

Modeling and Implementation of Renewable Energy Sources to Distribution Systems

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Abstract

Within new projects in the future in supplying local areas, a Power Operation and Power Quality Management System (POPQMS) must be developed. In order to model the parts of network with regulation programmable opened software in Matlab – DynaSolv was developed. DynaSolv can simulate multi-machine dynamics. The paper describes various principles of penetration synchronous machine type DGS into distribution network. This study provides possible complex analysis view on DGS stability issues, which can answer the *possibility* of connection.

Introduction

Deregulation in the power market has encouraged the move towards distributed generation, where many smaller generating plants located close to major loads, as opposed to a few large centrally located power stations, are penetrating into interconnected power systems. Nowadays, generating electricity using decentralized generators of relatively small scale is attracting a great interest from electric energy researchers. Such kind of generation is known as Distributed Generation Systems (DGS).

Main aim of using large amount of DGS in the future is to increase system reliability and lower the cost of power through the use of on-site generation. Since the DGS Penetration Level (PL) is still low (DG power generated less than 20% of power consumption in a sub-grid), the technical problems related to DG are limited to voltage profile support and control of interfacing conversion devices. When PL increases, several other problems will need to be faced and solved. *Stability* and *quality of electrical energy problems* may arise, *new planning tools* will be needed,

dispatching of energy sources with typical random production will be necessary, *protection systems* must be integrated and revised.

Distributed Generation

- Distributed Generation Systems (DGS) can provide energy solutions for some customers that are most cost-effective, environmentally friendly or provide better quality or reliability than conventional sources. DGS can be defined as not centrally planned sources, which operate on distribution network voltage level (LV or MV) and their one-unit power output is 5 kW – 5 MW (according CIGRE definition less than 50 MW).

Within new projects in the future in supplying local areas, a Power Operation and Power Quality Management System (POPQMS) must be developed. POPQMS will be a communication infrastructure and optimization tool for distribution grids which is expected to perform power

quality monitoring and control and to optimize grid operation through distributed generation control and demand side load management.

In synthesis POPQMS is expected to:

- collect information about topology situation and power quality in the network segments under control
- provide local strategies for power quality and security improvement
- observes and learns patterns of generation and consumption, including (over) load of grid infrastructure
- generates schedules for economically (cost) and technically (power quality) optimized operation of controllable generators and loads
- predict times with unbalance of generation and consumption of the grid segment and develop reaction strategies
- for medium and long term optimization reacts on local under- or over-voltage by increasing or decreasing generation or consumption accordingly for both active power and reactive power
- for short term reaction and intervention develop adequate reaction patterns for likely events, to be executed upon necessity
- instructs distributed components about their specific optimized reaction modes

Instruments for DGS Modeling

In order to model the parts of network with regulation programmable opened software in Matlab – DynaSolv was developed. DynaSolv can simulate multi-machine dynamics using principles described in [6]. Excitation model with PI regulation is in DynaSolv modeled as on the Fig. 1. T_R and k_R are PI regulator constants, T_e and k_e exciter constants.

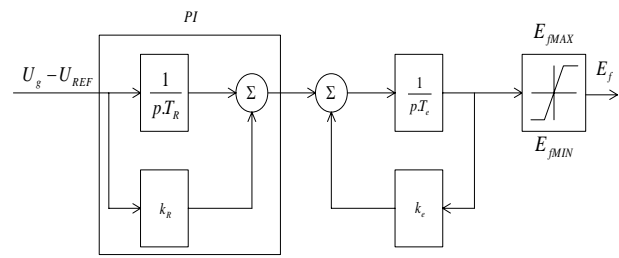


Fig. 1: Excitation system model

Fig 2. shows basic turbine model with PI regulation. Analogically T_R and k_R are PI regulator constants, T_t and k_t turbine constants. From turbine power output P_t is in the program computed mechanical torque T_m .

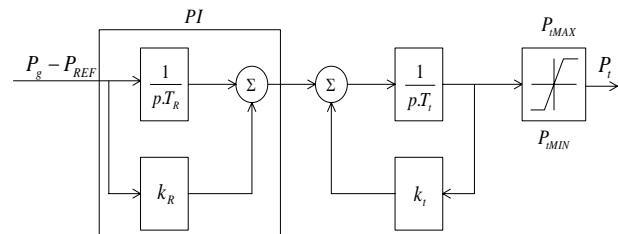


Fig. 2: Turbine model

Mathematical Background of Modeling

Basic technical models describe systems as a linearization problem. However, linear systems are insufficient for many applications. This chapter is theoretical introduction of linear and non-linear models.

Linear models

Powerful instrument how to model linear systems is state space modeling of linear dynamic system. The generic form of state space equation in continuous form is following:

$$\dot{\mathbf{x}}(t) = \mathbf{A}(t) \cdot \mathbf{x}(t) + \mathbf{B}(t) \cdot \mathbf{u}(t)$$

$$\dot{\mathbf{y}}(t) = \mathbf{C}(t) \cdot \mathbf{y}(t) + \mathbf{D}(t) \cdot \mathbf{u}(t) \quad (1)$$

where $\mathbf{x}(t)$ is a vector of state space variables, $\mathbf{u}(t)$ vector of input variables,

$\mathbf{y}(t)$ vector of output variables, $\mathbf{A}(t)$ $n \times n$ square *System matrix*, $\mathbf{B}(t)$ $n \times r$ *Input matrix*, $\mathbf{C}(t)$ $p \times n$ square *Output matrix*, $\mathbf{D}(t)$ $p \times r$ *Input - Output connection matrix*. In general, all the matrices are time dependent.

Nonlinear models

Nonlinear expression of state space model in common form is as follows

$$\dot{x}_1(t) = f_1(x_1(t), x_2(t), \dots, x_n(t), u_1(t))$$

...

$$\dot{x}_n(t) = f_n(x_1(t), x_2(t), \dots, x_n(t), u_n(t))$$

(2)

Nonlinear *autonomous* system can be defined as

$$\dot{x}_1(t) = f_1(x_1(t), x_2(t), \dots, x_n(t))$$

...

$$\dot{x}_n(t) = f_n(x_1(t), x_2(t), \dots, x_n(t))$$

(3)

At the opposite of linear model, solution of this type of model often can't be expressed analytically. Furthermore, no *superposition principle* (addition of two solutions is a solution again) can be applied. Linear autonomous systems have only one equilibrium point (steady state point) – zero vector $\mathbf{x}^* = \mathbf{0}$, nonlinear autonomous systems (3) could have more than one non-zero equilibriums (points resp. areas).

General nonlinear system solution is based on many types of numerical methods.

System stability

System stability is important notion for system description. Intuitive idea of stability is as follows: Let the system be in an equilibrium state. If on an occurrence of disturbance, the system eventually returns to an equilibrium position, the system is said to be stable. The system is termed stable also in the case of convergence from original steady state to other equilibrium.

Linear system stability

Linear system stability criterion is following:

$$\operatorname{Re}[\lambda_i] < 0, i = 1 \dots n \quad (4)$$

where $\lambda_i, i = 1 \dots n$ are eigenvalues of system matrix \mathbf{A} .

Linearization of nonlinear system

Depending on analyzed areas of solutions, nonlinear systems criteria have several formulations. Consider nonlinear autonomous dynamical system

$\dot{\mathbf{x}}(t) = f(\mathbf{x}(t))$ as

$$\begin{bmatrix} \dot{x}_1 \\ \dots \\ \dot{x}_n \end{bmatrix} = \begin{bmatrix} f_1(\mathbf{x}) \\ \dots \\ f_n(\mathbf{x}) \end{bmatrix}$$

(5)

In cases of system equilibriums $f(\mathbf{x}^*) = 0$, the nonlinear stability problem can be linearized due to Jaccobi matrix.

Direct Lyapunov's Method

For global nonlinear (autonomous) system stability analysis is feasible to use Direct Lyapunov's Method. Basic idea of the method is to find suitable Lyapunov's function $V(\mathbf{x}) = V(x_1, x_2, \dots, x_n)$, which satisfies specified assumptions.

Stability visualization, stability types

Often used method for stability visualization is *phase plot*. Phase plot axes are state space variables. Solutions of state space equations are displayed in phase plot as system of curves, where each curve corresponds to another set of initial conditions. Phase plot is thus special type of parametric plot, in multidimensional form can be written as:

$$\left. \begin{array}{l} x_1 = \varphi_1(t) \\ \dots \\ x_n = \varphi_n(t) \end{array} \right| \varphi(t) \text{ solution of } \dot{x} = f(x), x(0) = x_0, x_1, x_2, x_3 \dots \quad (6)$$

Node Distribution Network Example

Presented tools for DGS power system analysis are demonstrated on distribution network model. The network modeled in MATLAB (such as the illustrative examples from introduction of this chapter) contains 38 passive PQ loads at MV level 22 kV, 4 HV 110 kV substations and one EHV 400 kV slack node, which represents transmission system. Branch parameters chosen in the model are typical parameters of Czech distribution network. It can be noted, that this network represents an example of supplying a town with 50 thousand inhabitants and 30 km surroundings including suburbs and municipal supplies. Main aim of this study is to disclose this system behavior beyond high level of DGS penetration by sources with SM generators. For this purpose various types of SM generators (salient pole, round), two types of connection to distribution network. Due to system complexity primary *Odq* model was analyzed. Two main principles of DGS penetration were studied. As first is presented locally penetrated system, hence as second case is presented globally penetrated system. In both cases, sources are connected one by one to random nodes of affected area.

Globally Penetrated System

For globally penetrated system were taken same analysis principles as in the case of locally penetrated systems under consideration. DGS sources connection sequencing principle is applied to whole network MV nodes

Dynamic stability analysis

As in previous example, for the first part of study uniform source types were chosen.

Following figures are depicting only one source type, because same conclusions considering operable regions dependence on source types can be claimed. Hence the best option of uniform source (salient-pole machine example connected via 6.3/22 kV transformer) was chosen.

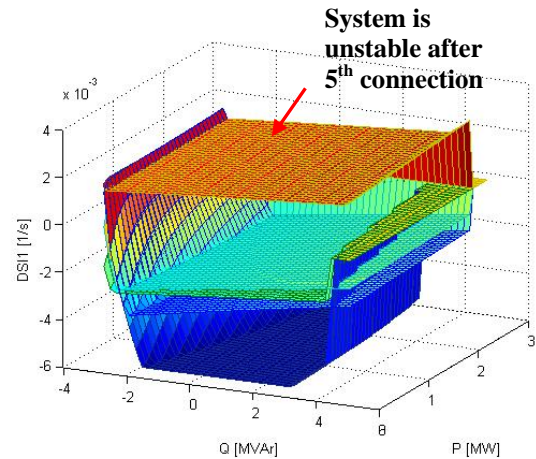


Fig.3: DSI₁ after 1-5 DGS sources connection (salient-pole 2.5 MW machines,)

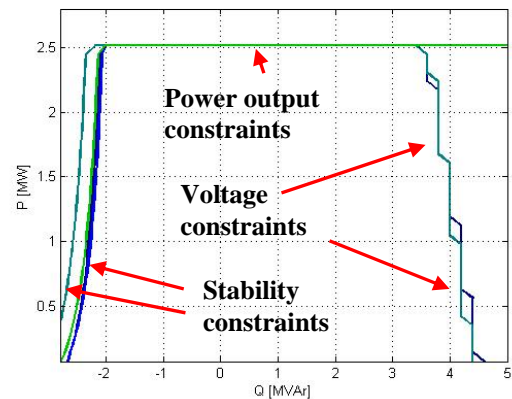


Fig. 4: Operable regions after 1-4 DGS sources connection (salient-pole 2.5 MW machines)

Figures 3 and 4 imply that for 5th connected DGS source can't be found any relevant operational point, which satisfies dynamic stability (note, that other connected machines are assumed as *PU nodes* in their connection points). To obtain a suitable steady state solution, new regulation principles must be applied. In further text is purposed simple regulation to target steady state values – proportional regulation of reactive powers (existing

similar systems in centralized generation is called ASRU). Steady state of other connected machines from $n = 5$ DGS sources is thus computed for *constant power factor* (purposed target values for proportional regulation).

Transient stability analysis

Following figures show voltages at selected 22 kV nodes. Same as in locally penetrated system, 4 fault nodes with clearing time 200 ms is applied for transient stability analysis. Tested cases respect the results from dynamic stability

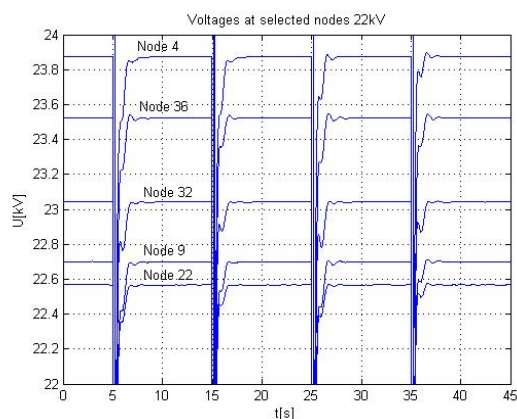


Fig.5: Fault voltages at selected nodes (13 random regulated machines)

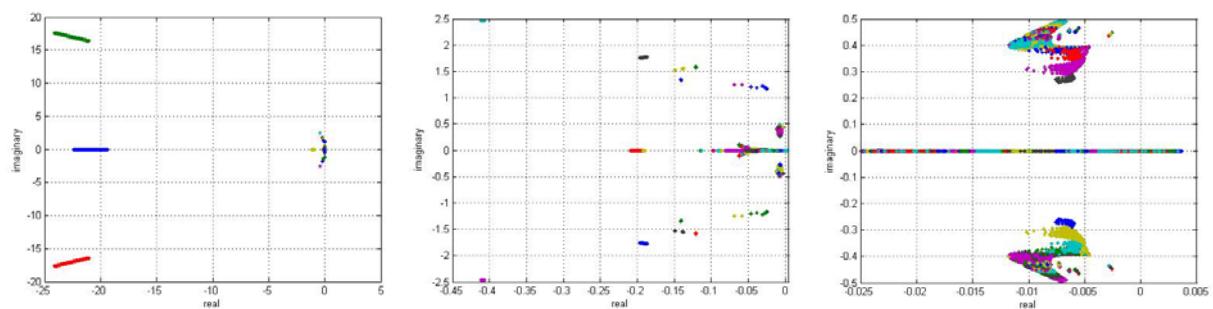


Fig.6: Oscillatory modes for DGS, eigenvalues spectrum for 13 uniform 6 MW sources

analysis. Fig. 5 shows the situation of 13 randomly chosen regulated machines. It is remarkable, that oscillation duration is less than in the case of uniform machines at same PL . Explanation this phenomena is apparent from eigenvalues depicted in 6

and 7, where machines' uniformity gives strong isolated resonant modes.

Conclusion

Presented paper describes various principles of penetration synchronous machine type DGS into distribution network. The study was aimed to possible operation area of the connected sources with regard to stable operation in steady state conditions and stable operation after clearing the fault. Note, that other important issues for successful DGS installing process were not discussed within this study (such as necessary increase of short circuit level, protection issues, peaking and premium power delivery issues, reliability issues and also some special cases of transients like pass into islanded operation state). This study however provides possible complex analysis view on DGS stability issues, which can answer the *possibility* of connection. From this point of view, following results are obtained.

It can be assumed, that in locally penetrated system (i.e. to one feeder) inter-machine couplings are smooth and voltages are similar and thus such a system's behavior is stable and thus

doesn't strictly require centralized regulation. On the other hand, system losses can be only slightly decreased in case of very small PL in accordance with local consumption. In case of higher PL , losses are growing. It is shown, that local

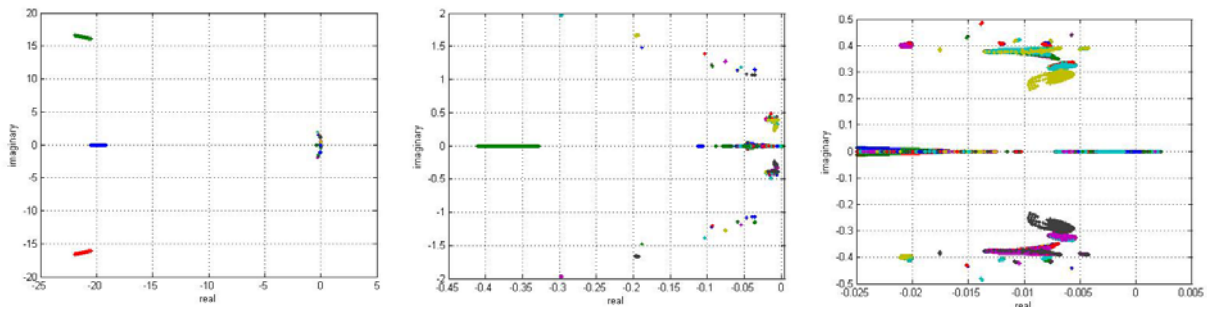


Fig.7: Oscillatory modes for DGS, eigenvalues spectrum for 13 random sources

penetration (which means centralized generation inside distribution network) could be possible low cost way, how to increase *PL* of distribution system with strongly restricted advantages of DGS use. Globally penetrated system requires from very small amount of installed DGS new centralized control strategies to maintain stable operation.. Except from using new control strategies with target steady state values, new phenomena such as subsynchronous resonance may arise and have to be resolved. New stabilizers must be developed to avoid danger oscillations, which may be caused on both demand and generation side.

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