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Research Article

Influence of Micro-Grid in Steady State Performance of Primary Distribution System

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Abstract: Steady state analysis of primary distribution system is an integral part of Micro Grid (MG) planning, design and operation of distribution system. In order to maximize performance and ensure secured operation of distribution system with MG, it is important to perform various analytical studies, both in static and dynamic domains. Static studies are the first step and static performance can be established by looking at a number of stead state aspects such as total power losses, voltage profile, feeder current and load ability of the system. This study presents such first step static analytical studies based on distribution load flow to see various steady state performances of primary distribution system due to the integration of MG. A 33-bus test distribution system has been used to present steady state performances. Results clearly show some useful contribution of MG in improving distribution system performance.

Keywords: Distributed generation, micro-grid, steady state

INTRODUCTION

Micro Grid (MG) can be defined as a group of DG units and load operating as a single entity and is integrated into a distribution system and operates in self-coordinated and independent manner. It appears to grid as a single load. MG architecture ensures that it follows grid and/or distribution codes and does no harm to existing consumers. MG concept will allow high penetration of DG without requiring redesign and reengineering of the distribution system (Lasseter, 2007).

Operation of MG can be divided into two modes, namely, Grid connected mode and Island mode. In grid connected mode, DGs are operated in such a way that they supply pre-specified amount of power so as to reduce imports from the grid. Each DG is rated in such a way that they always supply specific amount of real and reactive power to customer (PQ-bus) or supply pre-specified real power and regulate its terminal voltage (PV-bus). The excess load beyond DGs' capacity will be taken care by utility supply. MG is driven into island mode of operation due to faults in a power system, blackouts or voltage drop. During island mode of operation, depending upon load and generation capacity of the system, either total load or only a part of load will be supplied by MG. It means there may be a partial load shedding to match load demand and generation in distribution system where MG is located (Katiraei and Iravani, 2006).

In the recent past, several works have been reported in the area of MG. Economic feasibility study of the best possible combination and optimal size of DGs to supply energy demands of MG which electrify a rural area in India is discussed in Angaonkar and Dobariya (2006). A technique to determine optimal location and sizing of DGs in a MG based on simulated annealing technique on network configuration along with heat and power requirements at various loads points is presented in Vallem *et al*. (2005). An optimization algorithm for finding optimal combination DGs to form MG in distribution network is presented in Ghiani *et al*. (2005). Several islanding scenarios of a distribution system from the main grid and its autonomous operation as a MG are investigated in Katiraei *et al*. (2005). The study concentrates on stability issues and voltage quality at designated buses during islanding transients. Strategy behind having same protection for both grid-connected as well as islanded mode of operation during different types of fault conditions is discussed in Nikkhajoei and Lasseter (2007). However, no comprehensive steady state studies have been reported so far in MG related literature. Hence, the main aim of this study is to perform a comprehensive steady state analysis to establish the influence of MG in steady state performance.

METHODOLOGY

Location and size of MG within primary distribution system In this study, to find a proper location of MG within a distribution system, loss sensitivity reported in Acharya *et al*. (2006) has been

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used. In power system, sensitivity analysis can be used to predict changes in voltage, branch flows and system loss due to change in generations and loads. In this case, loads in different branches (except root node) are lumped together and sensitivity analysis is performed to find a proper location of MG. The Loss sensitivity factors used in this study help to determine how sensitive total real power loss is to real or reactive power injection at a particular location. It is an approach to select those locations in a network which have maximum impact on real power loss with respect to nodal real and/or reactive power injection.

Once MG location is identified, the next important task is selection of appropriate number, size of DGs and their suitable location within the MG. Selection of suitable size of DGs and their proper location within MG is an utmost importance task. An optimal size of DG is necessary as an under size DG may not meet expected target and an oversize DG may not be economical in operation. Also improper sitting of DG may not only affect the expected results from its installation but also hamper the system performance. Sizing and location of DG within MG depends upon objective which they have to meet.

In this study, the optimal placement and size of DG within MG area solved with the Repetitive Load Flow (RLF) approach. The computation procedure of RLF is given below.

Step 1: Run the base case load flow (without MG).
Step 2: Place DG at the bus within MG area.
Step 3: Change the size of DG in "small" step and calculate loss for each by running load flow.
Step 4: Store the size of DG that gives minimum loss.
Step 5: Compare the system loss with previous solution. Replace the previous solution if new solution is lower.
Step 6: Repeat from Step 3 to 5 for all buses in MG area.

Steady state analysis: In order to understand the influence of MG, steady state analysis is performed for two scenarios:

Scenario 1: Grid connected operation, with the MG loads being fed by the DGs as well as utility grid.

Scenario 2: An islanded operation, with DGs within the MG feeding all MG loads.

Load flow analysis: Power flow analysis forms the basis for most of the decisions made in planning, operation and control of power systems. Network equation can be formulated systematically in variety of forms. The node voltage method, which is the most suitable form for many power system analyses, can be used to calculate voltages and phase angles at various nodes. Thus, the resulting in terms of power, knows as the power flow equations, become nonlinear and must be solved by iterative techniques (Saadat *et al*., 1999). Many approaches for distribution system load-flow analyses have been developed (Augugliaro *et al*., 2008). Among these approaches, the ladder network theory and the Backward/Forward (BW/FW) sweep methods are commonly used due to their computational efficiencies and solution accuracies. In steady state analysis, constant power of load model is considered, however different types of loads model (Kundu, 1994) can also be considered.

Line flow and losses: After the iterative solution of bus voltages, line flows and line losses can be calculated. The complex power Sij from bus i to j and S_{ji} from bus j to i are:

$$S_{ij} = V_i I_{ij}^* \tag{1}$$

$$S_{ji} = V_j I_{ji}^* \tag{2}$$

The power loss in line i - j is algebraic sum of the power flows determined from summation of Eq. (1) and (2) as given in (3).

$$S_{Lossij} = S_{ij} + S_{ji} \tag{3}$$

Total system power losses can be calculated from (3) by adding the real part of all line losses, including transformer losses.

Voltage profile: The best voltage profile on feeders is to make all the customer's voltages of each feeder as close as possible to nominal voltage. It helps to efficient performance of the customer loads besides reducing system losses and improving system operation. This study presents comparison the voltage profile of the distribution system studied when it operates with and without MG.

Feeder loading: Feeder loading is the ratio of power through feeder during system operation with respected to rating of the feeder and it is defined as (4):

$$\text{Percentage loading of conductor} = \frac{MVA_i}{MVA_{rate}} \times 100\% \tag{4}$$

where,

MVA_i = The power flow through feeder i, MVA
MVA_{rate} = Rated power of the feeder, MVA

Load ability: Load ability is defined as the ability of distribution system to accommodate load and it is measured in terms real power. Load ability or Loading Margin (LM) of the system can also be considered as one performance indicator. In this study, load ability problem is formulated for given arbitrary load variation patterns where loads grow by the same percentage. The maximum percentage change is to be determined such that the distribution network can service the load while still satisfying the electrical constraints represented by acceptable limit operating constraints such as voltage magnitude, current flow and feeder capacity constraints. For purposes of the classical load ability studies performed in this study , a scalar parameter λ, which stands for uncontrolled parameters that may change during the system operation, i.e., loading levels and load at various nodes represented by (5):

$$\begin{cases} P_{Di} = P_{Di,0}(1+\lambda) \\ Q_{Di} = Q_{Di,0}(1+\lambda) \end{cases} \tag{5}$$

where, $P_{Di,0}$ and $Q_{Di,0}$ stand for the base active and reactive load demand at bus i respectively, P_{Di}, and Q_{Di}, are active and reactive load demand at bus i respectively, λ is load incremental parameter or Load Factor (LF) which is proportional to loading margin.

In this study, in order to obtain the P-V curves hence the Load Margin (LM) of the system for different cases, all the loads were represented as constant PQ and increased simultaneously, i.e., by keeping constant power factors at respective loads.

The following steps were followed in order to locate a MG and establish the performance of distribution system due to MG.

Step 1: Distribution system is modified by lumping all loads in lateral branches (except root node).
Step 2: Loss sensitivity factor is used in the modified distribution system to identify a proper location to form a MG.
Step 3: Number of DG and their appropriate sizes within MG are found out with the help of repetitive load flow.
Step 4: Steady state analysis is performed on the distribution system with MG and MG operating in isolated mode.

RESULTS AND DISCUSSION

Analytical tool and test system: The load flow analysis has been carried out in MATLAB (MATLAB 7.5, 2007). The branch numbering approach is used to solve load flow analysis based on backward/forward sweep method has been used in this work. Moreover, P-V curves and hence, load ability of the system was produced with the help of PSAT (Milaano *et al*., 2008). The distribution system used in this study is depicted in Fig. 1. The system is modified version of the system present in Kashem *et al*. (2000) (without MG). Bus data and branch data for 33-bus radial distribution system are presented in Kashem *et al*. (2000).

Configuration of MG: According to the loss sensitivity factor location marked as j with bold face found to be the best location for MG. In this study, the number of DG is defined as to two. The best configuration plan of DG within MG, solve by RLF, is found at buses 15 and 32 with sizes of 1.728 MW and 0.488 MW, respectively. Their optimal setting of reactive power found to be 1.264 MVAR and 0.224 MVAR, respectively (Fig. 1).

Steady state analysis of MG:

Scenario 1: Grid connected operation.

System loss: The comparison of system losses before and after installation of MG in distribution system is summarized in Table 1. The losses have decreased by 74.98 and 67.70% in real and reactive power, respectively. It is important to note that the MG not only save capacity losses (MW) but also energy losses (MWh) that would result from continuous capacity loss.

System voltage profile: The voltage profile before and after the installation of MG is shown in Fig. 2. It has been found that minimum voltage of 0.959 p.u. occurs at bus number 33 in the base case. After installation of MG, voltage at bus number 33 has improved to 1.05 p.u., while the lowest voltage of 1.015 p.u. is found at buses 26 and 28.

Voltage regulation at different end-nodes of the distribution system before and after installed MG is shown in Table 2. The lowest voltage is located at the bus 33 for base case with voltage regulation of 8.657 percent and it is shifted to the bus number 28 after installed of MG with voltage regulation of 3.308%.

As can be clearly seen from the results, the introduction of MG improves voltage regulation of the system significantly. All the end nodes voltage regulation has improved to an expectable limit, i.e., ± 5 percent from the nominal value.

Main feeder current: The current flowing through each branch is shown in Fig. 3. With the introduction of MG there is a drastic reduction in the feeder current. Figure 4 compares level of conductor loading of the first three segments of primary feeder, namely lines 1-2, 2-4 and 4-6, with and without MG. It can be seen that current in the main feeder is greatly reduced due to the introduction of MG leaving more room for accommodating new loads.

Load ability of the system: Loading margins with and without MG are shown in Table 3 and corresponding

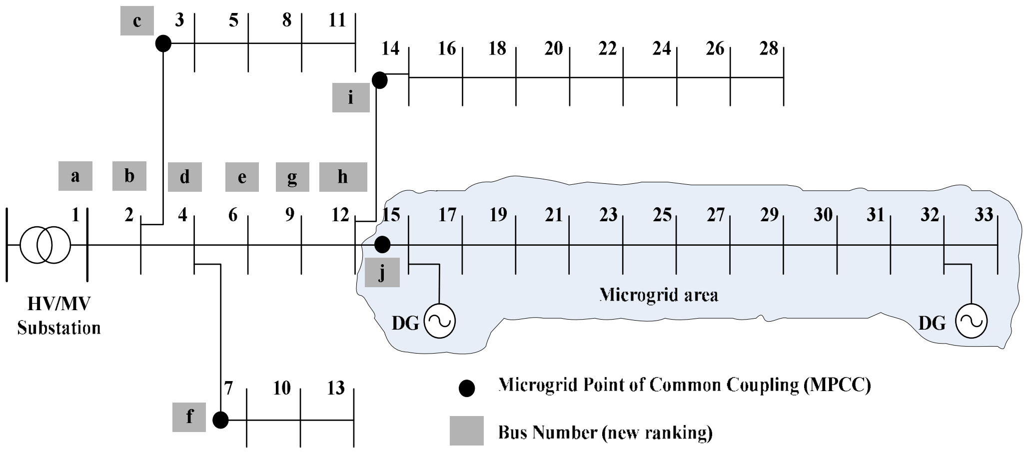

Fig. 1: 33-Bus radial system with MG

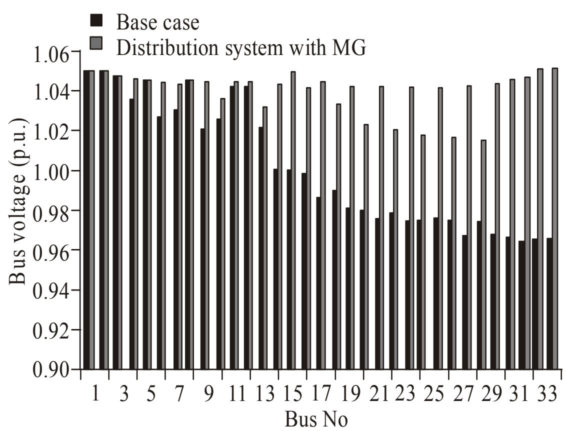

Fig. 2: Bus voltage profile before and after installation of MG

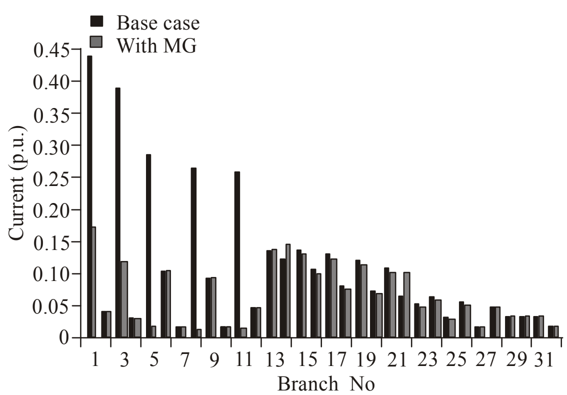

Fig. 3: Current profile at the each branch

load ability curves are presented in Fig. 5. The weakest bus is located at bus number 33 for base case. It got shifted to bus 26 with MG installed in the system. It is clear from Table 3 that the system with MG has increased loading margin. Notice from Fig. 5 that loading margin of the system has increased by 78 percent compared to base case as a result of MG. Here, in order to calculate realistic loading margin a low

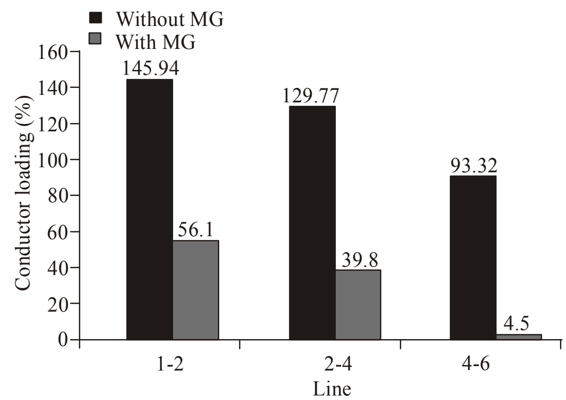

Fig. 4: Loading level of the first three segments of the main feeder

Table 1: Comparison of loss of 33 bus system

	Real power loss (kW)	Reactive power loss (kVAR)
Base case	188.64	127.88
With MG	47.20	41.30

Table 2: Comparison voltage regulation

	Base case		With MG	
Bus no	Voltage (p.u.)	V_{reg} (%)	Voltage (p.u.)	V_{reg} (%)
1	1.050	0	1.050	0
11	1.042	0.765	1.044	0.597
13	1.021	2.775	1.032	1.713
28	0.971	7.527	1.015	3.308
33	0.959	8.657	1.049	0.088

Table 3: Comparison of load ability for 33-bus system

	Loading factor (p.u.)	Load margin (MW)
Base case	0.091	4.053
With MG	0.872	6.954

voltage limit of 0.95 p.u. is introduced as shown in Fig. 5.

Steady state analysis of MG:
Scenario 2: MG in islanded mode of operation.

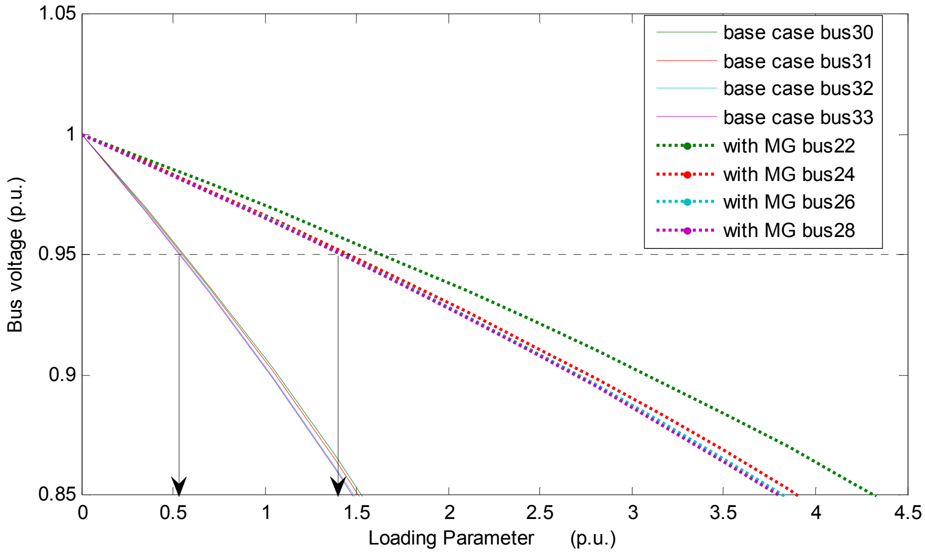

Fig. 5: Comparison voltage profile when the system with and without MG

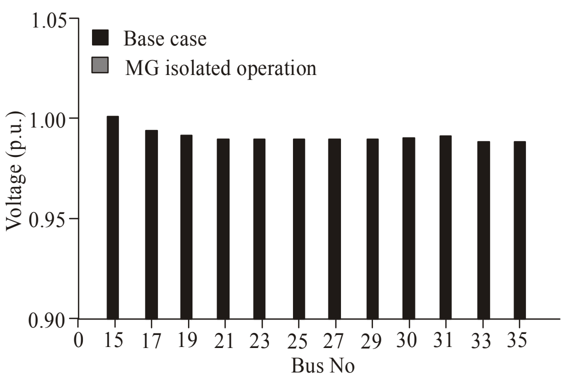

Fig. 6: Bus voltage profile

During disturbances in distribution system (or other reasons), MG isolates itself from distribution system and continues to supply load within its own area till the disturbance is cleared. During isolated mode of operation of MG section within 33 bus system, total load in that section is found to be 1,075 kW and 510 kVAR. Optimal size of DGs found is sufficient to supply this load which otherwise should have been partially cut off. DGs within the MG area feeding all MG loads DG at bus 15 is supplying 594.0 kW and 293.0 kVAR while that at bus 32 is supplying 485.0 kW and 221.0 kVAR. Total loss within MG is found to be 4.0 kW only.

- **Voltage profile:** Comparison of voltage profile of MG section in base case and MG isolated operation is shown in Fig. 6. The 33 bus system is dark out in the base case. It can be seen that, the MG in islanded of operation has voltage profile better that base case.
- **Voltage regulation:** The voltage regulation is infinite because of the system is dark out in the base case. The lowest voltage, in islanded is located at bus 25 with voltage regulation is 0.793 percent. As can be clearly seen from the results, the introduction of MG is continues to supply load within its own area and improves the voltage regulation.

CONCLUSION

The study presents influence of Micro-grid in steady state performance of primary distribution system. Two scenarios, namely, MG operating parallel to distribution system and MG operating in an isolated mode have been analyzed and discussed. According to the numerical results presented MG can improve performances of distribution system in both scenarios, i.e. MG can reduce total losses, improve voltage profiles, reduce main feeder current and increase load ability. Hence, MG could be considered as a way forward to integrate DGs in distribution systems. Moreover, following further studies are possible: an improved method for MG planning in case of difference types of load model, further analysis and improved optimization technique on a case of long term planning and systematical technique to identify a proper location of MG in a primary distribution network.

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