RECLAMATION Managing Water in the West

June 2012
Research and
Development Office
Bulletin 2012-21

The Knowledge Stream

Research Update

Advanced Algorithms for Hydropower Optimization

Determining the most economic way to operate generator units

Bottom Line

Although computationally intensive, these methods can solve difficult constrained optimization problems, like the dynamic economic dispatch problem, quickly and reliably.

Faster, Better, Cheaper

Improved dispatching efficiency will result in the generation of more electric power using less water—benefitting all water and power users.

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Collaborators

- **Colorado State University**
- **U.S. Bureau of Land Management**
- **Argonne National Laboratory**

Problem

On many of the large river systems in the West, Reclamation operates multiple hydroelectric powerplants, each with several electrical generators powered by the release of water from reservoirs. Every hour, night and day, Reclamation's powerplant operators must decide which powerplants and generators to operate and how much water should be released for each. Even small improvements in powerplant operations can provide substantial gains. For example, increasing the generation efficiency at Glen Canyon Dam by only 2 percent would yield approximately $4.5 millon (in 2010 dollars) annually.

Improving operations requires us to solve a mathematical problem known as the "constrained dynamic economic dispatch" problem. Stated in words, this problem is:

How much water should the hydropower plant release each hour through each generator to maximize the economic value of the electricity produced, given the amount of water available for release, the anticipated hourly price of electricity, and all of the other constraints (e.g., physical, environmental)?

This problem has universal, practical, everyday management applications at Reclamation hydropower plants. At least hourly, Reclamation's powerplant operators must solve this problem and decide how to operate the plant. The constrained dynamic economic dispatch problem is quite complicated and is shaped by a number of factors. It can be discrete, discontinuous, and non-convex—characteristics that preclude the use of traditional, calculus-based solutions.

Solution

This Science and Technology research project identified, assessed, and applied advanced optimization approaches to this problem, focusing on new optimization heuristics. Although computationally intensive, these methods can solve difficult constrained optimization problems quickly and reliably. This research project identified three promising evolutionary algorithms: the real coded genetic algorithm (RGGA), differential evolution (DE), and particle swarm optimization (PSO). Heuristic optimization approaches are based on applying rules and logic that reduce the search space, facilitating solving complex optimization problems.

These innovative search techniques are drawn from biological and physical processes. Evolutionary algorithms are based on the concept of biological evolution. These approaches are based on calculating the performance of a population of algorithms over a series of generations or iterations. Each algorithm provides one solution to the optimization problem. At each iteration, the algorithms producing the best solutions are carried forward, while the less optimal algorothms drop out. The quality of the solutions found thus improve over time. This ongoing process ultimately identifies the optimum solution. Current software can evaluate a very large number of "generations" in a short period of computation.

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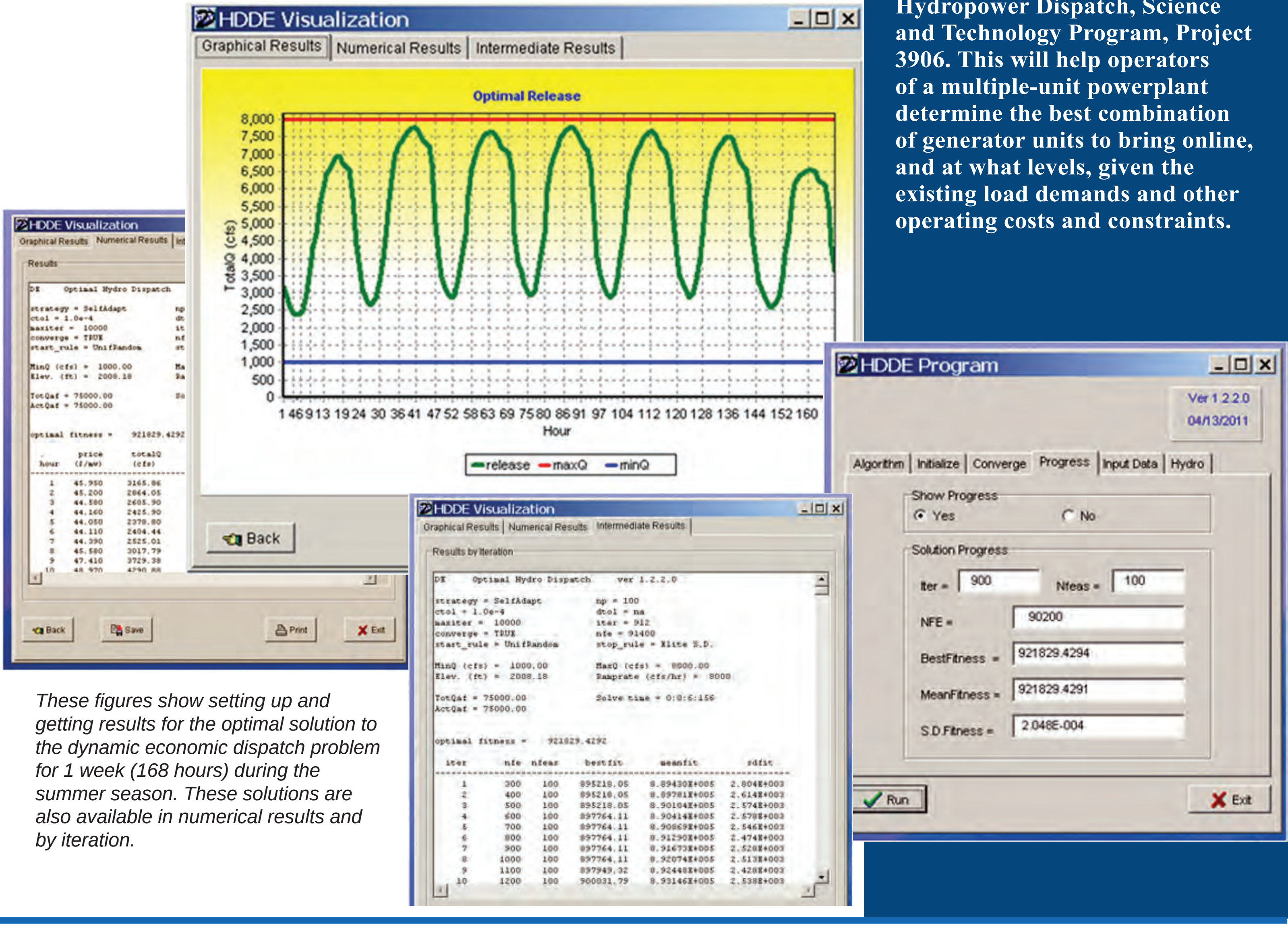
Advantages of these approaches include:

- Uses simple mathematical structures
- Allows concise, straightforward coding
- Easily accommodates many-dimensional problems
- Allows non-linear, continuous, discrete, or complex problems
- Can represent most types of constraints
- Provides a higher probability of identifying the overall optimum solution

Results

We applied these three evolutionary algorithms to the constrained dynamic economic dispatch problem and conducted multiple trials to gauge their success and compare their performance characteristics. The results indicate that these algorithms are able to accurately and reliably solve the constrained dynamic economic dispatch problem for a generic powerplant. For the test problems examined, these algorithms have longer solution times than calculus-based approaches.

However, the strength of these evolutionary algorithms is their ability to successfully solve more complicated problems, which cannot be solved with traditional, calculus-based approaches. Using these approaches can help guide Reclamation's hydropower economic dispatch decisions and improve efficiency, generating more electric power with less water.



```
DE     Optimal Hydro Dispatch

strategy = SelfAdapt          np
ctol = 1.0e-4                 dt
maxiter =  10000              it
converge = TRUE               nf
start_rule = UnifRandom       st

MinQ (cfs) =  1000.00         Ma
Elev. (ft) =  2008.18         Ra

TotQaf = 75000.00             So
ActQaf = 75000.00


optimal fitness =    921829.4292

  .       price      totalQ
 hour    ($/mw)      (cfs)
--------------------------------
    1    45.950     3165.86
    2    45.200     2864.05
    3    44.580     2605.90
    4    44.160     2425.90
    5    44.050     2378.80
    6    44.110     2404.44
    7    44.390     2525.01
    8    45.580     3017.79
    9    47.410     3729.38
   10    48.970     4290.88
```

```
DE     Optimal Hydro Dispatch     ver 1.2.2.0

strategy = SelfAdapt          np = 100
ctol = 1.0e-4                 dtol = na
maxiter =  10000              iter = 912
converge = TRUE               nfe = 91400
start_rule = UnifRandom       stop_rule = Elite S.D.

MinQ (cfs) =  1000.00         MaxQ (cfs) =  8000.00
Elev. (ft) =  2008.18         Ramprate (cfs/hr) =  8000

TotQaf = 75000.00             Solve time = 0:0:6:156
ActQaf = 75000.00


optimal fitness =    921829.4292

  iter        nfe  nfeas     bestfit       meanfit         sdfit
--------------------------------------------------------------------
     1        300    100    895218.05    8.89430E+005   2.804E+003
     2        400    100    895218.05    8.89781E+005   2.614E+003
     3        500    100    895218.05    8.90104E+005   2.574E+003
     4        600    100    897764.11    8.90414E+005   2.578E+003
     5        700    100    897764.11    8.90869E+005   2.546E+003
     6        800    100    897764.11    8.91290E+005   2.474E+003
     7        900    100    897764.11    8.91673E+005   2.528E+003
     8       1000    100    897764.11    8.92074E+005   2.513E+003
     9       1100    100    897949.32    8.92448E+005   2.428E+003
    10       1200    100    900031.79    8.93146E+005   2.538E+003
```

Show Progress
● Yes ○ No

Solution Progress
Iter = 900
Nfeas = 100
NFE = 90200
BestFitness = 921829.4294
MeanFitness = 921829.4291
S.D.Fitness = 2.048E-004

These figures show setting up and getting results for the optimal solution to the dynamic economic dispatch problem for 1 week (168 hours) during the summer season. These solutions are also available in numerical results and by iteration.

> ***"Improved efficiency will result in the generation of more electric power using less water, benefitting water and power users as well as the American taxpayer."***
>
> **Dr. David Harpman,**
> **Principal Investigator**

Future Research

We are now applying these evolutionary algorithms to the hydropower unit commitment problem in a follow-on research effort, Phase 2–Advanced Optimization Algorithms for Hydropower Dispatch, Science and Technology Program, Project 3906. This will help operators of a multiple-unit powerplant determine the best combination of generator units to bring online, and at what levels, given the existing load demands and other operating costs and constraints.