TECHNICAL AND ECONOMICAL EVALUATIONS FOR DISPERSED GENERATION CONNECTION POINT DETERMINATION

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ABSTRACT

Paper describes technical and economical proceedings for optimal dispersed generation network connection point determination. Different measures for rising of fault current ratings at connection point are presented: connection point shifting, network cabling, transformer upgrading, and connection of DG to separate bus. Technical and economical point of view of different DG connection solutions is presented.

INTRODUCTION

The common impression at DG connection research is that scientific society is much more favourable to new DG and RES than DSOs who have many technical difficulties with voltage quality at real network operation. To avoid operating problems the key task of DSO is appropriate DG connection point determination which is not necessary the closest point of the network [1]. In case of a weak distribution grid the alternate solution should be prepared following the instructions to assure operation conditions [2] and least cost network reinforcement solution [3].

MAXIMUM DG POWER DETERMINATION

The maximum DG power at specific network node basis on voltage drop equation formula which is simplified and derivated to expression which consist fault power at connection point:

$$P_{n\_DG}^{MAX} = \frac{S_{\text{fault}}}{k\,\cos(\psi - \varphi)}\Delta u_{\max} \qquad (1)$$

P_{n_DG} - *DG nominal power*
Δu_{maxv} - *maximum voltage drop/rise*
S_{fault} - *fault power (3 fase)*
k - *factor of DG power change $\Delta P/P_{n\_DG}$*
ψ - *impedance angle tg $\psi = R/X$*
φ - *power factor*

The main criterion is maximal voltage drop/rise which depends on disturbance frequency and presence of load on the same feeder [4].

Statical criteria

Statical criterion is used mostly for photovoltaic sources (PV) but also for a wind power generator (WG) and hydro power plant (HP) resources at nominal operation point:

- k =1; Δu_{maxv} =(*MV… 2%*, LV…3%) cosφ≈1

Dynamical criteria

Dynamical criterion is used mostly for a wind and small hydro power plant (HP) sources at dynamic or fast changing operational conditions (switch on/off generator):

- k =4-8; Δu_{maxv} =(*MV… 3%*, LV…6%) cosφ≈0,2

Considering described criteria and calculation by equation (1) the following different characteristics for PV and HP on LV (Figure 1, Figure 2) and MV network (Figure 3, Figure 4) are obtained:

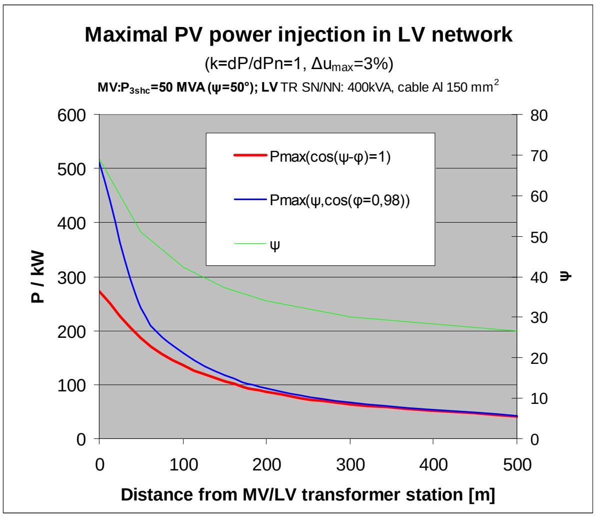

Figure 1

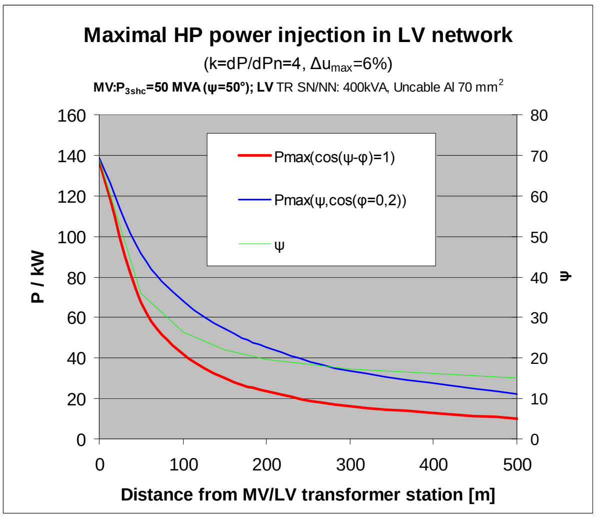

Figure 2

Considering real impedance angle for PV it is evident that maximal power at LV bus in transformer station is even

higher than nominal rated power of installed transformer. Deeper in the LV network importance of impedance angle could be neglected.
The situation is quite different for HP where maximal power at LV bus in TS is quite below the nominal rated power of transformer and the impedance angle deeper in the LV network rises permitted maximal power.

Maximal powers for PV and HP on the MV network characteristics is shown bellow:

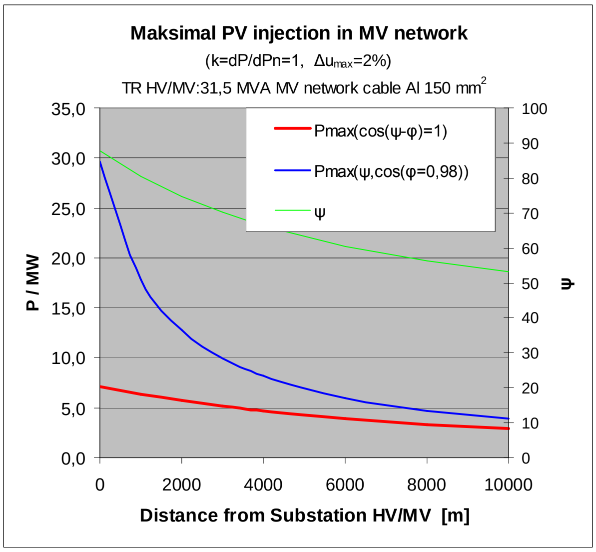

Figure 3

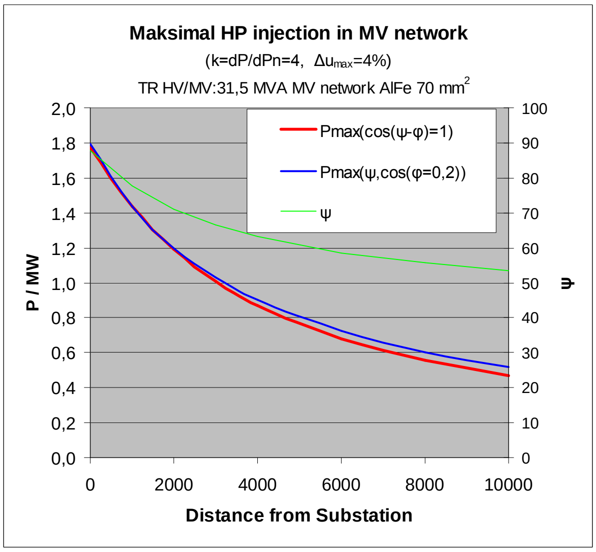

Figure 4

Impedance angle consideration for PVs is even much more important in MV networks where the maximal power at bus connected PV is almost equal to the nominal rated power of installed transformer. Neglection of impedance angle would lead to much smaller PV injection.

Maximal HP power at MV bus in substation is much lower then the PV ratings but impedance angle does not play significant role.

FAULT POWER RISE MEASURES

Fault power rate at specific point of the network actually illustrates grid strength of the network or disturbance resistance caused by DG. If the closest point from new DG to the network - due to long distance to TS or small cross section of lines does not correspond to technical conditions there are few basic approaches to meet required criteria for connection (Figure 5):

1. connection point shifting,
2. network reinforcement (line cabling),
3. transformer upgrading and
4. connection of DG to separate bus.

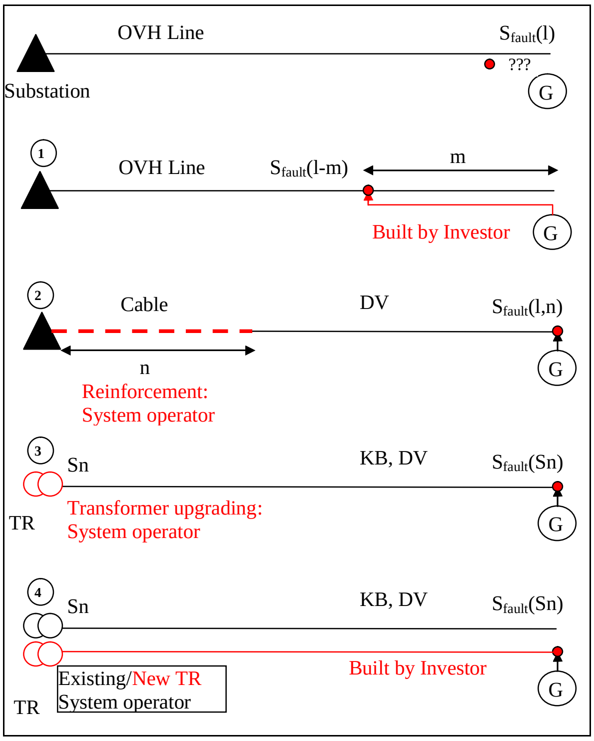

Figure 5

Connection point shifting versus network reinforcement

The most common question or dilemma is selection of optimal solution between measure (1) where costs are covered by investor and (2) where cost are covered by DSO. At this point we would rather not argue about deep or shallow network cost recovery approach. EU energy legislation is more favourable to the last one. The comparison between (1) and (2) is going to be only technical with further economical consideration.

The expression for the fault power at equal distance (m=n) in MV network in cases (1) and (2) is:

$$\frac{S_{fault}^{(1)}(x,m)}{Sk^{(2)}(x,n)} > \frac{z'_{110+TR} + l\, z'_{MV\_CB} - m\, z'_{SN\_Cable} + m\, z'_{MN\_OVH}}{z'_{110+TR} + l\, z'_{MV\_CB} - m\, z'_{MV\_CB}} \quad (2)$$

$$\frac{S_{fault}^{(1)}(x,m)}{S_{fault}^{(2)}(x,n)} >= \frac{K + m\, z'_{MV\_OVH}}{K} > 1$$

z'_{110+TR} - *impedance of HV network and transformer*
z'_{MV_CB} - *impedance of MV cable line*
z'_{MV_OVH} - *impedance of MV overhead line*

From above it is obvious that the shifting of connection point is more efficient measure for rising fault power than network cabling. Nevertheless in case of several DGs connected to the same network tree reinforcement of the grid can not be avoided.

Transformer upgrading versus connection point shiftinfg

Fault power depends on serial transformer and line impedance. Close to the bus the transformer impedance is much more significant and it can be efficiently reduced by upgrading transformer to higher nominal power. Farther from the bus the line impedance rises and prevails over the transformer impedance. The formula for maximal DG power expressed from impedances is:

$$S_{DG}^{MAX} \approx \frac{U^2}{k\left(l\, r_{line} + \mathrm{tg}(\varphi)\left(\frac{u_k^{TR}}{S_n^{TR}} + l\, x_{line}\right)\right)} \Delta u_{max} \quad (3)$$

u_k^{TR} - *leakage reaktance of transformer*
S_n^{TR} - *nominal power of transformer*

Two very different cases: PV on weak (Figure 6) and HP on strong LV network (Figure 7) were prepared to illustrate impact of transformer MV/LV nominal power and connection distance on maximal DG power.

Mathematical solution for optimal measure in specific point of the network could be derived by implementation of cost function and examination of parcial cost gradient function ($\partial S_{DG}^{MAKS}/\partial C_{TR}$ (Sn) or $\partial\, S_{DG}^{MAKS}/\partial\, C_{ine}$ (l)). In process of making practical decisions incremental accession to the problem is much more useful. The main reason is changing line cross section in the network tree. Both options should be checked for each DG connection. An approximate cost is 20-40 €/kVA for MV/LV transformer and 30-50 €/m for LV cables.

On the basis of real network and cost data the following conclusions can be made:

- Upgrading of transformer for PV connection is reasonable only very close to LV bus (below 100 m).
- Single line connection to TS LV bus for PV over 50 kW is mostly used solution.
- The effect of rising nominal power of transformer is much higher at small ratings of TR because of the rising of leakage reactance with the nominal power of transformer.
- At HP connection the influence of transformer nominal power is more significant but even at strong grid only to about 500 m.
- In the case of DG with nominal power over 100 kW and displaced to the MV network grid the only appropriate technical solution is building of new TS close to the DG although the costs for such solution are much higher (building of TS and MV line).

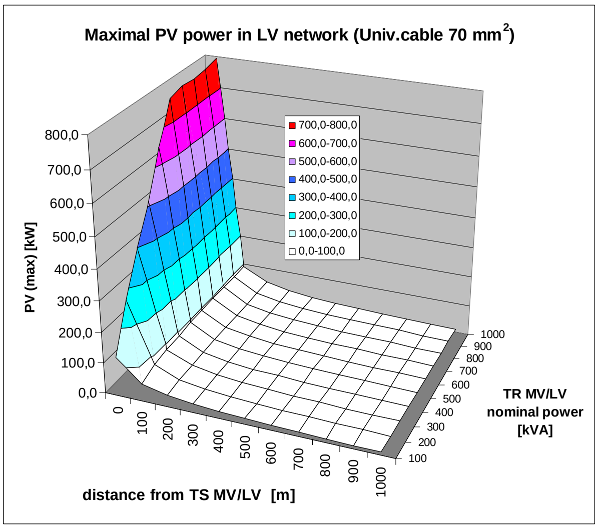

Figure 6

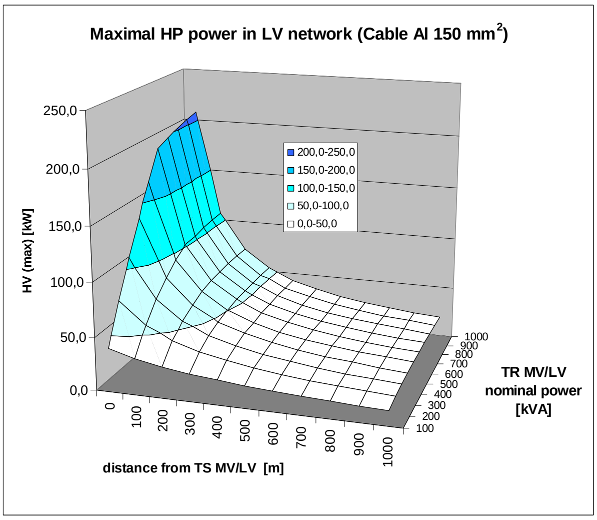

Figure 7

Separate bus connection

For large DGs sometimes the only suitable measure is the separate bus connection (Figure 8). The terms following to this solution are:

- fault power rating at the bus is too low for the applied DG power,
- high intermittence of DG,
- enormous cost for new substation.

In LV network redundant transformer is not installed for the case of reserve supply and the room for more transformers is mostly not foreseen. Therefore this solution is mostly applied in MV network. At shallow network cost recovery approach DG cover only connection cost.

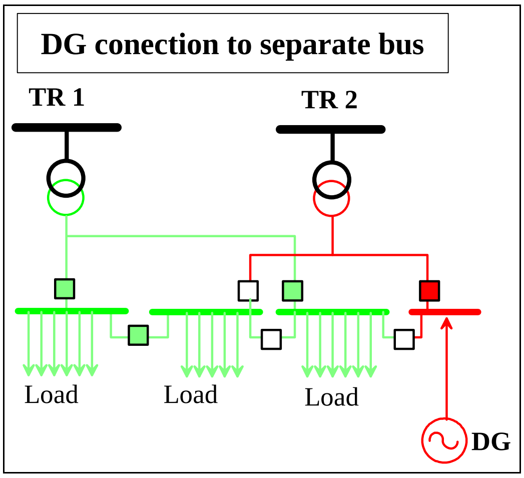

Figure 8

CONCLUSION

The main conclusions according to DG connection to the distribution grid are:

- in case of few DGs connection point shifting up to substation or transformer station is more efficient as cabling or reinforcement of the network:
  - fault power rate deeper in network is higher,
  - line reinforcement in urban area without cable sewage system has usually higher cost as building a new connection (Figure 9),
- in case of high penetration of DG network reinforcement could not be avoided,
- transformer upgrading is efficient only if connection point is close to transformer station,
- for large intermittent DG connection on separate bus is the most appropriate technical and economical solution.

REFERENCES

[1] T. Mohar, L. Valenčič: “Technical And Economical Proceedings For Dispersed Generation Connection Point Determination”, CIRED, Ljubljana 2011.

[2] SODO (DSO), 2008, "Connection Instructions for DG up to 10 MW, Ljubljana, Slovenia.

[3] SODO (DSO), 2010, "Distribution System Operational Guide, Ljubljana Slovenia.

[4] Technische und organisatorische Regeln für Betreiber und Benutzer von Netzen, (TOR), Version 1.7, Stand 19.09.2006, E-CONTROL, Austria, 2006.

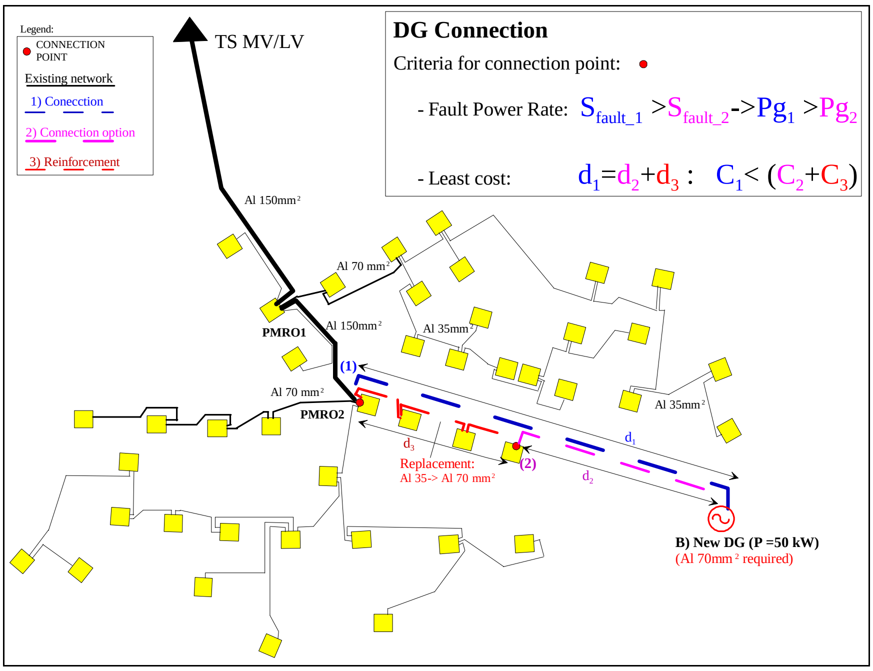

Figure 9