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POWER FLOW ANALYSIS FAULT ANALYSIS POWER SYSTEMS DYNAMICS AND STABILITY

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Abstract:

Power system is predominantly in steady state operation or in a state that could with sufficient accuracy be regarded as steady state. In a power system there are always small load changes, switching actions, and other transients occurring so that in a strict mathematical sense most of the variables are varying with the time. However, these variations are most of the time so small that an algebraic, i.e. not time varying model of the power system is justified. A short circuit in a power system is clearly not a steady state condition. Such an event can start a variety of different dynamic phenomena in the system, and to study these dynamic models are needed. However, when it comes to calculate the fault currents in the system, steady state (static) models with appropriate parameter values can be used. A fault current consists of two components, a transient part, and a steady state part, but since the transient part can be estimated from the steady state one, fault current analysis is commonly restricted to the calculation of the steady state fault currents.

Keywords – Steady state, transients, fault currents.

1. INTRODUCTION

It is of utmost importance to be able to calculate the voltages and currents that different parts of the power system are exposed to. This is essential not only in order to design the different power system components such as generators, lines, transformers, shunt elements, etc. so that these can withstand the stresses they are exposed to during steady state operation without any risk of damages. Furthermore, for an economical operation of the system the losses should be kept at a low value taking various constraints into account, and the risk that the system enters into unstable modes of operation must be supervised. In order to do this in a satisfactory way the state of the system, i.e. all (complex) voltages of all nodes in the system, must be known. With these known, all currents, and hence all active and reactive power flows can be calculated, and other relevant quantities can be calculated in the system. In the lectures ElektrischeEnergiesysteme it was studied how to calculate fault currents, e.g. short circuit currents, for simple systems. This analysis will now be extended to deal with realistic systems including several gener- ators, lines, loads, and other system components. Generators (synchronous machines) are important system components when calculating fault currents and their modelling.A model, and in power system analysis we al- most invariably then mean a mathematical model, is a set of equations or relations, which appropriately describes the interactions between different quantities in the time frame studied and with the desired accuracy of a phys- ical or engineered component or system. Hence, depending on the purpose of the analysis different models of the same physical system or components might be valid. It is recalled that the general model of a transmission line was given by the telegraph equation, which is a partial differential equation, and by assuming stationary sinusoidal conditions the long line equations, ordinary differential equations, were obtained. By solving these equations and restricting the interest to the conditions at the ends of the lines, the lumped-circuit line models (π-models) were obtained, which is an algebraic model. This gives us three different models each valid for different purposes.Often the voltage in the distribution systems is kept constant by controlling the tap-positions of the distribution transformers which means that power, active and reactive, in most cases can be regarded as independent of the voltage on the high voltage side.

2. POWER FLOW

The power flow can be formulated as a set of non- linear algebraic equality/inequality constraints. These constraints rep- resent both Kirchhoff's laws and network operation limits. In the basic formulation of the power flow problem, four variables are associated to each bus (network node) k:

- Uk: voltage magnitude
- θk: voltage angle
- Pk: net active power (algebraic sum of generation and load)
- Qk: net reactive power (algebraic sum of generation and load)

Depending on which of the above four variables are known (given) and which ones are unknown (to be calculated), two basic types of buses can be defined: • PQ bus: Pk and Qk are specified; Uk and θk are calculated • PU bus: Pk and Uk are specified; Qk and θk are calculated PQ buses are normally used to represent load buses without voltage control, and PU buses are used to represent generation buses with voltage control in power flow calculations1. Synchronous compensators2 are also treated as PU buses. A third bus is also needed: In "normal" power systems PQ-buses or load buses are the far most common, typically comprising more than 80% of all buses. Other possible bus types are P, U, and PQU, with obvious definitions.
The use of multiple Uθ buses may also be required for certain applications. In more general cases, the given values are not limited to the specific set of buses (P, Q, U, θ), and branch related variables can also be specified.One problem in the definition of bus type (bus classification) is to guarantee that the resulting set of power flow equations contains the same number of equations as unknowns, as are normally necessary for solvability, although not always sufficient. Consider a system with N buses, where NPU are of type PU, NPQ are of type PQ, and one is of type Uθ. To fully specify the state of the system we need to know the voltage magnitudes and volt- age angles of all buses, i.e. in total 2N quantities. But the voltage angle and voltage magnitude of the slack bus are given together with the voltage magnitudes of NPU buses. Unknown are thus the voltage magnitudes of the PQ buses, and the voltage angles of the PU and the PQ buses, giving a total of NPU + 2NPQ unknown states. From the PU buses we get NPU balance equations regarding active power injections, and from the PQ buses 2NPQ equations regarding active and reactive power injections, thus in total NPU + 2NPQ equations, and hence equal to the number of unknowns, and the necessary condition for solvability has been fulfilled.

3. SOLUTION OF POWER FLOW PROBLEM

The power flow problem cannot be solved an- alytically, and hence iterative solutions implemented in computers must be used. In this chapter we will review two solutions methods, Gauss iter- ation with a variant called Gauss-Seidel iterative method, and the Newton- Raphson method. A problem with the Gauss and Gauss-Seidel iteration schemes is that convergence can be very slow, and sometimes even the iteration does not converge despite that a solution exists.

Furthermore, no general results are known concerning the the convergence characteristics and criteria. There- fore more efficient solution methods are needed, and one such method that is widely used in power flow computations is discussed in the subsequent sections. Close to the solution point x∗, the Newton-Raphson method normally presents a property called quadratic convergence. This can be proved for the unidi- mensional case discussed above if it is assumed that x∗ is a simple (not a multiple) root and that its first and second derivatives are continuous. For transmission systems, a strong coupling is normally observed between P and θ, as well as between Q and U. This property will in this section be employed to simplify and speed up the computations. In the next section we will derive a linear approximation called dc power flow (or dc load flow). This linear model relates the active power P to the bus voltage angle θ. No approximations have been introduced in the functions P(x) or Q(x), only in the way we calculate the updates. The convergence of the decoupled scheme is somewhat slower than the full scheme, but often the faster solution time for the updates compensates for slower convergence, giving as faster overall solution time. For not too heavily loaded systems a faster overall solution time is almost always obtained.

4. FAULT ANALYSIS

We have dealt with steady state behavior of power systems under normal operating conditions. This chapter is devoted to abnormal sys- tem behavior under conditions of faults. Such conditions are caused in the system accidentally through insulation failure of equipment or flashover of lines initiated by a lightning stroke or through accidental faulty operation. In high voltage networks, short circuits are the most frequent type of faults. Short circuits may be solid or may involve an arc impedance. Fig illustrates different types of short circuits. Depending on the location, the type, the duration, and the system grounding short circuits may lead to • electromagnetic interference with conductors in the vicinity (distur- bance of communication lines), • stability problems, • mechanical and thermal stress (i.e. damage of equipment, personal danger) • danger for personnel The system must be protected against flow of heavy short circuit currents by disconnecting the faulty part of the system by means of circuit breakers operated by protective relaying.

The safe disconnection can only be guar- anteed if the current does not exceed the capability of the circuit breaker. Therefore, the short circuit currents in the network must be computed and compared with the ratings of the circuit breakers at regular intervals as part of the normal operation planning. As illustrated , the short circuit currents at network nodes are generally increasing over the years due to • more generators, This is primarily a problem for the expansion planning, where the impacts of long-term changes on the short circuit currents have to be assessed. If the short circuit current exceeds the admissible limit at a network node, the circuit breakers have to be replaced by breakers with higher ratings. Alter- natively, the impedance between feeder and fault location can be increased in order to reduce the short circuit current. In a modern large interconnected power system, heavy currents flowing during a short circuit must be interrupted much before the steady state con- ditions are established.

Furthermore, from the considerations of mechanical forces that act on the circuit breaker components, the maximum current that a breaker has to carry momentarily must also be determined. For selecting a circuit breaker we must, therefore, determine the initial current that flows on occurrence of a short circuit and also the current in the transient that flows at the time of circuit interruption.

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5. MODELLING

It is of course almost impossible to develop models that can describe all dy- namics in a power system and still being of practical use. Often one has to utilise a model that captures correctly the specific dynamic phenomenon or interaction that is the aim of the particular investigation. Depending on the purpose of the study the appropriate model of a given power system com- ponent could vary significantly. It is obvious that if the aim is to study rela- tively slow power oscillations between generators in the system, completely different models are required as compared with if one wants to analyse the influence of lightning impulses in the windings of the synchronous machine. Even if it were theoretically possible to develop a complete model of all the dynamics in the power system, it is questionable if such a model would be particularly useful. Firstly, such a model would require an enormous amount of parameter data to be uniquely specified. Secondly, the results obtained from such a model would be very hard to analyse and interpret. Critical review and understanding of obtained results is a necessary prerequisite for sound engineering. When making simulations and computations, which all are done with the help of computers nowadays in system sciences, it is important to have an expectation of what are reasonable outputs. Thus trivial errors due to wrong input data files, mistakes in modelling, etc. can be eliminated to a large extent. The human factor is of utmost importance in computer-based analysis and simulation. Models can in principle be erroneous in two different ways. Firstly, it can have the wrong structure. It can be too simple overlooking important interactions and processes or modelling them incorrectly. This is of course very serious and might give rise to detrimental consequences. But it is also very serious if wrong parameter data is used in a model of the correct structure. This latter shortcoming occurs not seldom in technical systems, which might look surprising at first sight. Since technical systems are man made, one should in principle have access to all design parameters defining the system. But it turns out that many parameters, e.g. the gain in the controller, could easily be changed after the system has been commissioned and such changes are not always reported to system analysts. It is obvious that the consequences could be very serious. In technical systems there are of course parameters that are “genuinely” unknown, e.g. the ground resistivity under a power line. In a large system like a power system, thousands of parameters are needed to define the system completely. It is a very difficult, but also very important, task to maintain and keep the data bases where all these parameter values are stored and updated. This is now a special activity usually referred to as data engineering.

CONCLUSION

A dynamic phenomenon in a power system is, as said above, initiated by a disturbance in the system. Such a disturbance could as an example be that a line impedance is changed due to an external cause. The behaviour of the system after this disturbance depends of course on a how “large” this disturbance is. A small disturbance results usually in small transients in the system that are quickly damped out, while a larger disturbance will excite larger oscillations. We all have an intuitive feeling for what is meant with stability in this context. Stability is associated with that the system oscillations decay and that the operation of the power systems can continue without any major impacts for any of the consumers.

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