Coordination of Distributed Energy Resources to Solve Voltage Problems in Distribution Networks

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***Abstract*—In this paper, a method to control distributed generation resources based on sensitivities matrices is presented, which allows to determine the necessary control action to correct voltage problems in the distribution networks.**

The proposed method begins by identifying the problem to be corrected first, based on its severity. Next, the sensitivity matrices that determine the relationship between the control variables and the magnitudes subject to operating limits are calculated, and the maximum control margins are computed based on the corresponding sensitivities, Finally, after selecting the most 'efficient' control action to correct the most urgent problem, the necessary control action is calculated.

The proposed technique has been tested in distribution networks in order to demonstrate the adequacy of the proposed method for the efficient selection and computation of corrective control actions.

I. Introduction

The increasing introduction of distributed generation, mainly of renewable origin, in the distribution networks, is increasingly complicating the operation of these networks, bringing them to a level of complexity similar to that which has always existed in transmission networks [1]. In this sense, there are several initiatives aimed at promoting a control scheme of the generation and storage resources in the distribution networks, in order to make them more controllable and allow a greater penetration of renewable energies. It is worth noting projects such as SmartNet [2], [3], aimed at exploring ways of coordinating both distributed generation and the demand to provide operating resources to the distribution network (DSO) managers, and, in some cases, to the transmission operator (TSO).

This article proposes a technique for selecting control actions in the distribution networks that allows, on the one hand, to select the most efficient controls in order to correct voltage problems, trying in all cases to respect the operation limits, and, on the other hand, to take into account the possible costs associated with these actions. These costs may arise from long-term contracts between the DSO and the suppliers of ancillary services, or from a short-term competitive market for the provision of ancillary services in the transmission and distribution networks.

The proposed technique is based on previous applications to transmission networks [4]–[6], adapting these proposals to the distribution networks and to the constraints inherent to the resources provided by the distributed generation.

The paper is organized as follows. Section II presents the proposed technique to select control actions in case of voltage problems in electrical networks. Then, in Section III, several examples of voltage correction in a common distribution network are presented, combining different actions in view of the resources provided by the distributed generation. Finally, Section IV presents the conclusions of this study.

II. Correcting Voltage Problems

In order to correct voltages in the transmission network, a sensitivity-based technique was proposed in [4] and extended in [5], [6]. This method uses the relationship between voltage in demand nodes and the available control variables, by means of a linear approximation of the load flow equations. This technique allows to use all types of control elements related with reactive power & voltage control in transmission networks, which can be extended to distribution networks with a strong presence of distributed generation. Furthermore, it is possible to take combined actions, which allows to minimize the cost of the required corrective control action and avoids exhausting the most sensitive, and probably the cheaper, control. Control actions are determined in a sequential process, in order to avoid new voltage problems and to minimize the cost of the required control actions by selecting the most efficient controls, and, between them, those that result in a lower cost.

To select the appropriate control actions, not only the sensitivity between control variables and the out-of-limit voltage is considered. The proposed method also allows to consider all the operational constraints, such as voltages in near nodes, the limits of the control variables (eg, reactive power of generation devices), and even the cost of the control action.

A. Overview of the Proposed Technique

The proposed method runs during the normal operation of the system, ie, periodically, the network state is obtained through the SCADA system, properly filtered by the State Estimator [7]. If a voltage is out of bounds, the corrective rescheduling module will be executed, as described below. If there is no voltage violation, the system could be optimized by reducing losses.

The method is based on [4] and consists of several sequential steps. Whereas some rules can be used with any network, others should be modified according to the network exploitation. When a voltage violation is detected, these steps are as follows:

1) Determine the node with the most urgent voltage problem.

2) Compute sensitivities matrices which relate voltages and operating limits to control variables.
3) Variables of higher sensitivities could be optionally selected, for each type of control. "A priori", these will correct the violation more efficiently.
4) Calculate the largest control action for each variable, checking the own limits of the control variables and the operating limits, so as not to create new contingencies.
5) Based on the so-called Efficiency Coefficient and its cost, choose the most efficient control variables.
6) Calculate the necessary control action.
7) Update the network state, by means of a power flow, and go back to step 1 until no voltage violations remain. Alternatively, the power flow could be run only once, when all voltage violations have been supposedly corrected. In this case, voltages must be linearly updated before returning to step 1, yielding a larger accumulated error.

In every iteration, the aim is to correct the most urgent problem. If the chosen control variable has enough capacity and no operating limit is reached, the voltage violation will be corrected. Should the selected control variable be limited by its own limits or by an operational limit, an insufficient action will be taken, and this problem will remain until another control variable is able to solve it. When control actions are taken, normally minor voltage violations are also corrected.

In the following sections, the above-mentioned steps will be discussed.

1) Determine the most urgent voltage problem (step 1 of the process): Depending on the operational procedures, the rule to determine the node with the most urgent voltage problem to be corrected may vary. In general, the node with the largest voltage violation will be selected,

$$\Delta V_k = \max_i \left\{ V_i - V_i^{max}, V_i^{min} - V_i \right\} \tag{1}$$

where

- ΔV_k Voltage deviation in the node k with the largest voltage violation.
- V_i Voltage in node i.
- V_i^{max} Upper voltage limit in node i.
- V_i^{min} Lower voltage limit in node i.

2) Compute sensitivities matrices and determine the potentially more efficient control variable (steps 2 and 3 of the process): Sensitivities matrices are required in order to compute *Efficiency Coefficients (EC)* for each control variable, and to check that no new violations are created. These matrices are obtained from the Jacobian of the AC power flow equations, evaluated at the current operating state. When one control variable, or two in the combined control action, is modified, the rest of the control variables will be considered as constants.

The required sensitivity matrices are $S_{V_c,u}$ and $S_{Q_g,u}$, providing the linear relationships between control variables, u, and voltages in demand nodes, V_c, and reactive power of generators, Q_g. Mathematically:

$$\Delta V_c = S_{V_c,u} \cdot \Delta u \tag{2}$$

$$\Delta V_g = S_{Q_g,u} \cdot \Delta u \tag{3}$$

An example of the calculation of sensitivity matrices is given in Section II-C.

Then, if there were a considerable number of control variables, for each different type of control, those whose sensitivities are below a certain threshold should be discarded (eg, controls with a sensitivity below a 20% of the highest sensitivity are discarded).

3) Choosing the most efficient control variable (steps 4, 5 and 6 of the process): In order to select the best control action, an Efficiency Coefficient (EC) for each control variable is used. The EC is defined [4] as the maximum amount of voltage correction that can be achieved by rescheduling the control variable, subject to its own limits and the operating limits. In a typical application, operating limits can be considered as voltages in other demand nodes and reactive power produced by distributed generation.

First, the available control action considering the own limits of the control variable is calculated. The upper limit, u^{max}, or the lower limit, u^{min}, is chosen depending on the required action (increment or decrement), according to the necessary voltage correction (increase or decrease) and the sign of the corresponding sensitivity,

$$\Delta u_0 = \begin{cases} u^{max} - u & \text{if } S_{V_c,u} \geq 0 \\ u - u^{min} & \text{if } S_{V_c,u} < 0 \end{cases} \tag{4}$$

Then, the maximum control action regarding voltages limits in other demand nodes is calculated to avoid new problems. As in the previous case, the limit, V_i^{max} or V_imin, is selected taking into account the sign of the corresponding sensitivities,

$$\Delta u_{V_c} = \min_i \left\{ \frac{V_i^{max} - V_i}{|S^i_{V_c,u}|}, \frac{V_i - V_i^{min}}{|S^i_{V_c,u}|} \right\} \tag{5}$$

where $S^i_{V_c,u}$ is the voltage sensitivity in the demand node i with respect to the control variable u.

The maximum control action taking into account the limits of the reactive power produced by generators is calculated in a similar way,

$$\Delta u_{Q_g} = \min_i \left\{ \frac{Q_{g_i}^{max} - Q_{g_i}}{|S^i_{Q_g,u}|}, \frac{Q_{g_i} - Q_{g_i}^{min}}{|S^i_{Q_g,u}|} \right\} \tag{6}$$

where

- Q_{g_i} Reactive power of the generator at node i.
- $Q_{g_i}^{max}$ Upper reactive power limit of the generator at node i.
- $Q_{g_i}^{min}$ Lower reactive power limit of the generator at node i.
- $S^i_{Q_g,u}$ Reactive power sensitivity of the generator at node i regarding to the control variable u.

The available control actions will be positive if they keep magnitudes within bounds. In other case, the value will be negative.

Once the maximum control actions taking into account the limits on u and the operating limits are calculated, the maximum available actions for each control type is determined as follows:

$$\Delta u^{max} = \min\left\{\Delta u_0, \Delta u_{V_c}, \Delta u_{Q_g}\right\} \quad (7)$$

If u^{max}, the control action must be discarded as some limit would be reached.

Next, for each control variable, the Efficiency Coefficient is calculated. They create a framework that allows to compare all the possible control actions and to select the most efficient one,

$$EC_u = S^k_{V_c,u} \cdot \Delta u^{max} \quad (8)$$

Then, variables whose EC are over a certain threshold are selected. For instance, control actions with an efficiency over the 80% of the highest EC. Among the remaining variables, the one leading to the lower cost is chosen (and in case of equal costs, the one with the highest EC). Finally, the necessary control action is computed as

$$\Delta u = \frac{\Delta V_k}{S^k_{V_c,u}} \quad (9)$$

If the control has discrete steps (transformer taps, switched capacitor bank), the action is rounded to the closest discrete value.

B. Control variables

The elements which will be rescheduled for correcting voltage violations are:

- Switched shunt elements.
- Conventional synchronous generator voltages.
- Transformer taps.
- Reactive power injected by inverters of photovoltaic plants or storage devices.
- Combined control action of active and reactive power injected by inverters of photovoltaic plants or storage devices.
- Load shedding, combining active and reactive power.

Note that the reactive power injected by an inverter depends on the active power injected, according to its characteristic curve,

$$Q^2_{max} = P^2_{max} - P^2 \qquad Q_{max} = -Q_{min} \quad (10)$$

where

- Q_{max} Maximum reactive power that the inverter can inject.
- Q_{min} Minimum reactive power that inverter can consume.
- P Active power given by the inverter.
- P_{max} Maximum active power of the inverter.

Rescheduling the active power injected by distributed generators is not considered a possible action, because its cost is always higher than modifying the reactive power. Therefore, when an active power control action in distributed generators is the best one, a combined action is always considered. This will also vary the reactive power injected by the inverter, so as to minimize the active power required. Furthermore, the cost of each action will depend on many factors, as this could include not only the cost of the action but also the cost due to the wear and tear in each control action.

C. Calculation of Sensitivity Matrices

Sensitivity matrices give a linear approximation of how a magnitude vary with regards to other parameters. Obviously, the relationship between voltages in consumption nodes and control variables is essential, when correcting voltages in these nodes. Moreover, is also important to know how the control actions affect to reactive power in generators, so as not to violate any operational limit.

Therefore, sensitivities matrices must be calculated for every variable. Below, an instance of the calculation for a shunt element is explained.

First, once a power flow in solved, the Jacobian matrix is calculated at the current state:

$$\begin{pmatrix} \Delta P \\ \Delta Q_c \\ \Delta Q_g \end{pmatrix} = \begin{pmatrix} \frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V_c} & \frac{\partial P}{\partial V_g} & \frac{\partial P}{\partial t} \\ \frac{\partial Q_c}{\partial \theta} & \frac{\partial Q_c}{\partial V_c} & \frac{\partial Q_c}{\partial V_g} & \frac{\partial Q_c}{\partial t} \\ \frac{\partial Q_g}{\partial \theta} & \frac{\partial Q_g}{\partial V_c} & \frac{\partial Q_g}{\partial V_g} & \frac{\partial Q_g}{\partial t} \end{pmatrix} \cdot \begin{pmatrix} \Delta \theta \\ \Delta V_c \\ \Delta V_g \\ \Delta t \end{pmatrix} \quad (11)$$

where P is the active power, Q_c and Q_g are the reactive power injected in a demand and generation node, respectively, θ is the angle of the complex bus voltage, V_c and V_g the voltage in a demand and generation node, respectively, and t the turn ratio of a tapped transformer.

Then, when reactive power in a demand node is modified due to a shunt element, ΔQ_c,

$$\Delta Q_c = \frac{\partial Q_c}{\partial \theta}\Delta\theta + \frac{\partial Q_c}{\partial V_c}\Delta V_c + \frac{\partial Q_c}{\partial V_g}\Delta V_g + \frac{\partial Q_c}{\partial t}\Delta t \quad (12)$$

As it was mentioned, when one control variable, or two in a combined control action, is modified, the rest of control variables will be considered as constants. Therefore, $\Delta V_g = \Delta t = 0$, and

$$\Delta Q_c = \frac{\partial Q_c}{\partial \theta}\Delta\theta + \frac{\partial Q_c}{\partial V_c}\Delta V_c \quad (13)$$

In order to obtain the sensitivity between ΔV_c and ΔQ_c, $\Delta P = 0$ can be used, taking into account that no changes in active power are permitted. Note that the *slack bus* is not included in ΔP. In consequence,

$$\Delta P = \frac{\partial P}{\partial \theta}\Delta\theta + \frac{\partial P}{\partial V_c}\Delta V_c = 0 \quad (14)$$

$$\Delta\theta = -\left[\frac{\partial P}{\partial \theta}\right]^{-1} \frac{\partial P}{\partial V_c}\Delta V_c \quad (15)$$

Then, the required sentivities are obtained as

$$S_{V_c,Q_c} = \left\{\frac{\partial Q_c}{\partial V_c} - \frac{\partial Q_c}{\partial \theta}\left[\frac{\partial P}{\partial \theta}\right]^{-1} \frac{\partial P}{\partial V_c}\right\}^{-1} \quad (16)$$

Likewise, the variation of the reactive power in a generator, ΔQ_g, due to a change in a reactive power injection in a load bus, ΔQ_c, can be obtained as follows:

$$\Delta Q_g = \frac{\partial Q_g}{\partial \theta}\,\Delta\theta + \frac{\partial Q_g}{\partial V_c}\,\Delta V_c \tag{17}$$

$$S_{Q_g,Q_c} = \left\{ \frac{\partial Q_g}{\partial V_c} - \frac{\partial Q_g}{\partial \theta}\left[\frac{\partial P}{\partial \theta}\right]^{-1}\frac{\partial P}{\partial V_c} \right\} S_{V_c,Q_c} \tag{18}$$

Note that sentivities S_{V_c,Q_c} permit to evaluate the change in all voltages (not only the one that must be corrected) due to changes in reactive power injections in load buses, and S_{Q_g,Q_c} permit to evaluate the effect of the reactive power injections on the reactive power provided by generators, so as not to create a problem in a generator due to the control action.

The sensitivities matrices for the rest of control variables can be calculated in an analogous way.

III. Application to a Distribution Network with Distributed Generation

The proposed voltage control technique has been applied to the distribution network described in [8], and presented in Figure 1. This is a 20 kV distribution network, whose structure is radial. It is connected to a 110 kV transmission network through two tapped transformers (nodes 0-1 and 0-12), and a switched capacitor is available for reactive power control in node 10. There are several distributed generators (DG) in nodes 3 to 10 of several types: PV generation, battery energy storage (BES), fuel cell in household, wind turbine, CHP diesel and CHP fuel cell.

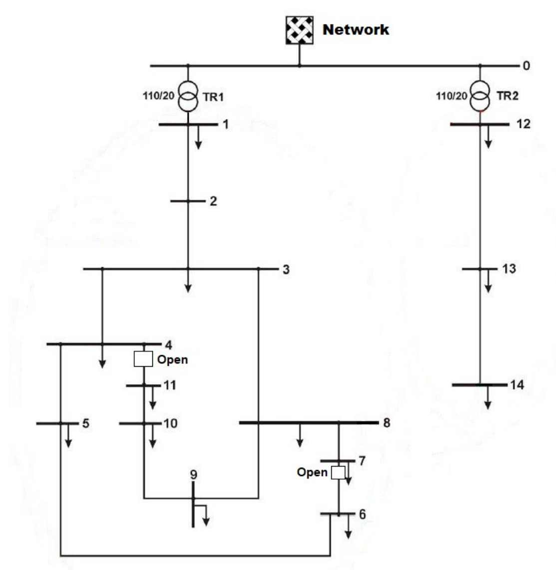

Fig. 1. Distribution Network.

All nodes are demand nodes, except the connection to the transmission network, which is taken as the slack node. Voltage limits are 1.02 and 0.98 pu for all nodes.

TABLE I
State in Example 1 before and after the control action.

Node	Magnitude	Angle
1	1.0012	-0.04
2	1.0242	-2.00
3	1.0333	-2.65
4	1.0334	-2.69
5	1.0334	-2.73
6	1.0335	-2.77
7	1.0367	-2.71
8	1.0347	-2.71
9	1.0347	-2.72
10	1.0346	-2.74
11	1.0346	-2.74
12	1.0001	-0.04
13	1.0073	-0.50
14	1.0078	-0.58
0	1.0000	0.00

Node	Magnitude	Angle
1	0.9827	-0.04
2	1.0054	-2.00
3	1.0143	-2.64
4	1.0144	-2.68
5	1.0144	-2.72
6	1.0145	-2.76
7	1.0177	-2.70
8	1.0157	-2.70
9	1.0157	-2.71
10	1.0156	-2.73
11	1.0156	-2.73
12	1.0001	-0.04
13	1.0073	-0.50
14	1.0078	-0.58
0	1.0000	0.00

The application of the proposed technique to the distribution network permit to correct all voltage problems in the initial state. Below, different corrective actions are discussed, included combine action of active and reactive power in inverters so as to dispose of a larger margin for reactive power injection.

The tables represent the network state (voltages) in different situations, before and after every voltage correction.

It is worth highlighting that 0.005 is added to the necessary action so as to correct the error due to the linear approximation and rounding, in case of discrete controls. Therefore, after an action, the voltage magnitude of the node with the highest violation should be around 1.015 or 0.985, depending on the exceeded limit.

Unless otherwise indicated, in the initial state, transformers ratio is 1, no reactive power is injected by the shunt element and distributed generators give as much active power as possible and no reactive power ($\cos\varphi = 1$).

A. Example 1: changing transformer taps

In this case, most of voltages are over the upper limit, due to a high distributed generation and a low demand (Table I). The highest voltage violation is 1.0367 in node 7 and the best corrective action is determined as a change in taps of the transformer 0-1. As this control is discrete, the necessary action must be rounded to an existing tap position. The new ratio is 1.01875, and, finally, a new power flow is solved to verify that all voltages keep within bounds (Table I).

In this case, the action does not entail an associated cost, as it is a resource of the DISCO.

B. Example 2: changing transformer taps and a combined action on a DG

In this situation, demand is also low and the distributed generation high due to a windy day. Most of voltages are again over the upper limit, as shown in Table II. Node 7 is the most urgent problem (magnitude 1.0393) and a change in taps of transformer 0-1 is determined as the best action. However, the necessary action is larger than the permitted one due to operating limits. Therefore, the action on the transformer is the maximum available and, after rounding to a discrete tap(new ratio 1.01875), the problem is not be solved (Table III).

TABLE II

STATE IN EXAMPLE 2 BEFORE THE CONTROL ACTION.

Node	Magnitude	Angle
1	1.0012	-0.03
2	1.0259	-1.95
3	1.0357	-2.58
4	1.0359	-2.62
5	1.0360	-2.65
6	1.0362	-2.69
7	1.0393	-2.63
8	1.0372	-2.63
9	1.0373	-2.64
10	1.0372	-2.66
11	1.0372	-2.66
12	1.0001	-0.04
13	1.0074	-0.49
14	1.0079	-0.57
0	1.0000	0.00

TABLE III

STATE IN EXAMPLE 2 AFTER THE CONTROL ACTION ON TRANSFORMER.

Node	Magnitude	Angle
1	0.9827	-0.03
2	1.0071	-1.94
3	1.0168	-2.57
4	1.0170	-2.61
5	1.0171	-2.64
6	1.0172	-2.68
7	1.0203	-2.62
8	1.0183	-2.62
9	1.0183	-2.63
10	1.0183	-2.65
11	1.0183	-2.65
12	1.0001	-0.04
13	1.0074	-0.49
14	1.0079	-0.57
0	1.0000	0.00

TABLE IV

STATE IN EXAMPLE 2 AFTER THE TWO SEQUENTIAL CONTROL ACTIONS.

Node	Magnitude	Angle
1	0.9826	-0,03
2	1.0042	-1,77
3	1.0124	-2,33
4	1.0126	-2,37
5	1.0128	-2,40
6	1.0129	-2,44
7	1.0150	-2,31
8	1.0136	-2,36
9	1.0136	-2,37
10	1.0136	-2,39
11	1.0136	-2,39
12	1.0001	-0,04
13	1.0074	-0,49
14	1.0079	-0,57
0	1.0000	0,00

TABLE V

STATE IN EXAMPLE 3 BEFORE THE CONTROL ACTION.

Node	Magnitude	Angle
1	1.0012	-0.03
2	1.0271	-1.90
3	1.0373	-2.50
4	1.0378	-2.53
5	1.0382	-2.56
6	1.0383	-2.60
7	1.0398	-2.58
8	1.0387	-2.56
9	1.0388	-2.56
10	1.0390	-2.58
11	1.0390	-2.58
12	1.0001	-0.04
13	1.0071	-0.50
14	1.0076	-0.58
0	1.0000	0.00

Again, node 7 is the most urgent problem (magnitude 1.0203), as it is the only voltage violation. The best action now is to change the active power injected by the wind turbine at node 7 and thus a combined action is taken to minimize the reduction of active power. The wind turbine was producing 1.47 MW and no reactive power. After this iteration, it will inject 1.2642 MW and consume 0.8073 Mvar. As this control has no discrete steps and the linear approximation has had a little error, the new magnitude at node 7 is exactly 1.015 (Table IV).

Note that in this case, the control action entails a cost as the wind generator must be compensated for reducing its active power and vary the power factor.

C. Example 3: changing transformer taps and the reactive power injected by and inverter

In this example, voltages are high again, as shown in Table V. The highest voltage violation is 1.0398 at node 7 and the best action is a change in taps of transformer 0-1. As in the last case, the necessary action is larger than the permitted one due to operating limits, so the control action is the maximum available. After rounding taps to a discrete position (new ratio 1.01875), the problem is alleviated but not solved.

Node 7 remains again as the most urgent problem (see Table VI) and the next best action is to modify the reactive power injected by the inverter of the wind turbine at node 7. Before this action, the inverter did not inject any reactive power. After that, it consumes 1.2882 Mvar.

When the network state is obtained so as to verify voltages, voltage at node 7 is between limits, 1.015 (Table VII). Note that in this case, the cost of the control action is associated to a change in the reactive power of the wind turbine, requiring a lower compensation than in the previous case.

D. Example 4: acting on the capacitor bank

In this case, it is supposed that there is no distributed generation, so as to show that the proposed technique also

TABLE VI

STATE IN EXAMPLE 3 AFTER THE CONTROL ACTION ON TRANSFORMER.

Node	Magnitude	Angle
1	0.9827	-0.04
2	1.0083	-1.89
3	1.0184	-2.49
4	1.0189	-2.52
5	1.0193	-2.55
6	1.0194	-2.59
7	1.0209	-2.56
8	1.0198	-2.54
9	1.0199	-2.55
10	1.0201	-2.57
11	1.0201	-2.57
12	1.0001	-0.04
13	1.0071	-0.50
14	1.0076	-0.58
0	1.0000	0.00

TABLE VII
STATE IN EXAMPLE 3 AFTER THE TWO SEQUENTIAL CONTROL ACTIONS.

Node	Magnitude	Angle
1	0.9825	-0.03
2	1.0050	-1.57
3	1.0135	-2.03
4	1.0140	-2.07
5	1.0144	-2.10
6	1.0145	-2.14
7	1.0149	-1.98
8	1.0144	-2.05
9	1.0145	-2.06
10	1.0147	-2.07
11	1.0147	-2.07
12	1.0001	-0.04
13	1.0071	-0.50
14	1.0076	-0.58
0	1.0000	0.00

TABLE VIII
STATE IN EXAMPLE 4 BEFORE AND AFTER THE CONTROL ACTION.

Node	Magnitude	Angle
1	0.9820	-0.21
2	0.9822	-2.52
3	0.9811	-3.38
4	0.9807	-3.42
5	0.9803	-3.46
6	0.9798	-3.51
7	0.9808	-3.52
8	0.9806	-3.48
9	0.9803	-3.49
10	0.9797	-3.51
11	0.9796	-3.51
12	0.9996	-0.17
13	1.0042	-0.68
14	1.0040	-0.76
0	1.0000	0.00

Node	Magnitude	Angle
1	0.9821	-0.21
2	0.9847	-2.76
3	0.9849	-3.73
4	0.9845	-3.77
5	0.9841	-3.81
6	0.9836	-3.85
7	0.9850	-3.90
8	0.9848	-3.86
9	0.9845	-3.88
10	0.9842	-3.95
11	0.9841	-3.95
12	0.9996	-0.17
13	1.0042	-0.68
14	1.0040	-0.76
0	1.0000	0.00

works properly in traditional networks. For this initial state, the ratio of taps of transformer 0-1 is 1.01875.

As shown in Table VIII the most urgent problem is the voltage 0.9796 at node 11, which is corrected by the shunt element at node 10. After rounding to a discrete value, it is determined that 1 Mvar should be injected. After the control action, all nodes are within bounds (Table VIII).

In this case, the action does not normally entail a cost because it is a resource that is normally owned by the DISCO, or, in the case of ownership of a third party, the cost is managed through contracts for the provision of long-term services.

IV. CONCLUSIONS

A method to control distributed generation resources based on sensitivities matrices has been presented,in order to determine the necessary control action to correct voltage problems in the distribution networks, using the available control resources provided by distributed generation.

The proposed method begins by identifying the problem to be corrected first, based on its severity. Next, the sensitivity matrices that determine the relationship between the control variables and the magnitudes subject to operating limits are calculated, and the maximum control margins are computed based on the corresponding sensitivities, Finally, after selecting the most 'efficient' control action to correct the most urgent problem, the necessary control action is calculated.

The proposed technique has been tested in distribution networks in order to demonstrate the adequacy of the proposed method for the efficient selection and computation of corrective control actions, including in the selection criteria the cost of the control actions.

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