Figure 12 shows the T(ω) characteristic of the system. It clearly defines the normal and the field weakening operation range of the interior permanent magnet synchronous motor (IPM) used as a basis for the simulations and a reference to validate the results. A slight wave in the simulation result can be seen due to the different resolution of the curves as the simulation is created by a vector with element number 200 in addition the reference curve consists only 20.

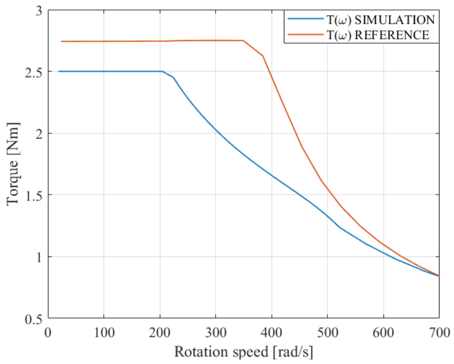

Fig. 12. T(ω) characteristic of the system

5. Conclusion and further investigation

The goal of this simulation is to get the $T(\omega)$ characteristic of the reference motor. As it can be seen there is a difference between the reference and the simulated results. There are two main reasons behind that. The motor model used in Simulink is an analytical model that utilizes constant parameters from the FEMM simulations given at a constant current. The parameters are highly dependent on the current and the load angle. This fact is not taken into consideration in the motor model. One further improvement is to use parameter matrices to utilize the result from FEMM simulations and to implement the current and load angle dependence. On the other hand, the represented control method could be improved as well, especially focusing on the field weakening operation range. To further utilize the capability of the finite element calculations, it is suitable to use maximum torque per ampere (MTPA) or maximum torque per volt (MTPV) control strategies. This assumes further improvements in the finite element calculations to get the $T(i_d, i_q)$ map of the motor topology. To summarize it, the control circuits torque response follows the variable load fast and accurately. The system responds to the change in the rotation speed reference signal as prompt and precise as expected.

By using the Figure 12 it can be decided if the designed concept can be used in an electric vehicle as its operational range meets the expectations. By implementing the equations summarized in the previous chapters, the entire electric powertrain of a vehicle can be modelled by determining the required boundary conditions. The results confirm that this model is a good starting point to perform further simulations at different operation cases. With further improvements and the verification of the model the design of a unique motor might be commenced. A specified model can greatly facilitate the early validation of expected measurement results. With the help of software suitable for finite element calculations it is possible to examine any motor topology, to determine the set of parameters that can serve as input values of the previously presented model. Using the characteristics specified by the manufacturers of the selected materials, the electrical losses can be approximated, furthermore a complete driving cycle can be examined, and the efficiency map can be drawn.

To reach the goal to create a software code which can assist the optimization of the design process of an electric motor the following investigation and improvements have to be carried out. During doctoral studies I would like to improve the utilization of finite element calculations, combine those fully with the complex powertrain presented in this paper. I hope, that experimental data based on measurements will be available for the model verification too. It is important to take advantage of cutting-edge technology with applying sufficient computer capacity to find the best solution in all cases. I think this research can help to create a cleaner future through e-mobility.

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