Voltage Regulation with Hybrid RES based Distributed Generation in the for Active Distribution Networks

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ABSTRACT

In this paper adaptive zone-based Volt/VAR management is proposed, which coordinates active participation of DGs with conventional voltage regulation equipment. To achieve a flexible and scalable solution while minimizing complexity and requirements for data-handling capability, DG management systems are integrated with decentralized parts of the Volt/VAR management system in smaller geographical zones. Coordination of DGs with conventional voltage regulation equipment is based on predefined control hierarchies. However, to reduce requirements for data handling capability, the distribution grid is divided into zones with individual voltage regulation and reactive support schemes. To add flexibility and scalability, these zones can be combined into larger zones with a common Volt/VAR management scheme. This is referred to as adaptive zoning. The results indicate that the control schemes successfully restore voltage to within limits after disturbance of grid conditions. Adaptive zoning effectively reduces system complexity and requirements for data handling capability, while still ensuring a grid-wide solution. The proposed concept is implemented to hybrid RES method the simulation results are presented by using Matlab/Simulink platform.

KEYWORDS: *Active distribution network, distributed generation (DG), reactive power support, Volt/VAR management system, voltage source converter (VSC).*

I. INTRODUCTION

The integration of renewable distributed generation (DG) units alters the distribution systems from their passive structures, with unidirectional power flow, toward active distribution systems (ADS), with multidirectional power flow [1], [2]. While numerous benefits are associated with the change toward ADS, such transition represents many challenges [3]. Voltage regulation is considered as one of the main challenges that are accompanied with high penetration of renewable energy sources. The intermittent nature of renewable energy sources, such as wind and solar energy, can significantly change the system voltage profile and interact with the conventional control of on-load tap changers (OLTCs) [4]–[6]. This interference may lead to overvoltage, under voltage, increasing in the system losses, and abnormal wear of OLTC due to excessive taping actions. Different control schemes are proposed in literature to overcome the effects of DG units on the voltage regulation. Traditionally, most of distribution network operators (DNOs) require all DG units connected to a distribution system to operate in a constant-power-factor control (PFC) mode [7]. The authors in [8] proposed a local reactive power control approach for voltage rise mitigation in ADS. In this approach, each DG absorbs a reactive power to compensate the effect of its injected active power on the voltage rise. The authors in [9] suggested the use of droop-based active power curtailment for voltage rise prevention in radial low-voltage feeders. Two intelligent local controllers are proposed in [10] to mitigate the impacts of DG on the voltage profile in weak distribution networks. A local voltage control scheme for multiple DG units in a distribution feeder is proposed in [11]. In [12], the authors introduced two local controllers to regulate the voltage profiles at buses, where wind power distributed generators are connected. On the other hand, the authors in [13] focused on the voltage regulation from a dynamic point of view rather than the steady-state point of view. An adaptive PI control algorithm is proposed, based on local voltage variations and the non-active power theory, to guarantee a satisfactory dynamic voltage response. Due to mis coordination between DG and OLTC local controllers, the following drawbacks are introduced: 1) high stress on OLTC, particularly in case of renewable power sources; and 2) the energy capture from DG units is not maximized. Some of these drawbacks have recently tackled in [14]–[16] using coordinated control schemes. In [14], the authors suggested an agent-based algorithm for the DG reactive power dispatch to provide proper voltage regulation with less communication requirements, as compared with centralized approaches. However, the coordination between the DG reactive power support and the OLTC is not considered. Moreover, no solution is provided when the DG reactive power reaches its limit. A coordinated control between distributed energy storage systems (ESS) and OLTC is proposed in [15]. The proposed method relies on minimizing the reverse power flow during light loadings by activating ESS chargers. This method assumes that there is an ESS attached to each DG; however, this is not a common practice. In addition, it does not take into consideration the case when the ESS is fully charged. In [16], the authors presented a new voltage estimation methodology to estimate the maximum and minimum voltages for multi feeder distribution systems. Nonetheless, the OLTC is assumed to be the only voltage control device, an approach that can stress the OLTC. In addition, relying solely on the OLTC can lead to an infeasible solution when the difference between the system maximum and minimum voltages exceeds the standard regulation band.

II. Voltage Regulation in Distribution Network with DGs

A. Impact of DGs on Distribution Network Operation

Traditional distribution system operation is based on unidirectional power flows from high voltage (HV) transmission networks to end-users connected to MV and LV feeders. Changes in power demand are compensated at transmission level and the distribution network distributes power while maintaining voltages and currents within allowed limits. Voltage regulation in distribution networks is therefore relatively simple and involves mainly OLTCs, line VRs, and switched or fixed capacitor banks. With the introduction of DGs in MV and LV networks, the possibility of bidirectional power flow occurs (Fig. 1). This might cause over voltages and might interfere with traditional voltage regulation.

B. Reactive Power Support from Actively Controlled DGs

Because of the possible negative impacts, a fairly low penetration of passively integrated DGs can be allowed in traditional distribution systems.

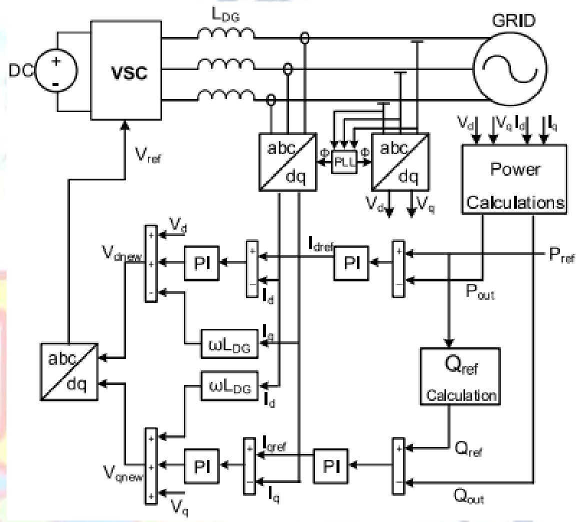


Fig. 2. Control scheme of a DG in power reference (Pref) mode.

However, if DGs are actively controlled, the benefits of distributed generation can be ensured and the penetration can be allowed to increase. With the proper market models and regulation in place, DGs could be used for reactive power (Q) support in addition to active power (P) production. The voltage source converter (VSC) interface is often preferred for integration of actively controlled DGs, since it offers the highest controllability compared to other interfacing technologies [3]. Today, the IEEE standard 1547 [23 does not allow DGs to actively regulate voltage, but it is currently being updated to address these questions and in some countries DGs are already required to provide active voltage regulation. Consequently, this paper deals with VSC-interfaced DGs in grid-supporting mode. Converter control for DGs can be implemented in many ways. A simple control scheme with reference signals for P and Q (Pref and Qref) is presented in Fig. 2. Equations (1) and (2) are control equations for the generation of Idref and Iqref. This control mode is referred to as power reference or Pref mode. The reference signal for Q is generated as in (3) from Pref and is based on the available current limit headroom after injection of active power. In normal operation, Pref is the rated power output of the generator. Pref could also be used to curtail power output or to regulate frequency, though it is not discussed in this paper. For a fixed power factor operating mode the current control changes the reactive power with the available active power within the current limit. The other alternative is to modulate the reactive power basedon local voltage with a limited relaxation in active power. P and Q can also be controlled with the aim to maintaina certain voltage at the PCC. In this case, a reference forQ is generated from the error between the voltage reference signal (Vref) and the actual voltage (Vpcc) (Figs. 3 and 4). In both control modes, a new reference signal for the VSC output voltage is generated via (5) and (6)

$$I_{dref} = \left(K_p + \frac{K_{ip}}{s}\right)(P_{ref} - P_{out}) \quad (1)$$

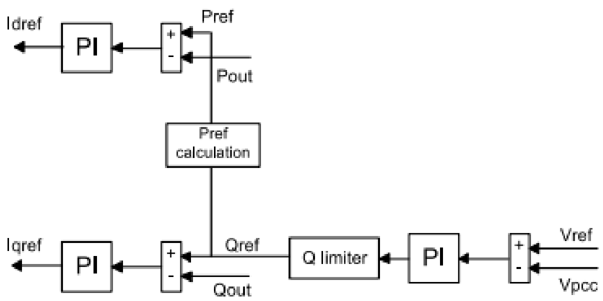


Fig.3.DG control in voltage reference (Vref) mode.

$$I_{qref} = \left(K_q + \frac{K_{iq}}{s}\right)(Q_{ref} - Q_{out}) \quad (2)$$

$$Q_{ref} \leq \sqrt{S_{rated}^2 - P_{ref}^2} \quad (3)$$

$$Q_{ref} = \left(K_v + \frac{K_{iv}}{s}\right)(V_{ref} - V_{pcc}) \quad (4)$$

$$V_{dnew} = V_d + \left(K_{vd} + \frac{K_{ivd}}{s}\right)(I_{dref} - I_d) - I_q \omega L_{DG} \quad (5)$$

$$V_{qnew} = V_q + \left(K_{vq} + \frac{K_{ivq}}{s}\right)(I_{qref} - I_q) + I_d \omega L_{DG} \quad (6)$$

Where the K:s are controller gains.

C. Other Voltage Regulation Equipment

It is important to note that reactive power support from DGs might interfere with existing voltage regulation equipment. Therefore, the management of actively controlled DGs should be coordinated with the operation of other voltage regulation devices. The voltage regulation devices considered in this paper are as follows: 1) OLTCs/VRs and capacitor banks (as key equipment in distribution system voltage regulation); and 2) STATCOMs (as they are increasingly considered for use in distribution grids). Capacitor banks and DSTATCOMs are connected in shunt with power lines and regulate voltage by providing reactive power support, while OLTCs/VRs are connected in series and regulate voltage directly. The different types of devices are therefore referred to as shunt and series devices in this paper.

III. Challenges in Volt/Var Management at High DG Penetration

Volt/VAR management is the process of optimizing power flows while maintaining acceptable voltages at all buses in the system. Presently, the two main challenges for Volt/VAR management are: 1) the impact on existing Volt/VAR management from increased DG penetration and 2) how to integrate power electronics interfaced DGs into Volt/VAR management. Generally, there are three control strategies for Volt/VAR management, which are as follows:

1) Independent and local control of compensation devices;

2) Centralized control based on a predefined set of rules, including some extent of coordination between devices of the same kind, for example a number of capacitor banks along a feeder;

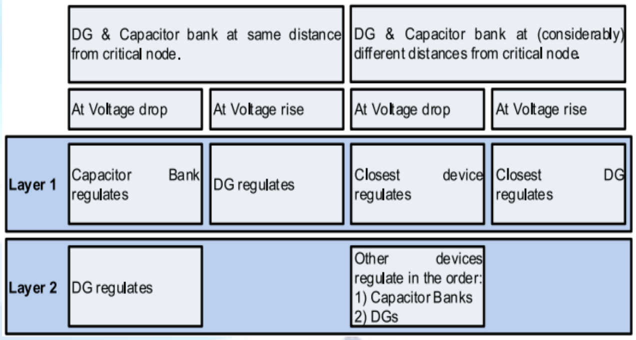


Fig. 4. Control hierarchy for DGs and capacitor banks.

TABLE I
Existing Volt/Var Management Methods

Volt/VAR management method	Advantages	Limitations
Local control	• Low cost • Low needs for communication • Scalable	• Possibility of negative interaction between devices • Requires higher safety margins • May not be able to handle integration of DGs
Centralized control	• More efficient than local control during most conditions • Smaller safety margins needed with access to remote measurements	• Requires more communication • Does not adapt to changing feeder configuration • Does not adapt to changing operation needs • No coordination between regulation devices of different kinds • Does not handle integration of DGs well
Model-based control	• Fully coordinated, optimal solution • Can handle changing operation and system configuration, due to real-time update of system state • Handles integration of DGs well	• Not very scalable – control system for whole distribution network • Technical challenges of system efficiency and robustness leading to high costs of implementation and operation.

3) Distribution system model-based Volt/VAR management, utilizing real-time data, state estimation, and online power-flow calculations. The advantages and limitations of the three

methods are listed in Table I. None of the two first alternatives considers issues related to integration of distributed generation, since they were developed previous to large-scale penetration of DGs. The third and most modern alternative allows integration of DGs as providers of reactive power support in Volt/VAR management. However, solutions that can avoid/reduce the technical challenges and high costs of model-based Volt/VAR management should be of high interest for distribution system operators (DSOs).

IV. Proposed Coordinated Control and Adaptive Zoning

The solution presented in this paper proposes integration of DG management systems into decentralized parts of a Volt/VAR management system. It is designed to address issues connected to increased DG penetration, while at the same time avoiding the challenges related to state-of-the-art model-based Volt/VAR management. Actively controlled DGs are coordinated with conventional voltage regulation devices to provide reactive power support without interfering with the function of existing equipment. Similar to centralized Volt/VAR management, the coordination follows control schemes based on predefined rules. The control schemes are referred to as control hierarchies. To create modularity, the distribution grid is divided into zones. Each zonehas its individual and decentralized Volt/VAR control scheme. In some cases several zones might be affected by a disturbance or there might be similar disturbances in adjacent zones. To ensure efficient voltage regulation in these cases a concept has been introduced, which allows zones to be combined into larger zones with a common Volt/VAR control scheme. This concept is named adaptive zoning and shares some features with model-based Volt/VAR management in that it requires extensive control and communication technology to be in place. However, since the system design is modular, the distribution system-wide computations of model-based Volt/VAR management are avoided. Adaptive zoning only combines as many adjacent zones as is required to solve the occurred voltage deviations and therefore keeps control as local as possible. If voltage exceeds limits in three zones for example, voltages and regulation devices only within these zones need to be considered when finding the subsequent control action. The benefits of the proposed solution compared to previous Volt/VAR management systems are as follows.

1) Less Complex Computations: Because control hierarchies and zones are predefined, the suggested solution will result in less complexity compared to a solution where control zones are continuously redefined and where control action is evaluated on a case-to-case basis instead of following a set of predetermined rules.
2) Lower amounts of data to handle since control action is carried out within the decentralized control zones, the contrast being a model-based Volt/VAR management system evaluating data from much larger areas with many more devices.
3) Based on the two points above, cost for the proposed system is thought to be lower than for a model-based Volt/VAR management system. Control, information, and communication technology cost depends largely on distance and solutions for shorter distances (smaller control systems with less communication technology) can achieve considerable cost reductions.
4) Scalable and Flexible: Since control is zone-based, the solution allows for gradual addition (or removal) of new control zones.

It must be noted that detailed techno-economic analysis is outside scope of paper. The following sections describe the coordination control hierarchies, as well as when and how zones are combined according to the adaptive zoning concept.

A. Control Hierarchies

Control hierarchies determine in what order the devices within a zone should contribute to voltage regulation in case of a disturbance such as a sudden load increase or a DG output change. For all regulation action, it is assumed that we want to maintain voltage within some limits. These limits could be the ±10% of the EN 50160 standard or they could be defined by the local utility standards. There is a different control hierarchy for each combination of shunt devices. If a series device is present in the zone, a separate logic is used to determine the control action. All control hierarchies have similar structures (Fig. 4): there are two different control hierarchies depending on device distance from the critical node (devices are at the same distance or at different distances from the critical node). Control layer 1 represents the control action that should be carried out first, layer 2 the control action that should be carried out if the first action cannot fully compensate the voltage change, layer 3 is activated if the second control action is insufficient, and so on. The control hierarchies are created based on the principles listed below.

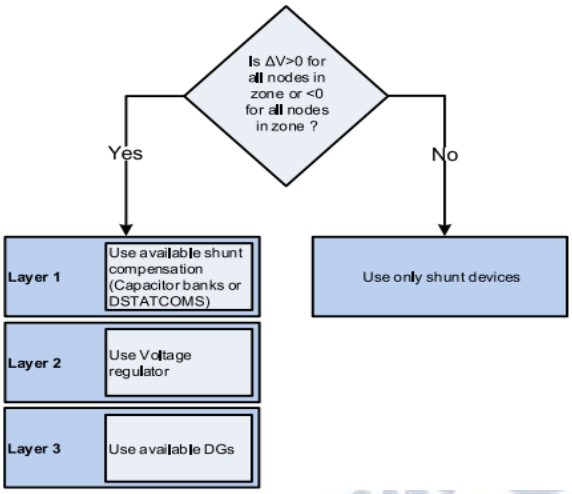


Fig. 5. Logic for coordination of shunt and series devices.

1) Of all shunt regulation devices in a zone located at the same distance from the critical node, the DGs should regulate last.
2) If shunt devices are located at different distances from the critical node, the closest device should regulate first.
3) Local shunt regulation should always be used before series regulation in a zone with both shunt and series devices, since this minimizes reactive power flows. The exception is DGs that should regulate after both conventional shunt regulation and series regulation devices have been used. In some cases, OLTC duty might be reduced if DGs would adjust reactive power output before OLTCs are used. However, the suggested method assumes that DGs are prioritized to supply active power, which is why other voltage regulation devices are activated first. An example of a control hierarchy for a zone with only shunt devices (in this example DGs and capacitor banks) is presented in Fig. 4. (The control hierarchy assumes that all capacitor banks are disconnected before disturbance and that all DGs are in P_{ref} mode.) The control logic for a zone containing both shunt and series devices is presented in Fig. 5.

B. Adaptive Zoning

This section describes the following. 1) Definition and location of different types of zones; 2) what conditions zones should be combined; 3) voltage regulation strategy for combined zones; and 4) practical considerations of adaptive zoning. Zones can be located in series or in parallel. An OLTC or a VR separates two zones located in series, whereas zones in parallel are connected to the same PCC. (Parallel parts of feeders with the same PCC do not always have to be in separate zones. This depends on the length and the impedance of the feeder parts and whether there is any regulation devices located along them.

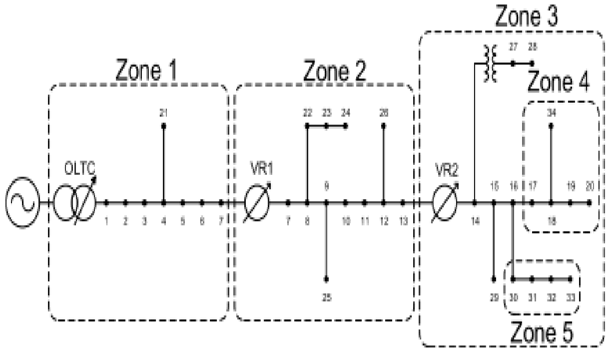


Fig. 6. IEEE 34-node test feeder divided into zones.

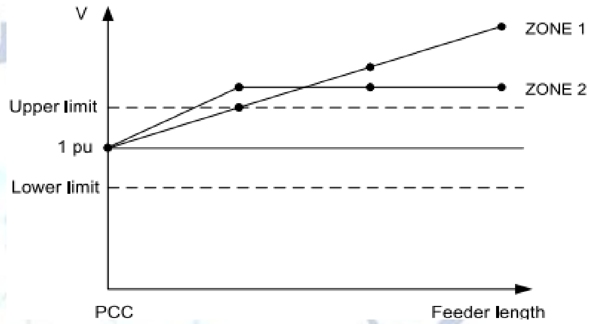


Fig. 7. Two parallel zones that should be combined according to adaptive zoning.

Fig. 6 shows the modified IEEE 34-node test feeder, which is divided into three zones in series according to these principles (Zones 1–3). Zone 3 also contains two parallel zones (Zones 4 and 5). Combining zones means that the decentralized Volt/VAR control schemes are coordinated. Zones are combined when certain requirements are fulfilled about voltage deviations at nodes within the zones. The requirements differ for zones located in parallel and in series. Parallel zones are combined if $\Delta V > 0$ (i.e., a voltage rise) at all nodes in both zones and$\Delta V < 0$ (i.e., a voltage drop) at all nodes in both zones, and at least one node is outside voltage regulation limits in both zones. Voltage needsto be regulated in the same direction in both zones and itis therefore possible to use a regulation device at or very close to the PCC, in addition to the devices within the zones. Fig. 7 shows an example of two zones in parallel that should be combined: Zones 1 and 2 consist of two parallel feeders with three nodes each and voltage is outside limits in both zones.

The prerequisite for combining two zones in series is that voltage is outside regulation limits at one or more nodes in both zones. If voltage is outside limits in only one of the zones, regulation should be carried out within the individual zone with available shunt devices. Even in the case when zones in series are combined, conventional shunt devices should be used prior to OLTCs or VRs. As a last option, available DGs can be used for voltage regulation.

To be able to know when to combine zones, voltage has to be monitored at many nodes in the distribution system.

However, it should not be necessary to monitor voltage at all nodes. Nodes where critical loads, DGs, or regulation devices are connected should always be equipped with monitor and communication possibilities. Depending on the network configuration, also other important nodes can be selected for monitoring.

When implementing adaptive zoning, a number of practical aspects will have to be considered.

1) Zone Division: Zones might not always be divided by a VR/OLTC or at a PCC of parallel feeders. Electrical distance needs to be considered when defining zone boundaries and a radial feeder might be divided into two zones without a VR/OLTC being located somewhere along it, at the point of maximum reach of reactive compensation devices.

2) Control Zone Addition/Reprogramming: To avoid having to reprogram the control hierarchies at the addition of each new DG unit, several DGs should be added at the same time. Until DGs are added to the control system they have to work in traditional curtailment mode and have to be treated as passive network components. If enough DGs and/or voltage regulation devices are added to a part of the grid that is not yet part of the adaptive zoning system, a new zone can be created and coordinated with adjacent zones.

3) Control Center Location: An important practical consideration is where to place the control centers for each zone and which control centers should be responsible for combining zones when feasible. The distribution control center will be implemented in the substations and depending on the substation location a higher one might lead the instructions. However, the control instructions go through the lower control center. The combination is only done in terms of control logic.

4) Dynamic Network Topologies: In meshed distribution grids that can switch network topology for protection purposes, these possible topology changes and how they affect zone boundaries need to be taken into account. Where this is the case, it adds some complexity to the concept. However, since the number of alternative grid topologies in distribution networks usually is very limited, so is the impact on complexity of the control schemes.

5) Third Party Ownership: Third party DG owners must be prepared to allow utility access to and control of their DG units. As mentioned, it is in this paper assumed that a tariff system in place that reimburses DG owners for reactive as well as active power, but the details of such a system are outside the scope of this paper.

C. Systems with Intermittent Energy Sources

Power output from intermittent DGs varies and therefore, the impact from the DGs on line power flow as well as line voltage. While the real-power deficiency is tackled with main grid, storage, and load shedding, reactive power shortage is primarily solved with other distribution equipment as described. If the fluctuation is below the Volt/VAR management control bandwidth, storage is one of the key components used to compensate for that. A high penetration of DGs with variable power thus requires more storage for leveling and firming. One possible storage product for such scenarios is PowerStore, which injects real and reactive power based on continuous frequency and voltage fluctuation. Furthermore, in the proposed control method DGs can actually compensate their own sudden power output changes by adjusting the relation between active and reactive power output. For slower variations of power flow and voltage (within bandwidth and beyond time delays), the capacitors and regulators participate in reactive support and voltage profiling. With advanced switched capacitors and power electronic tap changers it is possible to achieve a much improved device control for the proposed method in those scenarios. Advanced capacitor banks are available with a power circuit breaker, protection and control panel (e.g., ABB Modular Capacitor Bank) and there are some capacitors for variable load application. These offer power factor compensation and reduction of voltage drops with transient-free switching and advanced communication features, among other things. Power electronics tap changers are still in research and not yet commercially available. The main advantage is lower losses and four quadrant operation. These tap changers can work much faster, without significant jitters and can easily be integrated to Volt/VAR management system solutions via communications. Further information can be found.

D. Selection of Controllers

It must be noted that the controller selection for regulators, OLTCs, capacitor bank has significant impact on the Volt/VAR control of the proposed method. The most important settings for the regulators are set voltage, bandwidth, time delay, andline compensations. A brief discussion of these settings forthe proposed method is given below.

1) Set Voltage: The set voltage for each of the regulators is calculated based on the distribution transformer ratio, VR ratio, and the base voltage. The set voltage is controlled through the VR ratio and it must be ensured that the set voltage stays in the middle of the acceptable voltage range. In special scenarios for feeders with more overvoltage or LV problem, the set voltage can be set to achieve the total VR bandwidth.

2) Bandwidth: The bandwidth is the voltage range around set voltage, which the regulator can control. Usual 5/8% taps from minimum 2 to 32 taps are used to cover the bandwidth. The bandwidth setting in a multi zone system decides which regulator would respond first for a voltage deviation. In the proposed method, if the regulators are in series the regulator bandwidth can be controlled in two ways. In the first method, the regulator higher up in the distribution system will have lower bandwidth than the downstream one, and will thus react first. This ensures the headroom in the down zone with the second regulator. The alternative would be to have decreasing bandwidth from substation down along the feeder, so that the regulator furthest out always reacts first. In some cases the disadvantage would be frequent limit-hitting of the downstream regulator. It must be noted that the actual setting of the bandwidths for the distribution system must be selected based on the DGs, loads, and capacitors connected. It must be noted that in either case, the proposed zone-based control can be adopted to solve the Volt/VAR management within a zone and depending on the current tap positions of the regulators, they can be coordinated to provide the reactive support.

3) Time Delay: The time delay is the delay in seconds that the regulator control waits after the voltage deviation before tap change, to avoid the transient voltage fluctuation. In case of series operation of regulators, time delays can be set in two ways as bandwidth. Having the substation regulator responding first would help the feeder regulator to have the headroom after correction. On the other hand, a faster feeder regulator would first work locally. This may be effective in many situations with frequent local voltage variation (e.g., an intermittent DG with variable power output).

4) Line Compensation: Line compensation may be used if the regulators are intended to control voltage at some particular point down the feeder. But for local voltage control of the regulator no line compensation is used. Both types can be used for zone-based control. It must be noted that in this paper line compensation has not been used. If line compensation is used, it is important to adapt the compensation factor while combining the zones and regulating a voltage at a different point depending on the distance and line impedance.

5) Operating Modes: There are various operating modes possible with the VRs. With the proposed method and in presence of DGs, the VR operates in bidirectional or cogeneration mode depending on the DG owners. For a third-party power producer the VR is operated in cogeneration mode. As in this paper, all the DGs are assumed either to be owned by a utility or integrated to the DSO energy management system and only bidirectional mode is considered.

The capacitors in this paper are controlled based on the local voltage measurement for VAR support. They are automatically switched in in heavy load period and switched off at light load period. They can be also controlled with local or remote control, voltage or temperature override, adjustable over and under voltage settings and different operations counters. In the proposed method, the capacitors are switched in before DGs to improve local voltage, as the main aim for the DGs is to provide active power. The actual parameter selection will largely depend on the system structure. The key steps in the controller setting are as follows.

1) Forming the set voltages in the different zones based on load, DGs, and connected grid.
2) The set voltages can vary within the acceptable voltage in the network and desires reactive power flow.
3) Setting the bandwidths so the feeder controller reacts first during disturbances at feeder end.
4) Capacitors, DGs, and other regulation devices are also set with control bandwidth to act based on hierarchy to inject the reactive power at the connected node.
5) Time delays are set accordingly to control the activation time of each controller.
6) The controller settings are adapted while combining two or more zones into one.

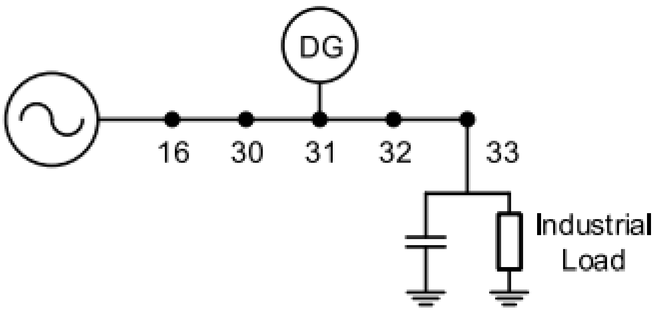


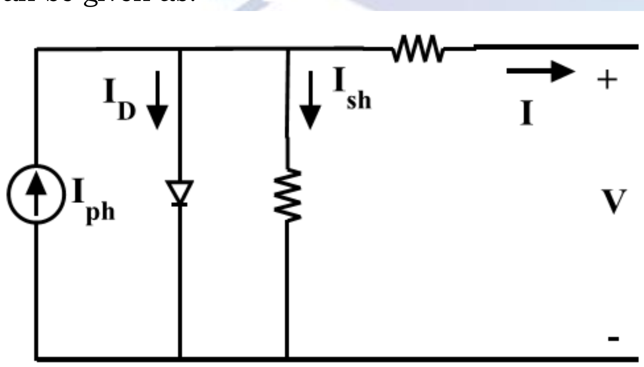
Fig. 8. Added devices for control hierarchy simulation.

V. Photovoltaic, Fuel Cell Operation and Hybrid Fuzzy

A photovoltaic system, converts the light received from the sun into electric energy. In this system, semi conductive materials are used in the construction of solar cells, which transform the self contained energy of photons into electricity, when they are exposed to sun light. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power [9]. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high.

PV array are formed by combine no of solar cell in series and in parallel. A simple solar cell equivalent circuit model is shown in figure. To enhance the performance or rating no of cell are combine. Solar cell are connected in series to provide greater output voltage and combined in parallel to increase the current. Hence a particular PV array is the combination of several PV module connected in series and parallel. A module is the combination of no of solar cells connected in series and parallel.

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.1.4 manifests the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.



Equivalent circuit of Single diode modal of a solar cell

$$I = I_{PV} - I_0\left[\exp\left(\frac{V+IR_S}{aV_T}\right)-1\right]-\left(\frac{V+IR_S}{R_P}\right)$$

Where

IPV–Photocurrent current,

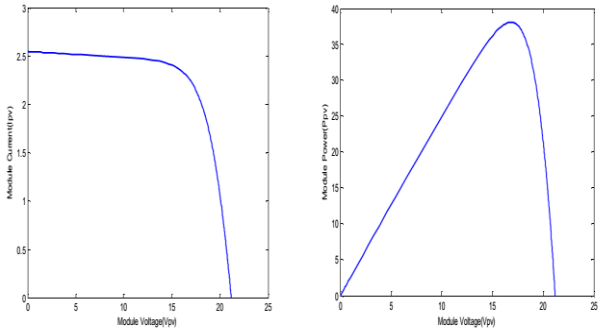
IO–diode's Reverse saturation current,

V–Voltage across the diode,

a– Ideality factor

VT –Thermal voltage

Rs – Series resistance Rp –Shunt resistance



Fuel Cell Operation:

Pressurized hydrogen gas (H_2) enters cell on anode side. Gas is forced through catalyst by pressure. When H_2 molecule comes contacts platinum catalyst, it splits into two H+ ions and two electrons (e-). Electrons are conducted through the anode. Make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell. On the cathode side, oxygen gas (O_2) is forced through the catalyst Forms two oxygen atoms, each with a strong negative charge. Negative charge attracts the two H+ ions through the membrane, Combine with an oxygen atom and two electrons from the external circuit to form a water molecule (H_2O).

How a fuel cell works: In the polymer electrolyte membrane (PEM) fuel cell, also known as a proton-exchange membrane cell, a catalyst in the anode separates hydrogen atoms into protons and electrons. The membrane in the center transports the protons to the cathode, leaving the electrons behind. The electrons flow through a circuit to the cathode, forming an electric current to do useful work. In the cathode, another catalyst helps the electrons, hydrogen nuclei and oxygen from the air recombine. When the input is pure hydrogen, the exhaust consists of water vapor. In fuel cells using hydrocarbon fuels the exhaust is water and carbon dioxide. Cornell's new research is aimed at finding lighter, cheaper and more efficient materials for the catalysts and membranes.

Fuel Cells Working

A single fuel cell consists of an electrolyte sandwiched between two electrodes, an anode and a cathode. Bipolar plates on either side of the cell help distribute gases and serve as current collectors. In a Polymer Electrolyte Membrane (PEM) fuel cell, which is widely regarded as the most promising for light-duty transportation, hydrogen gas flows through channels to the anode, where a catalyst causes the hydrogen molecules to separate into protons and electrons. The membrane allows only the protons to pass through it. While the protons are conducted through the membrane to the other side of the cell, the stream of negatively-charged electrons follows an external circuit to the cathode. This flow of electrons is electricity that can be used to do work, such as power a motor. On the other side of the cell, air flows through channels to the cathode. When the electrons return from doing work, they react with oxygen in the air and the hydrogen protons (which have moved through the membrane) at the cathode to form water. This union is an exothermic reaction, generating heat that can be used outside the fuel cell.

Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and potentially useful heat as the only byproducts. Hydrogen-powered fuel cells are not only pollution-free, but also can have more than two times the efficiency of traditional combustion technologies. The power produced by a fuel cell depends on several factors, including the fuel cell type, size, temperature at which it operates, and pressure at which gases are supplied. A single fuel cell produces barely enough voltage for even the smallest applications. To increase the voltage, individual fuel cells are combined in series to form a stack. (The term "fuel cell" is often used to refer to the entire stack, as well as to the individual cell.) Depending on the application, a fuel cell stack may contain only a few or as many as hundreds of individual cells layered together.

Hybrid Fuzzy:

This paper investigates two fuzzy logic controllers that use simplified design schemes. Fuzzy logic PD and PI controllers are effective for many control problems but lack the advantages of the fuzzy controller. Design methodologies are in their infancy and still somewhat intuitive. Fuzzy controllers use a rule base to describe relationships between the input variables. Implementation of a detailed rule base increases in complexity as the number of input variables grow and the ranges of operation for the variables become more defined. We propose a hybrid fuzzy controller which takes advantage of the properties of the fuzzy PI and PD controllers and a second method which adds the fuzzy PD control action to the integral control action.

The effectiveness of the two PID fuzzy controller implementations, PD and PI fuzzy controllers have the same design disadvantages as their classical counterparts. Therefore, in some cases a fuzzy PID controller maybe required. The fuzzy PID controller entails a large rule base which presents design and implementation problems. First, a reduced rule fuzzy PID scheme was implemented to take advantage of both PD and PI control actions. Some further research is required for the process of switching between the control actions. The second fuzzy PID control scheme used only the PD portion with an integral term added to eliminate steady-state error. Results from simulations of both control schemes demonstrate the effectiveness of the PID controllers.

VI. MATLAB/SIMULATION RESULTS

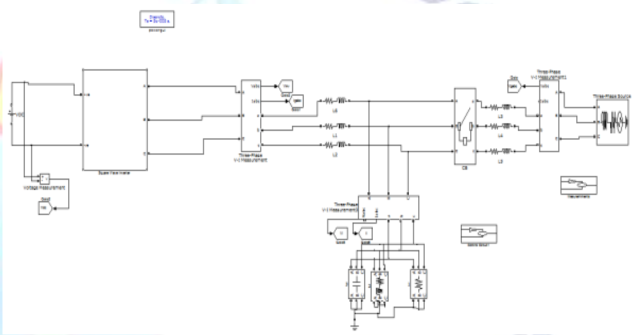


Fig 9 Matlab/simulation circuit of Control scheme of a DG in power reference (Pref) mode.

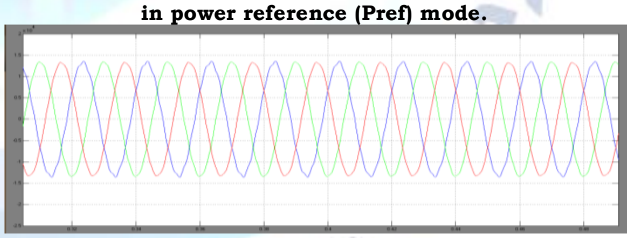


Fig 10 simulation wave form of output line voltage

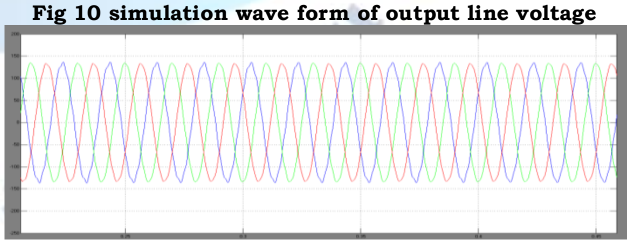


Fig 11 simulation wave form of output line current

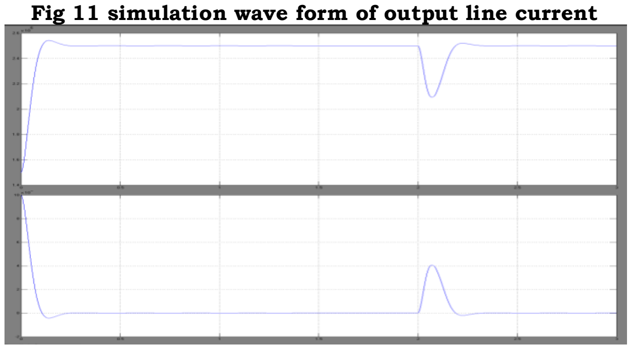


Fig 12 simulation wave form of active and reactive power

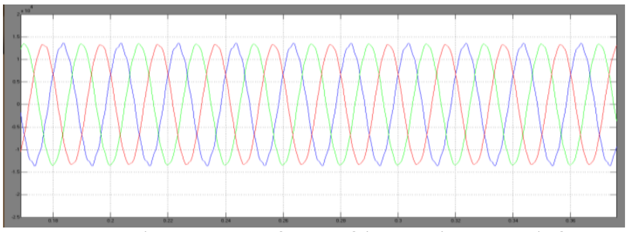


Fig 13 simulation wave form of line voltage with fuzzy controller

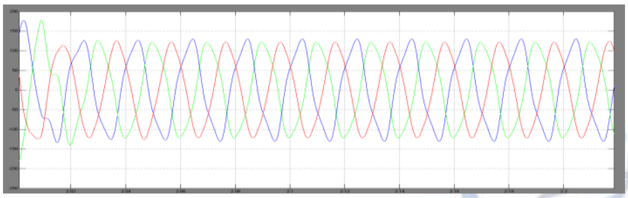


Fig 14 simulation wave form of line current with fuzzy controller

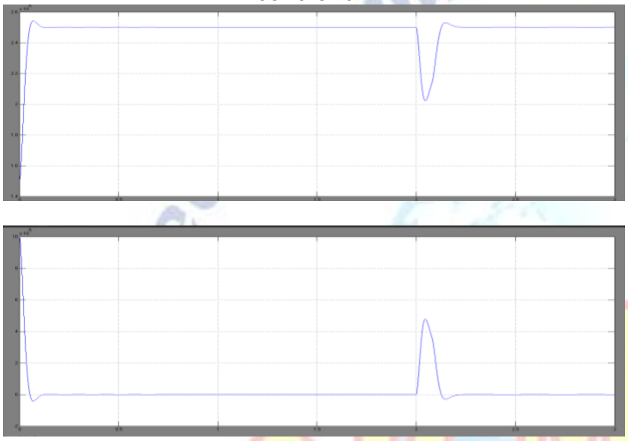


Fig 15 simulation wave form of active and reactive power with fuzzy controller

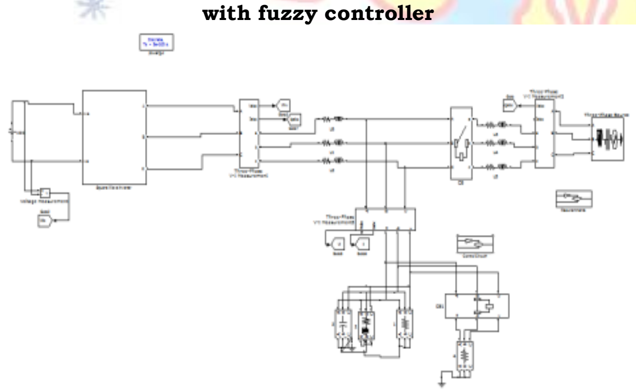


Fig 16 Matlab/simulation circuit of Control scheme of a DG in power reference (Pref) mode with different load

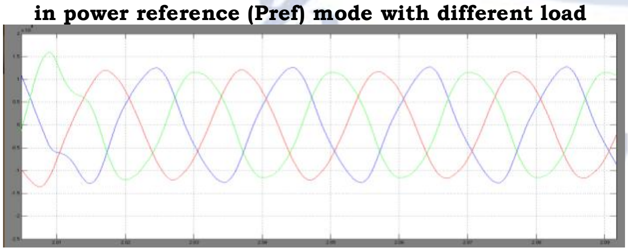


Fig 17 simulation wave form line voltage with different loads

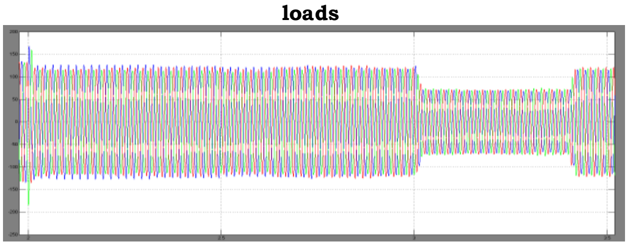


Fig 18 simulation wave form line current with different loads

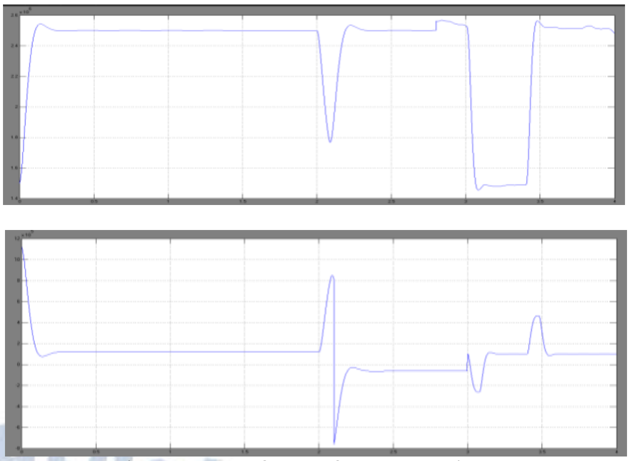


Fig 19 simulation wave form of active and reactive power with different loads

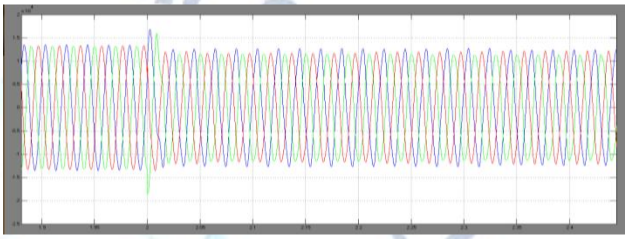


Fig 20 simulation wave form of line voltage with fuzzy controller

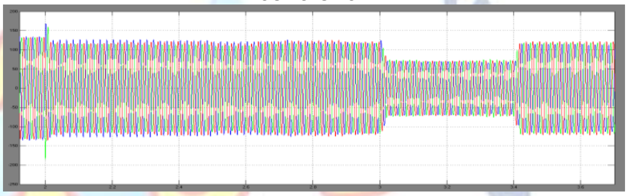


Fig 21 simulation wave form of line current with fuzzy controller

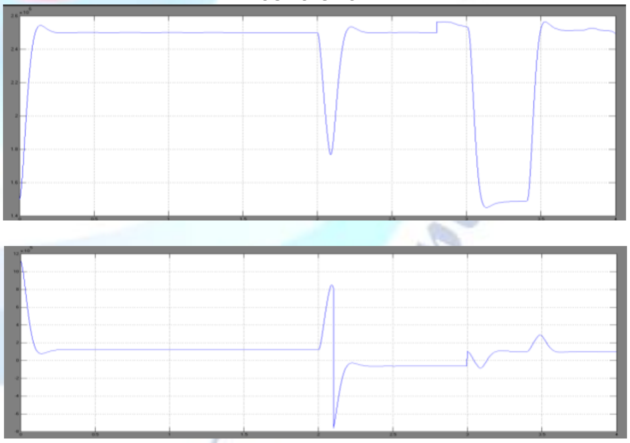


Fig 22 simulation wave form of active and reactive power with different loads with fuzzy logic

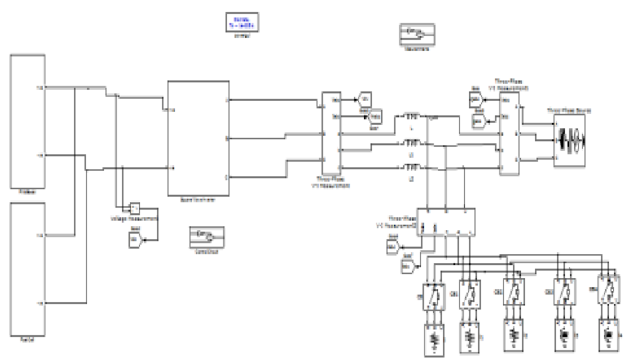


Fig 23 Matlab/simulation circuit of Control scheme of a REC in power reference (Pref) mode with hybrid fuzzy

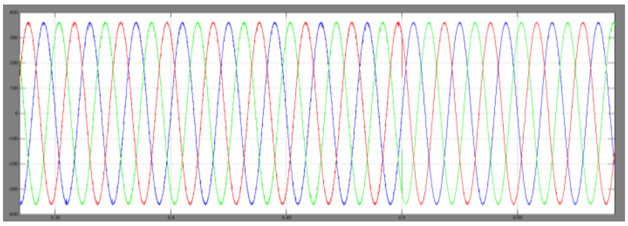


Fig 24 simulation wave form of grid voltage with REC hybrid fuzzy

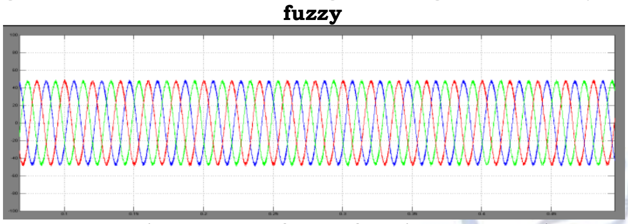


Fig 25 simulation wave form of grid current with REC hybrid fuzzy

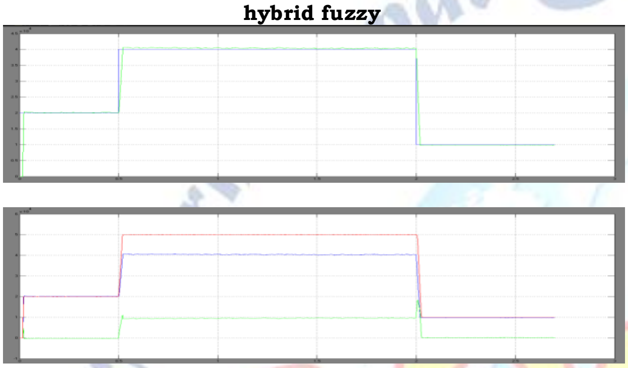


Fig 26 simulation wave form of active and reactive power with REC hybrid fuzzy

VII. Conclusion

The conventional control of OLTCs, which relies on a fixed target point, does not take into account the DG effect which complicates the voltage regulation due to reverse power flow and voltage estimation difficulties. In short, DG units start fixing the voltage violation by controlling their reactive powers. Then, if the problem still exits, due to DG reactive power limits, the proposed system OLTC controller starts to solve the problem if the solution is feasible with different load condition. In case of an infeasible solution, DG units curtail their active powers to restore a feasible solution from the OLTC prospective. In this paper a decentralized, adaptive zone-based Volt/VAR management solution is proposed, which coordinates active participation of DGs with conventional voltage regulation equipment. It is shown that DGs can successfully contribute to voltage regulation in the distribution grid, and this reduces the negative impacts on distribution system operation that prevent an increased DG penetration.

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