Mixed-Integer Nonlinear Programming and Oil Production Optimization

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Abstract: This work deals with solving (nonconvex) mixed-integer nonlinear optimization problems (MINLPs) of relevance to the oil and gas industry. Decision (integer) variables appear often in real life. For example, we may need to decide whether to open or shut a given well/valve -- it not being possible to operate in a continuous fashion (e.g., half open). Mixed-integer nonlinear optimization is still a difficult and under researched area. Our aim in this work is to delineate state-of-the art MINLP with practical approaches for the class of problems of interest.

The MINLP optimization methodologies considered in this study are essentially of two types. The first scheme is based on a branch-and-bound procedure, with upper bounds given by fixing decision variables, and lower bounds computed by solving the nonlinear program obtained when the decision variables are relaxed to real values. In the typical case of non-convex relaxed problems the issue of reliable bounds becomes significantly more complex. The second approach roughly proceeds as a sequence of (easier-to-solve) mixed-integer linear programs (outer-approximation decomposition algorithm). In all cases, the optimizers were implemented within a Bonmin framework, solving each nonlinear program by an interior point optimizer (IPOPT).

We will present two examples of MINLP oil production optimization with practical relevance. In both cases we minimize field water produced subject to a minimum field oil production target, by adjusting all the well controls (bottom-hole pressures, a real-valued variable with upper and lower optimization bounds) along several time intervals. The decision associated with the integer variables is whether a given well has to be open or shut during a certain control period. The optimization problems studied here rely on finite-volume reservoir simulations, and gradient information is computed efficiently by adjoint equations. The reservoir simulator used is Stanford’s General Purpose Research Simulator (GPRS). The results obtained confirm that the approaches studied are viable methodologies for real applications, and also help to identify some problematic aspects within common oil production optimization scenarios (for example, the presence of multiple optima).

Biographical information: David Echeverría Ciaurri received the Telecommunication Engineering degree and the MSc degree in Applied Mathematics from the University of Zaragoza (Spain) in 1998 and 2002, respectively. In 2007 he obtained a PhD in Numerical Analysis (Optimization) from the University of Amsterdam (UvA). He has worked at the Dutch National Research Institute for Mathematics and Computer Science (CWI) and at the Lawrence Livermore National Laboratory (LLNL). Since 2007 he is affiliated with Stanford University within the Smart Fields Consortium at the Energy Resources Engineering department. His research interests are efficient optimization and modeling, and signal processing.