CHARACTERISTIC RESPONSES OF DISTRIBUTION NETWORK CELL: THE EFFECT OF CELL STRUCTURE AND CONFIGURATION

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ABSTRACT

Establishing the range of responses that describe the behaviour of the distribution network cell (DNC) of certain structure and composition is the first step towards obtaining its equivalent dynamic model. In this paper, groups having similar voltage and corresponding power responses are identified qualitatively, for both external and internal fault, with the emphasis on the influence of cell structure and composition.

INTRODUCTION

The increased penetration of distributed generation (DG) has already altered the conventional views of distribution networks as passive terminations of transmission networks and opened the possibilities for introduction of new concepts in distribution systems. The applications based on small-scale generation technologies, using mainly renewable energy sources, have been improved in the recent years, allowing their wider implementation and at the same time, studies of power system performance under changed conditions. Facing the new challenges, the future distribution systems are envisaged as active networks, subdivided in autonomous distribution network cells [1-4], with local management of power flows between the local generators, loads and adjacent cells.

The examination of the DNC characteristics and the effects they would have on the power systems are of very high importance if these concepts are to be implemented in the future. So far, the performance of micro grid/DNC has been investigated, with special emphasis on island operation [5, 6], transient behaviour [7, 8], as well as on control and protection schemes. An adequate equivalent dynamic model, representing the DNC, has not yet been proposed even though it could be necessary for more thorough assessment of the performance of power systems with DNC.

The first steps towards development of the equivalent DNC model have been already undertaken, while studying about 500 DNC operating scenarios in order to identify the range of its possible behaviour, following internal and external disturbances [8]. Using detailed renewable energy sources (RES) models, the impacts of generation type, DG penetration and load type and size on DNC transient behaviour have been investigated. Continuing the same line of research, this paper analyzes qualitatively the effects of cell structure and composition on its voltage and power responses.

DNC STRUCTRE

The DNC study system, d is broadly based on the UK 11 kV distribution network. The DNC is connected to 33 kV external grid, represented by equivalent synchronous generator source. The grid supplies three 11 kV feeder system through 33/11.5 kV, 12/24 MVA transformer with 21 % impedance, Dy11 connection and voltage regulation at the low voltage side. The tap range is ±10 % of the nominal voltage, with 1.25% step change. The 11 kV feeders are connected to the point of common coupling (Bus 2) via fixed tap 11/0.433 kV transformers, with rating varying between 0.5-2.5 MVA and impedances between 4-6% depending on the load size. The converter connected (CCG) and fixed speed induction generators (FSIG) are connected on feeder 1 and doubly fed induction generators (DFIG) on feeder 3. Two synchronous generators (SG) connected to Bus 2, are driven by gas turbine units modelled as IEEE GAST type. Further details on DNC modelling, in DigSILENT PowerFactory software, can be found in [8].

CASE STUDIES

In total, 480 different case studies are considered comprising 10 generation scenarios, 4 load types, 6 load sizes and two fault locations. The Base Case (BC) generation scenario assumes that the two SGs supply power to the DNC and each DG type is represented by one unit. The penetration of DGs, as shown in Table 1, is simulated by replacing the SG generation with DG of type X (DFIG, CCG or FSIG), while keeping the total generation in the DNC constant (11 MW).

TABLE 1 PENETRATION OF DIFFERENT TYPES OF DISTRIBUTED GENERATION

Case	**SG1** (MW)	**SG2** (MW)	**X**
BC	**6**	**1.5**	***Unit rated***
X1	4.5	0	+3 MW
X2	0	1.5	+6 MW
X3	0	0	+7.5 MW

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For each generation scenario, the load type and the size are varied. The load types considered enable analyses of sub-cases with pure static (SL) or pure dynamic loads (DL) as well as cases with moderate share of DL. The load size is varied from 50% to 200% of the generation size, with step change of 25%. Two different fault locations are considered: external fault (EF) at the grid connection bus and internal fault (IF) at the low voltage side on feeder 2. Fault clearing time is 500 ms.

RESULTS OF THE SIMULATIONS

Voltage responses following the disturbances have been analysed and groups having qualitatively similar results identified. The influences of the change in DNC structure and configuration are discussed in the sequel through analyses of corresponding responses of each group. The identification number of each group is placed before the fault location abbreviation, i.e., YEF or YIF, where Y is group number.

The first group, 1EF, shown in Fig. 1, represents DNC responses when the generation in the network is predominantly DFIG or CCG, with quite high DG penetration (100-200%) and moderate to high DL share in the network.

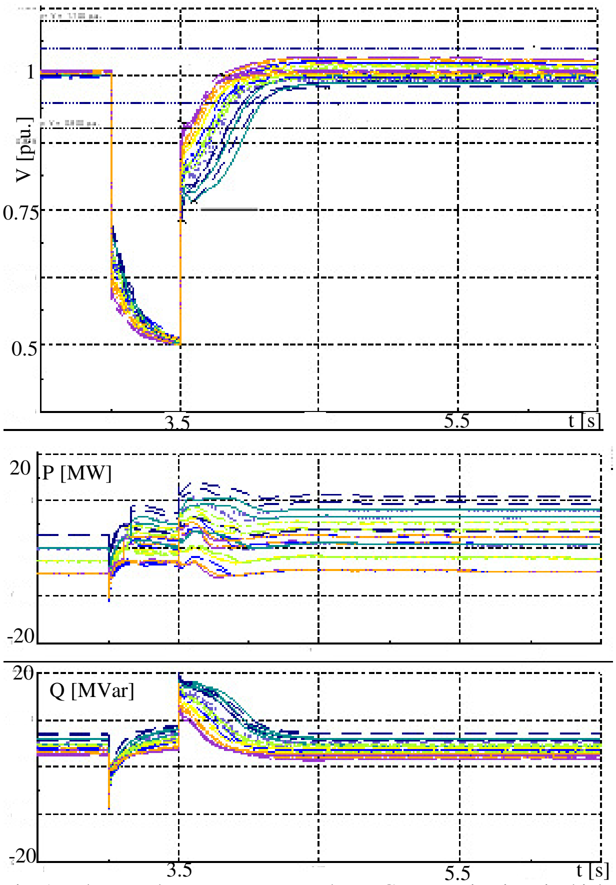

Fig. 1 Voltage and power responses when DG penetration is quite high, generation is predominantly DFIG and share of DL is moderate to high

The group also contains cases with lower DG penetration, and moderate share of DL. The whole group recovers in about 1s after the fault clearing time.

Group 2EF includes cases where generation is dominantly DFIG (CCG) and DG penetration is moderate to high. Cases with higher DG penetration (100-130%) and higher share of DL (60-100%) and cases with lower DG penetration (up to 80%) and moderate share of DL (40-60%) have similar voltage responses, as shown in Fig. 2. Similar behaviour is noticed for cases with dominantly FSIG generation, lower DG penetration and moderate share of DL.

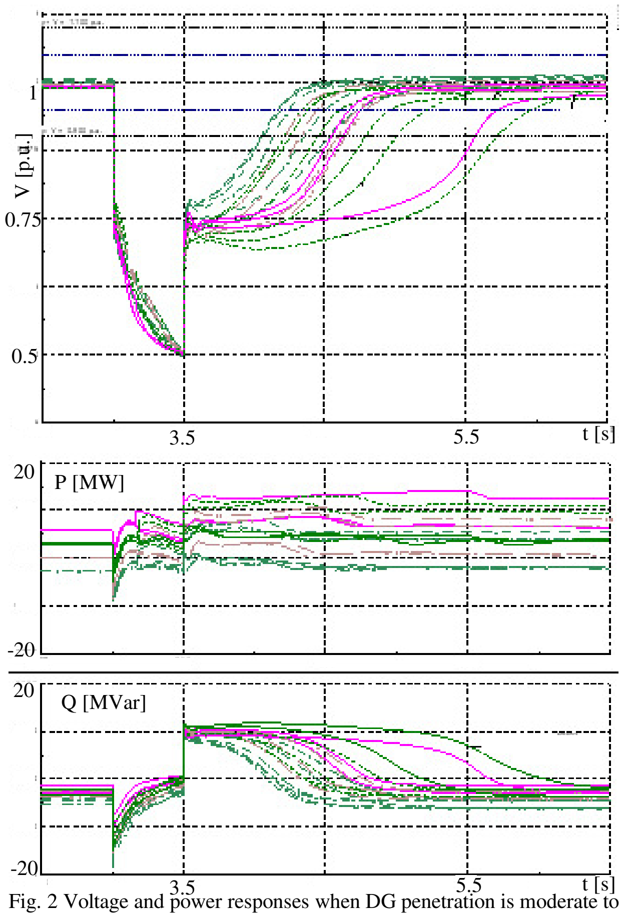

Fig. 2 Voltage and power responses when DG penetration is moderate to high, generation is dominantly DFIG or FSIG, share of DL is moderate to high

Group 3EF comprises cases with moderate to dominant SG participation, quite high DG penetration and moderate share of DL. Cases with pure DL also belong to this group, but the DG penetration in that case should be the highest (200%). Cases with lower DG penetration and lower participation of DL exhibit similar behaviour, but their recovery times are longer (the curves shift to the right from the existing group's responses). The voltage responses are quite similar to the responses shown in Fig.1. Similarly, group 4EF represents responses with moderate to dominant SG participation, but with lower participation of DL. DG penetration (67-133%) and moderate to high.

It can be noticed from the above responses that cases with higher DG penetration allow higher share of DL in the total load. For cases with 100-130% DG penetration, the load can be purely dynamic. The voltage and power responses for this group are similar, but more compact than the responses of 2EF.

Cases with predominantly FSIG generation and higher DG penetration belong to group 5EF (Fig.3). The participation of DL is about half of the total load. This group also contains cases with very high DG penetration and pure DL, as well as slightly lower DG penetration, but dominantly SL.

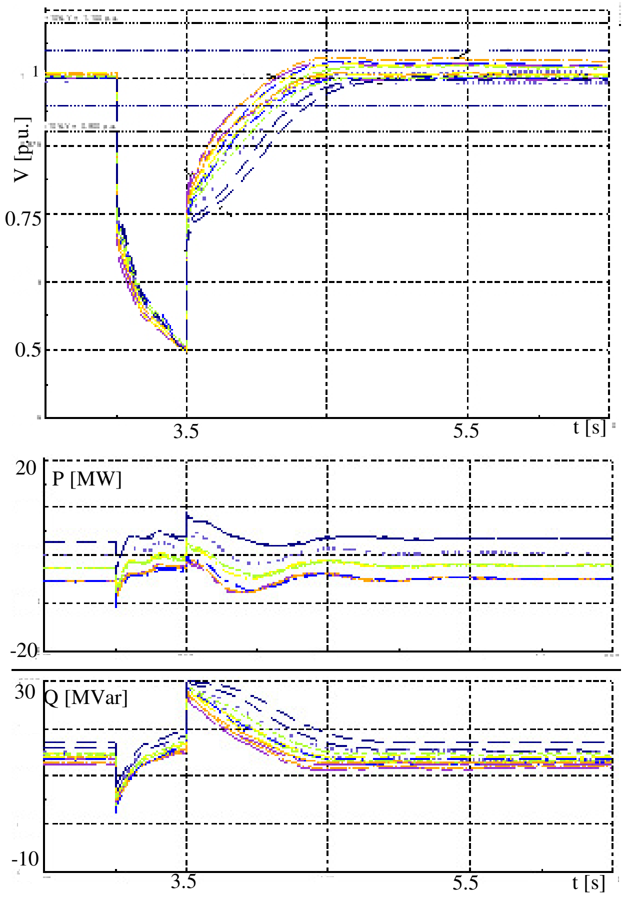

Fig. 3 Voltage and power responses when DG penetration is high, generation is predominantly FSIG and about half of the load is dynamic

Groups 6EF and 7EF include the cases with moderate to dominant SG as well as dominant FSIG generation and with dominant DFIG or CCG, respectively. For both groups the load is purely static and the DG penetration varies from very low to very high. Cases with the lowest DG penetration (red coloured curves) have the longest recovery times (see Fig.4 which depicts the results for group 6EF). Voltage and power responses for group 7EF are similar to 6EF, only the curves are smoother, with smaller oscillatory deviations.

The last group, 8EF, contains all the cases for which the pre-fault values of the voltage at Bus 2 have not been achieved. The group contains mainly cases with the lowest DG penetration. The loads are dominantly dynamic, regardless of the generation mix. To be in this group, cases with highest DG penetration should have very high induction load share and possibly, the generation mix should be dominantly FSIG (or even CCG).

Similar groups are created from responses following the internal fault. It can be noticed that the change of the fault location (closer to the induction machines) affects the stability of the DNC, except when the load is purely static. Thus, the number of cases in which the voltages do not recover to the pre-fault values, is increased.

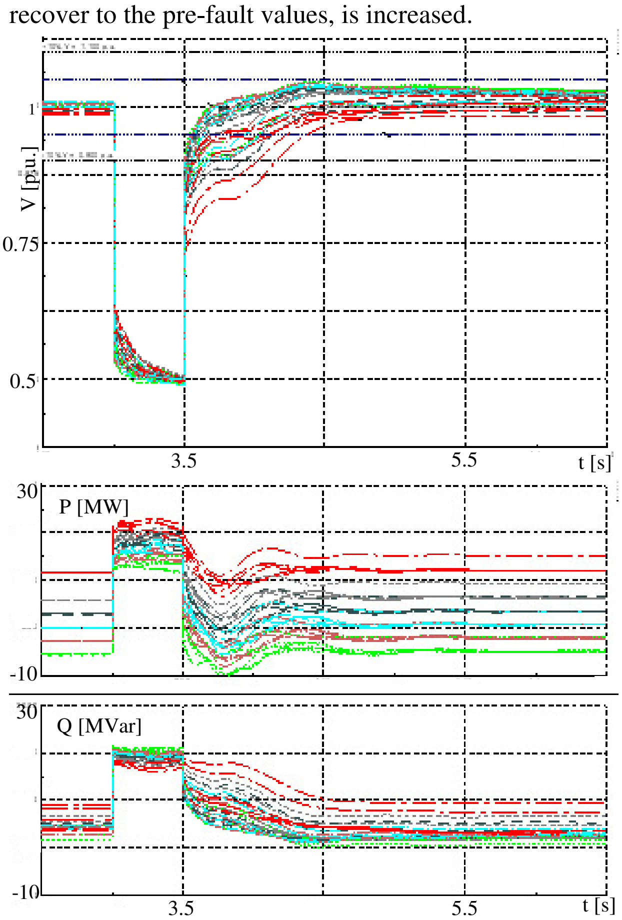

Fig. 4 Voltage and power responses with different levels of DG penetration, synchronous or dominantly FSIG generation and pure SL

The group 1IF represents responses when the generation in the network is moderately to dominantly synchronous, as well as cases with dominantly DFIG or FSIG generation (X2 in Table 1). The responses correspond to cases with high DG penetration, with moderate share of DL. The cases with dominantly DFIG/FSIG allow for only highest DG penetration levels (133-200%). The responses are similar to those shown in Fig. 1.

2IF comprises responses when the generation is dominantly DFIG, CCG or FSIG, with moderate DG penetration, while the DL is about half of the total load. The responses of this group are shown on Fig. 5.

The third group, 3IF, refers to cases with high DG penetration, moderate to high share of DL and predominantly DFIG or CCG generation.

4IF includes cases with moderately to dominantly SG and moderate to high share of DL. The responses are similar to 2IF, only the curves are smoother and have the shape of the letter S. Groups 5IF and 6IF correspond to groups 6EF and 7EF respectively. As the groups are quite similar, the groups 5IF and 6IF are not shown here.
The last group, 7IF comprises all cases in which the voltages do not recover to their pre-fault values.

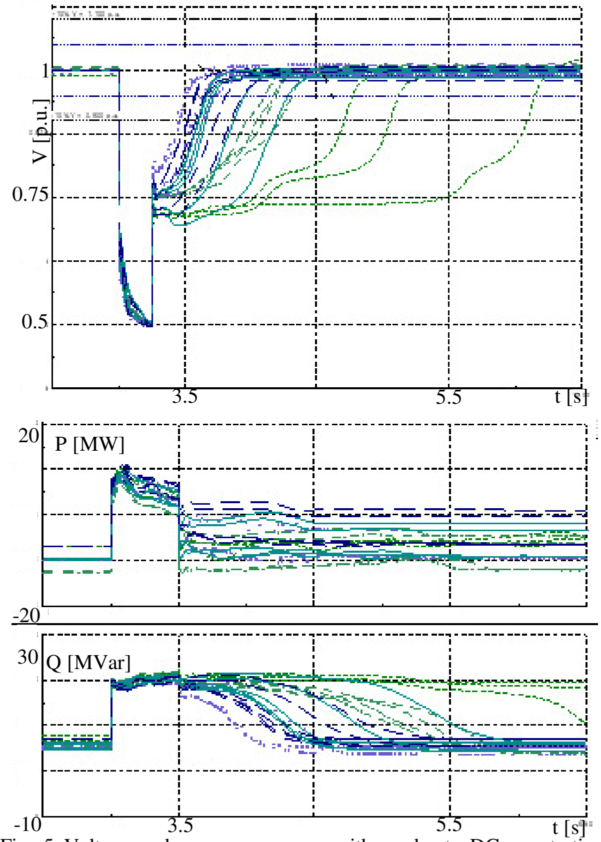

Fig. 5 Voltage and power responses with moderate DG penetration, dominantly DFIG/FSIG and the share of DL is about half of the total load

The analyses of the recovered cases show that the responses, observed after the fault is cleared, could be represented by simple exponential equation, as voltages in all groups recover, more or less, exponentially. Applying simple curve-fitting procedure, the following equation was derived:

$$V(t) = V_0 \cdot e^{a^{\frac{b+t}{c+t}}} \qquad (1)$$

where V_0 is the pre-fault value of the voltage. The performed principal component analysis of the responses justifies the use of this type of equation, as the primary component of the analysed curves is also exponential.
The change of the parameters *a, b* and *c* allows definition of ranges of curves which can describe the behaviour of DNC with certain structure. The range of responses for the group 1EF is shown in Fig 6.
The curves are obtained when *a* is varied from 0.06 to 0.07, *b* from -1.8 to -0.4, and *c* from 0.3 to 0.35. (Similar parameter ranges are defined for other groups formed by responses following the external disturbances.)

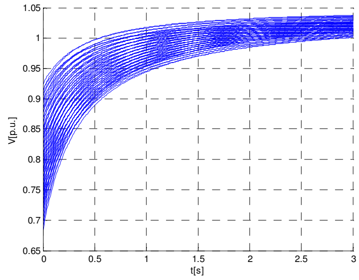

Fig. 6 Curves representing group 1EF; the range is obtained from (1), for different values of parameters a, b and c

CONCLUSIONS

The identified groups of results show that the cases with higher DG penetration have shorter recovery times following internal and external disturbances and allow for higher share of DL in the DNC. They also confirm that dominant DFIG or CCG contributes more to DNC stability than dominant FSIG. Further, regardless of DG penetration and generation mix, voltage at supply bus in case of DNC with pure SL always recovers to its pre-disturbance value. It has been also found that the groups identified in this manner can be described by rather simple exponential equation. The change of the parameters of the equation define the ranges of the responses of different groups and represent a step forward in development of the equivalent dynamic model of DNC.

Acknowledgments

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