Everyday, the modern society is facing a lot of arising optimization problems in the energy system. In this dissertation, we study the long-term electricity infrastructure investment to address the planning for capacity expansion in the electrical power system. The long-term capacity expansion planning aims at making the most effective and efficient investment decisions to meet the long-term future demand, considering both conventional generation units and wind farms. Due to the long-term planning horizon and the uncertain behavior of wind, there are a lot of parameters that cannot be perfectly forecasted, such as future investment costs, real-time demands, and the wind intensity. Therefore, these parameters are considered to be random. This dissertation adopts two optimization approaches that address the future uncertainties: decision-dependent stochastic programming and adaptive robust optimization. Decision-dependent stochastic programming approach presents the uncertainties as the expected value of discrete random outcomes. In addition, the decision-dependent feature enables its probability distribution to be dynamically adjustable according to optimization decisions. Adaptive robust optimization approach, on the other hand, focuses on finding the optimal solutions under the worst-case scenario(s).

The study of each problem consists of two main parts, the formulation of its mathematical model and the development of solution algorithms for the model. The formulation of mathematical model describes the process of transforming the real-world situations into the mathematical formulation. Because of the complex nature of the real-world problems with uncertainty, the solution approach to these mathematical models encounters great difficulty. The mathematical models involve complex frameworks, such as nonlinearity, bi- and multi-level settings, multistage-stochastic, and multistage-robust time frames. These frameworks usually also come along with large numbers of decision variables and constraints that further increases the computational complexity. In this dissertation, efficient algorithms are developed for these problems in the context of advance methodologies of optimization and operations research, such as KKT conditions, duality theory, quasi-exact approximation, Dantzig-Wolfe decomposition, and linear/affine decision rules. Computational experiments are implemented for each problem and the results are present and discussed. The research carried out in this dissertation provides discussions and results for both mathematical modeling methodology and solution algorithms to the complex optimization problems in power systems when uncertainty is involved.