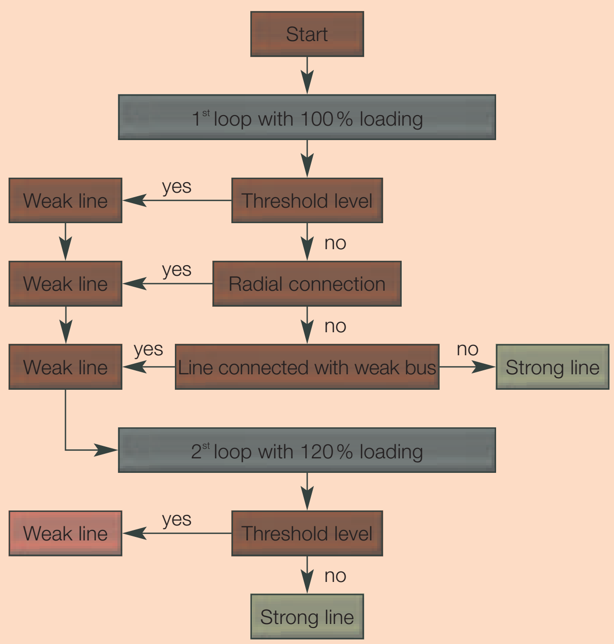
Data consistency is important

A minimum set of data is required to identify potential instability problems. Usually these data can be obtained from a model of the system in question. Any power system can be modeled as a set of generators (power plants) and a set of loads (electric distribution centers), interconnected via a transmission network. The transmission network model has nodes (buses), branches (lines), generators and loads. Different colors are used to indicate the different voltage levels. Although the system data can be provided in different forms, standard formats are preferred to ensure data consistency. For PSGuard Tool, it was decided to use the standard IEEE format.

Weak power system areas

PSGuard Tool was developed primarily to create a simple tool for determining a power system's weak areas, ie those areas with weak nodes or weak lines, or any combination thereof. Doing this quickly and precisely, however, is no easy task when the details – the system configuration and data – are not known. Using PSGuard Tool, weak areas can be identified without having to run a complete power system analysis. One mouse-click is all that is needed to locate the weak lines and weak nodes within a system and save the information with the original set of data in IEEE format.

After reading the data, PSGuard Tool calculates the required values and coefficients on the basis of P-Q curves for the buses and lines, and compares them with defined threshold levels. Decisions about areas and individual components, ie if they are weak and need strengthening, can then be taken.



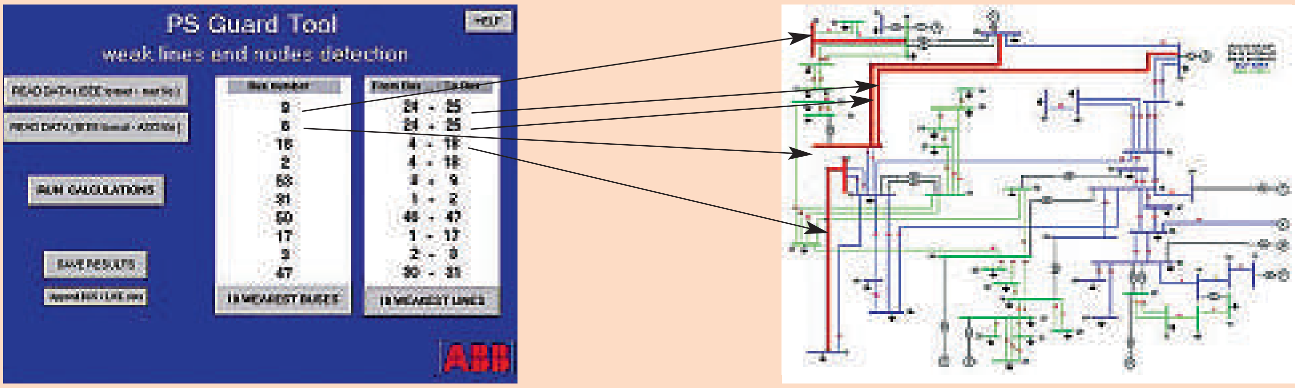
Algorithm for determining weak lines

P-Q curves

The first step in determining the weak areas of a power system is a very simple, standard steady-state flow calculation. After running this calculation, all the steady-state values for voltages, phase angles, active and reactive powers, etc, at all the nodes, are known. The P-Q curve describing the relationship between the active and reactive power can then be created for each individual node and transmission line (see figure on page 63).

The point representing the steady-state flow (P_o,Q_o) is found for each P-Q curve and then the minimal distance from this point to the voltage collapse point (P_c,Q_c), which is located on the curve's boundary (the point closest to the steady-state point). This minimal distance between these two points may be referred to as the degree of *voltage security*, being the distance to voltage collapse d_{vc} for a given element. It can be calculated as follows:

$$d_{vc} = \sqrt{(P_{cr} - P_o)^2 + (Q_{cr} - Q_o)^2}$$



PSGuard Tool provides immediate information about power system weaknesses

The lower the value of d_{vc}, the weaker the element will be in terms of its voltage stability.

The P-Q curves can also be used to calculate the *probability* p_{vc} of branch voltage collapse for uniformly distributed active and reactive powers within assumed limits. This probability is determined using the geometrical definition of probability. Rectangle ADEF represents the maximum possible ranges for change in active and reactive power for the analyzed element (P_{max}, P_{min}, Q_{max}, Q_{min}). The (blue) area outside of the curve but within this rectangle represents the area of voltage collapse. The geometrical definition of this probability can be calculated from:

$$p_{vc} = 1 - \frac{S}{(P_{max} - P_{min})(Q_{max} - Q_{min})}$$

where $S = \int_{P_{min}}^{P_B} \left(-cP^2 + \frac{0.25}{c} - Q_{min} \right) dP$

and c represents the line parameters (inductance and susceptance).

PSGuard Tool algorithms

PSGuard Tool starts by reading the power system data in standard IEEE format, and goes on to analyze the system with first 100% and then 120% nominal load. At each of these loads it calculates the steady-state power flow and creates a P-Q curve for every power system element. The coefficients are then calculated and compared with threshold limits to determine the state (weak or strong) of each element. It can happen that the state of some strong buses or nodes is determined already during the first run at 100% nominal load, but it usually takes a second run, with the system stressed to 120% nominal load, to obtain a clear result.

A simple, easy-to-use tool

The described algorithms were tested and verified with many different systems, and have now been launched as stand-alone applications. No special knowledge of power system analysis is required to use them. After the calculations have been run, the weak nodes and weak lines are listed in two separate windows, the weakest at the top and the strongest at the bottom.

PSGuard Tool provides immediate information about power system weaknesses, and can help users identify the critical nodes or transmission lines in even largely unknown power systems. It is also useful as a complementary tool; for example, it can help users determine the best location for other ABB applications in this domain, such as Inform^{IT} Wide Area Monitoring PSG 850, which uses phasor measurements at the most critical areas of the network.

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