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A PHYSICAL REVIEW ON POWER SYSTEM RELIABILITY FACTORS

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Planning and design engineers and management must necessarily take into consideration the funds available, the requirements of regulatory agencies, and other restrictions that may be imposed, as well as the availability of equipment and supplies. A well-designed electrical power system strikes a reasonable between reliability and cost. A prime responsibility of power system operators is to operate their systems in such a way that will provide the maximum reliability of service possible with the facilities under their control.

Key word: Reliability, Power System, Spinning, Reserve, transmission.

INTRODUCTION

Normally designs are such that many years of reliable service can be expected, even under adverse circumstances, such as storms, transient over voltages due to lightning or switching surges, and temporary over currents, and with a minimum of interruptions to customer services. A commonly used design criterion is to provide facilities and capacity to withstand, without interruption, a "single contingency," that is one foreseeable loss, such as the loss of one line, one transformer bank, or other credible occurrence.

Design dose not normally protect all loads for multiple contingencies because of excessive cost and reduced probability of two such events occurring simultaneously. There are sometimes special considerations given in design for special and important loads where design for more than the first contingency can be justified. However, after a system or facilities within a system are designed, constructed, and released for service, it is the responsibility of the operators of the system to perform their functions so that maximum reliability will be realized. Items that must be considered are to be sure that design limits are not exceeded, to be alert to conditions that may affect reliability, and be ready to take action to prevent hazardous situations from developing [1].

Often steps must be taken to avoid interruptions from single- contingency situations. This may require the use of computer programs or on-line energy management system (EMS) assessment in order to determine how system arrangement can be altered to avoid operating in a single-contingency situation.

Following trouble, when service is lost or normal equipment is not available, the system operators should proceed to restore the system to as near normal operation as quickly as possible so that all customer service interruptions are minimized.

FACTORS AFFECTING POWER SYSTEM RELIABILITY

Some of the major factors that affect power system reliability are

1. Reserve capacity- that is, the capacity over and above that required carrying the system load. There are several categories of reserve:
   a. Spinning that is, capacity within the system that is on the line over and above the actual load and is capable of increasing generation immediately, limited only by the response limitations of the machines.
   b. Quick start units that are off- line, such as gas turbines.
   c. Interruptible loads. Some power sale contracts provide for the interruption of service to some loads during emergency conditions. Such interruptible power is normally supplied to the customer at reduced rates and may be considered as a part of the reserve.
   d. Purchased reserve. Reserve capacity that is purchased from another interconnected system. Such reserves can be spinning and immediately available or made available after a start-up period.
2. Delayed reserves that can be made available after a time period. Such delays may be matters of minutes or hours if, for example, the start-up of a thermal unit that has been shut-down for some time is required.

Adequate transmission and station capability, that is, that the load carrying capacity of transmission lines and stations is sufficient to carry their normal loads and with enough overload capacity to carry additional loads that may be expected to occur. The amount of overload capacity to be provided is a management decision and could be affected by costs and the importance of the load in the area served. For example,
critical loads in a metropolitan area would justify greater efforts to ensure continuity of service than could be justified in rural area with a low load density.

3. The ability to restart generation equipment.
4. Prompt disconnecting of faulted lines or equipment and restoration of facilities.
5. The ability alters station arrangements to restore at least partial service by bus sectionalizing, etc.
6. The ability to operate equipment such as power circuit breakers without dependence on power system energy. Station batteries, and in some cases tanks of compressed air, are normally provided for this purpose, so that circuit breakers can be operated even with the station shut down, and which could be required to reenergize a station after a complete interruption.
7. The ability to provide alternative arrangements of lines or station equipment to restore unfaulted equipment to service completely.
8. Adequate and reliable interconnections with other systems.
9. Reliable indication of system conditions and communications with key generation and transmission station.
10. Provisions for and the performance of maintenance to ensure that equipment will function properly under all conditions.

The above list of items is by no means complete, but it covers major categories that must be reviewed in order to ensure reliability of power system operation. Some items listed are determined by design and are not within the control of system operators. The following discussion will attempt to point out factors over which system operators can exert control in order that maximum reliability can be achieved with the available facilities [2].

SPINNING RESERVE

Generating capacity that is on the line and that is in excess of the load on the system is called spinning reserve. Adequate spinning reserve is probably the primary security factor in power system operation.

The amount of spinning reserve that a system desires to carry is a policy has been established, it is the duty of system operators to attempt to meet the criterion each day so that the system will not be jeopardized by inadequate reserve. Because of the no-load fuel costs incurred by excessive reserve, system operators also should see that excessive reserve is not carried.

The amount of spinning reserve can be expressed as a percentage of the daily peak load or be based on the risks of loss of generating capacity that actually exist on the system. The determination of spinning reserve as a percentage of the daily peak load leaves much to be desired, since it may not take into consideration the actual risks that exist on system. Furthermore, particularly with thermal generating equipment, units usually require several hours from the time that they are ordered to be placed in service before they are actually available. Consequently, it is necessary to make estimates of load, which may be somewhat in error. If load is underestimated, the percentage of spinning reserve at peak time may actually be less than that required by criteria. Interconnection agreements sometimes provide penalties for inadequate spinning reserve.

Probably a more realistic method of specifying spinning-reserve criteria is to base them on risks, along with allowances for forecast error and regulating requirements. Elements of risk include the load on the most heavily loaded unit or the amount of power being imported into the system if there are interconnecting tie lines. In addition to the risk due to unit or tie-line load, allowance is made for forecast error and for regulation error. These factors are usually 2 to 3 percent each. In some cases another factor is added, an arbitrarily determined amount which takes into consideration abnormal system arrangements or other conditions which might result in a high- than- normal risk.

An example of calculating required spinning reserve on the basis just outlined is illustrated in Fig 1 for system B.

Another factor connected with spinning reserve that should be under the continuous scrutiny of the system operator is its location and makeup. In the event of loss of a large, heavily loaded unit, frequency will drop. The amount of frequency sag will depend on the proportion of total available generation lost, including that on interconnected system. It is desirable to restore frequency to normal as soon as possible, and in the event of interconnected operation to return tie lines to normal schedule as soon as possible so that instability or overloads will not occur, inadvertent energy accumulations will not become excessive, and the effect of the trouble on the interconnected area will be minimized.

Generating units have limits on the rate at which they can respond when a load pickup is required. With hydro units, rates of pickup are usually limited by the rate at which water can be accelerated in the penstocks, and with thermal units, after the initial energy stored in the boilers is used, by the rate at which steam can be produced to sustain a load pickup.

It is possible to determine the percentage of unloaded capacity that can be picked up by the various generating units in time categories such as 5 s, 10 s, 30 s, 1 min, 5 min, etc. For thermal units, pickup rates of 1 to 2 percent per minute are reasonable and in some cases as much as 3 percent per minute. With such determination of spinning reserve, it is possible to reasonably predict how well a system will respond to trouble in a frequency drop [3].

With large- scale interconnections, the loss of even a large, heavily loaded generating unit will not produce a significant frequency drop. In such cases the power angle of the system losing generation retards, and there is an immediate flow of power from other interconnected system with deficient generation. Since there is little or no frequency drop, the deviation of tie lines from normal schedules is the only indication of abnormal conditions. Tie- line- load frequency- control signals or telephonic orders to plants with reserve capacity are necessary to restore tie-line schedules to normal. In such cases spinning- reserve response is somewhat slower than when a significant frequency drop occurs.

A very important factor in maintaining proper spinning reserve is to have the reserve distributed over several units throughout the system.

If most or all of the reserve is on one large unit, the total response is limited to the rate at which that one unit can pick up load. When reserve is divided among several units, each can provide its share in restoring system condition to normal, and the possibility of instability, tie-line tripping, or line and equipment overloads is reduced.

To summarize, adequate spinning reserve is one of the major factors in maintaining power system security. The amount of spinning reserve to be carried is based on an evaluation of risk and is a management policy decision. After the policy has been decided, it is the responsibility of the system operators to ensure that the policy is met and that allocation of reserve among available units is such that proper response to loss of generation or tie lines will be achieved.

System operators should be familiar with normal and overload ratings of facilities under their jurisdiction. Some equipment, particularly transformers, can be operated at greater than nameplate rating for limited periods of time without damage. Generating equipment rating are established by the manufacturer and confirmed by operational tests following installation.

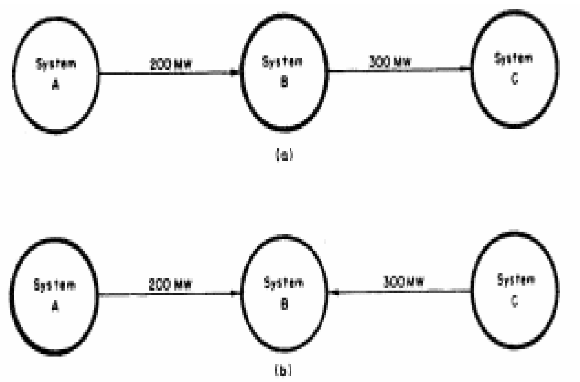

Figure 1 Diagrams showing the items to be considered in determining spinning-reserve requirements. (*a*) For system with no imported power; (*b*) with an assumed import of power of 500 MW and an arbitrary contingency factor.

(*a*) Assume a system peak load of 4000 MW with the most heavily loaded unit 350 MW, a 2 percent forecast error and a 3 percent regulation error, and no abnormal system arrangement.

Most heavily loaded unit = 350 MW
Forecast error = 80 MW (0.02 × 4000)
Regulation error = 120 MW (0.03 × 4000)
Contingency factor = 0
Required spinning reserve = 550 MW

(*b*) Assume the same system and largest unit loads as in *A* and an arbitrary contingency factor due to abnormal system arrangement of 100 MW.

Net imported power = 500 MW
Forecast error = 80 MW (0.02 × 4000)
Regulation error = 120 MW (0.03 × 4000)
Contingency factor = 100 MW (arbitrary)
Total spinning reserve = 800 MW

Figure 1:

TOTAL RESERVE

The total reserve of a system is made up of the spinning reserve and "quick start" reserve, with can include units which are off-line, but are capable of being started in a short period of time. Such units can down. In addition, contractual arrangements sometimes include, for a rate consideration, loads that a customer will agree to have interrupted during emergencies [4].

Another source of reserve that may be considered in emergency situation is the use of under frequency relays. While not strictly a reserve, the rapid disconnection of selected loads during an emergency, which results in a frequency decline, can arrest the decline and possibly prevent a major or complete interruption of a large area, or even a total shutdown of a system. Such a temporary, and in many cases only momentary, interruption of some service can prevent a much worse interruption.

The operation of under frequency relays is usually programmed in steps, so that after a predetermined decline of frequency, the relays will drop a preselected area, and further decline of frequency will result in dropping additional loads so that a total system blackout can be avoided. It is also possible, as frequency begins to increase, to pick up load in increments so that the time of load interruption can be held to a minimum. Both the load shedding and restoration can be done automatically or supervisory control.

TRANSMISSION AND STATION CAPABILITY

The power- handling capabilities of transmission lines and substation equipment are design factors, and are not under the control of system operators. However, after lines and equipment are installed and in service, the system operator is in a position to see those capabilities are not exceeded in normal operation. By frequently monitoring load and voltage conditions at various locations in a system, the operator can be kept aware of conditions and can adjust generation or alter arrangements to prevent overload conditions from occurring.

EFFECTS OF TEMPERATURE EQUIPMENT

The limiting loading factor on all electrical equipment is temperature rise. Temperature rises can result in insulation failures or may be the cause of lines sagging into trees. In any case, excess temperature can be the cause of equipment failure and service interruptions.

Maximum operating temperatures for generating and station equipment are specified by manufacturers and by information provided by system engineering and operating organizations. If ambient air and/or water temperatures are low, it is usually possible to load equipment to higher values than with higher ambient. With modern thermal generating equipment, it is possible to gain appreciable capacity temporarily at the expense of efficiency, for example, by cutting out feed water heaters. In emergency conditions the additional capacity available by this means may prevent overloads on other equipment or emergency load shedding. Increasing pressure in thermal unit boilers, within limits, can also be used to temporarily.

In some cases station transformers may be deliberately operated somewhat above their normal ratings (within predetermined maximums) for a period of time, accepting a reduction in life of the equipment as being of preferable to an interruption of service. Such measures are resorted to only sparingly, and should have guide lines to prevent such operation at other than previously agreed upon situations.

POWER FACTOR CONSIDERATION

Another factor that should be under the constant surveillance of the system operator is the power factor of generating equipment. If a unit is supplying a relatively large var output, its total rating may be exceeded even though megawatt load is below rating. When loading var is being supplied, there is an increased possibility of heating the end laminations of generator armatures. Temperature-sensing devices such as resistance thermal devices (RTD) or thermocouples are usually provided to monitor such conditions.

TRANSMISSION- LINE RATINGS

Transmission- line ratings are determined by conductor type, size, and line length ambient temperature, wind, and solar input. Also, tower height, the presence of under built lower voltage lines, or the presence of trees that must be kept trimmed can affect ratings of lines.

For short lines, the type and size of the conductor are major importance, because the electrical phase shift of the line under heavily loaded lines is not sufficient to cause a stability problem under steady- state conditions. However, the loss of a short line already operating at near its maximum and cause a stability problem. Consequently, such considerations must also be included in establishing line ratings.

Usually lines where thermal capacity limits capability are given summer and winter rating. The summer ratings are somewhat lower than the winter ratings because of higher summer ambient temperatures. Dynamic loading systems are not being used which are less constrictive.

On large lines, the rating may be determined by stability limitations rather than by conductor thermal capability. On such lines the stability limits are reached before the conductor current reaches its maximum limit.

A system operator who is familiar with line and station capabilities can take necessary action during both normal and trouble conditions to ensure that capabilities are not exceeded, or, if necessary, to modify switching arrangements or shed load to assist in providing maximum service reliability.

MATCHING GENERATION WITH LOAD

When a power system is operating at normal frequency, with tie lines to other system carrying scheduled loads, generation and load are matched. Any increase or decrease in load must be followed by a corresponding change in generation to match the new load condition.

The system operator is provided with various indicating devices, including system frequency, telemetered tie- line flows, and area control error, so that the operator can be kept continuously aware of these factors. Matching generation and load is the basic responsibility of the system operator. Devices such as load- frequency- control and automatic- dispatch equipment are provided to help match generation and load. It is only after this is accomplished that economic loading of generation is affected.

To make sure that there is always sufficient generation capability to carry any expected load, with provision for the loss of a major generating unit; spinning-reserve capacity is carried, as previously discussed. However, if serious troubles occur, such as the loss of all tie lines or a total generating station from bus trouble, the remaining generation may not be sufficient to carry the load on the system.

When generation is inadequate, system frequency will decline. It is of extreme importance that frequency be prevented from continuing to decline. In thermal plants particularly, auxiliary devices such as boiler feed pumps, draft fans, etc., must operate at or near normal speed and voltage to function properly. A frequency drop of more than a few hertz (5 or 6) may cause a loss of the plant, further reducing the available generation and increasing the possibility of a total system collapse.

If frequency decline continues, it is necessary to match load with the available generation. This can be done manually by dropping customer load promptly in sufficient quantity to arrest the frequency decay and start to restore frequency to normal.

Manual load shedding leaves much to be desired, since there usually is very little time for the system operator to assess the situation and take the proper corrective action. As a consequence, it is common practice to install under frequency relays to disconnect load automatically in amounts sufficient to match the remaining load with available generation. In developing load-shedding programs, it is customary to drop load in increments with declining of frequency. For example, if the credible incident could result in a loss of 30 percent of the generation, it might be decided to drop 35 percent of the load in stages, with 5 percent of load being dropped at 59 Hz and additional amounts dropped if frequency continues to decline, until the total 35 percent is dropped at some preselected frequency, such as 58 Hz.

Load-shedding programs vary among systems, but all are planned so that the maximum load is dropped before frequency is reduced to such an extent that plant auxiliaries are lost a total system collapse occurs.

Another factor that can be used to minimize the possibility of system collapse with declining frequency is to open tie lines at some predetermined frequency if power is being exported from the system. If power is being imported, opening the ties will worsen the situation. Tie-line opening in time of trouble should usually be a last resort and should be instituted only if power is flowing out of the system with continuing decline of frequency. Interconnection agreements and operating orders issued by various systems usually cover this procedure, and it is also covered in the North American Electric Reliability council (NERC) guides. In most cases, interconnections will serve to stabilize and limit frequency decay.

A more sophisticated procedure by which the rate of frequency decay is used to determine the amount of load to be shed can be applied. Relays that are sensitive to rate of frequency information to a central control computer, which can analyze frequency variations and send out control impulses to shed load when conditions require it.

As frequency recovers, load is reconnected in amounts that match the available generation. In some cases this is done automatically by relay and in others manually. In any event, it is much more desirable to interrupt a portion of a system's load for a short period of time than to permit frequency decline until the system collapses.

Matching generation with load also is necessary in the event that a large block of load is lost, or when tie lines which are exporting power relay. In such circumstances, load will be less than generation, and frequency will rise. The amount of frequency rise must be limited because it is accompanied by voltage rise and may damage customer equipment if it is not limited. Over frequency is less hazardous to a power system than low frequency. As frequency rises, the additional torque that is required from the prime movers tends to limit frequency rise. However, the total rise in frequency should be limited to some predetermined level. This is usually done manually be tripping generation of governor and automatic control action is not adequate.

The important principle to be remembered is that in power system operation, generation and load must always be matched. Any mismatch results in a variation of frequency from normal or results in deviations of tie lines from schedule. Inadequate generation results in reduced frequency and over generation in over frequency.

It is important to prevent serious frequency decline so that plant auxiliaries will not be lost, causing further mismatch of generation and load, which can result in a total system collapse. Present practice is increasingly trending toward application of under frequency relays to shed load during periods of serious frequency decline. Upon restoration of frequency, load can be automatically or manually restored.

In interconnected operation the tie lines will ordinarily help maintain frequency. However, if power is being exported at a time when ties, but this should be done only as a last resort, as it will make an adjacent area that is already deficient more deficient.

For over frequency operation resulting from loss of load, it may be necessary to drop generation to restore the match between generation and load.

The maintenance of the match between generation and load is a primary and continuing responsibility of the system operator.

DISCONNECTING FAULTED LINES OR EQUIPMENT AND RESTORATION OF FACILITIES

One important measure in maintaining power system security is the rapid disconnection of lines or equipment that are in trouble. Because rapid action is necessary, automatic devices usually are relied upon instead of manual operations.

The design and setting of protective relay system is a function of system engineering and operating staffs and is not ordinarily a matter over which system operators have any control. However, system operators should be aware of the protective devices at important locations in the power and their expected performance.

Knowledge of the type of the type of protective devices in use and the portions of lines and equipment protected is of value in determining the nature and extent of trouble after a relay operation. Such information should provide the operator with clues on how to proceed in restoring the system to normal, or as nearly so as possible, in minimum time.

Many types of troubles, such as insulator flashovers on transmission lines, often are only momentary. The protection system design therefore frequently provides for automatic reclosure following such incidents. On the other hand, transformer bank differential or generator-elevated neutral relay operations usually indicate more serious troubles.

As a guide to system operators, procedures are normally provided which outline the steps to be taken after different types of relay operation or after unsuccessful reclosure tests. System operators should be thoroughly familiar with such system policies in order to restore the system to as nearly normal as possible with minimum delay.

In the event that automatic reclosure is unsuccessful, or after relay action has occurred that indicates equipment trouble, the equipment should be disconnected and cleared for repairs. Alternative line or station bus arrangements should be affected in order to restore interrupted load or generating equipment to service, so that normal loads will be served and generation margins restored.

RESTARTING GENERATION EQUIPMENT

After a generating unit relays or is lost to the system because of line or station trouble, it should be returned to service promptly in order to restore generation margin if there is no machine damage.

Normally, restarting a generating unit does not present particular problems, other than those of the routine procedures that must be followed in putting it into service. However, if there is no power available at the generating station, from the system, or from local start-up or house units, there may be a long delay in getting the unit back into service.

CONCLUSIONS

From the discussion, it should be apparent that the highest importance is attached to power system reliability. Those responsible for the design and operation of power system devote a great deal of though to this subject and invest substantial sums to ensure reliability, including the reliability of communications. Modern SCADA systems frequently include security monitoring, state estimation, and on-line load-flow programs to provide system operators with indication of potential problems affecting the reliability of their systems.

When provided with the facilities outlined in this section, it should be possible for system operators to perform their functions properly in maintaining safe and operation of their systems.

[1]. Burgan, Arthur R., Power System Analysis, 4th ed., Prentice-Hall, Englewood Cliffs, McGraw-Hill, New York, 1987.

[2]. Fink, D. G., and H. W. Beatty, Standard Handbook for Electrical Engineers, 12th ed., McGraw-Hill, New York, 1987.

[3]. Weedy, B. M. Electric Power System, 3d rev. ed., Wiley, New York, 1987.

[4]. E Balagurusamy, Reliability Engineering, Tata McGraw-Hill, 2002.