Adaptive Voltage Regulation Scheme for Improved Power Management in Metropolitan

[1]Dr. Abhijeet Madhukar Haval, and [2]Taruna Chopra

[1,2]Associate Professor, Department of CS & IT, Kalinga University, Naya Raipur, Chhattisgarh, India.

Abstract:The problem of voltage regulation in metropolitan cities has been well studied. There exist different models to handle this problem, which consider the available voltage and number of connections in the part of city as the key in voltage regulation. However, the methods suffer to achieve higher performance in voltage regulation. To handle this issue, an Adaptive Voltage Regulation Scheme (AVRS) is presented in this article. The proposed method considers the number of high load connections, number of low load connections, no of commercial connections, no of household connections and so on. Based on the connection details, the method categorizes the micro grids into two categories like commercial support grid and household support grid. Based on the category of the grid identified, the method computes the Adaptive Voltage Rate (AVR) for various grids, which represent the voltage to be regulated for the grid at particular time. The AVRS scheme performs voltage regulation according to the value of AVR. This process is iterated at different time stamp of a day. This will be analyzed in different times like business hours and normal hours. Based on the AVR measured, the method performs voltage regulation and produces higher performance.

Keywords: Smart Grids, Voltage Regulation, AVRS, AVR, Power management.

1.Introduction:

The use of electricity has been increased in modern days. The human society performs variety of activities and their daily works with the support of various electric devices. To run any electric device like motor, fan, washing machine, refrigerator, air conditioner or any other device, it requires electric supply. But the electric power is highly scarcity and there will be scarcity at any point of time. The power generation and distribution systems struggle to produce electric power up to the required volts. However, the available electric power should be regulated to the required grids, so that the voltage loss can be minimized.

[1]ku.abhijeetmadhukarhaval@kalingauniversity.ac.in
[2]ku.tarunachopra@kalingauniversity.ac.in

The voltage regulation is the process of regulating the available or incoming voltage to the grids where the electric power is more essential and will be used without much loss in voltage. The metropolitan cities have number of locations and localities. Some of the locations would be covered with business centers and factories. Some of them would be covered with the residential sectors. In order to utilize the electricity in most efficient manner, it is necessary to identify the locality where the electric power is more essential at the current time.

The electric power cannot be saved in inverter for full and it must be used up to the maximum volts at any point of time. If the electric power is regulated with a micro grid where there is no requirement and if there is no consumer for the electricity at the current time, then the electric power regulated will be lost. This affects the performance of voltage regulation as well as affects the performance of power generation units. On the other side, there will be huge lost in the cost spent on the power generation. So, this encourages the power distribution systems in finding the micro grid with more requirements. By regulating the electric power through the micro grids which has higher requirement,, the voltage will not be lost and the performance of regulation can be improved.

On the other side, the electricity on any micro grid will not be utilized for full at all the times. The microgrid which supports or feeds the household connections will be in high utilization at morning and evening times. For the rest of the times, there will be huge voltage loss because of the non usage of electricity at the business and working hours. On the other side, the micro grid feeding the business area will suffer with voltage loss at the non-working hours. So, by regulating the voltage according to the time will support the performance development.

By considering all these, an efficient Adaptive voltage regulation scheme (AVRS) is presented in this article. The method is focused on categorizing the micro grid according to the type of connection it serves and measure the voltage required for any microgrid at various timing. Based on the Adaptive voltage rate measured for any grid, the method would regulate the required voltage for the grid. The proposed AVRS scheme would support the performance development of voltage regulation and reduces the voltage loss. The detailed working of the model has been sketched in the next section.

2.Related Works:

Numbers of voltage regulation schemes are available in literature and this section details some of the method around the problem.

A renewable energy integrated micro grid (REMG) is presented in [1], which works over the pumped hydropower energy storage (PHES). The model has a rely on the building to convert energy by pumping the water up to store energy where energy is generated by releasing the water. A decentralized self-healing strategy is presented in [2], which minimize the loss of load in thermal storage buildings. A building energy management system (BEMS) is presented in [3], which facilitate multiple (thermal and electrical) energy flows in renewable energy sources (RES) integrated buildings. Also the method uses a two-stage robust optimization (TSRO) model optimizes system operation for realization of any level of uncertainty in the upper level. In [4], the author analyze the potential of commercial buildings to act as frequency reserves providers through an experimental demonstration conducted in a multi-zone university building.

Hierarchical control architecture is proposed in [5], for the optimal day-ahead commitment of multiple grid support services within a virtual power plant (VPP). The method use a robust Model Predictive Control (MPC) approach is included to minimize the unbalance fees during real-time operations.

An energy management and control scheme is presented in [6], to manage the operation of an active distribution grid with prosumers is proposed. A multi-objective optimization model to minimize the prosumers electricity cost and the cost of the grid energy losses, while guaranteeing safe and reliable grid operation is formulated.

A stochastic energy/reserve mixed integer linear program is presented in [7], which for a community energy system with consideration of local network constraints.

An energy management strategy (EMS) is presented in [8], towards reconfigurable grid-tied hybrid ac/dc microgrid (HMG) architecture for commercial building (CB) applications.

In [9], the author analyze the thermal system's quasi-dynamic characteristics regional thermal networks, as well as the demand side of heating system. Based on the thermal inertia characteristics, the virtual thermal energy storage models of both thermal networks and buildings considering thermal comfort index are formulated synthetically for central heating system.

A home energy management system (HEMS) is presented in [10], which schedule the BTM resources under a tariff with export rates. The proposed HEMS is formulated as a multi-objective model predictive control problem.

In [11], the author assesses energy generation through a smart integrated decentralized solar energy system in the power hub of a commercial area in Taxila, Pakistan.

In [12], Gable roof buildings are widely used in industrial buildings. Based on wind tunnel tests with rigid models, wind pressure distributions on gable roof buildings with different aspect ratios were measured simultaneously. The same wind tunnel studies and its results are presented in [13], which is conducted over a rectangular building.

A novel typical daily power curve mining method is developed in [14], to support battery energy storage system (BESS) which uses power probability distribution and Bloch spherical quantum genetic algorithm.

Adaptive Voltage Regulation Scheme (AVRS) Model:

The proposed voltage regulation model monitors the incoming voltage for the power system at any point of time. In each duty cycle, the method collects the set of parameters like total micro grids available which are feeding power supply for various locations of metropolitan city. For each micro grid identified, the method collects high load connections, number of low load connections, no of commercial connections, no of household connections and so on. Based on the connection details, the method categorizes the micro grids into two categories like commercial support grid and household support grid. Based on the category of the grid identified, the method computes the Adaptive Voltage Rate (AVR) for various grids, which represent the voltage to be regulated for the grid at particular time. The AVRS scheme performs voltage regulation according to the value of AVR [15][16].

 https://doi.org/10.1051/e3sconf/202454008013

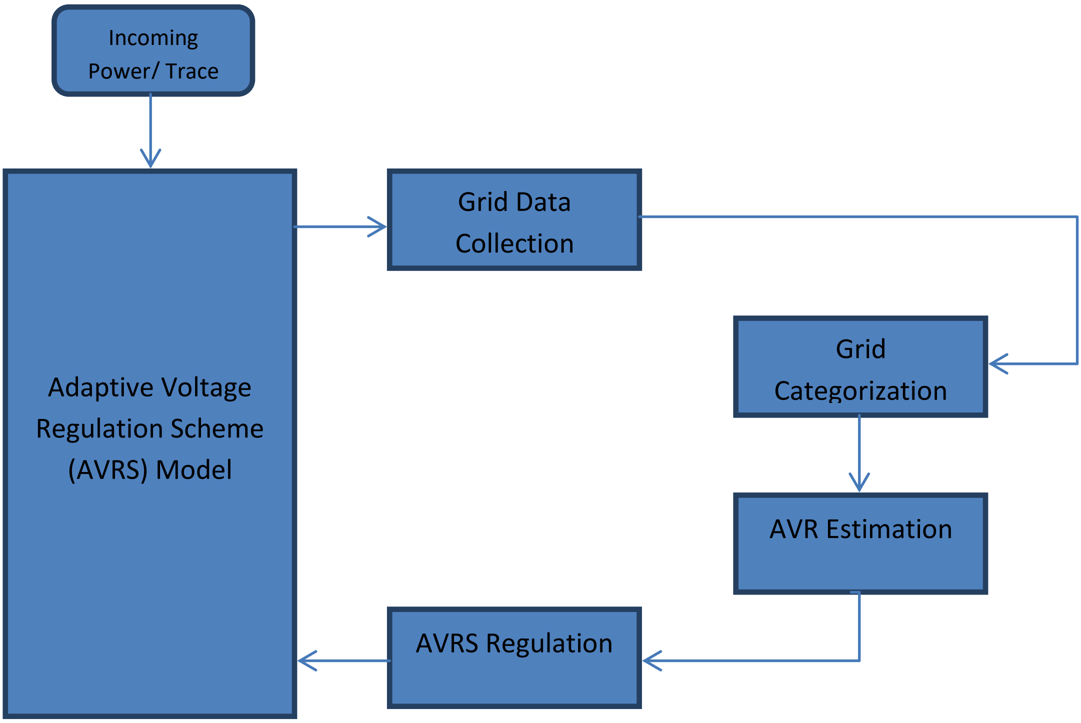

Figure 1: Architecture of AVRS Model

The functional architecture of AVRS voltage regulation model is presented in Figure 1, where the functions of the model are explained in detail in this part.

Grid Data Collection:

The proposed model maintains the power traces which contains information about the consumption of various micro grids and devices in various duty cycles. Using the trace, the method identifies the set of high load connections, number of low load connections, no of commercial connections, no of household connections present under any micro grid available in the distribution system. Also, the method collects the voltage consumed by each connection at different time stamp to compute the average voltage consumption. Such features collected are framed as feature vector to support voltage regulation [17].

Algorithm:

Given: Power Trace PT

Obtain: Feature Vector Set Fvs.

Start

Read PT.

Grid unit set Gus = $\sum_{i=1}^{size(PT)}(PT(i).GridId \ni Gus) \cup Gus$

For each grid unit g

Compute no of high load connections Hlc.

Hlc = $\underset{i=1}{\overset{size(PT)}{Count}}(PT(i).CType == Hl \,\&\&\, PT(i).GridId == g$

Compute no of low load connection Llc.

Llc = $\underset{i=1}{\overset{size(PT)}{Count}}(PT(i).CType == Ll \,\&\&\, PT(i).GridId == g$

Compute no of business connections Bc.

Bc = $\overset{size(PT)}{\underset{i=1}{Count}}(PT(i).CType == Bc \,\&\&\, PT(i).GridId == g$

Compute no of household connection Hhc.

Hhc = $\overset{size(PT)}{\underset{i=1}{Count}}(PT(i).CType == Hc \,\&\&\, PT(i).GridId == g$

Compute average voltage consumption Avc.

Avc = $\frac{\sum_{i=1}^{size(PT)} PT(i).VoltageConsumed?PT(i).gridid==g}{Count(\sum_{i=1}^{size(PT)} PT(i).gridid==g)}$

Generate feature vector Fv = {Hlc, Llc, Bc, Hhc, Avc}

Add Fv to feature vector set Fvs.

End

Stop

The grid data collection algorithm collects the set of grids present in the distribution system and the connections it services. For the connections it services, the method collects set of features from the trace to generate the feature vector set. Generated feature vector set has been used to perform voltage regulation.

Grid Categorization:

The grid categorization algorithm categorizes the grid as two cases. One as commercial grid and another as residential grid. To perform this, the method reads the feature vector set generated at the previous phase. Using the feature vector set, the method computes Grid Class Support (Gcs) according to the number of business, high load connections it has and no of household, low load connections the grid supports. Using these two, the method computes the value of GLs and based on that the connection has been categorized to support voltage regulation.

Algorithm:

Given: feature vector Fv

Obtain: Class Gc

Start

Read Feature vector Fv.

Compute Gcs(C) = $\frac{Fv.Bc}{Fv.Hlc} \times Fv.avc$

Compute Gcs(R) = $\frac{Fv.Hhc}{Fv.llc} \times Fv.avc$

If Gcs (c) > Gcs (R) then

Return commercial.

Else

Return residential

End

Stop

The grid categorization algorithm classifies the type of grid according to the grid features and average voltage consumption. Such classified result has been used to perform voltage regulation.

AVR Estimation:

The proposed voltage regulation model performs voltage regulation based on the value of AVR measured. AVR is the measure which represents the voltage to be regulated to the grid in turn will be regulated to the sector considered. To perform this, the method computes the value of AVR, according to the time and average voltage consumed by the grid at different time stamp. Estimated value of AVR has been used to perform voltage regulation.

 https://doi.org/10.1051/e3sconf/202454008013

Algorithm:
Given: Feature Vector Fv, Time T, Class C
Obtain: AVR
Start

Read Fv, T, C.

$$X = \begin{cases} T \text{ is working and } C \text{ is Commercial then } x = 1 \\ T \text{ is normal and } C \text{ is commercial then } x = \frac{1}{2} \\ T \text{ is working and } C \text{ is household then } x = \frac{1}{2} \\ T \text{ is normal and } C \text{ is household then } x = 1 \end{cases}$$

Compute $Avr = \frac{Fv.Avc}{x}$

Stop

The AVR estimation algorithm computes the average voltage rate to be circulated to the grid at the current duty cycle.

AVRS Regulation:

The proposed AVRS regulation scheme monitors the power system at each duty cycle. At each time stamp, the method performs Grid collection to obtain the available grid units and their conditions. With the statistics collected, the grid units are categorized according to the grid class support measured. Further, for each grid unit, the method computes the value of AVR to perform voltage regulation.

Algorithm:
Given: Power Trace PT
Obtain: Null
Start

Read PT.
While true
Receive incoming voltage
Grid unit set Gus = Perform grid collection.
For each grid unit g
Grid class gc = Perform grid categorization.
AVR = Perform AVR estimation (Feature vector , T, C)
Regulate voltage through grid according to Avr.
End

Stop

The AVRS regulation algorithm regulates the required voltage for the grid according to the type and class of grid with the value of AVR measured.

3.Results and Discussion:

The proposed AVRS voltage regulation model has been implemented using Simulink and the performance of the model has been measured and compared with other models.

Parameter	Value
Tool Used	Simulink
Number of Grids	5000
Simulation Time	10 minutes1

Table 1: Experimental Details

The experimental details used for the performance evaluation is presented in Table 1.

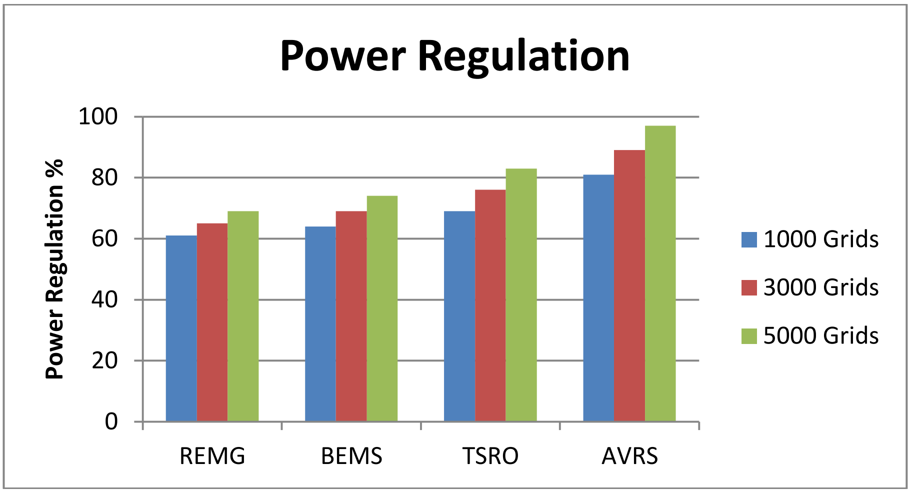

Figure 2: Power Regulation Performance

The performance of methods in voltage regulation is measured and presented Figure 2. The proposed AVRS method produces higher voltage regulation performance than others.

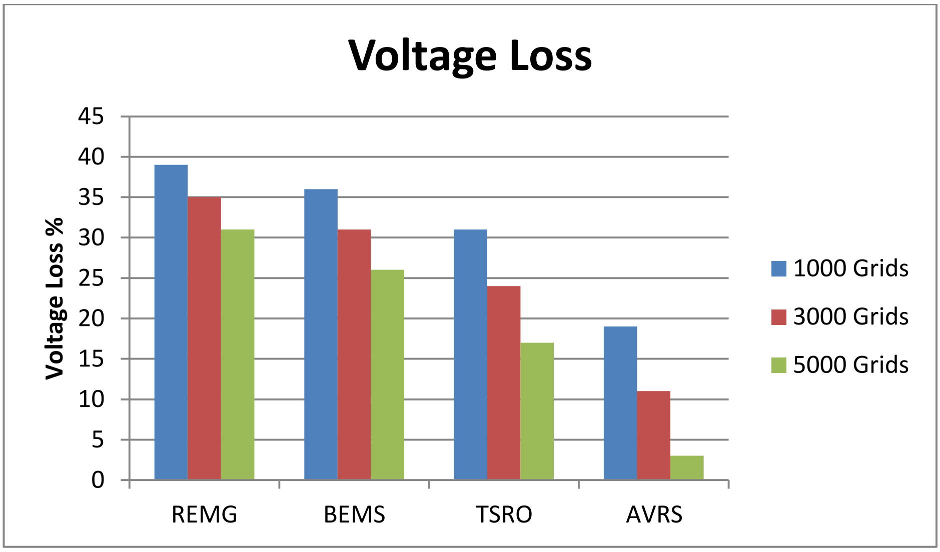

Figure 3: Voltage Loss

The voltage loss introduced by various models is measured and compared in Figure 3. The AVRS model introduces less voltage loss than other models.

4.Conclusion:

This paper presented a novel adaptive voltage regulation scheme (AVRS) in metropolitan cities. The method monitors the grids of the power distribution systems and collects the grids available. For each grid, the method collects statistics about the kind of connections and number of connections and their average voltage consumption. Using them, the grids are categorized and for each of them the method computes the value of AVR to regulate the voltage required. The proposed AVRS scheme produces higher voltage regulation performance and reduces the voltage loss.

5.References:

1. Y. Xu, C. Li, Z. Wang, N. Zhang and B. Peng, "Load Frequency Control of a Novel Renewable Energy Integrated Micro-Grid Containing Pumped Hydropower Energy Storage," in IEEE Access, vol. 6, pp. 29067-29077, 2018, doi: 10.1109/ACCESS.2018.2826015.
2. C. Lv, R. Liang and Y. Chai, "Decentralized Bilateral Risk-based Self-healing Strategy for Power Distribution Network with Potentials from Central Energy Stations," in Journal of Modern Power Systems and Clean Energy, vol. 11, no. 1, pp. 179-190, January 2023, doi: 10.35833/MPCE.2022.000436.
3. S. Sharma, A. Verma, Y. Xu and B. K. Panigrahi, "Robustly Coordinated Bi-Level Energy Management of a Multi-Energy Building Under Multiple Uncertainties," in IEEE Transactions on Sustainable Energy, vol. 12, no. 1, pp. 3-13, Jan. 2021, doi: 10.1109/TSTE.2019.2962826.
4. L. Fabietti, T. T. Gorecki, F. A. Qureshi, A. Bitlislioğlu, I. Lymperopoulos and C. N. Jones, "Experimental Implementation of Frequency Regulation Services Using Commercial Buildings," in IEEE Transactions on Smart Grid, vol. 9, no. 3, pp. 1657-1666, May 2018, doi: 10.1109/TSG.2016.2597002.
5. A. Bolzoni, A. Parisio, R. Todd and A. J. Forsyth, "Optimal Virtual Power Plant Management for Multiple Grid Support Services," in IEEE Transactions on Energy Conversion, vol. 36, no. 2, pp. 1479-1490, June 2021, doi: 10.1109/TEC.2020.3044421.
6. L. Tziovani, L. Hadjidemetriou, P. Kolios, A. Astolfi, E. Kyriakides and S. Timotheou, "Energy Management and Control of Photovoltaic and Storage Systems in Active Distribution Grids," in IEEE Transactions on Power Systems, vol. 37, no. 3, pp. 1956-1968, May 2022, doi: 10.1109/TPWRS.2021.3118785.
7. N. Good and P. Mancarella, "Flexibility in Multi-Energy Communities With Electrical and Thermal Storage: A Stochastic, Robust Approach for Multi-Service Demand Response," in IEEE Transactions on Smart Grid, vol. 10, no. 1, pp. 503-513, Jan. 2019, doi: 10.1109/TSG.2017.2745559.
8. K. Thirugnanam, M. S. El Moursi, V. Khadkikar, H. H. Zeineldin and M. A. Hosani, "Energy Management Strategy of a Reconfigurable Grid-Tied Hybrid AC/DC Microgrid for Commercial Building Applications," in IEEE Transactions on Smart Grid, vol. 13, no. 3, pp. 1720-1738, May 2022, doi: 10.1109/TSG.2022.3141459.
9. X. Chen, L. Bu, C. Chen, L. Gan and K. Yu, "An operational optimization method of regional multi-energy system considering thermal quasi-dynamic characteristics," in CSEE Journal of Power and Energy Systems, doi: 10.17775/CSEEJPES.2020.03830.
10. P. Munankarmi, H. Wu, A. Pratt, M. Lunacek, S. P. Balamurugan and P. Spitsen, "Home Energy Management System for Price-Responsive Operation of Consumer Technologies Under an Export Rate," in IEEE Access, vol. 10, pp. 50087-50099, 2022, doi: 10.1109/ACCESS.2022.3172696.
11. Syed Muhammad Kashif Shah, Tanzeel Ur Rasheed, Hafiz Muhammad Ali, "Smart Integrated Decentralization Strategies of Solar Power System in Buildings", International Journal of Photoenergy, vol. 2022, Article ID 9311686, 14 pages, 2022. https://doi.org/10.1155/2022/9311686.
12. Xiao-kun Jing, Yuan-qi Li, "Wind Tunnel Tests for Wind Pressure Distribution on Gable Roof Buildings", The Scientific World Journal, vol. 2013, Article ID 396936, 11 pages, 2013. https://doi.org/10.1155/2013/396936.
13. J. A. Amin, A. K. Ahuja, "Effects of Side Ratio on Wind-Induced Pressure Distribution on Rectangular Buildings", Journal of Structures, vol. 2013, Article ID 176739, 12 pages, 2013. https://doi.org/10.1155/2013/176739.

14. Xiyun Yang, Jie Ren, Xiangjun Li, Hang Zhang, "Typical Daily Power Curve Mining for Energy Storage Systems under Smoothing Power Fluctuation Scenarios", Mathematical Problems in Engineering, vol. 2018, Article ID 1503092, 12 pages, 2018. https://doi.org/10.1155/2018/1503092.
15. Masthan M., et.al Changed piezoelectric design regarding high electric power growing employing MEMS, Middle - East Journal of Scientific Research, V-20, I-4, PP:451-455, 2014.
16. Ha, J., Choi, Y., Choi, D., & Lee, H. (2014). Power Analysis Attacks on the Right-to-Left Square-Always Exponentiation Algorithm. Journal of Internet Services and Information Security, 4(4), 38-51.
17. Enokido, T., Aikebaier, A., & Takizawa, M. (2011). Computation and Transmission Rate Based Algorithm for Reducing the Total Power Consumption. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 2(2), 1-18.