Potential Technical Problems and Solutions Associated with Distributed Generation

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Introduction

Traditionally Distribution Electric Systems have been passive networks without any active element like generators. Thus, most of the technical problems observed in HV networks have not been considered in distribution networks. However, recent pressures for more sustainable energy have led to active efforts toward deploying smaller-scale power plants close to the end users and in the distribution side of the electric network. These plants are broadly referred to as distributed generation (DG).
Wide deployment of DG units in distribution networks is transforming current Distribution Electric Systems to future Distribution Energy Systems with more complicated structures and advance components . However, in this transition, some technical problems not addressed before may arise . This paper analyzes dynamic stability of a radial distribution network when two combustion turbines are locating in the network and providing 10% of total load.
The results show that by changing DG locations, frequency instability may occur due to strong coupling between DGs or between substation and DGs. In addition, low inertia of DGs can also increase coupling between DGs and lead to frequency instability in the network.

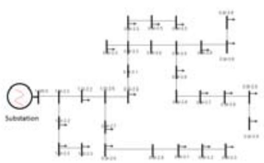


Figure 1. schematic of current Distribution Electric Systems

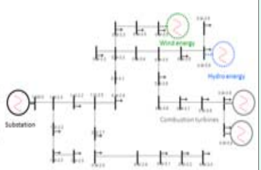


Figure 2. schematic of future Distribution Energy Systems

Challenges

- **Not being able to transfer power from one location to another location due to lack of voltage support**
- **Frequency instability due to abnormal locating of DG units**

Approaches to Analyze the Problems

- **Finding equilibrium point of the system (power flow solution) by simple Power Flow program and comparing the result with Optimum Power Flow (OPF) software**
- **Linearizing system dynamics around equilibrium point**
  - Analyzing dynamics of the system by state space model
  - Determining stability of the system by Eigenvalue analysis
  - Extracting nature of instability by participation factor method

Methods to Solve DG-related Technical Problems

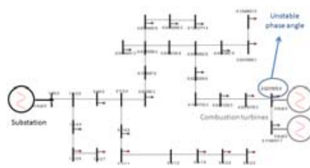
- **Optimizing voltage sets of DGs using OPF-based scheduling**
- **Choosing the best DG locations**
- **Increasing inertia of DG units**
- **Using appropriate communications and control**

Results

Static Analysis

Optimum locating of two combustion turbines with following real and reactive power capacity ranges in order to minimize loss;

$$0.7MW \le P_{DG} \le 0.8MW$$
$$-0.4MVar \le Q_{DG} \le 0.4MVar$$



simple Power Flow Algorithm:

$$P_i = \sum_{j=1}^{n} |V_i||V_j|\left[g_{ij}\cos(\delta_i-\delta_j)+b_{ij}\sin(\delta_i-\delta_j)\right]$$
$$Q_i = \sum_{j=1}^{n} |V_i||V_j|\left[g_{ij}\cos(\delta_i-\delta_j)-b_{ij}\sin(\delta_i-\delta_j)\right]$$

subject to:

$$P_{L,i} \;\&\; Q_{L,i} = Const \quad \forall\, i \in Loads$$
$$P_{G,j} \;\&\; V_{G,j} = Const \quad \forall\, j \in Generators$$

Figure 3. not being able to transfer power at optimum location due to lack of voltage support

Optimum Power Flow Algorithm:

$$Min\ P_{Loss} = \sum_{i=1}^{n_G} P_{G,i} - \sum_{j=1}^{n_{Load}} P_{L,j}$$
$$w.r.t.\ P_G \text{ and } V_G$$
$$P_i = \sum_{j=1}^{n} |V_i||V_j|\left[g_{ij}\cos(\delta_i-\delta_j)+b_{ij}\sin(\delta_i-\delta_j)\right]$$
$$Q_i = \sum_{j=1}^{n} |V_i||V_j|\left[g_{ij}\cos(\delta_i-\delta_j)-b_{ij}\sin(\delta_i-\delta_j)\right]$$

subject to:

$$P_{L,i} \;\&\; Q_{L,i} = Const \quad \forall\, i \in Loads$$
$$P_{\min} \le P_{G,j} \le P_{\max} \quad \forall\, j \in Generators$$
$$V_{\min} \le V_{G,j} \le V_{\max}$$

Figure 4. optimizing DGs' voltage set in order to minimize power loss

Dynamic Analysis

Combustion-Turbine-Generator Dynamics

$$M\dot{\omega}_G = -D\omega_G + cW_F - P_G$$
$$b\dot{V}_{CE} = -K_D\omega_G - V_{CE} + K_D\omega^{ref}$$
$$\dot{W}_F = W_F dot$$
$$\alpha \dot{W}_F dot = \alpha V_{CE} - \delta W_F - \beta W_F dot$$

Interconnected System Model

$$\dot{P}_G = K_P\omega_G + D_P\dot{P}_L$$

System Model

$$\dot{x}_{LC} = A_{LC}x_{LC} + C_M P_G + Bu$$

$$\begin{bmatrix}\dot{x}_{LC1}\\ \dot{P}_{G1}\\ \dot{x}_{LC2}\\ \dot{P}_{G2}\end{bmatrix} = \begin{bmatrix}A_{LC1} & C_{M1} & 0 & 0\\ K_P(1,1) & 0 & K_P(1,2) & 0\\ 0 & 0 & A_{LC2} & C_{M2}\\ K_P(2,1) & 0 & K_P(2,2) & 0\end{bmatrix}\begin{bmatrix}x_{LC1}\\ P_{G1}\\ x_{LC2}\\ P_{G2}\end{bmatrix} + D_P\dot{P}_L$$

Out of 900 possible candidate of locating DGs, 192 locations are unstable and even the optimum location with respect to loss minimization is unstable

Type 1 instability: two DGs are electrically close

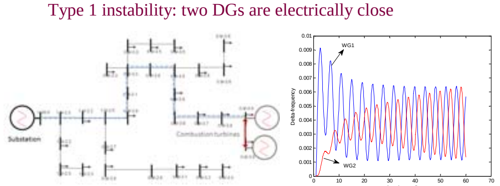


Figure 5. by small load disturbance at bus 15th, frequency becomes unstable because two DGs are strongly coupled

Type 2 instability: one DG is close to the substation

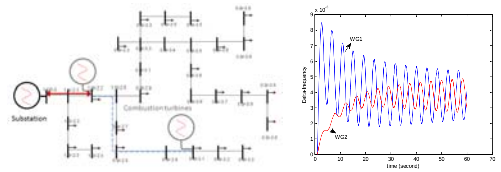


Figure 6. by small disturbance at bus 15th, *frequency deviation* does not converge because two one DG is strongly coupled with substation

Type 3 instability: two DGs are close to the substation

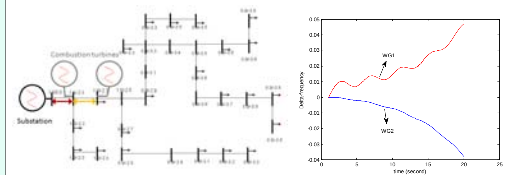


Figure 7. by small disturbance at bus 15th, frequency deviation does not converge because DGs are strongly coupled with themselves and with substation

Possible Solutions

- **Choosing stable locations based on the bound for minimum electrical distance (new result)**

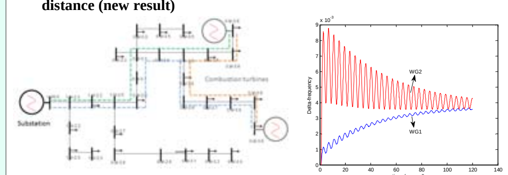


Figure 8. by small disturbance at bus 15th, frequency deviation converges because DGs are weakly coupled

- **Increasing the inertia of DGs (five folds), the number of unstable scenarios is reduced from 192 to 14.**

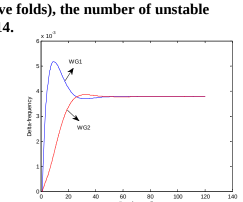


Figure 9. by increasing inertia five folds, type 1 and 2 instability become stable. Thus, by small perturbation in the system, frequency deviation diverges.

Future Work

- **Enhancing stability through communication and control**
- **Design of public policies to support system stability with DGs (based on technical analysis)**
- **Design of financial incentives to ensure stability of the system with any DGs**
- **Generalizing technical results to obtain industry standards**

Conclusions

- **This is work in progress**
- **Preliminary results show that there exists locations which may lead to new instability problems in Distribution Systems with DGs (trade of with minimum distribution loss objective)**
- **These could be caused by placing DGs electrically close to each other or to the substation or by deploying very small inertia DGs**
- **We have used participation factors method to identify causes of instability and to derive a bound for minimum distance between DGs to avoid instability**
- **These bounds can be used for planning new DGs**
- **Future work concerns control and communication designs for stabilizing unstable scenarios**

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