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Ancillary Services And Stability Analysis Of Distributed Generation System

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ABSTRACT
This paper considers a distributed generation system interconnected to the AC grid through power electronic interfaces and to provide energy service and system ancillary services (in particular voltage regulation and partial compensation or elimination of some power quality disturbances, such as waveform distortion etc.,). In addition to the above, the impact of Wind Energy Systems (WES) on DG network and the stability of the whole system was analyzed. This method is proposed to improve the power quality and stability of DG system. The experimental system was established using MATLAB software and their results are presented and discussed.

Keywords-Ancillary services, Distributed Energy Resources (DER), Distributed Generation (DG), FACTS(Flexible AC Transmission Systems), Micro Grid, Stability.

1.0 INTRODUCTION
Electricity networks are in the era of major transition from stable passive distribution networks with unidirectional electricity transportation to active distribution with bidirectional network [1]. The extent of penetration of DG systems with the grid is increasing rapidly and thus its role is gaining prominence in electrical industry. The major advantage of DG systems is the inclusion of renewable/non-conventional energy sources and its integration into low voltage distribution networks. DG technologies include Solar Photo-Voltaic, wind turbines, fuel cells, and micro turbines which reduce the emissions when compared with conventional plants, conserves natural resources and also improve power quality. It can supply power to local loads thus reducing the investment of conventional power stations also reduce the peak demand forecasted. With proper control over the distributed generation units, voltage sags are negated, reactive power flow is controlled. Thus DG units with control measures for parameters are termed as Micro Grid (MG). From the reliability point of view, micro sources must be equipped with Power Electronic Interfaces (PEI) and latest sophisticated controls so as to provide the required flexibility to ensure operation as single aggregated system and to maintain quality of power within the permissible limits and energy output [1]. Ancillary services are necessary to support necessary to support the transmission of electric power to maintain reliable operations of the interconnected systems. Unlike conventional power stations, micro grids are located close to the load, thus they are more suitable for providing ancillary services.

The impact of Distributed Generation (DG) units on the voltage stability, power quality and reactive power margins have become significant. It is well known fact that Reactive power is very difficult to transport. At high loadings, relative losses of reactive power on transmission lines are often significantly greater than relative real power losses. Reactive power consumption or losses can increase significantly with the distance of power to be transported. The major advantage of DG is that they provide reactive power capability locally. In fact, DG has better regulation than Flexible AC Transmission Systems (FACTS) devices [2] and the same has been discussed later in this paper. Voltage stability is the ability of a power system to maintain steady state voltage in the system under normal operating condition and also after the occurrence of a disturbance in the electrical power network. The main factor contributing to voltage instability is usually the voltage drops that limit the capacity of transmission networks to transfer power between buses. Insufficient reactive power margin to supply the load is a major cause for voltage instability problems. A voltage decrease may lead to increase in power consumption and causes more drops in voltage and finally a collapse due to this cumulative effect. The desired voltages can be obtained either by directly controlling the voltage or by controlling the reactive power flow which in turn will affect the voltage drop.

The advantages offered by DG can be observed in the case of interconnected grids where a fault arising in the synchronizing network (the network connecting a generating station to the grid) might affect the whole system. To overcome this problem, the synchronizing network should be made complicated that a fault in the network will have no affect on the grid.

2.0 SYSTEM AND ITS CONTROL

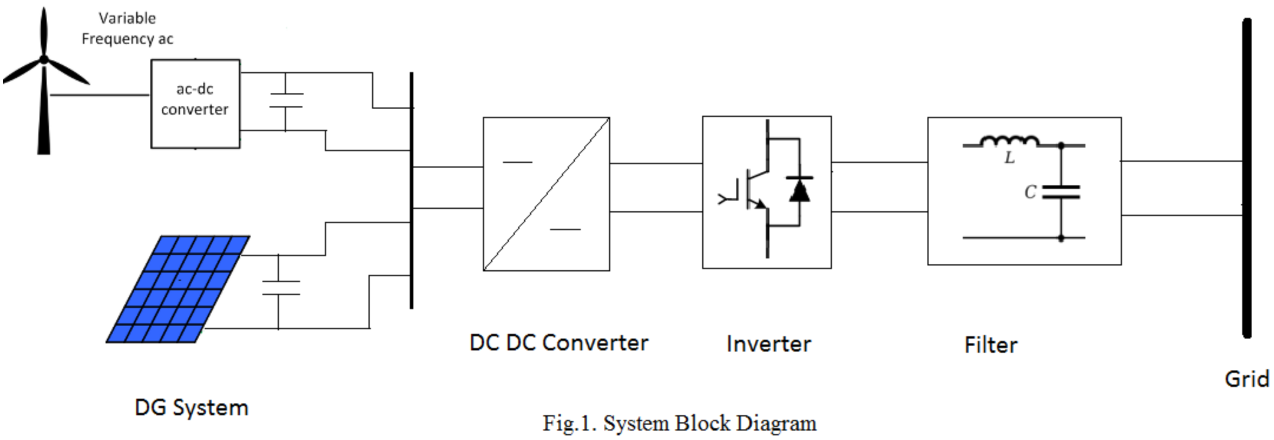

Fig.1. System Block Diagram

Micro Grid can operate either in grid connected mode or in islanded connected mode. This study deals with grid connected mode of operation. Main components of Micro grid include distributed energy resources, power electronic interface, controls and battery system for energy balance. From the grid point of view, the main advantage of micro grid is that it is treated entity within the power system. This ascertains its easy controllability and in compliance with grid rules without hampering reliability and security of power system utility. The structure of the micro grid is shown in figure 1.

3.0 SYSTEM DESCRIPTION

DG system is assumed to be a combination of AC and DC sources. The AC system is converted to DC using active power factor correction technique (boost type PWM). DC-DC converter is used for voltage regulation. Boost converter is used since electromagnetic interference (EMI) is less and so reduced filtering requirements. The output current is reduced. Seven level inverter is used. By using seven level inverter, the output waveform is improved and thus reducing its harmonic content. To obtain sinusoidal wave, LC filter is used. The control system is designed to reduce the time lag and surges thereby improving the communication between DG systems for optimal operation.

3.1. Voltage Control

In this study DG system comprises of DC and AC systems. The AC distributed energy resources are converted to DC. However, power converters draw pulsating input current from the line, this not only reduces the power factor but also injects significant amount of harmonics. There are harmonic norms such as IEC 1000-3-2 [3] introduced for improving power quality. Active power factor correction (APC) method is used. Boost converter is used since EMI is less so reduced filtering requirements. The DC- DC converter is used to regulate the voltage obtained from DG system. Though traditionally capacitor banks and voltage regulators are used, the reactive power supplied from capacitor banks drops as square of voltage [4]. This may lead to voltage collapse. But, a micro grid can perform smooth voltage regulation locally in response to controller settings. PWM techniques are used to increase the efficiency and control in voltage regulation. Reference voltage is obtained from the required load voltage and accordingly pulses are generated and control over voltage profile is obtained. Its power factor control also, in effect, results in voltage control. Thus the deployment of capacitors can be avoided at the consumer end if the power is provided by DG unit.

3.2. Frequency and Reactive Power Control

The voltage obtained is now fed to voltage source inverter. Technical recommendations like IEEE 1547 prescribe that DER's should be automatically disconnected from MV and LV distribution network in case of tripping of circuit breaker (CB). This is mandatory feature of inverter. Here, we use seven level inverter. By using seven level inverter, improving the output waveform thus reducing its harmonic content and hence the size of filtering requirements and electromagnetic interference (EMI) will be reduced [5]. Output current with better harmonic profile, less stress on electronic components owing to reduced voltage, switching losses that are less than conventional two level inverters, all of which make them lighter, cheaper and compact. The output of inverter used is shown in figure 2.

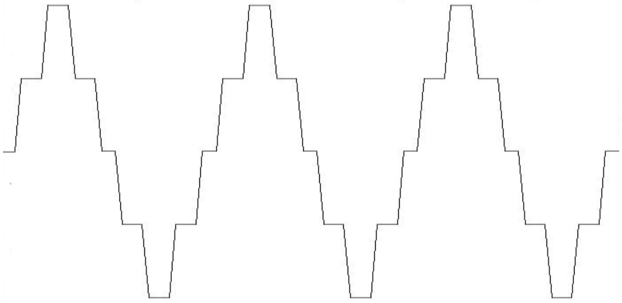

Fig.2. Inverter Output

To maximize the efficiency of power electronic converters, pulse width modulation is used. Using PWM technique and suitable topology, the output has been modified as shown in figure 3.

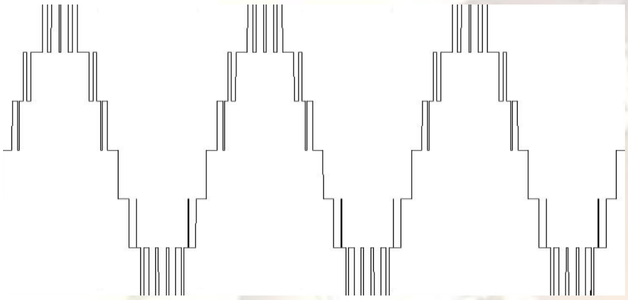

Fig.3. Inverter output using PWM

The maximum permissible value is limited to 10MVA as per IEEE recommendations. Supply of reactive powers from micro sources in response to local voltage signals is also more economic during distribution voltage sags. There are many algorithms used to control reactive power, direct power control (DPC) method [6] is regularly used. Moreover, local supplies of real and reactive power significantly reduce feeder losses. Since reactive power must be provided closer to the loads Micro grid is reliable source for reactive power supply than FACTS devices. The frequency can also be controlled using signals given to power electronic components used in inverter. Thus, reactive power and frequency can be maintained according to the load requirements. Micro grid with large number micro sources can suffer from reactive power oscillations without proper voltage control. Therefore these control systems must communicate among themselves for reliable operation.

4.0 LOAD FLOW ANALYSIS

The main purpose of installing DG will be observed in islanding mode, where DG alone is responsible for supplying the entire load. With the load isolated from the grid the DG has to take care of the complete load. But the installed capacity of the DG will not be sufficient to supply the entire load. In that case, important and sensitive loads are selected and are supplied power through DG and the remaining loads are disconnected from the system. The voltage profile has to be maintained same as that of the grid while supplying the load. Every DG unit has a voltage limit up to which it can maintain good stability but beyond certain load the stability is reduced and the continuity in the power supply is lost. To ensure continuity, a suitable load flow analysis algorithm is required to calculate the system voltage and stability. This analysis would help in calculating the system voltage and power and determine the maximum voltage that the DG or grid could withstand without collapsing.

5.0 MATHEMATICAL MODEL OF STABILITY INDEX

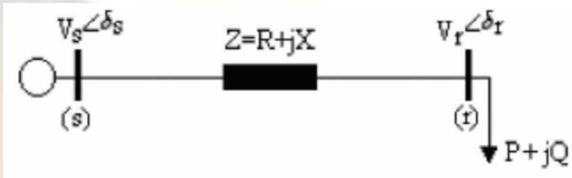

Fig.4. Single Line Diagram of the Model

For a distribution line model, given in fig.4. the quadratic equation which is mostly used for the calculation of the line sending end voltages in load flow analysis [7,8] can be written in general form as

$$V_r^4 + 2V_r^2(PR + QX) - V_r^2V_s^2 + |Z|^2(P^2 + Q^2) = 0$$

and from this equation, line receiving end active and reactivepower can be written as

$$P = \left[-\cos\theta_z V_r^2 \pm \sqrt{\cos^2(\theta_z)V_r^4 - V_r^4 - |Z|^2Q^2 - 2V_r^2QX + V_r^2V_s^2}\right]/|Z|$$

$$Q = \left[-\sin\theta_z V_r^2 \pm \sqrt{\sin^2(\theta_z)V_r^4 - V_r^4 - |Z|^2Q^2 - 2V_r^2PR + V_r^2V_s^2}\right]/|Z|$$

From the above equations the real and reactive power will exist only if

$$\cos^2(\theta_z)V_r^4 - V_r^4 - |Z|^2Q^2 - 2V_r^2QX + V_r^2V_s^2 \geq 0 \quad (1)$$

$$\sin^2(\theta_z)V_r^4 - V_r^4 - |Z|^2Q^2 - 2V_r^2PR + V_r^2V_s^2 \geq 0 \quad (2)$$

Summing the eqs. (1) and (2) gives,

$$2V_r^2V_s^2 - V_r^4 - 2V_r^2(PR + QX) - |Z|^2(P^2 + Q^2) \geq 0 \quad (3)$$

It is clearly seen that the value of the equation decreases with the increase of the transferred power and impedance of the line, and it can be used as a bus stability index for a distribution networks as

$$SI(r) = 2V_r^2V_s^2 - V_r^4 - 2V_r^2(PR + QX) - |Z|^2(P^2 + Q^2) \quad (4)$$

6.0 RESULTS OF THE ANALYSIS

In this paper, to assess the steady stability of the system with Wind Turbine Induction Generator (WTIG), the WTIG was connected to bus 12 of the IEEE 12 bus network, and buses 11 and 12 were isolated from the remaining network. The analysis is first done without interconnection of DG in the system with gradual increase in the load. The stability indices for base load without the connection of DG are given in table1.

Table1: Stability indices for base load without DG

Bus No.	Stability Index
1	0.99771
2	0.98916
3	0.97796
4	0.86103
5	0.85191
6	0.73392
7	0.64933
8	0.64905
9	0.64800
10	0.63258
11	0.61870
12	0.61834

The load is increased in steps and results are shown in table 2. With increase in the load, the current flowing through distribution lines increases and results in increase of losses and voltage drop.

Table2: Stability indices for maximum load without DG

Bus No	Stability Index
1	0.99956
2	0.97270
3	0.92931
4	0.66758
5	0.63935
6	0.40705
7	0.28038
8	0.28038
9	0.27891
10	0.26053
11	0.24466
12	0.24450

The WTIG is connected to bus 12 of the network and operated both in the grid connected and islanded modes. In islanding mode buses 11 and 12 are isolated. The results for the connection are as shown.

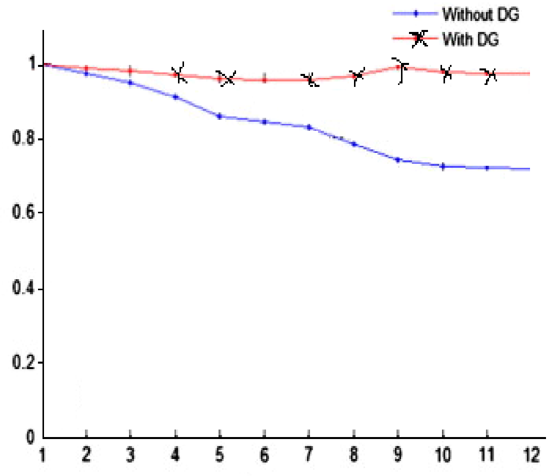

Fig.5. Bus voltages with and without DG

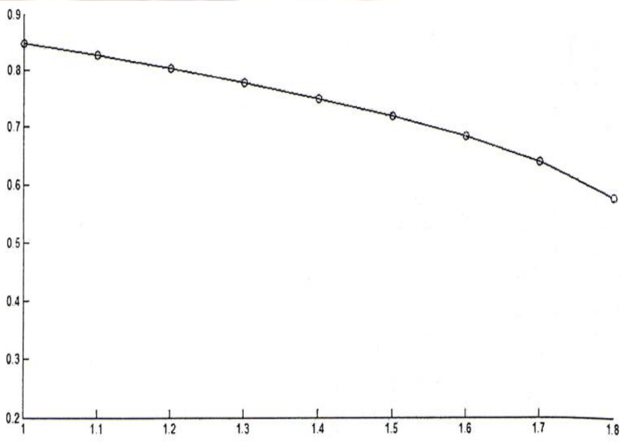

Fig.6. Reactive power loading (pu) vs. voltage at bus 12 without DG

The variation of the stability of the WTIG with respect to the wind speed is as shown in fig.7.

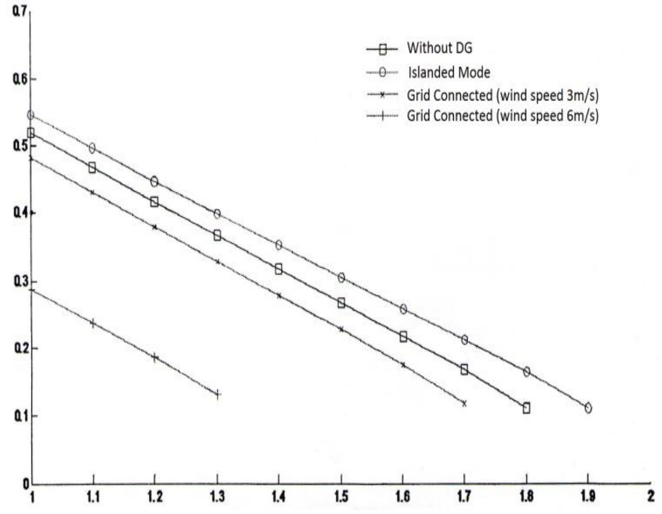

Fig.7. Real power loading (pu) vs. stability index

The maximum loading capacity of the system without DG is found to be 1.8 times the base load.

7.0 CONCLUSION

Energy services and system Ancillary services (voltage regulation and partial elimination of power quality disturbances) were provided and have been presented to explore a wide perspective. Methods for controlling parameters were discussed and presented with a view for further improvement. At distribution level, capacitor banks could result in high harmonic voltages and currents due to harmonic resonance. DG system synchronized to grid provides better regulation and stability for the complete network. Reactive power supply through DG system provides better regulation than FACTS devices. The concept of load shedding can be applied to a DG system which could help in disconnection of unimportant loads during islanding mode. Thus, the peak load reduces and the load factor will improve. Storage in batteries, at low voltage level can prevent over voltages and overloads due to solar power or small generation units. The DG system is stable if the stability index as in equation (4) is greater than or equal to zero. The control system in one DG unit has to communicate with other units to meet the systems local real and reactive power demand.

8.0 ACKNOWLEDGMENT

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