Operational Optimization of a Multipurpose Hydropower-Irrigation plant

PhD First year report

Bassam BOU-FAKHREDDINE

Supervisors: Dr. Imad MOUGHERBAL
Dr. Sara ABOU-CHAKRA
Dr. Alain FAYE
Dr. Yann POULLET

Ecole Doctorale des Sciences et de la Technologie
Universite Libanaise

École Nationale Supérieure d'Informatique pour l'Industrie et l'Entreprise
Conservatoire National des Arts et Métiers

September 2015

Contents

Introduction

This report summarizes my Ph.D. research progress from December 2014 to September 2015. This time period corresponds the first year of my Ph.D. candidacy. The goal of research is gaining an economic advantage through operational optimization of a hydropower plant and by the best irrigation practices while reducing environmental burdens. The challenge is to find the most realistic model based on the stochastic features of water resources, power demand and the irrigation profile. To achieve our goal, methods involving and joining data mining and mathematical programming will serve as a base for a Decision Support Tool (DST). This multi-functional tool for operation planning will be capable of enhancing the performance of a multi- purpose reservoir system on several levels starting with appropriate water releases, scheduled irrigation water allocation and cropping pattern. Based on the feature of DST, a distributed control structure is proposed according to the knowledge gained. LabVIEW is employed to develop human machine interface (HMI) and sequential control while MATLAB is used to implement analysis, optimization and simulation.

Research description

Overview of main goal

Small – medium distributed Hydropower-Irrigation plants are tending to be widely used in rural areas. The reason of dealing with such a subject is the importance of implementing a distributed hydropower-irrigation plants in agriculture rural areas and benefit from the available water resources as a hydro source for renewable energy power generation and for irrigation. The main objective of this study is to optimize the operation of such plants in order to:

1. Eliminate the local waste of water
2. Increase power generation efficiency
3. Improve crop production

Research Aims

The research deals with three main issues, river flow forecasting, energy management and agriculture planning.

1. **River flow forecasting**
    a. Data gathering
        i. Meteorological data (rainfall, humidity, temperature…)
        ii. Hydrological data (river flow)
    b. Data Analysis
        i. Data Transformation
        ii. Noise Filtering
        iii. Correlation
    c. Forecasting Model
        i. Autoregressive method
        ii. Constructive fuzzy systems method

2. **Energy Management**
    a. Power Optimization
        i. Electricity demand
        ii. Reservoir water release
        iii. Fitting power demand / supply
        iv. Solution tested on Hydro-turbine governing system
    b. Hydro-turbine governing system
        i. System dynamics
        ii. Setting and tuning controllers

    The optimal operation will be simulated along with the emulation of the dynamic response whereas the controllers parameters (such as the governor) are properly tuned to guarantee good performance.
3. **Agriculture Planning**
    a. Multi-Cropping system under deficit irrigation
        i. Crop pattern
        ii. Water allocation
        iii. Profit maximization
    b. Profit Distribution within farmlands
        i. Cooperative policy
        ii. Equity
        iii. Crop rotation
        iv. Profit deviation minimization

Proposed Approach

1. **Daily River Flow prediction**

    Daily river flow forecast is an essential step for real-time hydropower reservoir operation, its purpose is to asset the decision-making process of determining water storage in the reservoir in the course of ensuring optimal and reliable operational policy. our aim is seeking, in case of meteorological and hydrological data limitation, a data driven model based on Constructive Fuzzy Systems that is capable of extracting the foremost from the accessible data with high prediction efficiency relative to a Autoregressive (AR) method. A case study will consider the daily rainfall, temperature and river flow measurements. As a first step, correlation analysis is performed on the available data to investigate the relationship between variables and to identify models suitable inputs, afterwards a reference Autoregressive model (AR) and a Constructive Fuzzy System Model (C-FSM) are trained and validated.

2. **Short- term hydro generation scheduling for cascade hydropower plants**

    Short-term hydro generation scheduling (STHGS) problems is a typical nonlinear mixed integer optimization problem [1] and it aims at determining optimal hydro generation scheduling to fit power demand with supply for one day or week while meeting various system constraints. Those hydro power plants provided with a single penstock by the optimal distribution of the dispatched power among its available generating units.

The STHGS problem is set to determine which turbine should be on and the levels at which to generate in each turbine over the scheduled time horizon to meet a given power demand within water limitations.

Solution approach of the STHGS nonlinear problem

- Meta-heuristic approach
- Linearization

3. **Multi-cropping system and profit distribution**

   In this part we shall introduce two mathematical programming models. A Multi-Crop planning (MCP) optimization model for cropping pattern and water allocation throughout different stages (10 days) will be presented. The solution of the nonlinear problem will promote an efficient use of water with a flexibility to keep the chosen crops at either full or deficit irrigation so that the net financial return is maximized within certain production bounds and resources constraints. However the other optimization problem will be addressed as a Profit Distribution (PD) model. It will be responsible for distributing economical benefits among farmers based on the cooperative Policy taking into consideration the physical nature of the farmland and the carried management practices

   Solution approach of MCP and PD problems

   - Meta-heuristic approach
   - Linearization
   - Qualitative approach

Progress Report

Main Achievements

The following summarized the achieved work starting 20th of December 2014 to 10th of September 2015.

1. Literature review covering topics in Fuzzy logic, Clustering analysis (subtractive clustering), Expectation Maximization, Correlation analysis, Mathematical programming (linear and nonlinear), Meta-heuristic algorithms (Simulated Annealing and Particle Swarm Optimization), dynamics and control of hydro-turbine governing system, energy management and agricultural planning.
2. Gathering data
   a. Meteorological (Machghara weather station)
   b. Hydrological (Joub janan gauging station)
   c. Hydropower produced (EDL)
3. Finished paper (during submission process) entitled "Daily River Flow Prediction Coupled with Data Processing Techniques: A Comparative Study between Constructive Fuzzy Systems and Autoregressive Models"

Submitted to journal Advances in Water Resources

Abstract

Daily river flow forecast is an essential step for realtime hydro-power reservoir operation, its purpose is to asset the decision-making process of determining water storage in the reservoir in the course of ensuring optimal and reliable operational policy. Our aim is seeking, in case of meteorological and hydrological data limitation, a data driven model based on Constructive Fuzzy Systems that is capable of extracting the foremost from the accessible data with high prediction efficiency relative to an Autoregressive method. A case study was applied to Litani River in the Bekaa valley - Lebanon using 4 years of rainfall, temperature daily and river flow measurements. A reference Autoregressive model, a classical Constructive Fuzzy System Modeling and Constructive Fuzzy System coupled with moving average are trained. Upon validation, the last two models have shown primarily a competitive performance and accuracy for a multi-step ahead prediction task.

Keywords—Forecasting daily river flow, Data pre-processing, Fuzzy systems, Autoregressive model, Litani Rive

4. Implementing hydro-turbine governor on LabVIEW.
5. Initial decision support tool prototype (Figure 1.) for power generation (Qaraoun dam) implemented on LabVIEW.

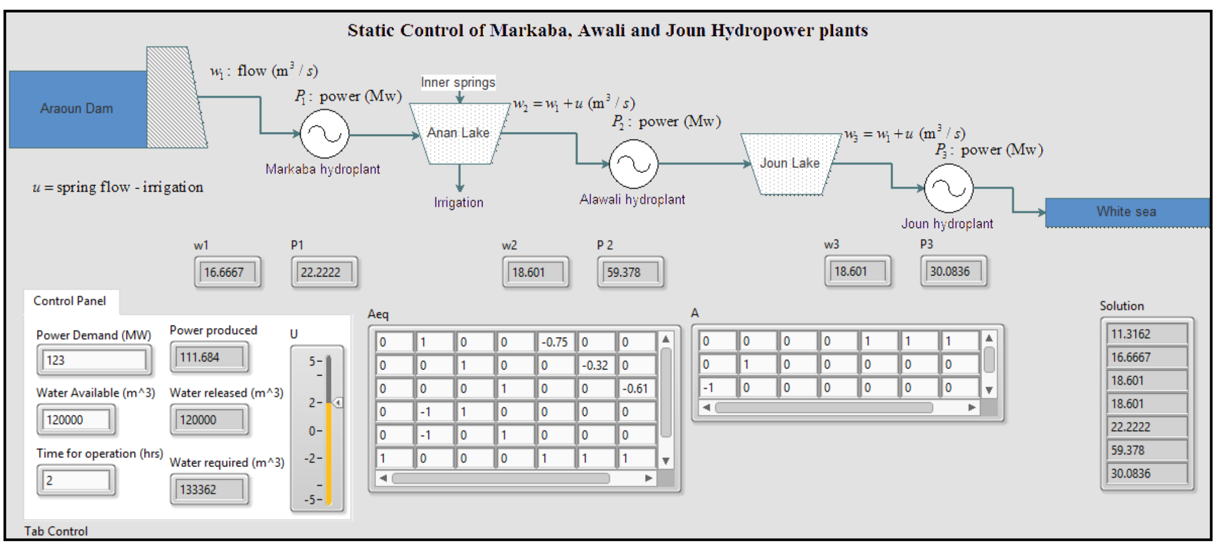

Figure 1 DST for Markaba, Awali and Joun Hdropower plants

Activities Distribution

The activities were distributed among two labs RITCH and CEDRIC. The table gives a brief representation of the tasks carried at each place.

Year	2014-2015									
Month	12	1	2	3	4	5	6	7	8	9
Task	Bibliographic review On Fuzzy logic, Clustering analysis, Correlation analysis ,hydropower dynamics			Paper on daily river flow prediction			hydro-turbine governor, readings on mathematical programming, heuristics algorithms and agricultural planning		On progress: paper on multi-crop system and profit distribution	
RITCH										
Cedric										

Future Tasks

The following developments are ongoing:

T1. Paper (finalizing) entitled "A Two-level Mathematical Programming Model for Optimal Multi-Crop Planning and Profit Distribution under Deficit Irrigation"
In this paper, we will purpose a decision- support tool based on a two level non linear mathematical programming model for optimal multi-crop planning, irrigation scheduling and profit distribution. At level one, the aim to maximize the net financial returns using Particle Swarm Optimization (PSO) and Simulated Annealing (SA) algorithms, while at level two it is minimizing the profit absolute deviations among farmers utilizing two steps linearization approach.
T2. Preparing a poster to present the work
T3. Looking for a suitable STHGS model that have the ability to find out the optimal hourly water discharge rate of each hydro station in the multi-reservoir system to minimize the power deficit.
T4. Publishing a paper on STHGS
T5. Hydropower system dynamics and control
T6. Simulations and validations
T7. Publishing a paper on hydropower and control
T8. Implementation of the whole system on MATLAB and LabVIEW [2-3]
T9. Writing of the thesis

Timeline of Remaining work

The following provide the work plan for the remaining duration of the research starting October 2015 till September 2017.

Year	2015-2016											
Month	10	11	12	1	2	3	4	5	6	7	8	9
Task	T1	T2	T3			T4		T5				

Year	2016-2017											
Month	10	11	12	1	2	3	4	5	6	7	8	9
Task	T6			T7		T8				T7		

Conclusion

All proposed effective algorithms will be implemented in a MATLAB and labVIEW environment. Then integrated into a SCADA (Supervisory Control And Data Acquisition) software package used for an efficient management of hydropower-irrigation plants.

Reference

[1]. Peng Lu, Jianzhong Zhou , Chao Wang, Qi Qiao, Li Mo, “Short-term hydro generation scheduling of Xiluodu and Xiangjiaba cascade hydropower stations using improved binary-real coded bee colony optimization algorithm”, Energy Conversion and Management 91 (2015) 19–31

[2]. MATLAB® is the high-level language and interactive environment used by millions of engineers and scientists worldwide. http://www.mathworks.com/products/matlab/

[3]. LabVIEW System Design Software, http://www.ni.com/labview/