Reservoir simulation is an important tool in the oil and gas industry, using computational models to predict the flow of fluids in sub-surface petroleum reservoirs. Oil and gas companies use reservoir simulations to make economic decisions and to develop and manage the production of new fields. The demand for accuracy and the typical size of reservoirs introduce the need for high performance computing in the domain. Reservoir simulation-specific aspects, such as complex geology and well modeling, create unique challenges to achieving good performance in parallel simulations of large-scale reservoirs. In this thesis, we considered domain decomposition strategies for parallel reservoir simulations and their impact on performance and numerical effectiveness. A new graph partitioning edge-weighing scheme that incorporates reservoir heterogeneity while maintaining communication volume minimization is presented. We studied efficient parallelization of linear solvers for reservoir simulation, and the impact of the preconditioning strategy on the overall performance. Understanding the underlying hardware architecture of modern computers is helpful for achieve resource efficient simulations. We introduce a new modeling methodology for estimating point-to-point MPI communication cost on computing platforms with heterogeneous inter-process interconnects. The research of the thesis contributed to the development of an open-source reservoir simulator.