A New Reliability and Security Oriented Technique for Optimal DG Placement in a Practical Distribution Network

Soumya Das
Dept. of Electric Power Engineering
NTNU, Norway

Olav Bjarte Fosso
Dept. of Electric Power Engineering
NTNU, Norway

Giancarlo Marafioti
Dept. of Mathematics and Cybernetics
Sintef Digital, Norway

Motivation

- A 88-bus LV distribution network at a remote Froan island in Norway is radial with only a single point grid connection.
- Power Flow (PF) solutions showed unacceptable voltage profile with high power losses even at lightly loaded conditions.
- At max. anticipated load, non-convergence of PF was observed.
- Therefore, a plan for placement of Distributed Generations (DGs) was initiated.

Objectives

- Minimize both real and reactive power losses at Froan network.
- Improve its overall voltage profile.
- Plan a reliable and adequately voltage-stable network with increased loadability.

Proposed Approach

- Network buses are ranked as per:
  a. Network Loss Sensitivity Factors (NLSF) [1]: $\frac{\partial P_{Loss}}{\partial P_k}, \frac{\partial P_{Loss}}{\partial Q_k}, \frac{\partial Q_{Loss}}{\partial P_k}, \frac{\partial Q_{Loss}}{\partial Q_k}$
  b. Voltage Stability Factors (VSFm) [2]:
     - For a feasible bus voltage, $VSF_m = \{V_k{}^2 - 2(r_{km}P_{eff_m} + x_{km}Q_{eff_m})\}^2 - 4(r_{km}{}^2 + x_{km}{}^2)(P_{eff_m}{}^2 + Q_{eff_m}{}^2) \geq 0$
     - and, $NVSF = \min_{m \in \Omega}[VSF_m]$
- A superset of top one-fourth buses from each ranked sets provide the possible DG locations.
- Optimal DG sizes at each bus location are found by solving Optimal PF (OPF) in 'Matpower' software.
- Optimal location is the one resulting in the lowest network losses.
- Finding next DG location starts by new ranking of the buses with previous DGs in place.
- A gradient search is performed to find the optimal tap settings:
  - Tap Sensitivity Factors, $TSF = \frac{\partial P_{Loss}}{\partial t_{km}} = \frac{\partial P_{Loss}}{\partial P_m} \times \frac{\partial P_m}{\partial t_{km}}$.
  - $t_{km}{}^n = t_{km}{}^{n-1} - TSF^{-1} \times a_{step}$

Here, P_{Loss} and Q_{Loss} are the real and reactive power losses; P_k and Q_k are real and reactive power injections at k th bus, V_k is the corresponding voltage magnitude; r_{km}, x_{km} and t_{km} are the resistance, reactance and transformer tap ratio between k th and m th buses respectively; P_{eff_m} and Q_{eff_m} are effective real and reactive loads at m th bus, Ω is the set of all buses, n is iteration count and a_{step} is the step size.

Results

❑ Initial Network Parameters at 40% bus loading without DG

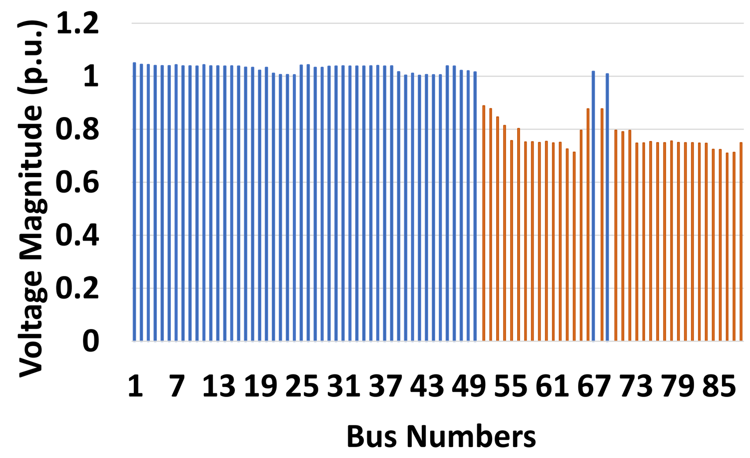

Fig 1. Network Voltage Profile at only 40% of Bus Loading

Total Power Generation		Total Load		Total Network Losses	
Real (kW)	Reactive (kVAR)	Real (kW)	Reactive (kVAR)	Real (kW)	Reactive (kVAR)
99.9214	22.7585	79.5968	10.8616	**20.3246**	**12.0074**
NVSF			**0.2435**		

- A poor voltage profile persists.
- Network near voltage collapse as shown by very low value of NVSF and high power losses.

❑ Final Network Parameters at Max. bus loading with DGs

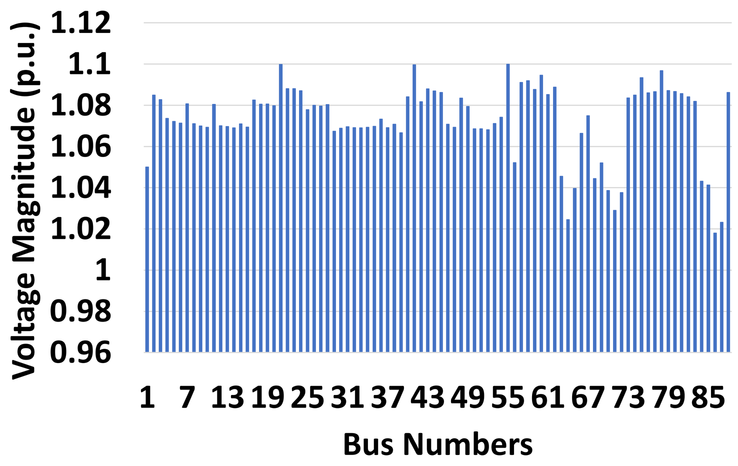

Fig 2. Network Voltage Profile at Max. Bus Loading with DGs

New DG Bus Locations: 55, 21					
Total Power Generation		Total Load		Total Network Losses	
Real (kW)	Reactive (kVAR)	Real (kW)	Reactive (kVAR)	Real (kW)	Reactive (kVAR)
205.0409	28.9604	198.9920	27.1540	**6.0623**	**1.9243**
NVSF			**0.9584**		

- Compared to the first case, it can be observed in the second table that even with 150% increase in bus loading,
  - active power losses reduced by 70.17%
  - reactive losses reduced by 83.97% and,
  - highly voltage stable network is obtained with 293.59% increase in NVSF value.

Conclusions

- A new sensitivity-based non-linear methodology is proposed for optimal DG location, sizing and optimal transformer tap settings.
- Using NLSF and VSF in DG placement resulted in better planning.
- Optimum DG sizes determined by solving non-linear AC OPF ensure conformity to all network constraints.
- Drastic improvement in voltage stability and reduction in losses.
- Use of entirely free and open-source software provide new, non-expensive tools to the utilities for testing their network reliability.

References

1. D. Q. Hung, N. Mithulananthan, and R. C. Bansal, "An optimal investment planning framework for multiple distributed generation units in industrial distribution systems," Applied Energy, vol. 124, pp. 62–72, 2014.
2. M. Chakravorty and D. Das, "Voltage stability analysis of radial distribution networks," International Journal of Electrical Power and Energy System, vol. 23, no. 2, pp. 129–135, 2001.

This work is funded by CINELDI - Centre for intelligent electricity distribution, an 8 year Research Centre under the FME-scheme (Centre for Environment-friendly Energy Research, 257626/E20). The authors gratefully acknowledge the financial support from the Research Council of Norway and the CINELDI partners.