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Reactive Power and the Blackout

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While the investigation into the August 14 blackout continues, problems with reactive power are being looked into and given lots of attention - apparently for good reason.

Voltage drops related to reactive power caused blackouts on the Pacific Coast in 1996 and in France in 1978. PJM itself came close to a blackout due to reactive power problems in 1999, avoided it, and took corrective steps. Yet, by having rigorous regional monitoring of reactive power and rules for its operation and compensation, PJM is unusual within the electric industry. Even though reactive power is essential to electricity reliability, many areas don't actively manage it - under-reacting to a long-known problem.

For example, no restructured transmission operator with real authority like PJM exists in the area where the blackout started, and no regional rules governing reactive power or its monitoring existed there on August 14 or today. If inadequate reactive power was a main element of the blackout, the balkanized agglomeration of individual utility control areas, the lack of any restructured regional coordination, and the absence of mandatory regional rules explain the existence of reactive power problems.

What is reactive power?

Generation and transmission cannot do anything without reactive power, a poorly understood but essential part of electricity. Often electricity is thought of simply as the electrons that flow through the wires. But there are a few component parts with familiar names - volts, amps and watts - that are not well understood.

Electric current, measured in amperes or amps, is the stream of electrons. The current can't go anywhere without voltage - the force that pushes the current through the wires. To make an analogy to water, the current would be the drops of water, and the voltage would be the water pressure that pushes it through the pipes.

Working together, amps and volts become the watts, or megawatts (MW) in larger volume, that define how much work the electricity can do. But both amps and volts travel in waves and only produce watts when the waves are in phase with each other.

Reactive power, measured in voltage ampere reactive (VAR), is when the amps and volts are not in phase and is, to some extent, an unavoidable by-product of producing megawatts. If these additional out-of-phase waves travel down the transmission line, they decrease the amount of megawatts (the in-phase waves) that can travel through the line.

The VARs wave can either be leading ahead of the in-phase wave or lagging behind it. If there is a VARs wave leading, then you want to produce some equivalent VARs waves that are lagging such that the leading and lagging VARs waves cancel each other out and leave only the in-phase wave. In this way the maximum amount of megawatts can travel through the line and voltage is maintained. If there's not enough voltage, the current cannot be pushed through the power lines, leading to a voltage collapse. Power plants and transmission lines are designed to shut down when there is inadequate voltage to prevent damage to the equipment.

How reactive power may have contributed to the blackout

Problems with reactive power did occur on August 14. The likely, though not conclusive, scenario is that several hours before the blackout, FirstEnergy noticed low voltage on its system, a sign of insufficient reactive power, and increased VAR production at nine of its plants. The Eastlake plant, northeast of Cleveland, experienced problems, and operators made several adjustments, but low voltage caused the plant to shut down, creating an even bigger deficit of reactive power.

About two hours before the blackout, a brush fire in southwest Ohio knocked out a power line, redirecting power onto the rest of the system, changing and/or increasing the need for reactive power on other lines. Then about one hour before the blackout, power lines between Cleveland and southern Ohio failed. And a few minutes before the blackout, all links between northern Ohio, known for some time as a weak spot for reactive power, and southern Ohio shut down.

How reactive power is managed

In the past, a single monopoly utility owned and controlled all of the generation and transmission lines in its own control area and had to provide reactive power just as it had to provide sufficient generation and voltage. Local monopoly control areas were part of a regional reliability council, but these councils were not responsible for dispatching generation or operating the grid.

In northern Ohio, in the East Central Area Reliability Council (ECAR), that's still the story. According to Tom Kraynak, Manager of Operations and Resources, ECAR has no guidelines on the provision of reactive power, leaving it up to the individual utilities.

However, the individual control areas east of the Rockies, north of Texas, and north into Canada, operate as part of an interconnected transmission grid. When electricity is transmitted between control areas, which happens all of the time, there has to be communication to properly operate the system, including adjustments to reactive power. The Midwest Independent System Operator (MISO) has not yet defined any system rules concerning reactive power, also leaving it up to the individual control areas.

To put it bluntly, many places do not really manage reactive power. This isn't news to the electric industry. Yet it's an abdication of responsibility that a system to provide reliable reactive power has not been implemented everywhere.

Reactive power in PJM

PJM, on the other hand, does actively manage reactive power, and not just within its own system.

Twice in July 1999, PJM experienced an extraordinary and unexpected peak load, reaching 51,600 MW, far above the forecasted peak load of 47,570 MW. On these two days, PJM saw voltages dip to dangerous levels, particularly in northern New Jersey.

PJM implemented emergency procedures to successfully avert major problems, but this severe stress on the PJM system revealed a number of unexpected vulnerabilities that PJM staff and stakeholders viewed as a wake-up call. PJM made some immediate procedural changes, but also undertook what Bob Hinkel, PJM General Manager of Strategic Integration, describes as a "painful root-cause analysis." PJM reviewed all operating procedures and produced a 61-page report identifying 25 primary root causes of the low voltage problem and 20 recommendations for improvement.

One of the key conclusions was that low voltage on these two days occurred because reactive demand exceeded reactive supply. PJM found that the actual capability of its generation units to produce reactive power was much less than their reported capability — 54 generation units in eastern PJM had actual maximum output of only 70 percent to 72 percent of what PJM thought they could produce. The unexpected shortfall in reactive power capability, along with some offline capacitor facilities, contributed to a near voltage collapse in eastern PJM.

PJM also concluded that it had good emergency plans and planning processes to deal with a shortage of megawatts, but inadequate plans for dealing with a shortage of reactive power. In many cases, generation owners within PJM had no contractual obligation to provide reactive power. Some generators also have to produce fewer megawatts in order to produce more reactive power. At the time, however, generation owners were paid for megawatts but not for reactive power, thus provided with no incentive to produce additional reactive power.

PJM adopted key changes to fix these and the other problems identified, and continues to assess and improve reactive power operating procedures and rules.

* PJM accelerated the implementation of a new Energy Management System that it had been testing, providing PJM with more accurate real-time information concerning voltage levels and the need for reactive power in different parts of the system.

* PJM adopted limits on the volume of megawatts it will allow to flow from one point to another in the system without local generation being present to produce VAR. Just like pumping to keep up the pressure in water pipes over a distance, the voltage that pushes current through the transmission wires and the reactive power that supports it must be produced and delivered at more points in the system than the current.

* Generators now receive “lost opportunity” payments to compensate for any lost energy revenue because they must provide additional reactive power.

* While the lost opportunity payments remove the financial disincentive to produce VAR, since November 2002, PJM also has been including specific VAR obligations and penalties for non-compliance in each new interconnection service agreement with a generator.

* On August 13, the day before the blackout, PJM announced plans to deploy an enhanced Voltage Stability Application, a software system designed to further increase PJM’s ability to monitor the need for reactive power.

Restructuring, reactive power, and the blackout

Reactive power problems alone can’t explain what caused the blackout. Whether managed solely by an individual utility control area or by a larger regional transmission organization, effective system management requires sufficient monitoring and adjustments to keep the power system stable. If intervention is too slow or not done properly, voltage on power lines can collapse suddenly, and the lights go out. The task is more difficult when there are multiple control areas that need to communicate and coordinate management. The task is simpler and more effective when a single RTO has all of the necessary information and rules, as well as the authority, to get the job done.

Reactive power and restructuring

Some have suggested that restructuring makes the problems of dealing with reactive power more difficult, highlighting two issues: merchant (non-utility) generation and related financial incentives; and transmitting power over longer distances with multiple transactions.

PJM has thousands of megawatts of merchant generation and the most sophisticated competitive restructured market in the country (perhaps the world), yet doesn't experience reactive power deficiencies. Reactive power must be produced and paid for, whether the generator is owned by the former monopolist or is a merchant generator. All it takes is a system of rules that provides incentives and/or requires sufficient reactive power.

It also makes no sense to suggest that a "sharp rise in long distance power transactions" is the problem. It is true that reactive power doesn't travel very far and that VAR must be produced locally to some extent, and at times more of it must be produced. Power can travel over dozens of paths at once, in complex, varying patterns. However, load is load, and the system must be managed to serve the load.

If a system isn't producing enough reactive power to maintain sufficient voltage to serve load, it's because the system doesn't have the information infrastructure or the necessary rules and communications to do so effectively. The remnants of balkanized, smaller control areas make it difficult - a fully restructured RTO is best able to effectively maintain sufficient reactive power.

The blackout proves the point. Reactive power problems in non-RTO control areas were the problem. On August 14, PJM experienced conditions worse than those experienced back in 1999, yet the PJM system held together well with minimal loss of load. The lesson to be learned is to focus on the need for MISO to get up and running, with rules that require sufficient reactive power, pay for it to be produced, and implement the sophisticated information and communication systems necessary to operate the system reliably.

Readers Comments (8 Comments)

Len Gould

11.5.03. Excellent discussion of the issues. Kudos.

Gerard Hughes

11.5.03 In 1994 CEI had an "almost" voltage collapse due to the unavailability of generation, specifically the Perry Unit, The Davis-Besse Unit and Avon-9. Eastlake 5 was limited to about 300MW for pollution abatement. I stood in for my supervisor when he went on vacation; the day he left we had a heat storm! I recall visiting the Eastlake control room for unit 5 that day and noted that the unit was being pushed hard for voltage support; the field temperature was running at the alarm point of about 110 C. We still had to do rolling blackouts. If the generator isn't paid for his lost opportunity costs because he has to support voltage, the pimping of the grid otherwise known as deregulation will never work.

Frederick (Fred) Plett

11.5.03. I worked for a utility in the days prior to deregulation and that utility based its rates to large industrial and wholesale customers on a kVA and kWh basis. This rate incented these large customers to correct power factor to 100%. This utility also actively installed fixed and switched capacitors as close to loads as possible on the distribution system to free up capacity from the point of the capacitors back through primary distribution, transmission and in the generators. This utility did so because it made economic sense to do so, resulting in lowest customer revenue requirements. I would like to contrast that behavior with that which may be more typical in today's world where utilities may have developed separate distribution and transmission businesses, and where generation may be in its own business or non-regulated. Rates to large entities are from generators are more likely kW based, not kVA, removing an incentive for power factor correction for the customers. transmission and distribution rates may be flat for small customers and on a kW basis for large customers. Again, no consumer incentive for power factor correction. The distribution entity may be on capped rates, and on its own. The distribution entity may not have significant incentive for installation of capacitors either, because of strict capital budget restrictions and the capped rates. The transmission entity may not be too sure who will own or operate the system next year, and as a result may not have incentive to spend money either, and may also be on capped rates. It may view poor power factor as a problem for the generators, not the transmission entity. And the generators have no significant incentive to produce reactive power because it eats into its profit making potential. In short, in a deregulated world, it's too easy for each entity to say "it's not my problem" and pass the buck. I think that there may have been a lot of this going on in the areas affected by the blackout.

Richard Gonzalez

11.5.03. The article makes many good points regarding the importance of adequate reactive power supply. Coming from a background which includes 20 years as a transmission planner, I'd like to emphasize that improving controls, communications, software, and authority available to the power system operators does not do any good unless they actually have reactive sources to work with. If it isn't planned, it doesn't get built.

Many transmission entities today don't have adequate technical staff to perform reactive power planning studies, and often don't have the capital budgets to implement any recommendations from such studies. Also, they typically don't make it a high priority to require that generators be required to provide reactive power.

In fact, my career experience includes an episode at one large multi-state midwestern utility whose power supply contract personnel have removed all reactive power requirements (which were placed there by the planning staff when we had vertically-integrated utilities that cared about reliability) from new Power Purchase Agreements. They did this because they claim/pretend that reactive power is an "ancillary service" (true) that will somehow be provided by "the market"...a market that does not exist, at least in this part of the world. This is of course lunacy, but unfortunately today most electric utilities are run by non-technical people who get rewarded for such inadvisable behavior.

It is frustrating to see predictable and avoidable power system disturbances occurring due to lack of attention to the fundamentals, such as proper planning, proper maintenance, and proper operating practices. There are many who are claiming that we need high-tech solutions (often at high cost) when what we actually need most of is attention to the basics. The power system must be planned, built, and operated by diligent, competent people, provided with adequate operating and capital budgets. Fancy, expensive high-speed solid-state switching devices or computerized control systems can't stop trees from growing into the lines, nor can they prevent voltage collapse due to inadequate reactive supply. To the extent that your article helps raise awareness of reactive power being part of the challenge, it is a commendable effort.

Sean Casten

11.11.03. Excellent article, to which I would add one point. Put the right price signals in place - especially with regard to distributed generation - and this problem will be substantially alleviated, if not eliminated entirely.

Under current regulation, utilities make no direct revenue off customers who install on-site generation behind the meter, even if that generation includes power factor correction to export VARS onto the grid. Thus, they are faced with a devil's bargain: they can either install capacitors around the grid to export VARs and get the capital cost put into the rate base or else ignore the problem. Depending on which way political winds are blowing with respect to grid reliability vs. rate increases, one or the other of these solutions is preferred. Meanwhile, the DG installation that would have the same impact on VARs AND create a new source of kWh (revenue) is at best ignored, and at worst actively discouraged through some combination of interconnection hassle or standby tariffs.

Our company, which has been installing DG since 1986 confronts this first barrier regularly. Every once in a while, we find a customer with a $/kVAR charge in their bill, and in these instances, it is in everyone's best interest to oversize the generator for VAR production and enhance local power quality. We size the system accordingly, and local power quality and reliability is enhanced as a result. In other words, the market responds to price signals. In most cases though, there is no financial encouragement for end-users to make these investments and they don't get done. (Indeed, even when these $/kVAR charges exist, they are usually at a customer with large inductive loads, so a generator designed to export VARs is really addressing a local rather than regional problem.)

In short - let's get the signals right. Given the importance of VARS, lets make sure that the market rewards people who produce them, even if they don't happen to be in the regulated utility.

Allen Cavedo

11.11.03. "To make an analogy to water, the current would be the drops of water, and the voltage would be the water pressure that pushes it through the pipes."

True, volts is the pressure of water in the pipe. Current would not be the water, electron charge would be the water. The current would be how fast the water flowed past any point in the pipe per unit time (like the current in a river). Watts would be how much water volume is flowing through the pipe. Watt hours would be the total amount of water having flowed through the pipe in an hour.

Tom Brumm

11.11.03. Excellent article and a great reply from Richard Gonzalez. AEP had a problems in the late 80's due to operator at plants refusing to raise VARS due to station bus voltage limits Voltage as low as 88%. I beleive this was elimated by training and setting of new limits for alarms. Many times rated reactive power from the plants is no where near what they can produce on a warm/hot/high load day. Too much emphasis is placed on megawatts and not on magavars. The majority of the large blckouts are due to reactive problems not megawatts

Douglas Preece

11.11.03. Billing on lagging kVA (or MVA) demand for ALL power delivery points, both retail and wholesale, could provide the economic incentives to make this issue "self managing".

http://www.energypulse.net/centers/article/article_print.cfm?a_id=529