Advanced Volt/VAr Control Element of Southern California Edison's Irvine Smart Grid Demonstration

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***Abstract*—Southern California Edison is developing a Smart Grid Demonstration project in Irvine California under ARRA funding from the DOE. The project, named the Irvine Smart Grid Demonstration (ISGD) is an integrated deployment of smart grid elements from transmission to the home. Subprojects of the ISGD include 1) Zero Net Energy Homes (ZNE), 2) a Solar Shade EV charging station, 3) Distribution Circuit Constraint Management using Energy Storage, 4) Advanced Volt/VAr Control, 5) Self Healing Circuits, 6) Deep Grid Situational Awareness, 7) Secure Energy Networking, and 8) Workforce of the Future. The demonstration site substation will also host a High Temperature Superconducting Fault Current Limiting Transformer being separately developed by a team headed by Waukesha Electric Systems. This paper describes the Advanced Volt VAr Control (AVVC) element.**

***Index Terms*— Inverter, Meter, Power capacitors, Reactive power**

I. Introduction

THIS document describes the Advanced Volt/VAr Control (AVVC) element of SCE's ISGD. VAr flow and voltage control are by their nature linked. Existing control schemes maintain voltage in an acceptable range, but opportunity exists to use closed loop control schemes to improve voltage control to meet other objectives. Conservation Voltage Reduction (CVR) is one such objective. In many or most cases, providing voltage to the customer in the lower part of the ANSI C84.1 range results in energy savings without any loss of performance by end use appliances. Another objective is to be able to provide reactive power support to the transmission system during times of heavy loading

A. The AVVC Described

Past experiments with CVR have shown the value of improved Volt/VAr control. Several new developments are making it timely to revisit the issue.

- Deployment of Smart Meters in an Advanced Metering Infrastructure (AMI) can make customer voltage readings readily available.
- Increased deployment of inverters for photovoltaic systems (PV) and chargers for electric vehicles (EV), which may include communications features, creates an opportunity to use these devices as reactive power control elements for voltage control.
- Advances in computer systems are moving utilities to deploy centralized Distribution Management Systems (DMS) which will be based on robust and detailed models of the distribution system and its circuits for real time analysis.
- Increased emphasis on energy conservation and reduced Carbon emissions is creating an imperative for utilities to exploit CVR and other circuit optimizing technologies as an economic solution.

The AVVC system to be included in the ISGD will exercise control over the capacitors for one bus and its circuits. It will receive customer voltage information from selected AMI meters on those circuits using a still to be developed algorithm. The algorithm will reside in a substation based controller (SVVC). It is expected the algorithm will utilize a DMS quality model of the bus and its circuits. In addition, the AVVC will communicate with a set of smart inverters and chargers on the circuits to demonstrate their use in Volt/VAr control. The total kVA rating of these inverters and chargers will be small and are therefore expected to have negligible influence on system Voltage.

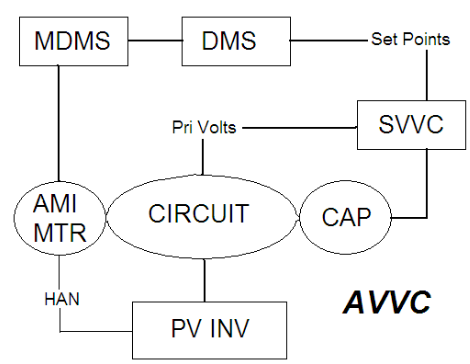


Fig 1. Overall schematic of the proposed AVVC

B. Control Methods

Two principle control methods are being compared. The first is a "fast" closed loop, in which voltage feedback from

AMI meters is used to directly control the capacitors. The second is a "slow" closed loop, in which voltage feedback from AMI meters over some time, perhaps a day or more, is used to compute new setpoints for the local capacitor controllers to achieve better voltage control. The new setpoints are then down loaded to the controllers.

The motivation for the slow closed loop scheme is to reduce the bandwidth requirement for communication systems and eliminate any need for a substation controller between the DMS and the capacitors. Both methods will be tested to determine whether the slow approach achieves performance comparable to the fast approach.

The algorithm for determining which capacitors to operate (in fast loop) or what setpoints to provide the capacitor controllers (in slow loop) would be based on a load flow performed on an accurate system model. Here "system" refers to the substation bus and its connected circuits. The load flow would be supervised by an optimizing algorithm which seeks to minimize the total energy losses from CVR and suboptimal VAr flow, subject to the previously noted constraints.

C. Technical Challenges

A number of technical challenges must be overcome to implement this AVVC.

First, the AMI communications and data management system is primarily designed to support billing. Moving voltage information through this system and over to an AVVC for processing puts a burden on a relatively low bandwidth system.

Second, AMI meters, field capacitors, and substation capacitors (and tap changers) communicate on different networks with different security trust levels. Building a system that crosses these boundaries without violating cyber-security principles will require care.

Third, how to involve potentially large numbers of inverters and chargers in this scheme is yet to be determined. A favorite idea is to use the slow closed loop approach and have these devices provide VAr support in accordance with an internal Volt/VAr schedule. The schedule parameters could be infrequently updated by the AVVC. The inverters and chargers could include more than one schedule, and a simple signal could have them switch between schedules or modes. This would be particularly useful for changing from a CVR to a higher voltage VAr support mode for transmission contingencies.

Fourth, the target customer voltage for optimal power and/or energy savings may be a moving target. Current theory that lower voltage results in energy savings is based on past studies. Moving forward, appliance designs are changing and their response to lower voltage may also change. For example, air conditioner compressors with variable frequency drives may respond very differently than simple across the line single phase induction motors which tend to stall at about 60% voltages depending on their ambient temperature. Moreover, the optimal voltage may change as weather or customer loads change. Reducing voltage tends to save energy on lightly loaded motors but cost energy on heavily loaded motors. Making a particular customer voltage the target of the AVVC also assumes that sub-optimal VAr flow on utility lines is negligible, which may not be true in all cases. An ideal AVVC may need to periodically determine and update the optimal voltage target automatically.

Fifth, any AVVC will be subject to certain constraints, including (1) power factor at the transmission interconnection, (2) limits on the number of daily operations for capacitor controllers, (3) high and low voltage limits for customers, (4) differences in phase voltages, (5) existing capabilities and limitations of the capacitor controllers and (6) conflicts between control elements, such as a small inverter trying to lower voltage when it is near a large capacitor trying to raise it.

D. Potential Solutions to these Challenges

The proposed slow closed loop control scheme is itself a potential solution to the inherent delays and bandwidth limitations associated with moving AMI meter voltage reads over to the AVVC for processing. In order to demonstrate the fast loop method in the near term(on the ISGD) it may be necessary to provide a number of redundant AMI meters at selected locations and have these send voltage data to the AVVC through a higher speed network.

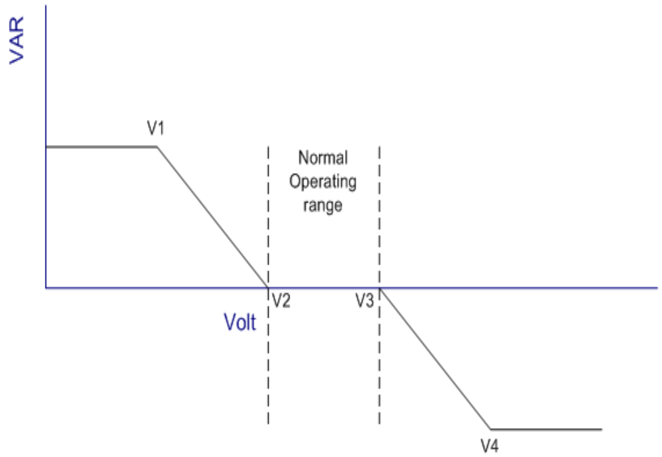
If a global solution to the problem of having the AVVC control substation elements normally controlled by systems in the higher security network, the capacitor(s) which must be controlled by the AVVC may be moved to a different controller for purposes of the demonstration. Operators would be provided a means to still directly operate these capacitors in a manner transparent to them.

Only a small number of inverters and chargers will be deployed as part of the ISGD. These can be custom designed to work with the AVVC for technology demonstration purposes.

Existing capacitor controllers can only contain one setpoint at a time. This is no problem for the slow loop control approach which works by updating this setpoint. For the fast loop, the local setpoint will have to be set in a wide band to allow the AVVC to control the capacitor in the narrower target range.

E. Inverters and Chargers

Inverters and chargers are to have an internal Volt/VAr schedule such as that shown below.



Typical Volt/VAr Schedule

In such a schedule, the maximum positive or negative VAr output shown would be a dynamic value based on the residual VAr capacity of the device after satisfying its Watt requirement. The inverter or charger could retain several such schedules and switch between them based on a simple mode request from the utility.

F. Next Steps

ARRA funds are expected to be released for the ISGD project in the third quarter of 2010. AVVC design will be finalized and deployed in 2011. Experiments and operational experience will occur during 2012 and 2013.

II. Acknowledgment

The author would like to acknowledge the contributions of fellow Southern California Edison engineers and IEEE members ……

III. References

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IV. Biographies

Russell Neal is a Strategic Program Manager for the Southern California Edison Company specializing in Smart Grid issues with an emphasis on distribution systems. He is a twenty year IEEE member and a graduate of the U. S. Naval Academy. He holds an MEEE from the University of Idaho and an MBA from Azusa Pacific University. He is a registered Professional Engineer in electrical and nuclear engineering.

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