# Microscopic and Macroscopic Voltage Quality Management

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***Abstract*— The voltage quality issues and their proper control, in modern power systems including renewable distributed power sources and FACTS devices such as harmonics, frequency flickering and voltage fluctuations, are very important. In this paper, the power and voltage are divided into microscopic and macroscopic levels to improve the consumers' microscopic and macroscopic voltage qualities, respectively. Based on this division, a new concept of voltage control in smart energy networks is presented as microscopic voltage management. Moreover, a new formulation with appropriate objective function to improve the microscopic and macroscopic voltage qualities is developed. The simulation results of the 15-bus distribution test system show considerable improvements on the voltage quality and voltage oscillation in distribution buses.**

***Keywords*— Voltage Quality, Microscopic Power Consumption, Smart Energy Network and Power Management**

## I. INTRODUCTION

Nowadays it is important to provide appropriate voltage quality demanded by consumers in distribution networks.

In the literature, a number of voltage control methods have been suggested [1]-[3]. Some common components that are used to improve voltage stability are Flexible Alternating Current Transmission Systems (FACTS) that are new devices emanating from recent innovative technologies that are capable of altering voltage, phase angle and/or impedance at particular points in power systems. Their fast response offers a high potential for power system stability enhancement apart from steady state flow control. Among the FACTS controllers, Static VAR Compensator (SVC) provides fast acting dynamic reactive compensation for voltage support during possibility events which would in other respects depress the voltage for a significant length of time. SVC also reduces system losses and moderates power drops by optimized reactive power control [4].

Using On Load Tap Changers (OLTCs) are another method to control bus voltages under changes in injection current. OLTCs are used between the multiple voltage levels to regulate and maintain the voltage which is supplied to consumers within statutory limits. The OLTC mechanism is a transformer component controlled automatically by a relay to increase or decrease macroscopic voltage by altering the tap position of transformer [5]. In addition, with the application of loads, the voltage profile tends to drop along distribution feeders below acceptable operating limits. Along with power losses and voltage drops, the increasing growth in electricity demand requires upgrading the infrastructure of distribution systems [6]. Moreover in grid-connected mode, some of the system dynamics are supplied by the main grid due to the small size of the micro-sources. In this operating mode, there is a significant potential for consumers to peak shaving and prepare ancillary services to electrical grid (i.e., reactive power supply, load following, spinning reserve, system black-start) [7].

Fluctuating loads are sources of oscillations in voltage and frequency [8], [9]. Some examples of these fluctuating loads are: alternative current electric arc furnace, welding instruments, motor equipment with alternative start (Fans, air conditioner), motors which are driven alternatively such as elevators, steel rolling instruments, instruments with high changes in motor speed such as industrial sawmills, iron plate producing instruments and materials recycling devices, large industrial motors with variable loads, switching power coefficient correcting capacitors, X-ray producing devices, lasers and high volume of photocopy machines in offices [8], [10].

Two methods to reduce the impact of variable loads is considered in [11], [12] first through the introduction of additional energy storage devices, such as flywheels and the second is through load coordination.

One approach to control bus voltages is direct load control (DLC) in residential load management [13]. In DLC programs, based on an agreement between the utility and the customers, the utility can remotely control the energy consumption and operations of particular appliances in a household. An alternative for DLC is smart pricing, where customers are encouraged to personally and voluntarily manage their loads [14].

In this paper voltage quality is divided into microscopic and macroscopic voltage quality and two appropriate objective functions to improve stability of voltage are proposed. Moreover, various electrical consumers require various voltage qualities. So, to reach to these targets, microscopic and macroscopic voltage quality improvement, a new priority base formulation, is proposed.

This paper is organized as follows. In section II, first by division of power consumption into microscopic and macroscopic power consumptions, microscopic and macroscopic power management are defined. Section III includes problem formulation. Section IV includes case study and simulation results. Finally, the conclusion can be found in section VI.

## II. MICROSCOPIC AND MACROSCOPIC POWER MANAGEMENT

### *A. Division of Power Consumption*

In this paper as shown in Figure 1, the power profile of a micro-grid with macroscopic and microscopic sampling periods is depicted. The macroscopic power is defined as the average of real power in its sampling period, and the microscopic (or variable) power is defined as fluctuation around macroscopic power. In addition, the voltage profile is also divided into macroscopic and microscopic voltage profiles, respectively. The microscopic voltage and power are considered as STD in the range of macroscopic sampling period.

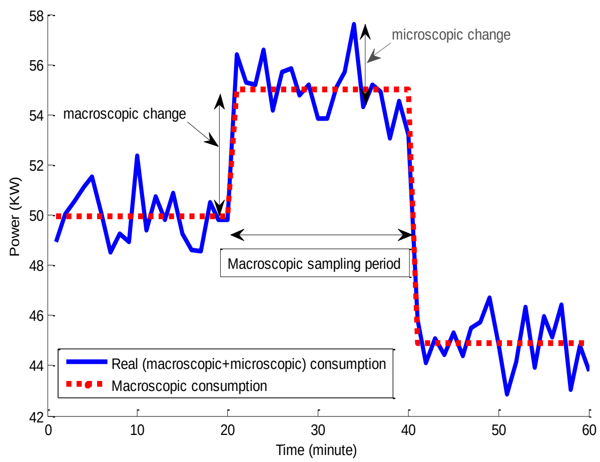


Figure 1. Microscopic and macroscopic power division

### *B. Microscopic and Macroscopic Voltage Quality Management*

Fig. 2 provides a hierarchical control framework of modern smart grids with microscopic and macroscopic voltage quality management based on microscopic and macroscopic price tariffs.

In this structure smart distribution network receives measured data involving real time microscopic and macroscopic consumption and also micro-grids' demanded voltage quality. It sends proper incentives to each micro-grid based on proposed method to reach requested voltage qualities.

## III. PROBLEM FORMULATION

### *A. Microscopic Bus Voltages Modelling*

If active and reactive parts of microscopic load changes are known, the relative voltage change can be calculated more accurately by using resistive and inductive parts of network impedance as follows:

$$\Sigma_V = \frac{X\,\Sigma_Q + R\Sigma_P}{V_n} \tag{1}$$

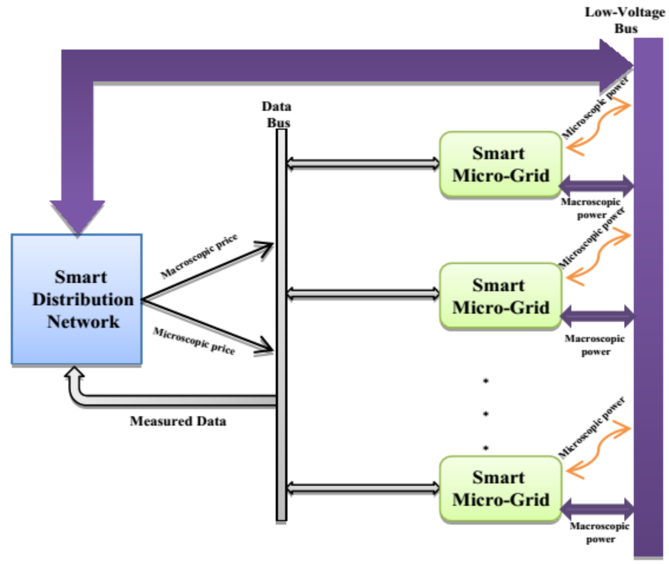


Figure 2. Microscopic and macroscopic energy management based on incentives

Where

$\Sigma_V = \left[\sigma_{V_1} \ldots \sigma_{V_m}\right]^T$ *Voltage STD of network*

$\Sigma_P = \left[\sigma_{P_1} \ldots \sigma_{P_m}\right]^T$ *Active part STD of network*

$\Sigma_Q = \left[\sigma_{Q_1} \ldots \sigma_{Q_m}\right]^T$ *Reactive part STD of network*

$V_n$ *Nominal voltage of network*

$X = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mm} \end{bmatrix}$ *Inductive matrix of network*

$R = \begin{bmatrix} r_{11} & \cdots & r_{1m} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mm} \end{bmatrix}$ *Resistive matrix of network*

In this formulation R and X are symmetric that show similar effect of microscopic consumption of buses on microscopic voltage quality of each other. For example change in power of bus number (i) affects voltage of bus number (j) via $x_{ji}$ and $r_{ji}$ which are inductive and resistive parts, respectively. According to (1), reduction in microscopic power consumption would improve voltage stability.

### *B. Priority Based Macroscopic Objective Function*

Macroscopic voltage of each bus is related to macroscopic apparent current of all network buses. For this reason, in this paper macroscopic voltage deviation from nominal voltage is minimized by adjusting voltage source of radial network (Vs) using macroscopic objective function as (2). $\lambda_i$ is macroscopic voltage priority factor for consumer (bus) number (i) that is normalized between 0 and 1. By this formulation each consumer demands its macroscopic voltage quality via sending appropriate value of $\lambda$ to Disco.

$$\min_{V_s}\left\{\sum_{i=1}^{m}\lambda_i\left(|V_n|-|V_i|\right)^2\right\}$$

$$St. \qquad V_i = V_s - \sum_{k=1}^{m}(r_{ik}+jx_{ik})I_k \tag{2}$$

### C. *Priority Based Microscopic Objective Function*

Equation (3) shows a microscopic objective function for microscopic voltages of network that minimizes STD of voltages. $\gamma_i$ is microscopic voltage priority factor for each consumer that is normalized between 0 and 1. Each consumer could determine its microscopic and macroscopic voltage quality via sending its microscopic and macroscopic priority factor to Disco, respectively.

$$\min\left\{\Sigma_V{}^T\Gamma\Sigma_V\right\} \tag{3}$$

$$\Gamma=\begin{bmatrix}\gamma_1 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & \gamma_m\end{bmatrix} \qquad \textit{Microscopic priority matrix}$$

Microscopic objective function could be minimized by reducing $\Sigma_P$ and $\Sigma_Q$. Hence, Disco needs to send proper incentives to consumers to encourage them to reduce microscopic consumption. Incentives for each consumer should be proportionate with their effect on microscopic objective function. Effect of consumers on microscopic objective function can be calculated accurately by deriving it respect to $\Sigma_P$ and $\Sigma_Q$ at microscopic demand which are shown in (4) and (5), respectively.

$$D_Q = \left.\frac{\partial\left\{\Sigma_V{}^T\Gamma\Sigma_V\right\}}{\partial\Sigma_Q}\right|_{\Sigma_Q=\Sigma_{Q0},\Sigma_P=\Sigma_{P0}} \tag{4}$$

$$D_P = \left.\frac{\partial\left\{\Sigma_V{}^T\Gamma\Sigma_V\right\}}{\partial\Sigma_P}\right|_{\Sigma_Q=\Sigma_{Q0},\Sigma_P=\Sigma_{P0}} \tag{5}$$

Where

$$D_Q=[d_{Q_1}\cdots d_{Q_m}]$$
$$D_P=[d_{P_1}\cdots d_{P_m}] \qquad \textit{Reactive and active sensitivity vectors}$$

$D_Q$ and $D_P$ include sensitivity of each consumer or bus to reduce microscopic objective function. By normalizing and ranking arrays of D, Disco can send proper incentives to each bus or use FACTs devices to increase microscopic voltage quality properly. In this paper Microscopic Demand Response is used to improving microscopic voltage quality via sending proper incentives to consumers to decrease their microscopic consumption. The incentive for each consumer is considered linear respect to D as below:

$$I_i = d_{Q_i}\times(\sigma_{Q_i0}-\sigma_{Q_i})+d_{P_i}\times(\sigma_{P_i0}-\sigma_{P_i}) \tag{6}$$

Each consumer improves voltage stability and receives incentive from Disco by reducing their microscopic consumption.

## IV. CASE STUDY AND SIMULATION RESULTS

The algorithm was tested on a 15-bus radial distribution system as Figure 3 [10] and priority factors for each consumer assumed as Figure 4. Characteristics of this distribution feeder are as Tables 1 and 2. It should be also noticed that all simulations were performed using Matlab, version 8.1 (R2013a).

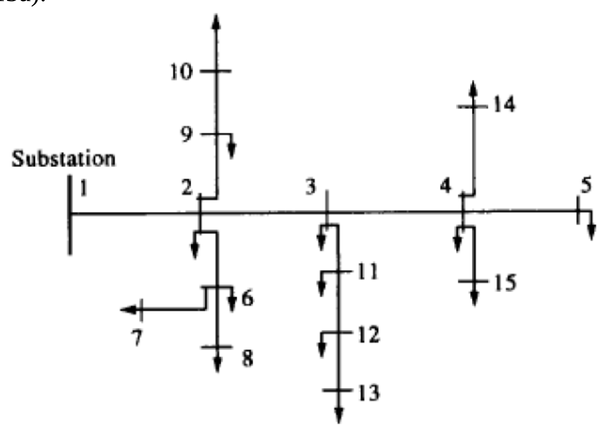


Figure 3. A sample 15-bus distribution network

Moreover, microscopic consumption of consumers assumed with normal distribution around macroscopic consumption. Microscopic consumption of consumers are considered as 5% STD around macroscopic consumption and power factor of the load is taken as $\cos\varphi = 0.70$. The only supply source in the system is the substation at bus no. 1 as a controllable voltage by OLTC which controls the macroscopic voltage of bus no. 1. Microscopic incentive elasticity of consumers in the time of simulation is considered constant based on Ref [15].

Reactive and active sensitivity of each bus respect to microscopic objective function is as Figure 5 that shows it is better to assign more incentives to more sensitive buses. Based on this idea, improved average and STD of voltage profile is as Figure 6 that shows the effectiveness of our proposed method.

## V. CONCLUSION

Division of power consumption and voltage quality to microscopic and macroscopic presents a new concept of voltage quality management. In order to control quality of voltage of network, smart energy networks provide an appropriate infrastructure for microscopic energy management programs requiring recording and processing data which are related to microscopic power consumption of Micro-Grids. Based on formulation developed in this paper each micro-grid can demand its requiring voltage quality, microscopic and macroscopic voltage quality were considerably improved based on their related priority factors by providing incentives and controlling OLTC located at bus 1, respectively.

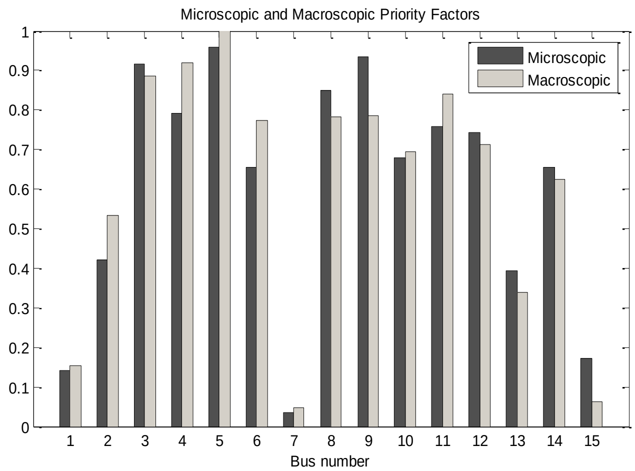


Figure. 4. Voltage quality priority factors

Table 1. Line data of 15-bus distribution feeder

| Branch number | Sending end node | Receiving end node | $R$ (ohm) | $X$ (ohm) |
|---|---|---|---|---|
| 1 | 1 | 2 | 1.35309 | 1.32349 |
| 2 | 2 | 3 | 1.17024 | 1.14464 |
| 3 | 3 | 4 | 0.84111 | 0.82271 |
| 4 | 4 | 5 | 1.52348 | 1.02760 |
| 5 | 2 | 9 | 2.01317 | 1.35790 |
| 6 | 9 | 10 | 1.68671 | 1.13770 |
| 7 | 2 | 6 | 2.55727 | 1.72490 |
| 8 | 6 | 7 | 1.08820 | 0.73400 |
| 9 | 6 | 8 | 1.25143 | 0.84410 |
| 10 | 3 | 11 | 1.79553 | 1.21110 |
| 11 | 11 | 12 | 2.44845 | 1.65150 |
| 12 | 12 | 13 | 2.01317 | 1.35790 |
| 13 | 4 | 14 | 2.23081 | 1.50470 |
| 14 | 4 | 15 | 1.19702 | 0.80740 |

**Table 2. Load data of 15 buses distribution feeder**

| Nodes | KVA | Nodes | KVA |
|---|---|---|---|
| 1 | 0 | 9 | 100 |
| 2 | 63 | 10 | 63 |
| 3 | 100 | 11 | 200 |
| 4 | 200 | 12 | 100 |
| 5 | 63 | 13 | 63 |
| 6 | 200 | 14 | 100 |
| 7 | 200 | 15 | 200 |
| 8 | 100 | | |

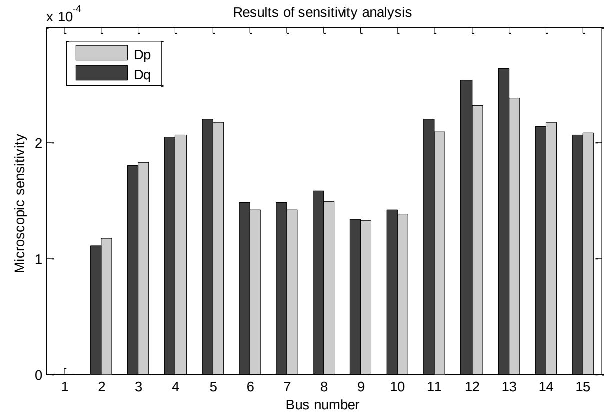


Figure. 5. Bus sensitivity in order to reduce microscopic objective function

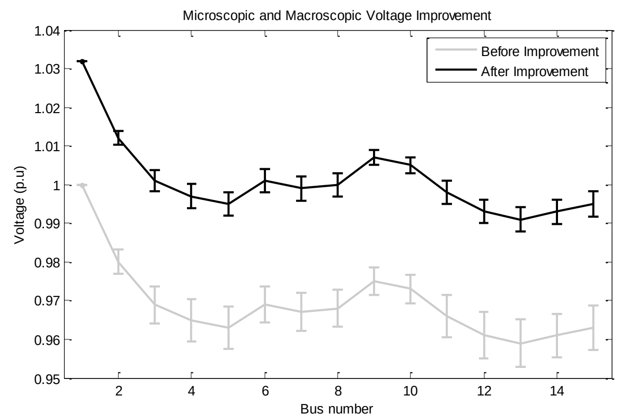


Figure.6. Average and STD of voltage profile before and after improvement

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