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Aggregation method for motor drive systems

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ABSTRACT

When many variable frequency drives are connected to a common switchboard, their aggregated effect on system dynamics can be significant. In this paper, the aggregation method for variable frequency drives and their motors in industrial facilities is proposed, which is suitable for power systems dynamic studies. The proposed method can be applied to various types of motor drive systems. There are two steps involved for the proposed aggregation method: (1) aggregate motor drive systems connected to the same bus, and (2) further combine the aggregated model of motor drive systems from Step 1 with upstream series impedance and/or transformers. Due to involvement of high-order transfer functions in dynamic models of individual motor drive systems, Pade approximation is used as a useful tool in the aggregation process. Using the proposed aggregation method, an equivalent aggregated dynamic model of motor drive systems can be obtained at the substation bus. A case study is conducted in the paper, and the proposed aggregation method is verified to be effective by the case study.

1. Introduction

In bulk power system studies, it is common industry practice to use relatively simple load models for power flow and dynamic simulations. To deal with a reasonable number of discrete load models, aggregate effects of possibly thousands of individual load components are lumped at the substation voltage level [1].

There are two basic approaches to obtain composite load characteristics: measurement-based approach and component-based approach. The measurement-based approach is to directly measure the voltage and frequency sensitivity of active power and reactive power at representative substations and feeders. The data of load modeling can be obtained by installing measurement and data acquisition devices at points where bus loads are to be represented. The parameters of a load model are estimated or identified by fitting the measured data to the assumed model [2]. The component-based approach is to develop load models by aggregating models of individual component forming the load. Component characteristics can be determined by theoretical analysis and laboratory measurement. This approach requires typical load composition, i.e., fractions of load consumed by each type of load component. The load modeling can be achieved via several processes: (1) component load modeling, (2) load composition estimation, (3) aggregation of component loads, and (4) aggregation of distribution system [2,3].

Load aggregation has been widely discussed in the literature [4–7], as it appears to be an essential part for the component-based approach. The aggregation methods for induction motors and synchronous motors have been successfully utilized for developing the dynamic model for industrial facilities in [8].

Similar to induction motors and synchronous motors, variable frequency drives (VFDs) and their motor loads are widely used in industrial facilities [9,10]. They also need to be aggregated to obtain the desired lumped load model at the substation voltage level. Based on extensive literature review, such aggregation method is not available.

In this paper, the aggregation method for motor drive systems in industrial facilities is proposed, which is suitable for power systems dynamic studies. This proposed method can be applied to various types of motor drive systems. However, the developed dynamic model for one particular type of motor drive system could be different from another type of motor drive system due to different components and control systems utilized. For example, the dynamic model for the voltage source inverter drive and the induction motor system will have 7th order transfer functions involved [11], while the dynamic model for the current source inverter drive and the induction motor system will have 10th order transfer functions involved due to different control schemes. If different types of dynamic models are present and their transfer functions have different orders, they cannot be aggregated directly using the

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proposed method, further procedure must be taken to make the aggregation possible, which is out of scope of this paper. Or to keep it simple, only the same type of dynamic models is aggregated together from the downstream all the way to the upstream using the proposed aggregation method directly.

The aggregation procedure starts from individual motor drive systems at the downstream of the circuit, and dynamic models of individual motor drive systems developed in previous work [11] are aggregated and combined first; after that, the branch impedance presented by cables, transmission lines and/or transformers can be further aggregated to form the desired upstream aggregated load model at the substation bus. The proposed aggregation method for motor drive systems in this paper together with the aggregation methods for induction motors and synchronous motors in [8] will achieve load aggregation for the whole industrial facility.

The paper is organized as follows: in Section 2, the dynamic model format of individual motor drive systems is briefly presented; in Sections 3 and 4, the aggregation method consisting of two steps, Step 1 (aggregate VFDs connected to the same bus) and Step 2 (combine the aggregated model from Step 1 with upstream series impedance and/or transformers), is established. The proposed aggregation method for this particular type of motor drive system in the case study is translated into Matlab programming code; a case study is conducted to verify the proposed aggregation method in Section 5.

2. Dynamic model of individual motor drive systems

The research in this paper starts from the previous work [11] in this section, and it will be extended to the new work in Section 3.

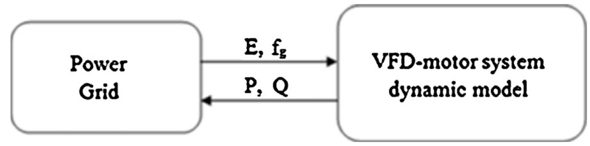

Fig. 1. Dynamic model of motor drive systems.

The dynamic model of individual motor drive systems is developed as follows [11]:

(1) Find differential equations of the drive, the motor, and the control system.
(2) Combine all equations to establish the relationship among them.
(3) Linearize the combined differential equations to obtain the dynamic model for motor drive systems.

The developed dynamic model as shown in Fig. 1 includes the influence of the drive, the motor and their control system on the overall dynamic characteristics. Both voltage dependence and frequency dependence are considered. The input variables for the model are the rms voltage per phase (E) (Note: E is the symbol for the bus terminal voltage V for individual motor drive system), and the frequency (f_g) of the drive power supply. The output variables are active power (P) and reactive power (Q) at the drive AC input connected to the power grid.

The dynamic model format for individual motor drive systems is derived in [11] as follows:

$$P = P_0 + G_{P1}\Delta E + G_{P2}\Delta E^2 + (G_{P3} + G_{P4}\Delta E)\Delta f_g \quad (1)$$

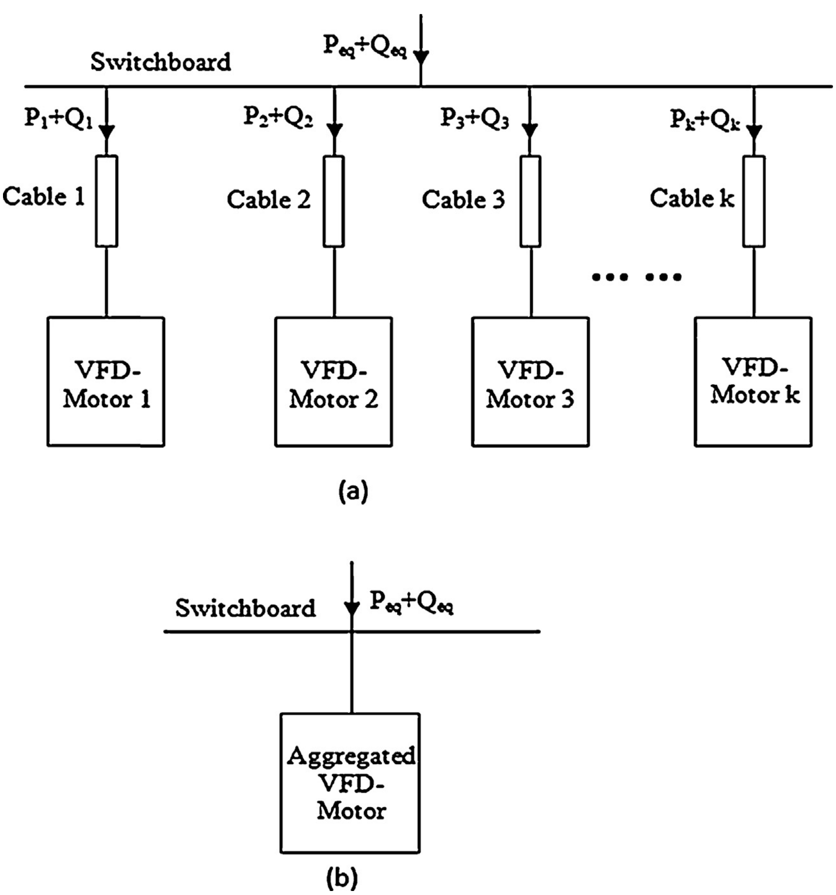

Fig. 2. VFDs connected to a switchboard (Step 1), (a) a typical configuration connecting a group of VFDs to a common switchboard, (b) the aggregated motor drive system.