A technical review: Opportunity for Voltage improvement of distribution network

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***Abstract*— Distributed generation system is the source of electrical power connected to the distribution network directly or to the consumer. Source of distributed generation system are fuel cells, micro turbine and renewable energy sources. The role of distributed generation is to meet the future energy needs of the consumers with the best quality and reliability. For large scale production, the distribution network is changed from passive to active mode. There are many challenges to be faced in the distributed generation out of which the voltage variation is the most significant. This paper discusses about the voltage control techniques in the distributed generation. The system should be reliable and stable. Distributed generation is combined with distributed storage in electrical and mechanical conversion systems e.g. static power converters, gas and wind turbines, photovoltaic and fuel cells. To minimize the active power losses and to enhance the voltage stability, it is very necessary to determine the optimal size and location of DG units.**

1. INTRODUCTION

Electric power is distributed to consumers through distribution networks fed from power generating units. The technological developments are used to a great extent in the present context. The system efficacy is further enhanced with the provision of renewable energy resources and are connected to the distribution network.

The distributed generation sources include combined heat power plants, hydro generators and biomass units. [11]In future contribution of renewable energy is likely to be substantial and it is expected, distributed generation will reduce fossil fuel consumption by reducing carbon dioxide emission. A challenge to power engineers is thrown by the expansion of distributed generation to voltage variation, increased fault, degraded protection, etc. A serious thought is to be given to utilize the surplus power in the distributed network when demand is very less. The distributed network operators should always operate within the statutory limits. The problem with voltage variation can be figured out by either upgrading the network asset or the generator or the network itself. The distributed generation power curtailment always mismatches with the policies of distributed network operators and distributed generation [9]

The power engineers are to make an analysis of expenditure and revenue collected from the consumers. In addition , the voltage variation is also to be tackled when hybrid generators and other distribution network is connected to the present distribution network.[23]

Now distributed generation[10] is upgraded to form smart grids. The site for DG units are mainly near the load centers, which causes problems like reduction in safety and security level, need for sensitive protective relays, reduced voltage stability, complexity of the control system and allocation and sizing. If the penetration level of DG increases by 30%, then serious thought is required for DG sizing and the siting. [23]The electric power companies are adversely affected by power loss. So for this reason DG units are installed to minimize the losses, and this will reduce DG sizing and sorting problem in the distribution system and they are to take action to reduce these transmission and distribution losses as per consumer requirement. As the need of electricity increases, the system security is at risk which gives rise to adverse voltage stability, which in turn may cause blackouts in the power system. So voltage stability is an important factor in DG allocation and sizing.

A multi-objective performance index has been introduced which includes minimization of active and reactive power loss and enhancement of voltage stability problem in the distribution network. [17]To improve the voltage stability in the distribution network capacitor banks are inserted into the network. This would have the twin effect on the distribution generation network. A power loss in the network is minimized and voltage stability can be enhanced. For PV curve, a continuous power flow method is used to get a voltage stability margin. Here enhancement of voltage stability and reduction of power losses is investigated simultaneously. Other optimization techniques such as particle swarm optimization and genetic algorithm are used to improve the voltage stability and type of short circuit in the distribution network. It helps us to select the best location and site for installation of DG units.

2. VOLTAGE CONTROL IN ELECTRICAL DISTRIBUTION NETWORKS:

THE VOLTAGE VARIATION IN A DISTRIBUTED NETWORK CAN BE REPRESENTED BY THE EQUATION:

$$\Delta V = (PR+QX)/V \quad (1)$$

where ΔV is the voltage variation, P is the active power, Q is the reactive power, X is the reactance and R is the resistance of the line that is connected with the distributed generation. Distributed generation has a nominal voltage V at its terminals. Distributed generation along with a radial feeder is shown in the figure. On load tap changer, line drop compensator, reactive power compensator, automatic voltage controller and an energy storage device are connected in the distributed network.

The X/R ratio is very small in the distribution network. So when power is injected in the distribution network there will be voltage rise as well as voltage variation in the network. Various researches have been done on voltage variation and following techniques are used in the distribution network.

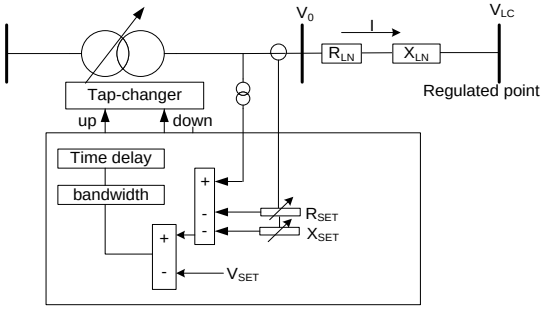

Figure 1: Simple radial feeder with connected DG

2.1 On load tap changers(OLTC)-

OLTC is the most familiar method of controlling voltage. A stable secondary voltage is maintained by choosing a convenient tap position. For voltage control, the phase angle and voltage magnitude have to be adjusted. The OLTC is always used in combination with AVC relay and LDC. The AVC relay keeps track of the output voltage. When the voltage exceeds the preset values, the tap change command is introduced. The extra voltage drop on the line between load and transformer is balanced by LDC.

A time delay of 30-60 seconds is always maintained in OLTCs to avoid operation of the tap changer operates unnecessarily on detection of transient. The time taken in a tap changer when the position is changed from one point to the other point is usually to 3-10 minutes.

The OLTC transformer keeps a constant voltage which requires limited the power injection. So Dai and Baghzouz proves that it is necessary to combine the output of distributed generation and OLTC transformer to improve stability and reliability of DG system.[5]

Kim and Kim suggested an algorithm in which use of line drop compensator integrates the distributed generation on multiple feeders keeping the on-load tap changer position unchanged .So this method will reduce the voltage variation and the use of on-load tap changing operation can be avoided very often.

By making use of OLTC, AVC and LDC will actually minimize the variation in voltage and the size of distributed generation without interrupting voltage profile.[22]

2.2 Generator power factor curtailment-

Previously in synchronous generators, the AVC relay is combined with a distributed generation system to adjust the reactive power. But this leads to overheating which disconnects the synchronous generator from the whole distribution network. To avoid disconnection of automatic voltage controller, power factor control technique is used in the distributed generation system.[8]

From equation (1), the P/Q is kept constant in power factor control. The value of P is directly proportional to voltage variation. So when P changes, the voltage also changes. Now the value of Q is compensated due to the voltage variation formed by P. This is adjusted in the opposite direction and the voltage variation is sustained within the statutory limits.

Wallace and Kiprakis proposed a method which keeps a light or heavy loading or both on the distributed generation system along with AVC and PFC which improves the transient capability and steady state condition.[24]

2.3 Power Curtailment-

When variation in voltage occurs in the distribution network, the distributed network operators switch off of the distributed network. But this leads to reduction of profit in the distributed generation and the renewable energy is wasted. So power curtailment technique is used when the production of distributed generation power can be decreased due to less demand. This technique is fit for use in biomass plant, wind plant and hydro plants.

Mogos and Guillaud initiate a two mode switching voltage method which is provided with a reactive power control mode and an active power control mode. Either control which can be used depending upon the type of voltage variation and power production in the distributed network can be controlled accordingly.[15]

2.4 Energy storage-

The main benefits of energy storage are to meet peak demand, to improve the reliability of the power system and to reduce the costs of purchasing power at higher rates. The biggest drawback of using energy storage is the cost factor. In the next five years, lithium ion battery will be highest in demand. Mass production is likely to reduce the cost. Storage increases the flexibility in the system and provides accommodation of variable renewable energy sources. It provides temporary solution when there is an outage in the distribution network.[12]

There are various energy storage devices that are connected to a distributed energy system like lead acid batteries, flywheel, pumped hydro storage, etc. of which pumped hydro and lead acid batteries are commonly used. All the energy storage devices have a power conversion system which compensates the voltage variation. If voltage variation problem persists for a long time, there should be an extra capacity for excess energy storage. Among all types of renewable energy source, wind energy is least costly.[4]

Thus storage and distribution of electricity consumers are very important factors because electricity supply generation and demand varies from time to time. Sometimes an excess of electricity is produced, but demand is low so there should be proper storage for energy. Storage is also necessary in some network when there is need of electricity in places of scarcity. Efficient storage technologies have been used which are described below:

- Advanced Batteries- Lithium ion batteries are used which are more efficient than lead acid batteries as it provides

more energy. It has deep discharge and can operate at high temperature. The charge of these batteries can be circulated to rechargeable and portable external units which can be transported to supply energy whenever needed.

- Fuel Cells- Fuel cells are used to provide primary as well as backup protection. It is invented in the eighteenth century. Its function is similar to batteries, but needs a constant fuel source of hydrogen. Due to availability of continuous supply of hydrogen, fuel cells can be used as a renewable energy source like wind and solar.
- Compressed Air Energy Storage- In this process air is compressed in the reservoir when demand is low, but during high demand air is released rapidly which operate the turbines to produce electricity
- Superconducting Magnetic Energy Systems (SMES) - SMES store energy in the magnetic field. It is used when there are short interruptions or quick fluctuations of a very short duration and produce high power for that small time interval.
- Flywheel Energy Storage (FES) - Flywheel works on a low friction shaft so very little energy is needed for rotation. When demand increases, the flywheel generation is used as a backup supply. Its response is very fast when there is peak demand on the distribution system.

2.5 *Network reconfiguration-*

Network reconfiguration serves the customers during a planned outage for maintenance purpose or during faults in the power system. It also minimizes the losses and balances the load in the network.[1] This method is very useful for loss reduction and to relocate the loads using appropriate switching operations. It changes the topological structure of the distribution system by changing the switching status (open/closed).[2]

In the radial network, the network reconfiguration allows flow to bidirectional. This increases the efficiency of the power system. [3]In network reconfiguration between two radial feeders a normal open circuit breaker is located which performs the ring operation. Some techniques like fuzzy logic and genetic algorithm are used to reduce the system losses, reconfiguration reduces power losses, eliminate overload and enhance voltage stability of DG network.[21]

2.6 Distributed FACT devices (DFACT)-

FACT devices are used to control the voltage collapse and to reduce real power losses in the distribution network by controlling multiple power system parameters like active and reactive power, harmonic distortion, voltage frequency and power factor. So DSTATCOM is installed in the power system to enhance controllability and power transfer capability.[18] The FACT devices optimize the various parameters and make the power system more reliable. During peak load conditions, a synchronous generator has a very poor voltage regulation so DSTACOM is used as a voltage controller. The DSTATCOM is a three legged IGBT based pulse width modulation voltage source converter (PWM-VSC) with a DC bus capacitor. DSTATCOM is both a facts device and a voltage source converter. At the input if voltage is DC, it is converted into AC to compensate the reactive power. The DSTATCOM regulates the reactive power to get a suitable AC voltage on the bus. If the terminal voltage of the voltage source converter is more than that of the AC voltage, the DSTATCOM produces reactive power and if the voltage source is lesser than that of the AC voltage the DSTATCOM absorbs reactive power. Voltage can also be controlled in both transmission and distribution system. Now, modern, technologies use linear, quadratic voltage regulator (LQR) for voltage control.

2.7 *Demand side management (DSM)-*

Demand side management is to encourage the consumers to use less energy during peak hours and use the energy during off peak period. This method is used to decrease peak demand of power temporarily. Incentives are proposed to consumers who use power off peak period.[6]

The investigation of DSM can be analyzed by assuming a network 11KV having four load controllers. [19]Each load controller 415 KV has been set with pre-decided value and as when load exceeds this value ,the load controller will be activated and switched on. This method enhances the performance of network ,avoid blackouts, increase the stability and reliability of the network, reduces cost and reduces undesired emissions from the system . Following reasons can be sited in support of DSM:

(a) As seen above, the cost of energy is reduced and meet the increased demand for energy.

(b)Harmful emissions are reduced, hence environments improves and reduces greenhouse gases

(c)Reliability and stability of the network have increased. Voltage interruptions and blackouts are mitigated to a large extent.

(d)The economic viability of the system improves and decision for load dispersal during high demand can be taken suitably

In addition to benefits to the utility, customer satisfaction is enhanced and following benefits accrue to the customers. The energy bill is reduced and thus energy consuming industry entities become competitive in the market. Overall air quality improves and thus health care cost reduces.[20]

2.8 *Hybrid and cooperative control methodologies-*

As the distribution network is becoming more and more complex and customers are very demanding, a single methodology does not serve the purpose. The complex problems are tackled with multipronged strategies.

A simple but excellent methodology has been devised by Hird. In a substation 33KV/11KV, voltage controller is designed to control AVC relay by using a state estimation algorithm. From state estimation techniques, to calculate voltage $|V|$ at each node. For solving these problems, Newton Raphson method and weighted least square method are used. The voltage variation values are pre-decided by the operator and the calculated values are compared with node wise voltage in state estimation technique.[16]

OLTC and LDC are combined to make SVR in Japan. But adequate and proper operation is not given by SVR due to the time delay in it. There are some other FACTS devices that are used to control the voltage variation in the distribution network. Unified Power Flow Controller(UPFC) are also used. Thus, finally SVR and UPFC as a hybrid are employed in the distribution network.

3. Distributed generation in wind and solar energy-

(a)Use of solar energy in distributed generation:Solar Energy is the most clean, convenient and reliable source of energy in the most part of the world. Sun shine days and duration throughout the year at a location are estimated for designing the solar power plant using solar PV cells. In the present scenario, solar energy is injected into the local grid to supply to the consumers. If planners decide to use this energy during non-sunshine time, energy storage technology is to be employed and cost of such storage facilities is to be investigated and factored into the cost of generation. In such cases, 3 phase inverter is to be used and to be synchronized to the grid voltage.[7]

(b)Use of wind energy in the distributed generation: Depending on suitable location having wind data, period of wind availability, wind energy form is to be designed. This is one of the best renewable energies which is quite clean and least harmful to the environment. On a large wind farm, it is feasible to reduce the cost of energy produced. End users benefit from the assured electric supply from the neighborhood.[14] The wind turbines(constant speed or variable speed) are connected with the synchronous induction generators. Direct energy injection to the grid or energy storage technologies can be investigated here also.[13]

4. Use of capacitor banks in distributed generation-

Capacitor banks are used for controlling power flow, power factor correction, minimization of losses and voltage stability improvement. Shunt capacitors are used having lagging power factor. It reduces the lagging component in the circuit. Improves voltage regulation and reduces I2R and I2X losses. It is used to increase the power factor of the generator.

(III) Future Considerations Of Voltage Control Techniques On Electrical Distribution Networks Including Distributed Generations:

The power network has previously worked on the threshold values to meet the load forecast. To make the power system more reliable, the network system will be operated in automatic mode, which will provide feedback information from the DG and consumers and thus action to be taken can be detected.

In the near future, intelligent distributed controllers are used to handle with the any changes in the network. For controlling purpose there are two types of control level-local level and coordinated level. The local level controls voltage in the DG units and the coordinated level controls the voltage of the whole distribution network. It controls various network configurations and control actions.

The “fit and forget” DG policy ensures minimum voltage variations, the consumers should be able to consume most amount of DG energy. To improve the efficiency, STATCOM and UPFC are used widely in the network.

5. CONCLUSION

Voltage control of the distributed network is very tough to proposition handle for the DG owners and consumers as well. At the present DG network have become very much complex due to a large number of connections(consumers). The voltage control technique using oltc will provide stable voltage by changing tap position. The power factor control technique using AVC relay improves the stability in the distributed generation. The various technologies in the energy storage like fuel cells and advanced batteries provide wide usable to the consumers. Use of DSTATCOM in the power system enhances stability. The DSM technique reduces the voltage variation problems and increase stability.To make the network more simpler, hybrid technologies are used to handle complex situations. A voltage control technique in DG, the cost and technical issue thereof should be the foremost issue and to be tackled in real time.

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