Modeling of Local Controllers in Distribution Network Applications

I. Roytelman, Senior Member, V. Ganesan, Member
Siemens Power Systems Control
Brooklyn Park, MN 55428-1540

Abstract: Local automatic controllers are an integral part of a modern distribution system. They control transformer Load Tap Changer (LTC) positions and statuses of switched capacitors to ensure voltage and loading constraints are satisfied under changing operating conditions. Distribution Network Applications, which traditionally have been used for planning, account for the presence of local controllers in a simplified manner. Distribution Management Systems (DMS) bring Network Applications to the operational practice which requires much more detailed modeling of local controllers, both for the purpose of real-time power flow monitoring, and for centralized control. In the latter case, the local controllers create both opportunities and restrictions for DMS optimization functions such as Volt/VAr Control and Feeder Reconfiguration. This paper describes how the LTC and capacitor local controllers are modeled as a part of the Power Flow solution, and how they interact and affect DMS optimization functions. The impact of the local controller modeling on Power Flow, Volt/VAr Control and Feeder Reconfiguration is illustrated by numerical examples.

1. Introduction

Local automatic controllers are an inalienable part of modern distribution systems to ensure voltage quality and to prevent overload violations under changing power demand and network topology. They control tap positions of the transformers (autotransformer voltage regulators) with LTC capabilities, and statuses of the switched capacitors. The logic behind the majority of the local controllers is to keep a power system parameter, which is directly measured at the controllers' locations or calculated based on these measurements, to be equal to a desired value (setting). The settings are calculated in off-line studies for typical operating conditions. It is assumed that controllers' actions affect a monitored parameter directly (e.g. voltage for LTC) or indirectly but closely correlated (e.g. voltage for switched capacitor).

In addition to keeping the power system parameters within constraints, the local controllers can provide economic improvement in the operation of the system. For example, unity power factor setting for capacitor controllers provides reactive power flow compensation along the feeder and decreases power losses.

The most common and the simplest local controller is a voltage regulator, which keeps voltage at the transformer buses close to a desired value. This voltage regulator became a part of the LTC mechanism, in a substation transformer or a step-type line voltage regulator, at least fifty years ago. The assumption about constant voltage at the substation transformer low voltage buses, used in the distribution systems power flow calculations, serves as the first primitive model of the local controller. The desired voltage can be reached by any voltage regulator only within certain tolerance (bandwidth). A line drop compensator became a logical development of the constant voltage regulators. The requirement to simulate the voltage regulator with a line-drop compensator, and a bandwidth as part of the power flow solution, was formulated in [1]. The voltage regulator model presented in [2] satisfies some of the requirements specified in [1].

Modern microcontroller based devices, installed on the LTC and switched capacitors, represent a new generation of the local controllers. They are able to measure voltages, currents, phase angles and calculate any combinations of the above values (power factors, reactive powers, etc.) as needed parameters. These parameters are compared with the desired settings, which are constant values or functions of the above measured parameters.

Bandwidth, setting limitations, and time delay are the common properties of the local controllers. They determine the controllers' behavior in the real-time system operation. Controller's bandwidth, together with a step granularity of the controlled device, determines how close to the desired value the controller can reach. When controller settings are calculated based on measurements (as opposed to constant settings), there are limitations on the maximum and minimum values of the settings. Time delay determines how quick the controller's response is to a change in the measured parameter. It includes the controller's time delay setting and the executable mechanism's delay.

The presence of a variety of local controllers results not simply in a set of automatic devices, but in a locally distributed, non-centralized control system. The key feature of this control system is the coordination between different local controllers in the same distribution subsystem. The traditional objective of this coordination is to avoid oscillations. The need for the coordination becomes obvious from the observation that both tap changers and capacitor controllers respond to, and affect, the same power system parameters - voltages and currents [3]. Typically, this type of coordination is done through controllers' time settings.

0-7803-5478-8/99/$10.00 © 1999 IEEE.

Microcontroller based modern devices might have more sophisticated methods of coordination.

Distribution Management Systems (DMS) bring Network Applications to the operational practice. They require much more detailed modeling of the local controllers both for the purpose of real-time distribution system monitoring and for centralized control. Local controllers create opportunities and restrictions for the DMS optimal control functions such as Volt/VAr Control (VVC) and Optimal Feeder Reconfiguration (OFR). VVC, which affects the same LTC and capacitor switches as the local controllers, should also provide correct interaction.

In the following sections a general algorithm for local controller modeling is developed. A description of LTC and capacitor actions is presented. The local controllers interaction with DMS control functions is discussed as well. Numerical examples illustrate how the local controllers affect Power Flow, VVC and OFR solutions.

2. General Algorithm for Local Controllers Modeling

The goal of the local controller modeling in the power flow analysis is to determine LTC tap positions and the number of capacitor banks to be connected. A local controller changes tap positions or the number of capacitor banks in such a way that desired setting becomes equal to the corresponding parameter within the range of the bandwidth. The parameter value is measured directly or calculated based on the real-time measurements:

$$Setting\,(V_{meas}, I_{meas}, \varphi_{rmeas}) - Param(V_{meas}, I_{meas}, \varphi_{meas})| < \delta \qquad (1)$$

where voltage V_{meas}, current I_{meas} and phase angle φ_{meas} are measured values, δ is one half of a bandwidth.

Local controllers are simulated as an additional part of the power flow algorithm. After the initial power flow is solved under some assumptions about LTC positions and capacitor bank connections, *Setting* and *Param* terms in (1) are determined based on calculated values for voltages, currents and angles. The controller's actions are determined based on their internal logic, and in a case of discrepancy with initial LTC positions and banks connections, the procedure is repeated. For real-time power flow, which is calculated based on SCADA measurements, the power flow solution takes into consideration all available measurements. For a study case (off-line, non real-time) power flow, there are no real-time measurements and all values are calculated values.

There are two possible ways to simulate controllers actions in the power flow calculations. The obvious way is to set the tap positions and the number of capacitors directly, based on the controllers' logic. Another way is to move the taps and the banks only one step at the time in the desired direction. In both approaches, after the control actions are simulated and power flow is solved again, the controllers are checked against the new values of the power flow results. Few iterations are typically needed in order to set the tap positions and capacitor banks in both these approaches. If the first approach is used, the number of iterations may be smaller, but internal oscillations are possible (taps and banks are simulated to be moved in opposite directions in consecutive iterations). In the case when controllers' settings are not coordinated and their number is significant, this approach is not effective. The second approach prevents oscillations, but on an average requires more iterations.

There are two types of simple capacitor controllers which are widely used, whose actions are not based on the measurements of power system parameters, but depend on the time of the day and the temperature. These controllers are not simulated as a part of the power flow, but as part of the pre-processing before obtaining the power flow solutions.

As it was mentioned above, different local controllers within the same distribution subsystem are usually coordinated through time delays. Time delay coordination means that the response time of different types of controllers to changing power flow conditions is different. Typically, substation transformer controllers have the shortest time delay (quick response), feeder voltage regulators have a slightly longer delay, and capacitor controllers have the longest delays (slow response). After quick response controllers' actions are implemented, they change the power flow conditions in the subsystem. Therefore, when the slow response controllers start to act, they react to a different (not initial) voltages, currents and angles. In order to simulate such a sequence of events correctly, the impact of controllers with shorter time delays should be simulated before the controllers with longer time delays are considered.

Distribution system power flow does not consider the dynamics of the power system transition from one condition to another. That is why the absolute values of the time delays for different local controllers are not so important. The key to the correct simulation is to determine the correct sequence of controllers' actions based on the relative comparison of their time delays.

Time coordination between controllers assumes that a time delay of the quick response controllers (time setting plus time delay of the executable mechanism) should be less than time setting of the slow response controllers. If this condition is violated (e.g. delays of executable mechanism are too long), the slow response controllers will send signals to their executable mechanisms before the quick controllers complete implementation of their actions. This may result in oscillations or incorrect controller settings and actions.

In the algorithm described below, it is assumed that time coordination between different controllers is done correctly. Controller modeling should start with the controllers having the smallest time delays and then consider controllers with higher delays. In addition it is assumed that restrictions on the number of control operations (capacitors may not be switched on/off more than a certain number of times during certain periods) and restrictions on the time between two consecutive executions of the same device, are checked in advance and are included in the algorithm.

The general algorithm for the modeling of local controllers may be described as follows:

1. Solve the power flow with initial LTC tap positions and capacitor bank connections.

2. Among all available controllers, find the controllers with the smallest time delay and tag them for a simulation. If no controllers are tagged, EXIT.

3. For tagged controllers, calculate *Setting* $(V_{calc}, I_{calc}, \varphi_{calc})$

and *Param* $(V_{calc}, I_{calc}, \varphi_{calc})$terms of inequality (1) where subscript "calc" refers to values calculated in the power flow.

4. Check *Setting* $(V_{calc}, I_{calc}, \varphi_{calc})$ against maximum and minimum limits. If any of these limits is violated, set to be equal to the violated limit. For example, a voltage regulator with line drop compensation has the desired voltage V_{des} as setting:

$$V_{des} = |V_{set}+(R_{set}+jX_{set})(I_{act}+jI_{react})| \quad (2)$$

If $V_{des} < V_{min}$ the controller sets $V_{des} = V_{min}$

If $V_{des} > V_{max}$ the controller sets $V_{des} = V_{max}$

5. Check inequality (1) for each tagged controller. If the inequality is satisfied, the controller is not simulated.

6. Based on the values of *Setting* $(V_{calc}, I_{calc}, \varphi_{calc})$ and *Param* $(V_{calc}, I_{calc}, \varphi_{calc})$, bandwidth, and the device step granularity, determine the direction and number of additional steps (positions or banks) needed. For example, for LTC with voltage regulator, V_{Des} is the controller's setting and calculated voltage V_{calc} is the parameter. The number of additional LTC steps is calculated as follows:

If $V_{Des} > V_{calc}$ LTC is moved up to increase voltage. Number of steps is calculated as

$$N = (V_{Des} - V_{calc} - \delta)/(StepSize) \quad (3)$$

If $V_{Des} < V_{calc}$ LTC is moved down to decrease voltage. Number of steps is calculated as

$$N = (V_{calc} - V_{Des} + \delta)/(StepSize) \quad (4)$$

7. If any controller from the tagged group, has the additional number of steps not equal to zero, solve the power flow with control actions simulated, and return to step 3.

8. Put a tag "unavailable" on all controllers currently tagged for modeling. Return to step 2.

This algorithm covers local controllers such as LTC voltage regulators, which are a part of LTC mechanisms, or are microcontroller based devices installed within a LTC. It also covers capacitor banks controllers such as voltage regulators, reactive power flow or current flow based controllers, and their combinations.

3. Simulation of Control Actions in Power Flow Analysis

Multiple power flow solution is the most laborious part of the local controller modeling. One fact which helps in reducing the time for this procedure is that the power flow is solved for the network with unchanged topology. It means that a factorized matrix (nodal admittance matrix for bus voltage methods type [4] or loop impedance matrix for loop current methods type [2]) is factorized only once. All controlactions may be simulated in the power flow not as corrections of impedances and admittances, but as fictitious (compensation) injected currents.

In a case of switched capacitors, this current is calculated from the equation:

$$J_c = V(\Delta Y) \quad (5)$$

where ΔY is a negative (positive) admittance of the additional capacitor banks which were switched ON (OFF) by a local controller.

Let's consider how to simulate a change in the transformer tap position. The transformer, connected between buses K and M, has initial tap ratio t and physical admittance Y (Figure 1a). Admittances, which simulate no-load losses, are not shown, because they do not affect the solution. This transformer is described by the Π model with indirect representation of the transformer tap ratio (Figure 1b) by its series and shunt admittances.

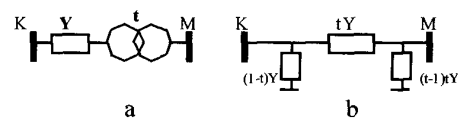

Figure 1.Transformer (a) and it's model with indirect representation of the tap ratio (b)

When the transformer tap ratio is changed from t to $T=t+\Delta t$ (local controller moved LTC to the new position) the transformer model should be changed as it is shown in Figure 2a. In this case correspondent matrix should be re-factorized. Another way to simulate the tap positions change is to modify model 1b by adding fictitious injection currents as it is shown in Figure 2b.

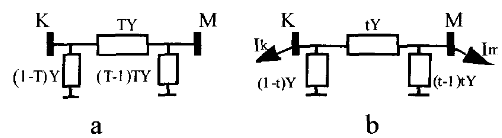

Figure 2. Transformer model with a new ratio (a) and an equivalent with fictitious current injections (b)

In order to make voltages and currents in the systems 2a and 2b to be the same, fictitious injection currents are calculated as follows:

$$I_k = -V_M \Delta tY \qquad I_m = ((2t + \Delta t)V_M - V_K)\, \Delta tY \quad (6)$$

4. Interaction of Local Controllers with VVC and OFR

Local controllers have a direct interaction with centralized VVC because they affect the same transformer LTCs and capacitor switches. Typically, all LTC and capacitor switches have local controllers, but only some of them may be remotely controlled and used by VVC. Coordination between the local controllers and VVC for remotely controlled devices is done on the hardware level. LTC and switched capacitors which are not remotely controlled affect VVC solution indirectly through power flow parameters. The same type of indirect interaction exists between the local controllers and OFR. The local controllers respond to any change in the topology through associated changes in voltages and currents, and, therefore, affect OFR solution.

The local controllers installed on the LTC and switched capacitors with remote control capabilities, may interact with centralized VVC in one of the following two ways.

1. *VVC substitutes local controllers*: VVC directly operates LTC tap positions and capacitors switch statuses. Local controllers are used as a backup. Additionally, they might have overriding capability and serve as protection against wrong actions. For example, capacitor voltage regulator can always switch OFF if voltage is higher than predefined maximum, even if VVC action is trying to set this capacitor ON.

2. *Local controllers are used as an intelligent interface between VVC and power system objects (LTC taps and capacitor switches)*: This means that centralized VVC changes settings for local controllers which in turn cause the local controllers to react. For example, when VVC determines a new LTC tap position, this position is not set on the tap changer through SCADA functionality. The new tap position is translated to voltage regulator settings, the settings are then changed through SCADA, and the regulator with new settings will move the tap changer to the desired position.

The second approach has an obvious advantage over the first one: local controllers can adjust the optimal solution which they receive from the centralized functions to current power system conditions. This fact is significant for distribution systems. VVC solution is typically based on one snapshot of real-time measurements. During the time between this set is taken and optimal solution control actions are decided upon and implemented, continuously changing power system conditions may result in this solution not being optimal.

It is clear that if VVC solution actions are implemented through local controllers, desired LTC positions and number of capacitor banks may not be reached. For example, because of a voltage regulator bandwidth, a tap changer position increase stops few steps before the optimal position. In this case, VVC algorithm should be executed again with settled state of the devices which can not reach desired points. It is possible that additional control actions are needed.

Therefore, if VVC interacts with a tap changer or capacitor switches through local controllers, optimal solution should be recalculated for the new local controllers settings. Then local controllers are simulated in order to determine LTC positions and number of capacitor banks which may be reached. If these positions and numbers are different from optimal, VVC algorithm should be applied again.

It is obvious, that local controllers, which are not under centralized control, will respond to different power flow conditions after VVC control actions are implemented. The same is true for OFR determined topology. These new power flow conditions may trigger LTC or capacitor switches to change initial state of the devices and, as a result, to change power flow conditions. If VVC or OFR optimal solutions have more than one control actions, local controllers may be triggered during the intermediate time between the implementation of any two consecutive actions.

Therefore, the local controllers that are not under centralized control should be simulated based on final VVC or OFR power flow solution. If any local controller operates, the corresponding function (VVC or OFR) should be executed again by starting under this condition. In addition, local controllers should be checked in each intermediate step if VVC/OFR solution has more than one action. Controllers acting in the intermediate step may operate only if these temporary conditions are expected to stay longer than controllers' time setting. If any local controller is acting during the intermediate step, it should be taken into account.

5. Numerical examples

The following examples illustrate how local controller modeling affects distribution system network applications. The goal of these examples is to show dependence of the final results of Power Flow, VVC and OFR on the accurate modeling of local controllers. A production grade software which includes Power Flow, VVC and OFR, operated as a part of the DMS network application subsystem, is used in this study. Local controller modeling is done as an additional part of the Power Flow calculation as described in Sections 2 and 3. This Power Flow is used as an internal tool for VVC and OFR algorithms as described in [5] and [6] respectively.

The first three examples show how the Power Flow results are affected by different features of local controller modeling. A detailed study of the impact of local controllers on power flow is required because of the importance of power flow for both planning and real-time studies. In addition, power flow serves as an internal tool in optimization functions such as VVC and OFR. The first example illustrates a fact that a response of the automatic controller with a bandwidth depends on the initial relation between the regulating parameter and the setting (regulating process pre-history). The second example shows how time delay simulation affects the power flow final solution. The third example illustrates the impact of the local controllers' limits. The last two examples illustrate how the local controllers' simulation may change VVC solution and affect OFR.

A simplified diagram of the system, used in the power flow studies, is shown in Figure 3.

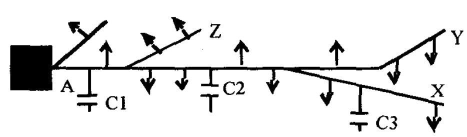

Figure 3. Simplified Diagram of the Test System

The system has 20 loads and 25 lines. The substation transformer is equipped with a low side tap changer with a step size 0.625% per step and 16 raise and lower positions from a neutral. The local controllers are installed on the substation transformer LTC and on all switched capacitors. The substation transformer controller (voltage regulator) targets transformer low side voltage and has voltage setting 122 volts and bandwidth 2 volts. It has a line drop compensator. Capacitors have time-of-day based controllers combined with voltage regulators, which have overriding capabilities. The voltage settings for the capacitor voltage regulators are 123 volts for maximum and 118 volts for minimum voltage. LTC controller has quick response, and capacitor controllers have slow response.

The first results, presented in Table 1, show three different ways how the LTC voltage regulator model, with the same target voltage, may affect the power flow results. In the first case the LTC voltage regulator was simulated without a bandwidth (ideal regulator). The substation transformer low side voltage is practically equal to the desired voltage - 122 volts. LTC position, switched capacitor statuses, total power losses (100% corresponds to base case value), and minimum voltage values with corresponding areas where the minimum voltage occurs are shown in row 1.

In the second case, the bandwidth was simulated and initial tap position provided lower voltage than desired. The voltage regulator moved the LTC up to position 5, not 6. Because of this, the voltage at the bus C3 was less than the minimum setting for the capacitor voltage regulator, the capacitor C3 was switched ON. The power flow solution is given in the row 2. In the third case an initial tap position provided higher voltage and LTC was moved down to position 8. Because of this, the voltage at the bus C1 was higher than the maximum setting, and C1 was switched OFF. As it is seen from the results in row 3, this power flow is different from both previous cases.

Table 1: Effect of bandwidth and initial conditions on the Power Flow solution

N	Case	Sub. V [Volts]	LTC	C1	C2	C3	P loss [%]	Min V [Volts]	Min V area
1	No bandwidth	122.03	6	on	on	off	100.00	117.1	X
2	Band, move up	121.31	5	on	on	on	96.64	116.7	Y
3	Band, move down	122.68	8	off	on	on	101.75	117.8	Z

The second example (Table 2) illustrates how the time delay simulation may affect the Power Flow results. The first row in Table 2 corresponds to the initial power flow when the local controllers are not simulated. The second row shows power flow results when LTC and capacitor local controllers are simulated simultaneously. The third row corresponds to the case when the local LTC voltage regulator (quick response) is simulated to operate before the capacitor voltage regulators (slow response), and C2 controller has smaller time delay than C1 and C3.

Table 2: Effect of controllers' time delay simulation on the Power Flow solution

	Case	Sub. V [Volts]	LTC	C1	C2	C3	P loss [%]	Min V [Volts]	Min V area
1	No contr.	118.24	0	off	off	off	100.0	115.2	X
2	No delay	120.59	3	on	off	on	93.39	116.3	Y
3	With delay	121.23	5	off	on	off	94.65	117.5	X

The third example considered simulation of the line drop compensator (R=4 volts and X=6 volts). Calculated value for the LTC desired voltage may be less or higher than the limit (124 volts), which produces different power flow results.

The first row in the Table 3 corresponds to the case when maximum limit is not being taken into account. The second row shows that when controller's setting is higher than the limit, the limit serves as setting and the power flow results are different.

Table 3: Effect of line drop compensator limits on the Power Flow solution

	Case	Sub. V [Volts]	LTC	C1	C2	C3	P loss [%]	Min V Volt	Min V area
1	No limits	124.42	9	off	on	on	100.00	118.71	Z
2	With limits	123.49	7	on	on	on	95.82	117.93	Y

As it can be seen from the above examples, the impact of local controller modeling on the power flow results is produced not only by different substation low side voltages because of different LTC positions, but also by capacitor switchings triggered by the response of their voltage regulators.

Volt/VAr Control and local controllers interaction is also illustrated in the test system Figure 1. Both LTC and all switched capacitors are assumed to be under centralized control. VVC interacts with LTC through voltage regulator and with capacitors directly (their voltage regulators have overriding capabilities and serve as protection). The initial status of LTC, capacitors and some power flow results are shown in row 1, Table 4. Optimal solution with an objective of power loss minimization, requires moving the LTC up by one step, switching capacitor C2 ON, and C3 OFF (row 2). Due to the regulator bandwidth, the LTC desired position cannot be reached. Therefore, LTC is set at the current position and the VVC solution is different (row 3), which is only slightly worse than the initial value.

Table 4: VVC interaction with local controllers

	Case	LTC	C1	C2	C3	P loss [%]	Min V [Volt]	Min V area	Max V [Volt]	Max V area
1	Initial	5	off	off	on	100.00	115.21	X	120.9	A
2	Optimal	6	off	on	off	89.15	118.82	Y	123.1	A
3	Sub-optim	5	on	off	on	90.78	117.90	Z	122.8	A

Indirect interaction between local controllers and feeder reconfiguration is illustrated by the last example which is performed on the test system with simplified one-line diagram shown in Figure 4.

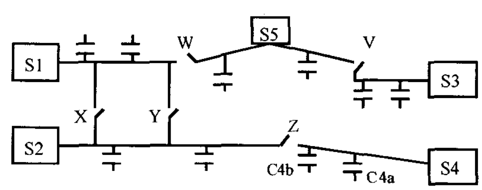

Figure 4. Simplified Diagram of the OFR Test System

The system has 80 loads, 95 feeder sections. There are five subsystems connected through the tie switches. All five substation transformers have LTCs with voltage regulators. There are two single bank switched capacitors with voltage regulators installed along each feeder.

Initially open switches V, W, X, Y, Z provide topology shown on Figure 4 with corresponding power flow results shown in row 1, Table 5. In this case the most loaded subsystem is S2, which has highest power losses (31.95% of total) and the lowest voltage (114.2 Volts).

Optimal topology for objective power loss minimization is reached by closing normally open switches X and Z and opening normally closed switches X1 and Z1 (switches X1 and Z1 are not shown on Figure 4). As it is seen from power flow results, shown in row 2, subsystem S4 became critical in this case. Because of voltage constraints violations (113.8 Volts is less than -5%) OFR calculation procedure continues optimization and comes to a sub-optimal solution by closing switches V, W, Y, Z and opening switches V2, W2, Y2, Z2 (switches V2, W2, Y2, Z2 are not shown on Figure 4).

As seen from a comparison of the sub-optimal (row 3) and optimal solutions (row 2), power losses are close, and the sub-optimal solution does not have voltage constraints violations. But the optimal solution still looks more attractive, because it requires only two pairs of switches to change status compare to four pairs of switches in sub-optimal solution.

As it was mentioned in the system description, LTC and switched capacitors with local controllers are available. If these controllers are simulated as part of the internal power flow solution, tap changers S4 and S2 together with switched capacitors C4a and C4b will automatically remove voltage violations and even slightly improve the optimal solution. Optimal solution with local controllers simulation is shown in row 4. This solution require only two pairs of switches to change status, the similar to the solution shown in row 2.

Table 5: Local controllers impact on the OFR solution

	Case	P Loss [%]	Max Loss Subsyst.	Max Subs. Loss [%]	Min V at Subsyst.	Min V [Volts]	Switches closed
1	Initial	100.00	S2	31.95	S2	114.2	
2	Optimal	91.45	S4	25.31	S4	113.8	X, Z
3	Sub-optimal	92.78	S1	26.90	S1	115.3	Z, Y, W, V
4	Opt. & loc. cntr.	91.08	S1	24.87	S4	114.3	X, Z

Conclusion

The modeling of local automatic controllers as part of distribution systems network applications was discussed, and the need for accurate models was shown. A general algorithm for local controller modeling as an additional part of the Power Flow was developed. The algorithm takes into account bandwidth and step granularity, setting limitations, and relative time delay of different controllers in the same sub-system. The algorithm is illustrated by equations which describe the LTC voltage regulator. An approach to simulate LTC and capacitors control actions as fictitious injected currents inside the Power Flow algorithm is presented. Local controllers' interaction with DMS optimization functions (Volt/VAr Control and Optimal Feeder Reconfiguration) is discussed, and some algorithmic solutions are proposed.

Numerical examples illustrate how the accurate simulation of local controllers' bandwidth, time delays and limits affects the Power Flow solution. Interaction between Volt/VAr Control and local controllers shows how the accurate modeling of controllers can affect LTC tap position, statuses of switched capacitors and final power flow results. A relation between Optimal Feeder Reconfiguration solution and the effects of local controllers is illustrated.

References

1. W.H. Kersting "Radial Distribution Test Feeders", IEEE Distribution Planning Working Group Report, IEEE Trans. on Power Systems, Vol. 6, No. 3, 1991, pp. 975-985

2. C. S.Cheng, D.Shirmohammadi "A Three-Phase Power Flow Method for Real-Time Distribution System Analysis", IEEE Trans. on Power Systems, Vol.10, No. 2, May 1995, pp. 671-679.

3. N.S. Markushevich, "Voltage and Var Control in Automated Distribution Systems", Third International Symposium of Distribution Automation and Demand Side Management", USA, Florida, 1993, pp. 478-485.

4. T. H. Chen, M.S. Chen, K.J. Hwang, P. Kotas, E. A. Chebli "Distribution System Power Flow Analysis - A Rigid Approach", IEEE Trans. on Power Delivery, Vol.6, No. 3, 1998, pp. 1146-1152.

5. I. Roytelman, B.K. Wee, R.L. Lugtu, "Volt/Var Control Algorithm for Modern Distribution Management System", IEEE Trans. on Power Systems, Vol.10, No. 3, 1995, pp. 1454-1460.

6. I. Roytelman, V. Melnik, S.S.H. Lee, R.L. Lugtu "Multi-Objective Feeder Reconfiguration by Distribution Management System", IEEE Trans. on Power Systems, Vol. 11, No. 2, 1996,pp. 661 - 666.

Ilya Roytelman (SM' 93) received his Electrical Engineering Diploma with honors from the Kiev Polytechnical Institute (Kiev, Ukraine) in 1976 and Ph.D from the Siberian Power Industry Research Institute (Novosibirsk, Russia) in 1983 (both in power systems). He received the academic rank of Senior Scientist in 1989. From 1976 till 1991 Dr. I. Roytelman worked at Kiev Division of Electric Power System Design and Research Institute (Energosetproekt) mainly in the development of network applications for distribution systems operational planning. In 1992, after seven months at the Illinois Institute of Technology, he joined Siemens Power Systems Control, Distribution Management Systems Department. His research interests include distribution power systems analysis, optimization and control.

Vijay Ganesan (M'89) received his Bachelor of Technology degree in Electrical Engineering from the Indian Institute of Technology, Madras, India in 1989, and Master of Science degrees in Electrical Engineering and Operational Research in 1991 and 1993 respectively, from North Carolina State University. From 1993 to 1994 Mr. Ganesan worked as an engineer at Distributed Energy Systems Group Inc. in California. In 1994, Mr. Ganesan joined Siemens Power Systems Control in Minneapolis where he works in the Distribution Management System Department. His interests include network applications for power distribution networks and object oriented software design.