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CIGRE US National Committee
2014 Grid of the Future Symposium

A Reactive Power Controller to Optimize Performance of Dynamic Reactive Power Compensation Devices

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SUMMARY

American Electric Power (AEP) engineers have developed a Reactive Power Controller (RPC) which attempts to optimize the performance of a nearby Dynamic Reactive power compensation Device (DRD), most typically some Flexible AC Transmission System (FACTS) device. The need to accomplish this task arises based upon the behavior of the DRD. Most of the AEP installed DRDs operate as voltage regulation devices, assuming the DRDs have the reserve capacity to perform the task. When holding system voltage constant, typical Static Shunt connected Devices (SSDs) are unable to perform their normal automatic switching based on their common voltage bandwidth control function. Additionally, only when the DRD exhausts all reserve capacity can the common voltage bandwidth control function operate to control SSDs. This is most often not sufficient to gain optimal performance from an asset designed to assist with dynamic system events, therefore, the RPC was conceived. The RPC coordinates SSDs by monitoring two system parameters, voltage and reactive power flow from the DRD, and taking action based upon their behavior. The device then chooses the most logical SSD to respond to the system problem with. Erroneous behavior, unique circumstances, and contingency scenarios are also considered. Having the RPC control SSDs allows the DRD to become offloaded from responding to normal system voltage deviations occurring from everyday loading variations. In offloading the DRD, the full range capacity of the DRD is available to respond to dynamic system events, like faults and swings. In this way, the performance of the DRD is optimized.

KEYWORDS

Reactive Power Controller, FACTS, Automation, Reactive Power Compensation

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INTRODUCTION

Over the past several decades, America Electric Power (AEP) has chosen to install nearly twenty Flexible AC Transmission System (FACTS) devices. These devices have included such technology as Static VAR Compensators (SVCs) and Static Synchronous Compensators (STATCOMs). This technology is generally used as voltage regulating devices, and is usually very good at achieving its desired goal. In fact, these devices are usually so good at achieving this goal that they will exhaust their resources trying to accomplish it. This means that if these devices are installed in locations where VAR support is weak, these devices will commonly utilize all of their available resources during periods of heavy load in an attempt at regulating voltage to their desired set point. If this occurs, than the device is not available to respond to dynamic system events, like power swings or faults. In an attempt at correcting this functional limitation, these devices are being installed alongside capacitor banks and reactor banks. This is being done so that when the Dynamic Reactive Resource (DRD) (the voltage regulating device) is about to run out of reserve capacity, a Static Shunt Device (a capacitor bank or a reactor bank) can act to replace the DRD resources. To illustrate this behavior, consider the system of Figure 1.

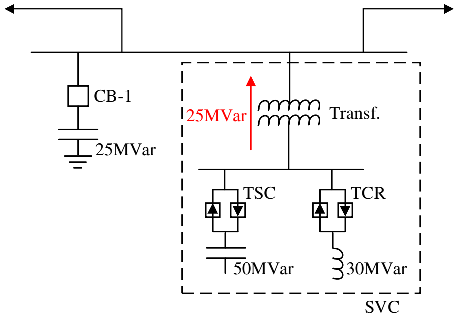


Figure 1 – Example System with DRD and Coordination of SSD

As shown in Figure 1, the SVC system is acting to supply the transmission system network with 25MVar worth of capacitive power in an attempt at holding transmission system bus voltage constant. Initially, the 25MVar capacitor bank is not connected to the system because CB-1 is open. If the capacitor bank circuit breaker (CB-1) then closes, the bus voltage will instantly raise. This rise in system voltage will reduce the delivered MVar from the SVC to a lower level. If set properly, it may even reduce the delivered MVar from the SVC to zero. If this is true, the capacitor bank has then replaced the delivered MVar from the SVC with the delivered MVar of the capacitor bank. In this way, the resources of the SVC are replaced with the resource of the SSD. If the SVC is able to achieve zero output, it is then able to reserve its maximum dynamic range; in this case, 50 MVar capacitive and 30 MVar inductive. If the capacitor bank of Figure 1 had been installed with traditional automatic bandwidth switching controls, the bank would only close when voltage was below some voltage threshold, and would only trip when above some voltage threshold. Assuming the set points of the capacitor bank controls were set so as not to interfere with the SVC control system, only when the DRD device ran out of resource range would voltage either drop or raise to a level which would allow the capacitor bank controls to act. This would mean that the DRD would first have to exhaust its entire resource range, in one direction, before any assistance comes from the SSD, based on the nature commonly inherent in DRD control systems. This is undesirable because if the DRD has exhausted all resources, there is no device which can act as fast as the DRD to respond to dynamic system events.

AEP has detailed some of the individual installations of reactive power controllers which help to coordinate SSDs against DRDs [1][2]. This document intends to present a general methodology that AEP has developed a standard approach towards in regards to achieving optimum performance from an installed DRD. Though there are others that have developed controllers which operate to perform similar tasks [3][4], AEP's approach takes a function which is common to the DRD controller and removes it from vendor specific equipment thereby allowing a consistent method across all installed DRDs. The approach is employed in a device that AEP is calling the Reactive Power Controller (RPC). There are two main goals that are achieved by employing this device. The first goal is to regulate voltage at a substation. The second goal is to minimize the reactive power output of a DRD so that it may reserve a maximum amount of capacity for system transient disturbances. A tertiary benefit to this controller lies in the fact that the device will automatically control static reactive devices, requiring less operator intervention than attempting to coordinate these devices manually. In addition to these benefits, when SSDs are being coordinated by the RPC, the commonly utilized bandwidth switching function voltage setpoints and delays within the control relays of the SSDs is not used. This means that a mis-coordination of these settings would not affect the system, reducing mis-operation risk. In previous installations of RPCs, the DRD control system has needed to provide information to the RPC, making each installation dependent on the DRD manufacturer's equipment. The development of a standard approach to RPC installations has allowed these installations to become vendor independent, which provides for quicker installation, commissioning, and unexpected problems associated with unique installations.

GENERAL DESCRIPTION

The RPC obtains two parameters from the system: voltage and reactive power flow thru an adjacent connected DRD. With these two parameters, the device determines whether there is a need to 'increment' (inject positive, capacitive Vars) or 'decrement' (inject negative, inductive Vars). As soon as the RPC determines whether there is a need to increment or decrement, it checks to see how it should perform this action. One way to increase positive capacitive Vars to the system is to close a capacitor bank. Another way is to trip a reactor bank. The opposite is true when attempting to decrement. Depending on which devices are opened or closed at the time the RPC makes this decision, it will call upon an SSD to trip or close. The RPC delays action on these decisions so that transient disturbances, like system faults, do not cause the RPC to take action. The fastest acting mode of the RPC, which will be covered in more depth in later sections, is the Voltage Control Mode, which has typical delay times of more than 30 seconds. Meaning, the fastest that the RPC will take action upon changes in system voltage would be at least 30 seconds after the system change occurs. After the RPC performs an action (tripping or closing a device), it will enter a mode which will simply force the RPC to wait before timing to take action again. If this mode is entered into after taking action to minimize the reactive power output of a DRD, and the DRD is forced to reverse reactive power flow, the RPC will enter an alarm mode and will be forced to wait a long time before being allowed to take another action.

OPERATING PARAMETERS

As mentioned earlier, the RPC obtains two important pieces of information about the system around which it is connected. System voltage and reactive power flow from a DRD. Because the RPC is not a relay, it has to obtain these parameters by use of some communications process. Because these parameters are obtained by a communications process, it is prudent for multiple devices to provide these two parameters. This is necessary for redundancy purposes and contingency scenarios. There are typically at least two microprocessor driven relays immediately adjacent to the zone covered by the SVC protection, and these are typically used to supply the redundant information about the system. In the instance where one of two sources of the system voltage parameter fails to communicate properly to the RPC, the RPC then switches to the source with successful communications. A scenario where system parameters may be telemetered to the RPC and indicate incorrect value is when the device sending the parameter is in a test mode or is out of service. The RPC takes this into account as well, and will switch to the back-up source of information in this scenario as well. The RPC accomplishes the task of switching from a primary source of information to the backup source by using the data source of greater analog quantity. It will also switch sources if the data validity flag associated with the communications process shows that the source of information is invalid. The figure below, Figure 2, is an example of the logic implemented to achieve this task.

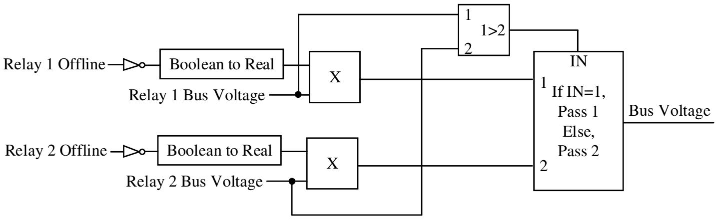


Figure 2 – RPC Analog Quantity Throwover Logic

CONTROL STRATEGIES

The RPC has two independent and simultaneous control strategies; the voltage control and the reactive power control strategies. While these two modes may act simultaneously, they do not have to. If the voltage control strategy is active, the reactive power mode may not be, and vise-versa. If the two strategies are active at the same time, the first one to reach the end of its delay time will cause either an increment or decrement. If one of the strategies is waiting to increment and the other strategy is waiting to decrement, the RPC will block the reactive power mode from allowing an action to be taken. This means that if the two strategies have conflicting goals, the voltage strategy will always override. This was done to accommodate the situation where some DRD has become functionally disruptive to the system and its behavior needs to be ignored and offset by the RPC.

VOLTAGE CONTROL STRATEGY

The voltage control strategy of the RPC uses only the voltage parameter that is obtained thru some communications process and handed to the function after the analog throwover logic. The voltage control code takes the voltage it was given from the outside device, divides by system nominal voltage and obtains a per-unit voltage from the calculation. It then checks to see if this value is between 1.08 and 0.78 PU. If it is not, the RPC will do nothing. If the voltage is within those parameters it checks to see if voltage is outside of the current deadband parameters. The dead band parameters are defined by a midpoint voltage, and a deadband range. In the following figure, Figure 3, the midpoint voltage setting is 1.00PU and the voltage deadband is 0.02PU. This means that for any system voltage ‘V’ where V<0.78, or V>1.08, or (1-0.02)=0.98<V<1.02=(1+0.02) the RPC will do nothing. Figure 3 shows these criteria as ‘Do Nothing’ zones.

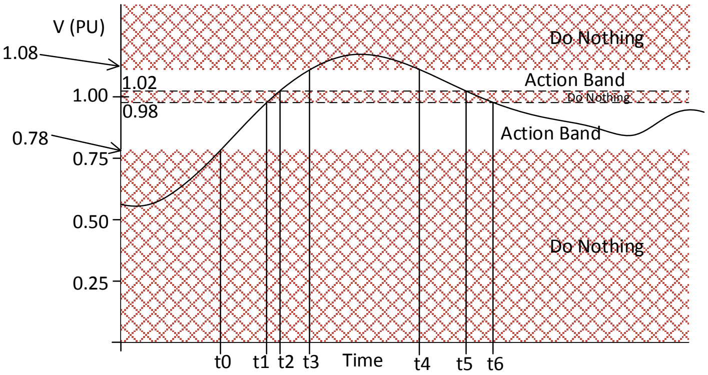


Figure 3 – Graphical Representation of RPC Voltage Control Strategy

Considering the preceding figure, Figure 3, when system voltage is operating between time t0 and time t1 the RPC will recognize that system voltage is too low and will start a timer at t0 the instant the system voltage is outside the ‘Do Nothing’ zones and within an action band below the deadband. If the timer that started reaches its terminal value (setpoint value) before t1, the next ‘Do Nothing’ band, the RPC will determine that an increment must occur, or capacitive Vars must be increased to the system. If the timer had not reached its terminal value before t1, the RPC will reset the timer it initially started and will do nothing, waiting until the next time system voltage is within an action band. Therefore, between t1 and t2 nothing will happen within the RPC from the Voltage Control Strategy. Consider the times when system voltage is between t2 and t3. Because system voltage is higher than the deadband window, within an action band, the RPC will start a timer at t2, and if the terminal value of the timer is reached before t3, than the RPC will determine that Vars need to be decreased to the system. If the timer does not reach its terminal value before reaching t3, than the timer that initially started will stop and reset. Nothing will happen within the RPC between times t3 and t4. Again, between t4 and t5, system voltage is outside the RPC deadband high. At t4 the voltage decrement timer will start and if the timer reaches its terminal value before t5, a 'decrement' (decrease in capacitive Vars) will be requested. If the timer does not reach its terminal value, the timer will stop and reset at t5. Nothing will happen in the RPC from the Voltage Control Strategy between t5 and t6. The voltage increment timer will start at time t6, because system voltage is again below the deadband window, and will continue to time until it reaches its terminal value or is reset by entering another 'Do Nothing' zone. If it reaches its terminal value, it will request an increment.

REACTIVE POWER CONTROL STRATEGY

The reactive power strategy within the RPC utilizes only the reactive power output of some DRD. However, as noted earlier, if the reactive power control strategy and the voltage control strategy have conflicting goals as any one point in time, the voltage control strategy will supersede the reactive power control, making the reactive power control strategy effectively disabled. This quantity is given to the reactive power control function after the analog throwover logic so that the RPC can be assured of the quality of the data. Similar to the voltage control strategy, the value is then checked to see whether or not it lies within a deadband window or is outside of the deadband window. The reactive power control deadband is defined by a midpoint and a deadband value. The following figure, Figure 4, illustrates this description graphically. In Figure 4, the midpoint value is zero, and the deadband value is 50.

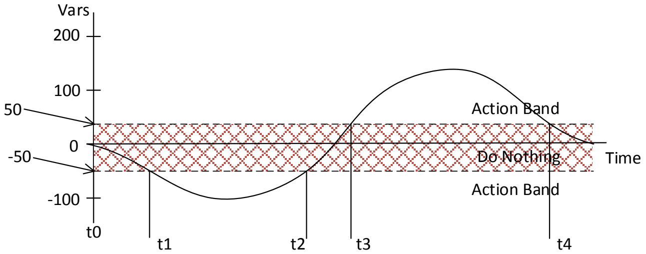


Figure 4 – Graphical Representation of RPC Reactive Power Control Strategy

To illustrate how the reactive power control strategy works consider Figure 4. Between time t0 and t1 the strategy will not act to take any action. This is because the output of the DRD lies within the deadband window. Between times t1 and t2, the RPC recognizes that the DRD is supporting the power system with inductive vars. The RPC will start a timer at t1, and if the timer (known as the reactive power decrement timer) reaches its terminal value before the Var output quantity reaches t2 the RPC will decrement, decrease vars to the system, in an attempt to allow the dynamic reactive resource to reduce its inductive power output. If the timer does not reach its terminal value before t2, the timer will reset and no decrement will occur. Between time t2 and t3 the RPC will take no action by the use of the reactive power control strategy. At time t3, the RPC will recognize that the output Vars of the dynamic reactive device have again reached outside the deadband window of the RPC and will start a timer (the reactive power increment timer). If the timer that started at t3 reaches its terminal value before t4 the RPC will attempt to increment, or increase capacitive Vars to the system. If the timer does not reach its terminal value, at t4 the timer will reset and no increment will occur.

SSD ORDER

SSD order number is important after an increment or decrement decision has been made. Typically, SSDs will be ordered to take action starting from the lowest order number being assigned to reactors and highest order numbers assigned to capacitor banks. This is so that when incrementing the first thing that occurs is that reactors are tripped, and when decrementing the first thing that occurs is that cap banks are tripped. This ensures that no cap banks and reactor banks are on at the same time, unless under an unusual circumstance, such as communications failure or tripping being blocked from an SSD. This is done so that a resonant condition can be avoided. If these unusual circumstances occur, the RPC will skip the SSD of interest and move on to the next SSD that meets the requirements of the increment / decrement logic.

SIMULATIONS

In the development of the RPC, the controller was tested against the system of Figure 5. The system houses two SVCs, each with a fully linear dynamic range of –62.5 MVar (inductive) to +150 MVar (capacitive), allowing for a total system delivered range of -125 MVar to 300 MVar. Also installed at the site are four reactor banks each with ratings of 345kV and 50MVar and two capacitor banks each with ratings of 345kV and 130MVar. These SSDs are labeled in Figure 5 as they were assigned per the SSD ordering philosophy noted earlier. A series of simulations were developed using a Real Time Digital Simulator (RTDS) so that RPC behavior could be validated. The SVC system was simulated and the response of the output of the SVC was measured.

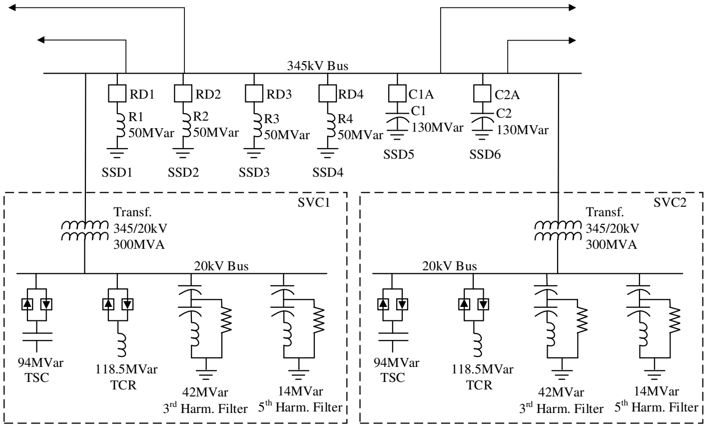
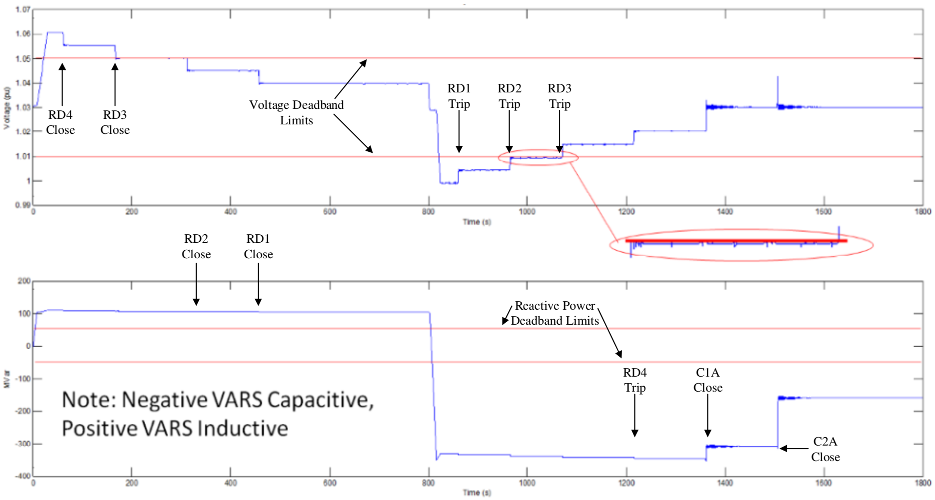


Figure 5 – Simulated System

In the case of this particular system, the reactive power output that the RPC acts upon is the sum of all reactive power output of both SVCs. A simulation of this system was performed and the results of the simulation are shown in Figure 6. The simulation initially has all SSDs offline or SSD circuit breakers open. System configurations change at first causing voltage and reactive power output of the SVCs to rise initially. This rise causes the system voltage and reactive power output to shift outside the tolerable range of the RPC operating parameters (shown in Figure 6 as the deadband limits). Because both strategies have now been engaged by having their operating deadband limits breached, the first strategy which reaches the end of its delay time will make the request to decrement. In the case of this simulation, the delay times associated with the voltage and reactive power strategy were 40 and 80 seconds, respectively. As can be seen from Figure 6, the first strategy to request a decrement is the voltage control strategy. The RPC commands circuit breaker RD4 (SSD4) to close. This is because the decrement strategy uses the first available device in descending SSD order to respond to a given request with. In this case, because both capacitor banks were initially open, SSD5 and SSD6 could not assist with a decrement order, forcing the use of SSD4. After SSD4 closes the first reactor bank, both RPC operating parameters are still outside the acceptable deadband range thereby requiring further action be taken to bring system conditions to an acceptable level. Therefore, after a short reset delay following action on SSD4, 65 seconds, both strategies, again, begin racing to the end of their delay times. Once again, voltage strategy reaches the end of its delay time and orders another decrement. Using the same reasoning as the decision to use SSD4, the first device available to respond to the new decrement request is RD3 (SSD3). After RD3 closes this time, system voltage settles to within acceptable deadband limits. However, reactive power output of the SVC is still operating outside the reactive power strategy deadband limits. Therefore, after waiting a short reset delay time (65 seconds), the RPC again begins timing until the end of the reactive power strategy timer (80 seconds). At nearly 330 seconds into the simulation, SSD2 is ordered to close upon the decrement request. Because this action still does not bring the reactive power output of the SVC to within the RPCs reactive power strategy deadband limits, the RPC waits for a short time to reset (65 seconds), and then again commands SSD1 to operate, at nearly 450 seconds based on another decrement order. This time, after the RPC resets, there are no more resources available to the RPC to assist with SVC regulation. This is why we see no activity occurring between 450 and 800 seconds in the simulation. At 800 seconds into the simulation, a system configuration change occurs and causes a reversal in reactive power output of the SVC. At this time, the operating parameters of the RPC shift outside their deadband range on the opposite side. Once this occurs, the goals of the RPC is to begin attempting to increment. The voltage and reactive power strategies, again, being timing. Once again the voltage strategy reaches the end of its delay time first (due to a shorter timer value) and orders an increment. Because the increment request uses the first SSD available, in ascending order of SSD number, to respond to a request with, SSD1 (RD1) is the first device to be commanded to operate. After SSD1 trips, system conditions are not alleviated so the RPC continues attempting to increment. RD2 opens at 960 seconds due to voltage strategy increment, RD3 opens at nearly 1065 seconds due to voltage strategy increment, RD4 opens at 1210 seconds due to reactive power strategy increment, C1A closes at nearly 1350 seconds due to reactive power strategy increment, and C2A closes at about 1510 seconds due to reactive power strategy increment. After C2A closes, there are no more assets available to the RPC with which to respond to the continued system parameter deviation. This is why after C2A closes, there is no further system activity.



Note: Negative VARS Capacitive,
Positive VARS Inductive

Figure 6 – Simulated System Response to RPC Control Actions

CONCLUSIONS

Illustration of AEP RPC usage has been justified and explained by illustrating the limitations of utilizing standalone traditional SSD control systems. These limitations include being forced to exhaust all DRD resources before assistance from SSDs. RPC behavior assists with DRD device operation by coordinating SSD operation with DRD and system operating parameters. Simulations have been illustrated showing actual RPC operation. The behavior and operation of AEPs RPC is as designed and illustrates the usefulness of the function. In particular, the RPC provides regulation and control to the surrounding system and DRD without the need to interface to the DRD control system In this way, the RPC optimizes DRD operation.

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