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Steady State Voltage Rise and Its Control in Distribution System with Distributed Generation

D. N. Gaonkar*[1], G. N. Pillai+, and R. N. Patel#

Abstract *– The continued interest in the use of distributed generation in recent years is leading to the growth in number of distributed generators connected to distribution networks. Steady state voltage rise resulting from the connection of these generators can be a major obstacle to their connection at lower voltage levels. The present electric distribution network is designed to keep the customer voltage within tolerance limit. Thus distribution network operators (DNO) need proper voltage regulation method to allow the significant integration of distributed generation systems to existing network. The aim of this paper is to examine the voltage rise problem in practical radial feeder and present the conventional and emerging developments in steady state voltage regulation methods used for distribution network with distributed generation (DG) system.*

Keywords – Distributed generation, microgrid, reactive power control, voltage regulation.

1. INTRODUCTION

The combination of utility restructuring, technology evolutions and recent environmental policies are providing the basis for DG system to progress as an important energy option in the present scenario. This is resulting in integration of large number of distributed generation systems to utility network. Distributed, embedded, or dispersed generators are generally defined as a plant which is connected directly to utilities distribution network or can operate independently. They are generally considered to be less than 100MWin capacity and are not centrally planned or dispatched. Distributed generation can be based on renewable technologies such as wind turbine, photovoltaic or recent promising non-renewable technologies such as microturbine and fuel cell. The term distributed generation is sometimes used interchangeably with the term distributed energy resources (DER). DER is intended to encompass non-generating technologies such as power storage devices like batteries, super capacitors and flywheels in addition to generators [1].

The impact of DG integration to the distribution network can be positive or negative depending on the operating conditions of the distribution system and DG [2]-[6].The positive impacts include improved power quality and reliability, environmental benefits, loss reduction, transmission and distribution support. Achieving these benefits in practice is much more difficult than often realized [2]. This is due to fact that, the ability of the existing system to integrate this form of generation is characterized by several technical problems. Hence, special requirements for connecting DG to the utility grid are critical to ensure safe and reliable operation [2], [3].With the large number of DG connected to distribution network, the unidirectional nature of the power flow in distribution system can be changed. This has significant effect on voltage regulation, the behavior of the system during faults, system protection, and safety procedures [4]-[6].

One of the main technical obstacles against installation of large amounts of distributed generation is the steady state voltage rise and its control. This is very important as keeping customer voltages with in the tolerance dictated by statute is always been a top priority for utility [5]. The range of voltage which must be met under a number of different standards does not exceed ±10%, with some standards being even tighter than this [6], [7]. Certain types of modern customers are more sensitive to voltage excursions outside statutory defined limits as they are vulnerable to financial loss when such excursions occur. Present network design practice is to limit the generator capacity such that the upper voltage limit does not exceed with maximum generation and minimum load. This may require a reduction in connectable generation capacity, under utilization of appropriate generation sites, and shortfalls in new generation capacity which has to be compromised with [6]. The existing voltage control equipment were designed and operated based on a planned centralized generation and on the assumption that the current always flows from the substation to the medium voltage (MV) system, and then to low voltage (LV) customers; and that the Voltage level go on decreases towards end of the feeder. The introduction of DG in distribution network makes this assumption no longer valid [5], [7]. DG generally will increase voltage at its connection point, which may cause over voltage during low load conditions [8].Thus they need proper modifications or new techniques or a method has to be adopted.

This paper examines the voltage rise problem in a typical practical distribution network with DG. An attempt has been done to provide an up-to-date survey of the research effort in providing new solutions or improving conventional methods to regulate the voltage rise for successful introduction of DG to distribution network. This will help in further research in this direction. The microgrid concept of integration of DG system is also presented.

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2. STEADY STATE VOLTAGE RISE

When generator is connected to the radial feeder, its active power export reduces the power flow from the primary substation and so reduces the voltage drop along the feeder. If the generator power export is larger than the feeder load, power flows from the generator to the primary substation and this causes a voltage rise along the feeder. Typically, worst case scenarios are: a) no generation and maximum system demand, b) maximum generation and maximum system demand, c) maximum generation and minimum system demand. In the context of the voltage rise effect, minimum load - maximum generation conditions are usually critical for the amount of generation that can be connected [7]. However, it may also be necessary to consider maximum load – maximum generation conditions.

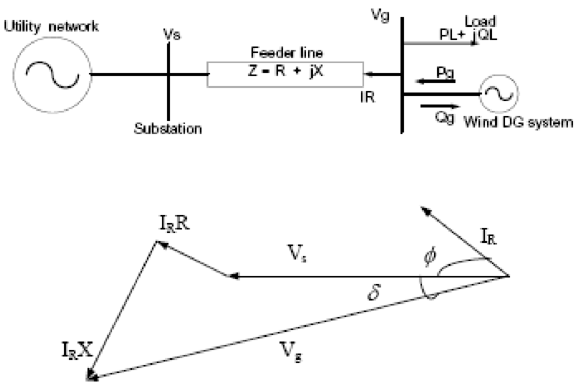


Fig. 1. Voltage rise from a typical distributed generator

Figure 1 illustrates a connection of typical wind power generator consisting of the induction machine and wind turbine to the distribution network. The active and reactive powers of the wind generator are P_g and Q_g respectively; P_L and Q_L represent the active and reactive power of the load connected to the distribution system. I_R is the net current through the line impedance Z = R + jX and SR the net power supplied. The substation voltage and connection point voltage are V_s and V_g, respectively.

$$S_R = P_R + jQ_R = P_g - jQ_g - P_L - jQ_L \quad (1)$$

$$S_R = V_g I_R^*, \quad I_R = (P_R - jQ_R)/V_g^* \quad (2)$$

$$V_g = V_s + I_R Z \quad = V_s + (R + jX)(P_R - jQ_R)/V_g^*$$

$$= V_s + (P_R R + XQ_R)/V_g^* + j(P_R X - Q_R R)/V_g^* \quad (3)$$

Considering the phasor diagram in Figure 1 gives:

$$V_g \sin\delta = (P_R X - Q_R R)/V_s \quad (4)$$

Since the voltage angle δ is very small,

$$(P_R X - Q_R R)/V_s$$

The above term is also very small and the magnitude of voltage rise ΔV is approximately given by:

$$(P_R R + XQ_R)/V_g^*$$

or alternatively

$$\Delta V = ((P_g - P_L)R - X(Q_g + Q_L))/V_g^* \quad (5)$$

The above equation gives the steady voltage rise magnitude for wind power DG System. Figure 2 shows the typical five bus practical radial feeder considered for study. In case of a radial system the voltage level decreases along the feeder from supply end to the end of the feeder. The voltage for bus number (n+1) for the radial system considered for the study is determined by (6) and the corresponding voltage profile for the feeder is shown in Figure 3. Figure 4 shows that if the generator is connected at bus no. 4 with its full capacity, the voltage rise is above the limit at the connection point.

$$\overline{V_{n+1}} = \overline{V_1} - \sum_{k=1}^{n} \frac{(R_k + jX_K)(P_{k+1} - jQ_{k+1})}{\overline{V^*_{k+1}}} \quad (6)$$

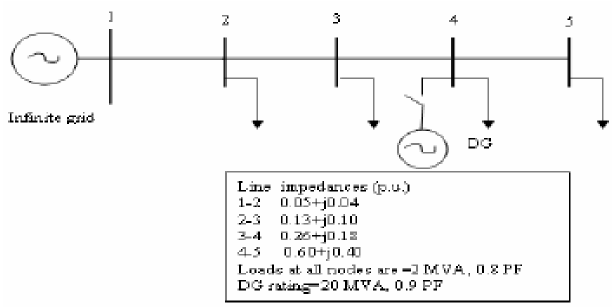


Fig. 2. A trypical radial network

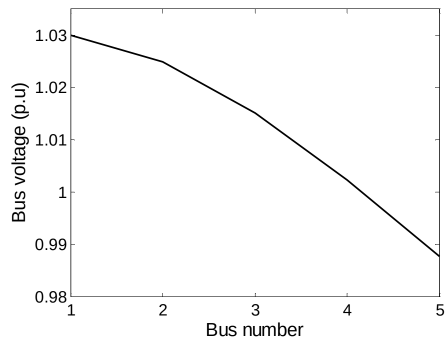


Fig. 3. Bus voltage without DG connection

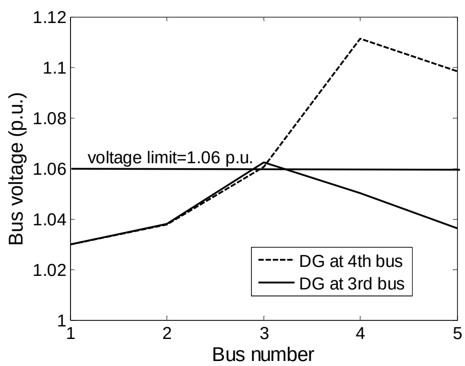


Fig. 4. Bus voltages with DG connected at the 4th bus and 3rd bus

The level of generation that can be absorbed onto the distribution system is determined by many factors, such as voltage level, voltage at the primary substation, distance from the primary substation, size of conductor, demand on the system, other generation on the system and operating regime of the generation [7], [8]. Figure 4 shows that if DG is connected at bus no. 3, the voltage rise will be slightly above the limit but lesser than when it is connected at bus no. 4. It can be observed from Figure 4 that rise in the voltage level is maximum at DG connecting point; another observation is that voltage rise level will be high with increase in distance of DG connection point from the supply point of the feeder (i.e. substation).

3. GENERATION TECHNOLOGY

Three different generator technologies are used for DG: synchronous generator, induction generator and power electronic converter interface. Synchronous generators are typically utilized by the following DG technologies: internal combustion, engines, gas turbines and combined cycle gas turbines (CCGTs), solar thermal, biomass and geothermal. Synchronous generators have the advantage that they can be controlled to provide reactive power by adjusting their excitation. Induction generators are extensively used in wind farms and small hydroelectric plants [9]. Synchronous generators are not common in wind farms, because a synchronous generator works at a constant speed related to the fixed frequency, which is not well suited for variable-speed operation in the wind farms. Induction generator combined with a converter interface is currently becoming common in wind power DG. The induction generator connected to the grid draws reactive power from the network. DG interfaced with power electronic converters is used in solar photovoltaic generation, fuel cells, and microturbine as well as battery storage systems. Different designs for power electronic converters used for DG exist. DG interfaced with power electronic converters can control their reactive and active power output. The interfacing topology of prominent DG source to grid is shown in Figures 5 and 6. DG system with several other topologies can be found in [9], [10].

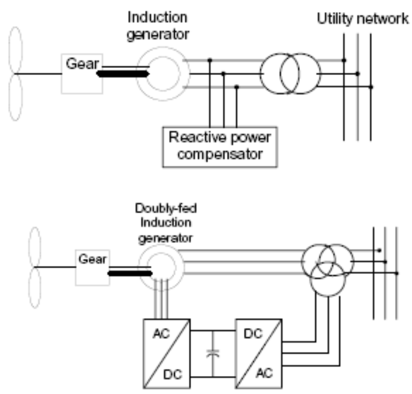
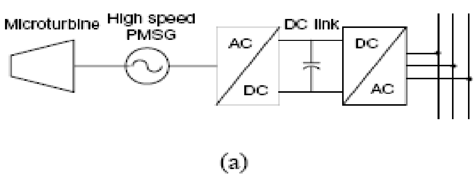


Fig. 5. Wind generation topologies: (a) with induction generator (b) doubly-fed induction generator



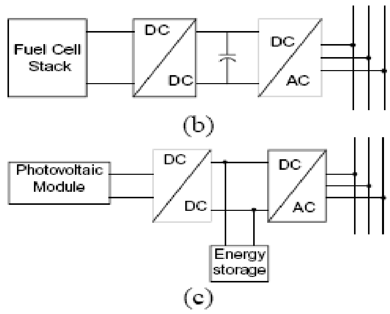


Fig. 6. (a) Single shaft microturbine generation system, (b) Fuel cell generation system, (c) Photovoltaic generation system

4. METHODS FOR STEADY STATE VOLTAGE REGULATION

If the connection of a DG to distribution network causes an excessive voltage rise [11], there are number of methods that can be employed to alleviate the situation. The system presented in Figure 7 illustrates the facilities that can be used to compensate voltage rise effect.

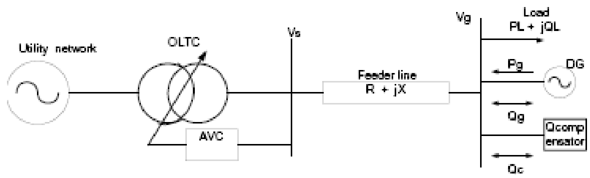


Fig. 7. A simple system illustrating the options for voltage rise effect compensation

A distributed generator, DG (PG, QG), together with a local load (PL, QL) and a reactive compensator (QC), are connected to the distribution system (DS) via a distribution overhead line with impedance Z and an on-load tap changer (OLTC) transformer [12]. In the Figure 7 rotating machine based DG system is shown. Similarly, in case of power electronic interfaced DG systems as shown in Figure 6, the interfacing circuit can be used as facility to control. The methods can be given as follows:

1. Reduction of line impedance
2. Reduction in substation voltage
3. Voltage control by AVC using regulating transformers
4. Reactive power management
5. DG reactive power control
6. DG active power control
7. Coordination of the above methods and other innovative techniques.

Reduction in line impedance is usually achieved by upgrading the distribution feeder through reinforcement. Study presented in [7] shows that it is an effective method. However replacing the conductors will be expensive and make the scheme uneconomic. The DNO can reduce the set point voltage at the primary substation, thus reducing voltage further down the feeder. However, owing to the variability of the renewable energy sources and non-dispatchable nature of the DGs, the possibility of loss of generation cannot be neglected. Should this happen, the voltages would be further reduced, perhaps below the statutory limits. One of the technique which is generally followed is constraining the operation (reducing the output level) of the connected distributed generator. Figure 8 shows the bus voltages when DG is operating at 50% of its output. In this case voltage rise is within the limits. But this method reduces the efficiency.

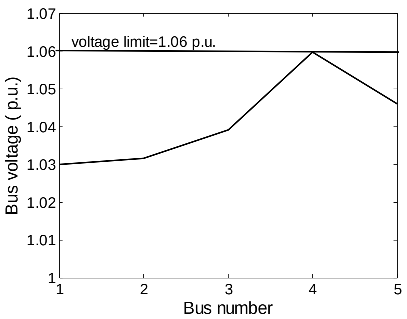


Fig. 8. Bus voltages with DG connected at the 4th bus with 50% output

Voltage Control by AVC Relay Using Regulating Transformers

Traditionally distribution system voltage is regulated using various regulating transformers, the most common being the on load tap changing (OLTC) transformer. Figure 9 shows basic OLTC arrangements. Each OLTC has an associated automatic-voltagecontrol (AVC) relay which in the simplest case monitors the voltage of the transformer secondary and instructs the tap changer to tap up or down as required [13], [14]. A dead band is included and must be adjusted to be slightly larger than the transformer step size to prevent hunting. The presence of distributed generation causes the reduction, or possibly reversal, of real power flow through the distribution feeder. This change in power flow will effect the operation of AVC relay. These effects are highly dependent on the configuration and settings of the relays. The voltage drop caused due to variation in load current in distribution system is compensated in AVC relay through different compensation methods. The compensation methods can be line drop compensation (LDC), true-circulating-current detection and negative reactance compounding [13]. Line-drop compensation technique is used to keep the voltage constant, at some remote end of the feeder. Figure 10 shows basic arrangements of OLTC with LDC.

The effect of the operating strategies of a remotely connected generator have on the voltage profile of a long associated 11 kV feeder has been investigated in [15]. In this paper authors are particularly investigated the use of such connected generator to help the associated AVC relay to keep network voltages and voltage at the connection point of the generator, within the statutory limits. Two operating strategies have been considered. These are constant power factor mode and constant voltage mode of operations the amount of reactive power which has to be handled by the generator in constant voltage mode is found to be considerably reduced if the generator is connected to the system via a transformer and when source voltages are not excessive.

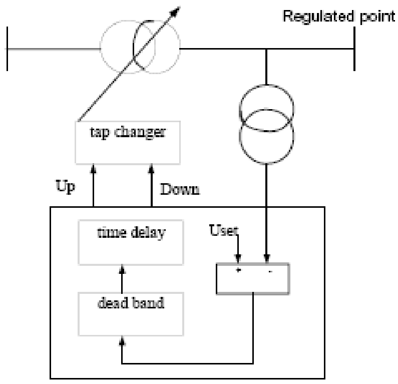


Fig. 9. Basic OLTC arrangements

A new method for determining the introduction limit, when DGS is introduced into distribution system of which the voltage is generally controlled by LCT (Load-tap Changing Transformer) and LDC (Line Drop Compensation) is presented in [16]. The relations among the sending end reference voltage, power factor and capacity of DGS are used to determine the introduction limit of DGS from the viewpoint of voltage regulation. Two approaches are presented to determine the limit, one is using the equation of real and reactive power of DGS and the other is using the equation of real power and power factor of DGS. This method is applied to a 22.9 kV class power distribution system, and its validity is proved through the simulation results [16]. A new voltage regulation coordination method of DGS (Distributed Generation System) for proper voltage regulation in distribution system using LCT (Load tap Changing Transformer) and LDC (Line Drop Compensator) is proposed in [17]. In this method DGS coordinates with the distribution system voltage regulation by controlling its reactive power output according to its real power output. The method is applied to power distribution system model, and its effectiveness is verified through simulation results.

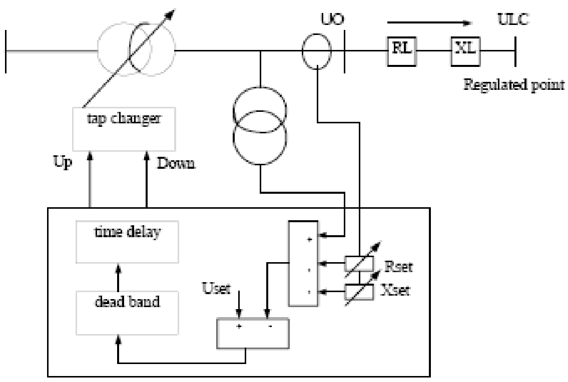


Fig. 10. OLTC with line drop compensation

An attempt has been made to design an AVC relay based on the application of Artificial Neural Network (ANN) in [18]. It was found that the proposed ANN-based AVC relay has the ability to properly control voltage magnitude of distribution network as load changes. In this method performance of the relay is not affected by the connection or disconnection of DG. Consequently, no readjustment of the relay is required compared to conventional AVC relay. However using ANN-based AVC relay method needs reliable data for the training of ANN, which is not easy to obtain [19]. The voltage control using AVC relay in association with on-load tap changing transformer and with different compensation methods such as, line drop compensation, true-circulating-current detection and negative-reactance compounding are dealt in detail in the context of integration of DG system in [13], [14]. In these papers modification required for the existing compensation techniques are also discussed.

The effect of unbalanced load diversity among feeders on the conventional LDC voltage regulation method is analyzed in [20]. A new voltage regulation method MLDC (Multiple Line Drop Compensation**)** is proposed considering the unbalanced load diversity among feeders, the random operations of DGS, and the hysterical tap changing mechanism of ULTC (Under Load Tap Changer). Case study presented show that MLDC method is more accurate and flexible than that of conventional LDC method. In [21] evaluations of various existing voltage regulation methods are done to accommodate distributed generation without degrading network voltage.

An efficient approach for Volt / VAr control in radial distribution networks considering DGS performance has been presented [22]. This approach minimizes power losses at distribution system through controlling of OLTC, size of substation capacitor, local controller settings and voltage amplitude of DGs. An optimization problem has been solved by using Genetic Algorithm and tested on IEEE-34 bus radial feeder. Coordination between distributed generator outputs and OLTC is necessary in order to allow large integration of DGS [23]. Otherwise power injection levels can be severely limited if substation voltage is kept constant by the LTC transformer.

A new approach based on optimization for minimizing voltage deviations for distribution system with distributed generation using nested evolutionary programming (EP) is presented in [24]. The proposed approach takes into account both the space location of the voltage controllers and time variability of loads, power generation and voltage reference at the HV/MV Substation. In the presented approach, in order to consider variation of load with time, active and reactive power of loads are defined by means of their load profiles. The method is implemented on smaller system and it is simple. It has been shown that way to control the network voltage is to control the target voltage of AVC relays at primary substations [25]. A statistical state estimation algorithm is used to estimate the voltage magnitude at each network node supplied by the primary substation, using real-time measurements, network data and load data. A control algorithm alters the AVC relay target voltage, based on the maximum and minimum node-voltage-magnitude estimate. Simulation study using this algorithm on a four-feeder network showed that the generator power export is doubled without voltage limit violation.

Fast optimal setting method for the transformer and step voltage regulators with LDC functions is proposed in [26]. The method utilizes Tabu search method for generating the optimal setting values. The method has been applied to practical system model and compared with conventional optimal setting. This method can lead the same voltage profile as that of the conventional optimal setting method by drastic speed up. Voltage regulation problem of distribution feeder, whose voltage is regulated by LTC transformer with LDC, has been presented in [27]. In this method, maintaining the substation voltage at the highest permissible value by disabling the LDC controls may result in over-voltages, when sufficiently large DG units are installed towards the feeder end. As a consequence, coordination between distributed generator output and LTC transformer tap controls is necessary to avoid voltage regulation problems.

Reactive Power Management

The reactive power management is a dynamic solution whereby the VAr consumption of the generation is increased to offset the voltage rise from the real power injection. This can be achieved via static VAr compensators, switched capacitor banks, or via existing inverters in the case of power electronic based DG system. However, end distribution systems have low X/R ratios (typically around 1) and hence relatively large VAr flows are required to counteract voltage rise from real generation output. This requires higher equipment thermal ratings, increases system losses, increases the burden on network VAr sources, and can interfere with power factor sensitive transformer tap changer schemes [28]. Many distribution businesses also charge for VArh. The costs of such a scheme are dominated by the capital set up costs and VArh charges. Capital costs can vary considerably, but can be kept low if existing power factor correction capacitors are used in the case of induction machine wind generators, or existing inverters in the case of variable speed wind generators. PFC is only a good option when the additional VAr requirements are low.

Several strategies for steady-state voltage and reactive power flow control of a wind farm equipped with a STATCOM were investigated in [29]. The control technique used can prevent large over voltages due to self excitation at islanding if a controller with a fast enough speed of response is used. Recent developments involving mixed voltage/power factor control have shown that by intelligently controlling the synchronous generators, voltage variations can be mitigated and reinforcement may be avoided [30]. Distributed generators are normally operated in automatic power factor control, although this can be more difficult in weak areas of the distribution network as they are frequently connected to long open-ended radial feeders, which have low X/R ratios and high resistance. A hybrid control algorithm of the synchronous generator based DG, that combines automatic voltage and power factor control has been presented in [31] and shown that it is viable alternative to line voltage rise / drop compensation method.

A flexible distributed generation (FDG) scheme in which the utility can get its requirements for improving power factor or voltage regulation and mitigating other power quality problems has been proposed in [32]. This concept replaces the use of STATCOM and other devices for power quality problem mitigation and reduces the cost. A novel utilization of the existing DG nonlinear interface helps not only to control the active power flow, but also to mitigate unbalance and harmonics, and to manage the reactive power of the system has been proposed in [33]. The control loop combines a Fuzzy Logic Controller (FLC) for voltage regulation, and a processing unit using ADALINE (adaptive linear neuron) structure, to deal with unbalance, harmonics and reactive power compensation. One advantage of the proposed control system is its insensitivity to parameter variation, which is a necessary for distribution system applications [33].

A hybrid compensation method using active and passive filters is discussed in [34]. The distributed passive filters can solve the reactive power problem and major harmonics locally. However, if the loads / DGs are located closely (very short electrical distance), care should be taken to design these passive filters. One passive filter may be better suited for a group of closely connected loads/DGs. An investigation has been made to determine the suitability of various control strategies for a three-phase voltage source inverter with second order filter for control of the grid voltage continuously [35]. The control scheme incorporates a capacitor voltage control, a fixed switching frequency, and a variable duty cycle modulation to produce sinusoidal output voltage with minimum harmonic distortion [35]. The principle of operation and performance of each control scheme are compared. Finally, the perturbation rejection based control system with a resonant controller is implemented on a DG in an electrical network. It has been shown that the voltage is kept with in certain limits in each node of an electrical network.

An adaptive control method for reactive power compensation is proposed and its performance is evaluated [36]. Performance of the system is robust regardless of distortions in voltage and current signals, including harmonics, inter-harmonics, transient disturbances and unbalanced conditions. The reactive current component is extracted based on the concept of instantaneous symmetrical components. The extracted signals are then utilized by a shunt, PWM, voltage sourced converter to adaptively compensate the reactive power [36]. A fuzzy logic based automatic power factor controller is proposed in [37]. Fuzzy inference system adjusts the reference setting of the automatic power factor controller in response to the terminal voltage. Extensive simulations have been verified that the proposed approach may increase the export of real power while maintaining voltage within the statutory limits as compared to hybrid method of voltage and power factor control proposed in [30].

DG Active and Reactive Power Control

When the reactive power control is not sufficient to keep the voltage on the appropriate range, an action on the active power must be considered. This type control is suitable for power electronic converter based system. The converter interface provides the flexibility in control of one or more power quality problems. There is continuous interest to equip wind turbines with voltage control capability. Currently the operation of wind turbines is based on three concepts [38], [39], which are: a) Grid coupled squirrel cage induction generator b) Wind turbine with doubly fed (wound rotor) induction generator (DFIG) with voltage source converter feeding the rotor winding. c) Direct drive synchronous generator coupled to the grid via a converter.

It is proposed that one possibility of developing new structures of control systems for inverter interfaced distributed generators, is to exploit the fast response of power electronics devices [40], [41]. This ensures the correct operation of the sources in all the possible operating condition without interfering with the existing system. A control method is presented to let dispersed power sources participate in voltage control and primary frequency control [41]. This method is based on independent control of active and reactive current of the power electronic interface within the limits imposed by the prime mover and the converter rating.

A voltage regulation algorithm for a grid-connected DG based on active and reactive power control is presented in [42]; also, review of different DG reactive power control solutions is made. When the reactive power control is not sufficient to keep the voltage on the appropriate range, an action on the active power must be considered. Two DG operating modes are identified and two switching methods between those modes are compared in respect to DG dynamics. The operating modes switching may induce some oscillations that can be eliminated using an appropriate control algorithm. A method to use the voltage source inverters with distributed generation to control the voltage in a distribution network is proposed in [43]. A droop line is used to prevent hunting between controllers. The method can be applied to any load or generator with reactive-power control capabilities, like solar panels, microturbines, and also synchronous machine based distributed generation and load with an active front end.

Other Techniques

The novel approach using consumer load control is discussed for countering steady state voltage rise in distribution system with wind generation plant [28]. Simulation case study has been made to compare this method with the existing methods such as system reinforcement and connection point changes. Disadvantage of this method is installation and use of load control for voltage regulation alone requires significant capital.

A rule-based adaptive system technique for selecting the control of the generator's excitation system and the automatic governor control system is proposed in [44]. When operating in parallel with the grid, the excitation and governor systems are operated to control the power factor and to regulate active power generation. The autonomous control strategy can automatically adapt to the control of excitation and governor systems of the dispersed generators and it can operate in both grid-connected and islanded mode of operation. This research has highlighted further opportunities to enhance the response of both the excitation and governor control of dispersed generation system [44]. A new optimization model called evolutionary particle swarm algorithm (EPSO) inspired in both evolution and particle swarm optimization algorithm has been proposed in [45], for volt/var control in general. The fundamentals of the method are described and study of voltage control problem using this method has been presented.

The integration of relatively large capacity of wind power generation into a weak distribution network may cause a voltage rise problem during low demand periods. A case study based on this with real life distribution network has been presented in [46]. The combination of control of the power factor, reactive power compensation, reduction of HV/MV substation voltage setting, ring-operated distribution network and consideration of the stochastic nature of wind are used to counter the voltage rise problem. The reduction of the voltage setting and the consideration of the stochastic nature of wind are the most promising and interesting methods. However, the application and the acceptance of these methods need more detailed studies, field tests and measurements.

A multi-objective performance index based quantification of distributed generation impact on total losses, voltage profile and short circuit currents is presented in [47]. It is used as objective function in an evolutionary algorithm aimed at searching the best points for connecting distributed generators. Using this IEEE medium voltage distribution network is analyzed and results presented are encouraging. Introducing power electronics and storage devices in networks containing a large amount of dispersed generation may result in autonomously controlled networks. In such network by controlling MV voltage at just a few points, it is possible to maintain an optimal voltage profile with small variations for all low voltage customers [48].In this a concept of intelligent node consisting of storage device and power flow controller (PFC) is used at few points to keep the voltage within limits along the feeder.

5. THE INTEGRATION OF DG: MICROGRID CONCEPT

Microgrid represents a new approach to integrating distributed energy resources, especially small generators, into utility distribution systems. The microgrids are formed by the interconnection of small, modular generation (micro-turbines, fuel cells, Photovoltaic, etc.), together with storage devices (flywheels, energy capacitors and batteries) and controllable loads at low voltage distribution systems. Such systems can be operated interconnected to the power grid, or islanded, if disconnected from the grid. To the utility grid, a microgrid operates as a single, controllable system such as a dispatchable load that can reduce grid congestion and offset the need for new generating capacity. Being a systematic organization of DG systems, a microgrid has larger power capacity and more control flexibilities to fulfill system reliability and power quality requirements, in addition to all the inherited advantages of a single DG system [49], [50]. Figure 11 shows the typical microgrid architecture.

Significant research is currently carried out regarding operation and control of microgrid [51], [52]. The operation of micro-sources in the network introduces considerable complexity in the operation of an LV grid, but at the same time, it can provide distinct benefits to the overall system performance, if managed and coordinated efficiently. Microgrid controls need to ensure that new micro sources can be added to the system without modification of existing equipment. The multi agent based control for microgrid is explored in [52].

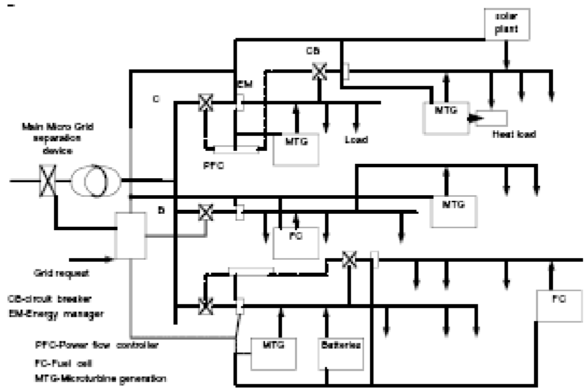


Fig. 11. Microgrid architecture

The microgrid can connect to or isolate itself from the grid in a rapid and seamless fashion; reactive and active power can be independently controlled, and can meet the dynamic needs of the loads. This concept needs research effort solving many challenging issues. Power electronic interfaces introduce new control issues and new possibilities. Real and reactive power management strategies of electronically interfaced distributed generation (DG) units in the context of a multiple-DG microgrid system are addressed in [53]. Three power management strategies (PMS) are proposed based on the reactive power controls. The simulation results of the operation of microgrid under the proposed control are presented. The studies indicate that controls of electronically interfaced DG units and the adopted PMS have significant impact on the microgrid dynamic behavior when islanded from the grid and operates as an autonomous island [53].

6. SCOPE FOR THE FUTURE WORK

DG has much potential to improve distribution system performance and it should be encouraged. However, distribution system designs and operating practices are normally based on radial power flows and this creates a special challenge to the successful introduction of distributed generation. The existing voltage control mechanism, which has been developed well before distributed generation era and based on using automatic voltage control (AVC) relay, is designed to control voltage magnitudes of a distribution network which either has very little generation or no generation at all. The DGs are usually distributed into distribution networks at rural areas far away from main substations and these generators may be induction, synchronous or power electronic converter based. Some of the issues which can be considered for further research are as follows:

- To allow greater penetration of distributed generation, a suitable active distribution network would comprise the capability for bidirectional power flows, intelligent voltage control methods and data recording/monitoring systems. Thus, development of new voltage control devices/schemes has the potential to revolutionize the control of distribution network. Intelligent control methods can be developed for voltage control using AI techniques mainly fuzzy logic and genetic algorithms and Particle swarm optimization tools can be used.
- Control over active and reactive power flow, real time monitoring of network loading conditions, redesigning the AVC relays and its associated control for reverse

power flow and use of software agent based distribution network control are the other factors which require further research. Optimal voltage control coordination between LTCs, fixed and controllable shunt capacitors, and distributed generation can be considered.

- The interaction of various voltage regulating devices/schemes can also be explored further. Integration of large numbers of small generators into utility distribution systems in the form of microgrids represent a new approach to integrating DER. Technical challenges associated with operation and control of this concept are immense. Software agents can be designed to control the operation of microgrid and distribution system.

7. CONCLUSION

To pave the way to a sustainable energy future based on a large share of DG, there is a clear need to prepare the distribution electricity system for the large-scale integration of distributed energy sources. To this end research on the key technologies will allow a transition towards interconnected DG sources using common operational systems. As the issues are new and are the key for the future power supply, a lot of research is required to understand the effects of distribution generation systems and exploit them to the full extent. The problems of controlling steady state voltages on distribution systems are becoming more difficult. Voltage control can be accomplished using a variety of methods. Since each method has its strengths and weaknesses, an engineering solution based on the best balance between cost and technical impact is needed. This paper examined the steady state voltage rise in typical radial feeder and recent up-to-date developments in regulation methods are also reviewed. This helps in improving the existing methods or exploring the new techniques which are necessary to integrate large number of DG sources without degrading the utility performance.

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