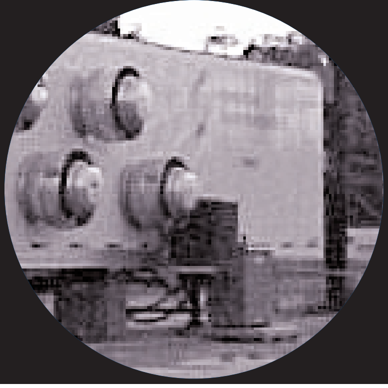

ApplicationStudy

APPLICATION: POWER SYSTEM LOAD MODELING
PROBLEM: INABILITY TO ASSESS WHETHER A TRANSMISSION SYSTEM IS SUBJECT TO VOLTAGE COLLAPSE
SOLUTION: ACCURATE LOAD MODELING
RESULT: PROBLEMS IDENTIFIED AND SOLUTIONS OPTIMIZED

Introduction

When evaluating a possible voltage stability problem on a power system, few factors are more important than accurately modeling the electric characteristics of the load. Voltage instability is defined as the inability of a given system to bring voltage back to nominal levels following an event. Equipment failure, human error or environmental events can cause such faults. Such events depress system voltages. In strong systems, voltages return to pre-event levels immediately after a fault is cleared. In weaker systems with long transmission lines, remote generation, low fault power or substantial amounts of shunt capacitors, such events may lead to voltage instability or voltage collapse. In weaker systems voltage may remain at an unacceptably low level for an extended period of time, even indefinitely. Typically, areas of voltage instability are also characterized by a high percentage of large and small motor loads (e.g., air conditioning).

Voltage collapse occurs when, during the few cycles in which the fault is on the system and voltages are depressed, motors in the area begin to slow and draw more reactive current. This increase in VAR consumption also increases the I^2X reactive loss in the system when reactive power supplied by line charging, capacitor banks, and even SVCs is severely diminished. As a result, area voltage may not recover once the fault is cleared and may even fall further, amplifying the problem and forcing the system into voltage collapse, with widespread involuntary tripping of customer loads.

Once a system is in voltage collapse, the only way to correct the problem is to shed load. In some cases, the motors trip themselves and save the remaining system, but often the motors in air conditioners or similar equipment do not have low voltage protection relays. In addition, most utilities do not have a three to five cycle low voltage triggered load shedding scheme. The greatest concern about voltage collapse is that a small, remote system may fall into collapse, spread unchecked and eventually drag down larger portions of the grid.

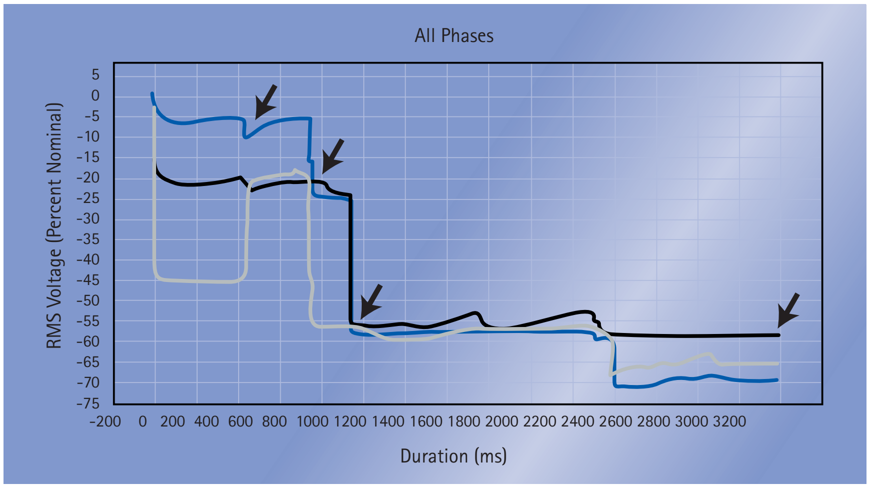

Fig. 1
Plot of actual fast-collapse situation.

Many utilities are unable to study their systems for voltage collapse because they have not modeled their loads using dynamic simulations. This can be difficult and is not always needed to find problems such as transient instability. As a result, accurate load modeling is often overlooked, causing major problems. This paper outlines an effective method to model load in order to accurately determine that a given system is susceptible to voltage collapse.

Procedure

American Superconductor, with guidance from Power Technologies Inc., GE Power Systems, IEEE papers and standards, and various utilities, has developed a procedure to accurately model load for voltage collapse studies. This involves a three-step effort.

1. Accurately represent transmission-to-distribution voltage transformers.

2. Model distribution (power factor correction) capacitors as capacitors, rather then lumping them into the load.

3. Break load into large motor, small motor, discharge lighting, constant power, transformer saturation, and remaining load, and represent total load with appropriate stability models.

These three steps can be performed with any power system simulation software, but this paper is based on PTI's PSS/E package.

It is unlikely that any utility will have recorded all the data needed to create a detailed load model. Estimates may be used and sensitivity analysis should be performed to qualify them. Often a best, worst, and intermediate case scenario should be created and evaluated to judge the validity of assumptions. As each step is outlined, 'typical data' will be provided. These figures may be modified, as necessary, so that their values are as accurate and reasonable as possible. There are also some general "rules of thumb" to keep in mind when setting up a model load study:

- Data within the study area is more important then data outside the area. As you move further away from the region of concern, it becomes less important to the accuracy of the study to correctly model that load.

- Accurate load modeling (step 3) is somewhat more important than accurate capacitor modeling (step 2). Accurate capacitor modeling is somewhat more important then accurate transformer modeling (step 1). There are clear exceptions to this general comment, and due diligence is necessary for the best possible accuracy.

- Above all, the area generation, capacitors, SVCs, DC lines and other system elements modeled in a dynamic study must be correct.

Step 1: Transformer Modeling

Accurate representation of the transmission-to-distribution-voltage transformers is important for two reasons. If the load is simply modeled on the transmission bus it is likely that the steady state I^2X losses in the transformers are taken into account in that equivilized load. But the increase in these losses during a low voltage event will not be accounted for. The increased I^2X loss during a voltage dip must be included to get an accurate system representation, and the only way to do that is to model the transformers. Also, during voltage collapse scenarios there tends to be a significant voltage drop across the impedance in these transformers. If the transformers are not modeled, engineers may not be able to determine actual distribution voltage at the load by simply looking at transmission bus voltage.

Whenever possible, a transformer should be modeled according to the nameplate values for that transformer. If the MVA rating of the transformer is known, but the actual per unit impedance is not, a typical value for your utility may be used. (NOTE: the impedance of US distribution transformers varies from ~6-15%.) If the size of the transformer is unknown, an estimate must be made. A reasonable estimate might be 150% of the peak load on the transformer. If estimates are used, sensitivity analysis using alternate assumptions is recommended. Once the distribution transformers are modeled, all loads should be moved to their medium voltage or low sides and any transformer losses that were originally accounted for in the load should be removed. Note that we are not modeling the actual distribution lines or the distribution-voltage-to-480V transformers. If this can be done, the accuracy of the results will be improved, but such detail is probably unrealistic. This omission is part of the margin of error accompanying all simulation studies of this type.

Step 2: Distribution Capacitor Bank Modeling

It is common practice to equivilize or net the distribution bus loads with the capacitors that accompany the feeders. It is not uncommon to see load power factors at .98 or better when in reality it is unlikely that a feeder would have such a good p.f. without distribution capacitors. The concern with capacitor modeling is that a capacitor's VAR output capability is directly proportional to the square of the voltage. Ironically, the time when capacitor VAR output is seriously reduced is exactly the time it is most needed. This is one of the major causes of voltage collapse.

To correctly model distribution capacitors, engineers must know the power factor without capacitors. We then change the reactive portion of the load to match the new p.f. by adding a capacitor to the distribution bus such that the sum of the new load and the new cap equals the old load. Most utilities keep very accurate records of the power factor of their customer loads as it is often a billing issue. If the true p.f. is unknown, it can be estimated. The ANSI/IEEE standard 141-1986 of the IEEE red book gives typical power factors for different load types. Typical power factors tend to range from .7 to .8, with industrial customers at the low end and residential customers at the high end of the spectrum. Any significant amount of estimation in power factors warrants a sensitivity analysis.

Step 3: Load Modeling

Correct load modeling is the most important part of this procedure as well as the most time consuming. All loads can be categorized as belonging to one of the six groups below:

- Large Motors (LM): motors greater then 100 horsepower
- Small Motors (SM): motors smaller then 100 horsepower
- Discharge Lighting (DL): fluorescent bulbs and similar lighting
- Transformer Saturation (TxSAT):
- Non-motor Constant Power (CTMVA): computers and similar devices
- Remaining load (REM): everything else

It is unlikely that a utility can easily divide customer loads directly into these six groups. We have devised a way to simplify the process, while maintaining a reasonable level of accuracy. Rather than go directly to these six load groups, we recommend that utilities break their load into the following three categories for each load bus: industrial, residential, and commercial. Bus A is 10% industrial, 20% commercial, and 70% residential. Bus B is 80% industrial, 20% commercial, and 0% residential, etc.

Once the load is broken into these three categories, we estimate the typical breakdown of each category in terms of large motors, small motors, etc. The breakdown typically used at American Superconductor is:

	%LM	%SM	%DL	%TxSAT	%CTMVA	%REM
RES	0.0%	64.4%	3.7%	1.0%	4.1%	26.8%
COMM	0.0%	46.7%	41.5%	1.0%	4.5%	6.3%
INDUS	65.0%	15.0%	10.0%	1.0%	5.0%	4.0%

We find these values fairly represent most loads, although individual utilities are encouraged to adjust the values if better local data is available. Using a spreadsheet to perform this function will save time and can be reused on other studies. Once the load has been divided into the six groups the data can be entered into the model.

Conclusion

Power system load modeling is a powerful tool for assessing whether a transmission system is subject to voltage collapse. Under appropriate conditions, D-SMES can be a valuable tool in addressing the problems of voltage instability and voltage collapse. American Superconductor's skilled personnel, using proprietary software, can assist utilities in modeling the power loads of their systems as well as the applicability of D-SMES to individual situations.

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