EXCITATION LIMITER PERFORMANCE IS CRITICAL TO VOLTAGE SECURITY

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Voltage instability occurs when there is insufficient reactive power to support voltage following a contingency. It can be aggravated by having insufficient 'dynamic' reactive power available to control voltage (SVC, generator or condenser). New shunt capacitor banks can usually be combined with existing generation to avoid voltage instability for single contingencies. However, generators will be an effective source of dynamic reactive power only if they are equipped with effective field current limiting. The important features of generator field current limiters are reviewed in this article.

The typical voltage collapse scenario begins with a line or generator trip. The voltage falls when the trip cause loadings to increase. As voltage falls, the reactive power produced by line and cable charging and shunt capacitors decreases, thereby increasing the reactive demand and causing voltage to fall further. Subsequently, load tap changing transformers restore distribution voltages, thereby restoring load and further increasing line loadings, which pushes transmission voltage lower yet. If the voltage decay is not halted by switching on capacitor banks or undervoltage load shedding, voltage can reach a level that causes motor stalling or angular instability and thereafter, a separation or blackout.

As a part of this process, generator voltage regulators in the area of low voltage will respond to the decaying voltage by increasing generator field current. The higher field current will increase generator reactive power output, often sufficiently to stabilize voltage. However, if the generator field current rises above the field winding rated current, the improved voltage condition will be only temporary. Within about one minute, the generator field winding overcurrent protection will operate.

The overcurrent protection triggers an override circuit in the voltage regulator to bring field current down to its rated value. As field current drops, generator reactive power drops, and system voltage begins falling again as reactive power flows into the area from more remote generators. If remote generators can meet the local reactive demand and the reactive power flow into the area does not cause excessive voltage drop, voltages will stabilize. However, if the lines are long and/or heavily loaded, the voltage drop is likely to be excessive, in which case voltages will drop to a level that results in motor stalling or steady state angular instability, either of which is likely to result in a blackout.

The thirty to sixty seconds of high reactive power that generators can provide is invaluable in that it gives operators some

(continued on Pg. 2)

BENEFITS AND PITFALLS WHEN OPTIMIZING DISPATCH

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Dispatch optimization programs can save millions of dollars by advising which equipment to operate and at what loading levels. The savings apply wherever there are multiple units available for dispatch. This includes units that produce power, as in power plants, or that consume power, as in industrial plants; either electrical (kW) or thermal (steam/hot water) power can be considered.

A dispatch optimization program determines the single optimum unit loading strategy. Because the optimum dispatch configuration often runs contrary to conventional intuitive loading strategies, the savings potential is increased. For example, Figure 1 shows the Input/Output curves for two equal capacity units available for dispatch. Unit 1 is less efficient and consumes, on average, 5% more fuel than Unit 2. It is typical to find such units being operated with the load shared between them. A more inefficient strategy would be to operate the most efficient equipment (Unit 2) at full load and the least efficient equipment (Unit 1) at part load. However, the optimum dispatch for these units would be to run the least efficient equipment (Unit 1) at full load and the most efficient equipment (Unit 2) at partial loads. This can be understood by noting that the example equipment runs nearly the same at full load, so it is better to take advantage of the savings offered by operating the more efficient unit at partial loading.

Figure 1. Input/Output Curves. Conventional loading practice would first load Unit 2, then Unit 1 to satisfy current load demand. The application of an optimum dispatch system to this application would reverse this, to yield the savings shown in Figure 2.

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EXCITATION LIMITER PERFORMANCE IS CRITICAL TO VOLTAGE SECURITY

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time to take corrective action to save the system. It also gives automatic devices, such as undervoltage controlled capacitor banks and undervoltage load shedding, more time to operate and prevent collapse.

The behavior of field current limiters is thus critical to voltage stability. If even one field current limiter responds too quickly or reduces generator reactive power more than necessary, the risk of a black-out is greatly increased. Even a moderately severe contingency can lead to collapse if a generator near the contingency does not respond to the reactive demand properly.

Most field current limiters fall into one of three groups:

- The limiter switches the exciter to a manual rheostat that has been pre-set by an operator. The excitation system is later manually reset to automatic voltage regulator control (manual follow).

- An automatic follower runs the rheostat up to the rated field current setting when high field current is detected. The exciter is then switched to the rheostat. The excitation system is later manually reset to automatic voltage regulator control (automatic follower).

- A continuously acting circuit reduces the voltage regulator setpoint or overrides the voltage regulator output to reduce field current to its rated value. Automatic voltage regulator control is restored automatically when the voltage regulator calls for field current below rated value (continuously acting).

The manual follow type of limiter works well if the operator is able to ‘follow’ field current from its pre-disturbance level up to its rating in the minute or two between the time a contingency occurs and field protection switches the exciter to the manual rheostat. Unfortunately, however, an operator is very unlikely to be able to confirm that a system problem has occurred and raise the manual setting in such a short time. In the worst-case scenario the generator is operating close to unity power factor prior to the contingency and the field current drops to this low level when the field current protection operates — today, shunt capacitors are often used in voltage limited systems to hold pre-disturbance generator reactive loading close to unity power factor in order to provide ‘spinning reactive reserve.’ The manual follow field current limiter is very likely to leave the system with much less reactive power than is assumed by engineers conducting planning or operating studies.

The automatic follower type of limiter will raise the manual rheostat setting within 5 to 10 seconds when a contingency causes field current to rise. With this type of control field current will be properly reduced to rated value when the field overcurrent protection operates. Only an equipment or maintenance problem will keep this system from operating. Though cases of slow following have been reported, this system is clearly superior to a manual follow type.

A significant problem with both the manual and automatic follower types is that they can cause severe and damaging overvoltages should the low voltage lead to system collapse. The loss of motor load and system transfers during a voltage collapse are likely to leave islands or radial lines with modest load and more line charging and shunt capacitor banks than are needed by losses and loads. One or more generators in such an island or area, on manual control and set for rated field current, can drive voltages to the point of insulation or arrester flashover. Transformer bushings, circuit breakers and cables are subject to insulation failure. Such failures will cause the island to fail completely, and each failed device is likely to interrupt or slow restoration.

Continuously acting field current limiters generally avoid both the problem of field current dropping below rated value as voltage decays and the problem of having generators on manual control during system break-up. With a properly designed continuously acting field current limiter, field current is gradually reduced following the maximum possible time above rated value and is returned to voltage regulator control quickly when the reactive demand subsides or break-up causes voltages to rise.

Continuously acting field current limiters are thus the only sensible choice in voltage-limited systems. Unfortunately, many generators today are equipped with one of the manual or automatic follower types. Planners of voltage-limited systems need to check every generator to ensure it will provide the reactive power that is assumed in power flow and voltage stability studies.

Field current limiting and its impacts can be explored through power flow analysis [1] though PTI clients are increasingly turning to ac contingency analysis [2] and extended-term dynamic simulations [3]. Contingency analysis shows the effects of unavailable generator reactive capability on system security, and extended-term dynamic simulations show the interaction of field current limiters, operators, undervoltage switched capacitor banks, load tap changers, automatic generation control systems, undervoltage load shedding, and other elements critical to voltage security.

Simulations can also reveal a problem with some continuously acting field current limiter designs: loss of stabilizer action during limiting. The effects of low voltage make voltage limited systems particularly susceptible to break-up from growing oscillations. Limiters that disable the voltage regulator while limiting field current also disable the stabilizer and thus increase the risk of growing oscillations. A limiter that reduces field current by biasing the output of the regulator or the comparator circuit at the regulator input will only limit average field current and thus does not pose this threat.

REFERENCES:


BENEFITS AND PITFALLS WHEN OPTIMIZING DISPATCH

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Further complicating dispatch is the fact that the optimum strategy changes with time. An optimum strategy under one set of conditions can be an inefficient strategy under another. The dotted line in Figure 1 represents an 8% increase in fuel input for Unit 2. The optimum dispatch strategy is now exactly the opposite of what it was. Such a reversal in optimum loading strategy can be short term (due to weather changes, for instance) or long term (due to equipment deterioration or maintenance changes). Therefore, a dispatch program must monitor and adapt to changes in the Input/Output curves.

Figure 2. The savings of an adaptive optimizer (solid lines) are a function of total plant power output and of the current Input/Output curves. (A 2% savings for a 500 MW plant is $2,000,000 a year.) However, an optimizer which does not adapt to changes in Input/Output curves (dotted lines) can cost money!

Figure 2 shows the savings an optimizer provides over the conventional loading strategy. The middle solid line represents the Figure 1 case, where the average difference in fuel input is 5% between Units 1 and 2. Note that the adaptive optimizer yields an increasingly larger percentage of savings at lower plant capacity factors. As expected, the savings is zero if both units are always dispatched at 100% load. The actual magnitude of fuel savings will depend on the relative performance characteristics of the unit mix, the fuel mix and the system operating profile.

Figure 2 also shows the effect of implementing an optimizer that does not adapt to changing Unit 2 performance. The losses result when the optimizer fails to recognize and adjust the algorithm when the Input/Output characteristics of Unit 2 change. The non-adaptive optimizer now operates on an incorrect strategy, resulting in the losses shown whenever this change occurs. The magnitude of the losses will also vary with the many unpredictable events that change the unit performance characteristics. The losses resulting from a non-adaptive optimizer can be larger than the expected gain. The non-adaptive optimizer will also incorrectly commit Unit 2 at loads below 50%, resulting in additional fuel penalties.

Figure 3 shows another example of Input/Output curves for two units operating at 80% total plant capacity. The optimum, equal incremental loading level is where Unit 1 runs at less than 80% of its capacity and Unit 2 at more than 80%. Figure 4 shows the benefits of this optimized strategy (A) vs. the alternatives of: (B) equal loading, (C) loading Unit 2 fully and letting Unit 1 operate at partial load, or (D) the least efficient case, to load Unit 1 fully and operate Unit 2 at partial load. The savings for the optimized strategy, in this example, can be as much as 3% greater than the alternatives. The adaptive monitor is one that continually updates the Input/Output curves, like those shown in Figure 3, in order to ascertain when the optimum loading strategy changes from alternative (A) to alternatives (C), (D) or something in between.

Figure 3. Input/Output Curves. In this example, optimum dispatch is neither equal loading, nor is it to load either unit fully.

Figure 4. The optimum dispatch strategy, A, is more efficient than conventional loading strategies B, C, or D. An adaptive optimizer advises when the optimum switches.

TO SUMMARIZE:
1. Dispatch optimization applies wherever there are multiple units that produce power, as in power plants, or that consume power, as in industrial plants. The power can be electrical (kW) or thermal (steam/hot water).
2. The optimum dispatch strategy is constantly changing with changes in unit performance. Unit performance varies with many factors, including ambient conditions, fuels, loads, cleaning, maintenance and unit deterioration.
3. Applying an adaptive dispatch optimization program, namely one that continuously updates the Input/Output curves, can result in significant savings.
4. Applying the wrong optimization program, namely one that does not adapt the Input/Output curves to the current conditions, can lead to significant losses.
A NEW APPROACH TO HVDC GROUNDING SYSTEM DESIGN

Over the course of a 20-year program, the staff of Osmos Technology has developed a unique analytical insight into electro-physical and electrochemical phenomena related to electrical grounding, corrosion, cathodic protection, and electroosmosis applications in civil, mechanical, and industrial engineering. PTI currently cooperates with Osmos Technology in commercial exploitation of these technologies.

Grounding system design has usually been referred to companies specializing in electrodes and electrode materials rather than being included as a part of the overall terminal design. This division discourages a common design philosophy for all station elements and sometimes leads to grounding systems which are very inefficient due to exaggerated surface area with non-uniform current distribution. The latter design weakness has caused extravagant use and highly non-uniform erosion of costly electrode materials, increased effective ground resistance and adverse ecological impacts on the ground or marine medium. This article outlines a new approach to grounding system design based upon specially developed optimization methods.

To evaluate efficiency of the operating surface of a grounding system, it is useful to define the coefficient of grounding usage as:

\[ k = \frac{i_{av}}{i_{max}} \]  

(1)

where \( i_{av} \) and \( i_{max} \) are the average and the maximum current density, respectively, at the grounding surface. Coefficient \( k \) will then vary over the range \( 0 < k \leq 1 \). In the limit where \( k = 1 \), current distribution is absolutely uniform over the grounding surface. In contrast, small values of \( k \) indicate poor grounding efficiency since the main current load is applied to only a small part of the operating surface while other parts may remain practically unloaded. The latter is most dramatically demonstrated in seabed anodes used in some dc links where \( k \) turned out to be less than 0.1.

A certain increase in usage coefficient can be achieved by careful design of the grid geometry. However, the most effective increase results from a recently developed method of section-by-section screening. This allows control of the current distribution irrespective of the grid configuration. The method makes it possible to develop a variety of standard grounding units for various conditions, using the most promising electrode materials for each condition or electrode configuration. Thus, the total process of grounding design can be standardized, narrowing the process to the determination of the number of elements or modules needed based on performance and terminal operating requirements.

Maximum current density at the ground electrode operating (continued on Pg. 5)
A NEW APPROACH TO HVDC GROUNDING SYSTEM DESIGN

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surface ($j_{\text{max}}$) and the maximum exposed current density at the surface of a ground electrode contact with the nearby environment ($j_{\text{an}}$) are considered the principal electric parameters in grounding module design. For underwater implementation $j_{\text{max}}$ should be measured at any surface that can be reached by fish and other sea organisms. The values $j_{\text{max}}$ and $j_{\text{an}}$ are interrelated and both determine the intensity of a number of deleterious physical-chemical processes both at the electrode surface and in the nearby environment. They are also determinants of grounding system reliability and service time requirements. Primary design focus should be on reducing these densities and defining limiting values of $j_{\text{an}}$ and $j_{\text{max}}$.

The most stringent restriction for in-ground electrodes is elimination of excess electroosmotic drying of soil near anode electrodes. Permissible limits of electroosmotic drying at the anode/soil interface depend on soil type and properties. To simulate these conditions, thereby defining permissible anodic surface current density, a series of long-term experiments were conducted using a specially designed test bed, 15' by 9' by 3'. The bed reproduced actual electroosmotic, thermal and hydrophysical processes in a variety of soils. Changes in temperature, electric resistivity and moisture content as a function of distance from the anode were measured for various current densities. A detailed analysis of study results for soils typical to different regions of the former Soviet Union established that, even in the most unfavorable case (clays), the danger of excessive electroosmotic drying can be eliminated completely for anode surface current density of less than 0.5 A/m². The same laboratory procedure can establish this design parameter for any soil type.

The corresponding current density limit for the sea electrodes is set by the safety of nearby fish and other marine organisms. Several biological studies established the limiting criterion:

$$j_{\text{max}} \leq \gamma E_0,$$

(2)

where $E_0 = 1$ V/m, the limiting permissible (“safe”) electric field strength in the marine medium and $\gamma$ is the sea water electric conductance. This criterion also limits the maximum permissible current density at the electrode surface, ($j_{\text{an}}$). Since $j_{\text{an}}$ and $j_{\text{max}}$ are interrelated, fulfillment of the criterion in (2) not only meets important ecological requirements, but also contributes to more effective use of grounding electrode material.

From an overall system standpoint, the most important parameter of a dc grounding installation is its resistance - a direct determinant of ground losses. Methods and supporting software have been developed to achieve a given resistance objective in a grounding system of any form.

These grounding calculation methods take into account such specific factors as the actual heterogeneity of the environment (a significant consideration for soil grounding), electrochemical polarization of the electrodes (particularly important for electrodes that can operate as cathodes) and changes of near-electrode zone parameters caused by electroosmotic processes. Optimization, considering both intermediate and final stages of a project, minimizes area requirements, material cost, losses, erosion, and ecological impact.

A special feature of the approach allows detailed consideration of the ground’s possible corrosive effect on underground or underwater metal structures. Here, the first challenge is to determine danger zones, i.e., zones where there is a potential for corrosion of long pipelines, cables or other structures. Up to now this exercise has often ignored local damage to protective coatings on the surface of the buried structures. However, damage to or irregularities in protective coatings concentrate corrosive effects. It is noteworthy that taking this and some other factors into consideration could completely change the attitude towards implementation of deep earth electrode systems.

The developed method takes into account the actual “as found” condition of surface coatings, including the detailed soil environment surrounding them. Obviously the more constructive application of this technology is in optimal initial location for grounding point and identification of structures or structure zones that need additional corrosion protection. This, in turn, makes use of recently developed methods for assessing the condition of existing coatings.

Prospective builders of new dc terminals should pay very careful attention to grounding systems and make certain that the most advanced methods have been used in optimizing these systems as a part of overall terminal design. Operators of existing dc terminals should review existing grounding systems in the light of new technology to offset more expensive means of retaining adequate system reliability. Such reviews can help when assessing the condition of grounding electrodes, evaluating damage exposure of buried structures and examining possible economic incentives for upgrading or replacing the existing system to reduce losses, and/or considering the feasibility of introducing monopolar operation for extended periods.

For both new and existing dc terminals, a common terminal design philosophy which incorporates these optimization methods offers an integrated approach to HVDC grounding system design.

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<td>Manchester, U.K.</td>
</tr>
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CANCELLATION POLICY
Occasionally, unforeseen events or insufficient enrollment may necessitate the cancellation of a course. If a course is canceled, PTI will attempt to notify each registrant no later than 14 days prior to the start of the course. PTI is not responsible for any cancellation charges imposed by airlines, hotels or travel agents. The tuition payment will be refunded in full or credited toward another course.

For further information on courses or registration in the United States contact:

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