FINAL TECHNICAL REPORT

UPGRADES TO ALABAMA POWER COMPANY HYDROELECTRIC DEVELOPMENTS

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LIST OF ACRONYMS

Acronym	Definition
APC	Alabama Power Company
ARRA	American Recovery and Reinvestment Act
CFD	computational fluid dynamics
DOE	Department of Energy
FERC	Federal Energy Regulatory Commission
FOA	Funding Opportunity Announcement
HEM	Hydro Energy Model
NDE	non-destructive examination
NEPA	National Environmental Policy Act
RTD	resistance temperature detector
SCS	Southern Company Services

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I. EXECUTIVE SUMMARY

From 2010 to 2014, Alabama Power Company ("Alabama Power") performed upgrades on four units at three of the hydropower developments it operates in east-central Alabama under licenses issued by the Federal Energy Regulatory Commission ("FERC"). These three hydropower developments are located on the Coosa River in Coosa, Chilton, and Elmore counties in east-central Alabama.

The main objectives of these upgrades were to:

1. Increase efficiency of the Coosa River flows through replacement of the 1940s to 1960s vintage turbines with state-of-the-art turbines. Power generation would increase with little increase in or change to the flow through the upgraded units;

2. Increase power generation at the Coosa River hydroelectric developments to provide customers with additional low-cost, renewable hydro generation to meet peak and off-peak power demand;

3. Increase individual unit reliability, including increasing the ability of each unit to perform at its maximum efficiency when needed to meet power demand; and

4. Continue Alabama Power's commitment to the development and maintenance of clean, renewable energy sources and responsible stewardship of natural resources and local habitats.

The selection of units for upgrade was based on studies conducted in years previous to the license application which, in turn, preceded the grant application. Alabama Power compiled technical data and hydraulic parameters for all the Coosa developments and solicited potential upgrade responses from three major turbine suppliers. This broad approach achieved the objective of selecting the best candidates for the upgrade projects.

Once the four units were selected, Alabama Power prepared detailed technical specifications, based on the desired post-upgrade performance, which in each case was increased efficiency. A formal competitive inquiry was issued to a host of qualified turbine vendors, who specialized in turbine design, turbine manufacturing, refurbishment of existing components, and disassembly/reassembly of the entire hydro unit. Once the bids were received, a lengthy evaluation process took place, which took into consideration pricing, guaranteed performance, and adherence to the commercial terms and conditions of the contract. In the final analysis, three units at two of the developments were awarded to Andritz Hydro Corp., and one unit at the third development was awarded to American Hydro Corp.[1]

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[1] See discussion on page 15 below regarding the acquisition of American Hydro Corporation by Weir.

After completion of the upgrade process, which included many months of manufacturing followed by many months of site work, performance testing was conducted by a third-party testing organization (Alden Research Laboratory).

The final test results proved that Alabama Power had successfully achieved improvements in capacity, unit efficiency, and energy with resulting energy increases of 13.2%, 7.9%, 11.6%, and 10.8% for Lay Units 1 and 4, Bouldin Unit 2, and Jordan Unit 4, respectively, with an average per-unit increase of 10.9%. These results exceeded the initially expected average energy increase of 7.3%.

II. INTRODUCTION

The Department of Energy ("DOE") Office of Energy Efficiency and Renewable Energy ("EERE") and its Water Power Program focus their research and development efforts on "improving the performance, lowering the cost, and accelerating the deployment of cutting-edge technologies that generate renewable, environmentally responsible, and cost-effective electricity from the nation's water resources."[2] Alabama Power's project achieved exactly those objectives by upgrading the turbines at four units at three developments along the Coosa River: Lay Units 1 and 4, Bouldin Unit 2, and Jordan Unit 4.

Each of the four unit upgrades resulted in an increase in generation and a more efficient use of river flow. The expected generation increase for the Coosa Upgrades, an average of 7.3 % for the four units, would assist in meeting a growing demand for electricity in the Southeastern United States. Alabama Power's upgrade of its turbines to increase the energy efficiency at existing hydropower units therefore aligns with the EERE's stated vision of "strengthen[ing] energy security, environmental quality, and economic vitality."[3]

Newly re-designed, high efficiency turbines fabricated of stainless steel material were installed in the four units selected for upgrade. The Lay units' initial diagonal-flow turbines were replaced with newer, state-of-the-art diagonal-flow turbines. The Bouldin propeller turbine was replaced with a modern diagonal-flow turbine. The Jordan turbine was a Francis design, which was replaced with a modern re-designed Francis turbine.

By replacing the turbines with state-of-the-art technology, the units can now increase power generation with little to no increase in or change to the flow through the upgraded units. This will increase the ability of each unit to perform at its maximum efficiency when needed to meet power demand, thus increasing individual unit reliability.

The resulting energy gains over the existing baseline conditions were 13.2% and 7.9% from Lay Units 1 and 4, respectively, 11.6% from Bouldin Unit 2, and 10.8% from Jordan Unit 4. These figures were measured using Alabama Power's proprietary modeling methodologies

[2] http://energy.gov/eere/water/research-and-development
[3] http://energy.gov/eere/about-us

comparing the pre-upgrade performance to the post-upgrade performance, as described in more detail below in Part IV (Results and Discussion). This resulted in an average per-unit energy increase of 10.9%, which exceeded the 7.3% expected increase for the upgrade project as stated in the application.

III. BACKGROUND

A. Overview of Project Dams (Lay, Bouldin, Jordan)

Alabama Power has played an important role in water management across the state since beginning work on Lay Dam in 1912. Today, Alabama Power owns and operates 14 hydro facilities on the Coosa, Tallapoosa, and Black Warrior rivers, providing low-cost renewable energy and supporting local economies along Alabama's lakes and waterways. Alabama Power strives to meet the needs of lake-goers and property owners who enjoy the recreation these lakes provide as well as the many species and ecosystems that depend on their habitat.

Alabama Power's hydroelectric plants provide about 6% of the company's power generation. These dams impound more than 157,000 acres of water and provide more than 3,500 miles of shoreline for the use and enjoyment of the public. Largely because of Alabama Power's existing hydro generation, Alabama was ranked seventh in the nation in 2013 by the U.S. Energy Information Administration for net generation from renewable energy resources.[4]

1. Lay Dam

Shortly after organizing Alabama Power on December 4, 1906, Captain William Patrick Lay received authorization from Congress to construct the company's first dam and electric generating plant on the Coosa River, which was then named the Lock 12 dam. The dam was renamed Lay Dam in November 1929, in recognition of Captain Lay's service to the company and the public.

Having been in service since 1914, Lay Dam has six generators rating 29,500 kW each. The gravity concrete dam measures 2,120 feet with a maximum height of 129.6 feet. The Lay Reservoir sits 396 feet above sea level with an area of 12,000 acres and 289 miles of shoreline, with approximately 9,087 square miles of watershed draining into the reservoir.

2. Jordan and Bouldin Dams

Jordan Dam is located on a stretch of the Coosa River starting 14 miles north of Wetumpka, Alabama and ending at a bridge linking the two sides of town. The falls and

[4] http://www.eia.gov/state/?sid=AL

standing waves along this stretch of river were so great that you could hear the water roar a mile from the stream, earning this stretch of river the nickname "Devil's Staircase", where Jordan Dam was completed in 1928.

Forty years after completing Jordan, the Walter Bouldin Dam was constructed on Jordan Lake. Bouldin was the last dam built as part of the Alabama Power's Coosa River project. Bouldin has the largest generating capacity of Alabama Power's 14 hydro facilities and is unusual in design because it was built on a canal. Walter Bouldin Dam is unique in both its placement on a canal and its ability to generate the most power of any of Alabama Power's facilities. Some people refer to it as the "plant built in a cornfield".

The Jordan Dam has been in service since 1927, with four generators rating 25,000 kW each. This gravity concrete dam has a length of 2,066 feet and a maximum height of 125 feet. The Jordan Reservoir lies 252 feet above sea level with a surface area of 6,800 acres (including the Bouldin forebay). With 118 miles of shoreline, the Jordan Reservoir has a maximum depth at the dam of 110 feet, with approximately 10,165 square miles of watershed draining into the reservoir. The bay part attributed to the Bouldin Reservoir has a length of 3 miles, with a maximum depth at the dam of 52 feet.

The Bouldin Dam water retaining structures have a total length of 9,428 feet, including two earth embankments and a concrete intake section. There is no spillway structure as Jordan Dam spillway serves both developments. The concrete powerhouse is constructed integral with its intake. The Bouldin powerhouse contains three 75,000 kW generators.

B. Project Alignment with Grant Objectives

Alabama Power's upgrades were well suited to achieve DOE's objectives and wholly aligned with the objectives of the American Recovery and Reinvestment Act ("ARRA") and of Funding Opportunity Announcement Number DE-FOA-0000120, Hydroelectric Facility Modernization ("FOA"). In short, the upgrades achieved FOA objectives by using proven technology to increase renewable generation at Alabama Power's existing facilities with a minimum of regulatory delay. Because the upgrades were nearly "shovel-ready" due to the advanced state of their regulatory review, the upgrades were well poised for selection for DOE funding. The federal funds enabled Alabama Power to accelerate the construction schedule significantly and to begin the upgrade project as soon as the regulatory process concluded, rather than wait until a later date.

The capacity upgrades were made to four existing units at three hydropower developments licensed by FERC. These three developments are part of the Coosa River Project ("FERC Project No. 2146"), which was involved in a ten-year FERC relicensing process. Alabama Power began the relicensing process for this project in 1999 and submitted its relicense application to FERC on July 28, 2005. FERC issued an environmental assessment in 2009, which endorsed the four proposed unit upgrades. Therefore, the time-consuming regulatory approval process, which is often a primary impediment to beginning a capacity upgrade project at a federally-licensed dam, did not cause any undue delay in the initiation of Alabama Power's capacity upgrades.

As part of the FERC licensing process, Alabama Power's proposal to upgrade the four Coosa units reflected a full and comprehensive consideration of the potential environmental, socio-economic, and recreational impacts of the upgrade project. The upgrades were fully considered and evaluated in the Coosa relicense application development process before being ultimately included in Alabama Power's application. Because the upgrades were evaluated as part of the relicensing process, the proposed upgrades had already been subjected to significant review and analysis in the contexts of the Endangered Species Act, the Clean Water Act and the National Environmental Policy Act ("NEPA"). Consultations were made and assurances were obtained from both the U.S. Fish and Wildlife Service and the Alabama Department of Environmental Management. In accordance with NEPA requirements, which fully considered all potential environmental, socio-economic, and recreational impacts, FERC staff issued an environmental assessment in 2009, which found that the preferred alternative analyzed in the assessment (which includes the four unit upgrades) would not have a significant impact on the quality of the human environment. FERC issued a new Coosa River Project license on June 20, 2013, which formally authorized the unit upgrades.

Alabama Power followed a five-year plan for developing the relicense application that included a substantial amount of stakeholder participation. The primary purpose of this stakeholder consultation was to identify, discuss, and resolve all issues of concern related to the Coosa Project. The participants addressed every conceivable resource related to hydropower including the environment, recreation, water supply, navigation, flood control, fish and wildlife, and power generation. After thoroughly discussing and analyzing all of these issues, the stakeholders included consensus solutions in the relicense application filed with FERC on July 28, 2005. Because the four upgrades at issue in this grant request were included in the relicense proposal, the impacts of the upgrades included in the grant request on all resources listed above were fully considered in the relicensing process.

Finally, any FERC-issued license must comply with various Federal Power Act standards. Of particular relevance to this grant application, Section 10(a) of the Act requires that, in issuing a license, FERC must determine that the project "will be best adapted to a comprehensive plan for improving or developing the waterway or waterways for the use or benefit of interstate or foreign commerce, for the improvement and utilization of waterpower development, for the adequate protection, mitigation, and enhancement of fish and wildlife (including related spawning grounds and habitat), and for other beneficial public uses, including irrigation, flood control, water supply, and recreational and other purposes . . . ." FERC's issuance of a new Coosa Project license (which includes the four unit upgrades) clearly indicates that the upgrades meet this statutory standard, and therefore the grant application reflected a full and comprehensive consideration of the potential environmental, socio-economic, and recreational impacts related to the upgrades.

Alabama Power's upgrades effectively and successfully achieved objectives described in the FOA. First, by replacing turbines that had been in service since the 1920s with modern, state-of-the-art technology, Alabama Power achieved a corresponding "increase [in] both the quantity and value of hydropower generation . . ."[5] Second, the entire amount of federal dollars received were spent directly on the vendor who was supplying materials and labor associated with the new turbines and their installation (as opposed to any of Alabama Power's administrative or other indirect costs), thus achieving one of the FOA's "important" criteria by maximizing the "potential for increased power generation per federal dollar spent . . . ."[6] Third, the upgrade project precisely matched the FOA's focus on "supporting the deployment of turbines and control technologies to increase and maximize system generation at existing non-Federal hydroelectric facilities."[7] Fourth, the project had the added advantage of using a newer, more efficient technology that will significantly improve upon the decades-old technology currently in service.[8] In terms of regional diversity,[9] although all of the hydroelectric upgrades occurred along the Coosa River in Alabama, the upgrades occurred at three different locations within two different counties, and in two Congressional districts.

Additionally, the FOA expressly encouraged applications for projects "that can be developed with a minimum of regulatory delay, such as upgrades of equipment and operating procedures at existing power plants to increase generation and improve system flexibility or generation profiles so as to maximize the value of energy produced."[10] As described above, the process for receiving regulatory approval for the proposed upgrades was nearly complete at the time of the grant application. Furthermore, the upgrades did not require construction of new dams or diversions,[11] but rather utilized existing dams that have been in place for more than 70 years.

A final consideration in determining the fit of this project to the FOA objectives was the degree to which the plan was clearly stated, organized, achievable, and technically feasible, including the adequacy and completeness of proposed tasks and the resources identified to

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[5] FOA, page 9, Part I.B., Description.
[6] *Id.*
[7] *Id.*
[8] *Id.*
[9] *Id.* ("Regional diversity of projects and level of cost share will be important policy factors to be applied during the selection process.")
[10] *Id.*
[11] *Id.* ("Projects that require the construction of new dams or diversion will not be considered.")

successfully address all elements of the technical plan. Each of these considerations was clearly established by the fact that the proposed upgrades were already fully evaluated in the Coosa license application process, had been sufficiently analyzed in FERC's environmental assessment for the Coosa application, and were included in the new FERC project license. Because Alabama Power used a proven technology with which it has substantial experience, these upgrades were achievable and technically feasible. Indeed, Alabama Power has upgraded ten units at five different hydro projects in recent years. Based on this experience, Alabama Power was highly confident that it could complete these upgrades as planned and that they would achieve the desired operational results.

Finally, in addition to achieving the FOA objectives, the upgrades also aligned perfectly with the ARRA's goals and objectives. First, the upgrades increased renewable generation and thus lessened American dependence on oil and other fossil fuels by contributing to the transformation of our energy infrastructure. Second, the fact that the regulatory process required for these upgrades was nearly complete at the time of the grant application (and accelerated by the influx of ARRA funds) ensured relatively minimal regulatory delay, and therefore created a hydroelectric project that was as "shovel-ready," if not more so, than any other project proposed by a FERC licensee. Finally, the voluminous monitoring, reporting, and transparency obligations inherent in the FERC hydroelectric process, when combined with Alabama Power's compliance with the ARRA's additional reporting obligations, ensured that the proposed project would promote the ARRA's twin goals of transparency and accountability.

C. <u>Qualifications and Past Experience of Project Team Members</u>

The Principal Investigator and recipient for this project, Alabama Power, assigned an initial management team with proven leadership and strong technical experience. This team represented some 183 years of combined experience and expertise, with the majority of time being spent at either Southern Company or its affiliate Alabama Power. This dedicated project leadership, along with its existing engineering and construction expertise, ensured that outstanding and experienced resources were provided for the project.

Each team member had significant experience in executing his or her respective role in prior projects similar to the scope and nature of the role described. As might be expected over the period of over four years, some of the initial team members transitioned to different roles over time, while being replaced with members of equivalent experience and expertise. The roles and backgrounds of a few of the more primary team members with the most significant involvement and supervision are described below:

- **Herbie Johnson** has been Alabama Power's Hydro General Manager since 2012. Herbie began his career with Alabama Power in 1994 in Reservoir Management as a Senior Engineer. In 1997, he transferred to the Hydro Organization and served in the Hydro Plant

Specialist role and as the Hydro Superintendent at Thurlow Dam. In 2000, he moved into an engineer role working on the combined cycle projects at Plant Smith, and in 2005, he served as a project manager at Plant Gaston. He also served as the Assistant to the Executive Vice President of Engineering and Construction Services before moving into a role as Lake Resources Manager in 2008. Herbie re-joined the Hydro Organization as the Hydro Operations & Maintenance Manager in April 2011 prior to being named Hydro General Manager. Prior to joining Southern Company, he was a Staff Sergeant in the Alabama Air National Guard. Herbie graduated with a Bachelor's Degree in Civil Engineering from Auburn University. Herbie assumed the role of Hydro General Manager from **Gene Allison** after his retirement, who was general manager at the time of Alabama Power Company's initial grant application. Mr. Allison had 35 years of hydro experience including more than 21 years in managing large, complex projects and multiple staff in various locations.

- **Jim Crew**, Hydro Services Manager, brings 22 years of experience in coordinating major hydro construction, capital project management, hydro unit reliability/availability, and expertise in managing large federal license permitting activities for all Alabama Power hydro projects. Mr. Crew managed the project's regulatory compliance and consultation with federal, state, and local resource agencies, and remains the primary contact for the project.

- **Danny Minor**, Senior Project Engineer, manages all activities associated with major and minor capital projects including coordination with plant managers, design teams, supply chain, accounting, and generation planning. He has served as a project engineer for all 10 previous APC hydro upgrades at 5 hydroelectric stations from 1996 to 2004. Mr. Minor was responsible for developing and reviewing vendor information and bid packages, selecting and managing vendors, overseeing the work progress, and managing the budget and schedule.

Alabama Power's hydro team enjoys a high degree of success and innovation. From the period 1996 to 2004, Alabama Power performed upgrades on 10 units at 5 hydroelectric facilities. These previous upgrades used state-of-the-art materials and turbine innovation and were managed on budget and on schedule. The specific plants and associated units include:

Plant	Units Affected
Yates Hydroelectric Plant	Units 1 and 2
Thurlow Hydroelectric Plant	Units 1, 2, and 3
Bankhead Hydroelectric Plant	Unit 1
Holt Hydroelectric Plant	Unit 1
Martin Hydroelectric Plant	Units 1, 2, and 3

These previous upgrade projects have provided an estimated net increase of 93 MW, as well as overall increased efficiency to the APC hydro system.

D. <u>Scope of Work</u>

Although the basic scope of work for upgrades to hydro units can often vary on a case-by-case basis, the scope of work selected for each of the four Alabama Power units was very similar, and each unit's scope of work differed mainly with the turbine design.

Newly re-designed, high efficiency turbines fabricated of stainless steel material were installed in each of the four units. The original Lay units were diagonal-flow turbines, and were to be replaced with state-of-the-art diagonal-flow turbines. The original Bouldin propeller turbine was replaced with a modern diagonal-flow turbine. The original Jordan turbine was a Francis design, which was replaced with a modern re-designed Francis turbine.

A complete analysis of existing turbine and generator components was performed. The units were completely disassembled. All components were inspected, using visual as well as non-destructive examination ("NDE") methods. An extensive field machining process was utilized to bring all the embedded components into compliance with industry standards and tolerances.

The head cover and bottom ring components were refurbished for more effective wicket gate operation. Wicket gates were either refurbished or replaced with stainless steel material. All turbine and generator components were either blasted with abrasives or otherwise cleaned and painted. New bushings and sliding plates were installed on the gate operating system components. New stationary seals were installed on the head cover and bottom ring components. All pivot pins and link mechanism shear pins in the gate operating system were replaced.

The turbine guide bearings were refurbished and outfitted with new lignum vitae material. The gate servomotors were reconditioned, with replacement pistons and rings installed if needed. The turbine shafts were machined, with stainless steel sleeves installed at the packing box and journal area. New dual element resistance temperature detectors ("RTDs") for generator thrust and guide bearings were installed.

The generator brake systems were refurbished to include re-boring and honing of cylinders, replacement of brake pads, proving of non-asbestos shoes, and replacement of piston rings and seals. The generator brake rings were re-machined to restore the true condition. The thrust bearings were refurbished to include NDE inspection of babbitt area adherence. The rotational locks were NDE tested and the vacuum breakers were re-built.

The units were completely re-aligned, which involved the aforementioned extensive machining of stationary components. The units were commissioned to return to service, which involved unit testing as well as generator balancing as required. The units were then performance tested to verify conformance to flow and efficiency guarantees.

IV. RESULTS AND DISCUSSION

Upon completion of the upgrades at Lay, Bouldin, and Jordan, performance testing revealed that the upgrades have not only provided increased reliability for the future, but have also increased the generating capacity and operating efficiency over the old equipment. From a practical standpoint, those capacity and efficiency improvements have resulted in an increase in energy production over the old equipment. **Table 1** below provides an estimate of the resulting energy gains as a percent of existing (baseline) conditions:

Table 1. Table of Resulting Energy Increases at Upgraded Units

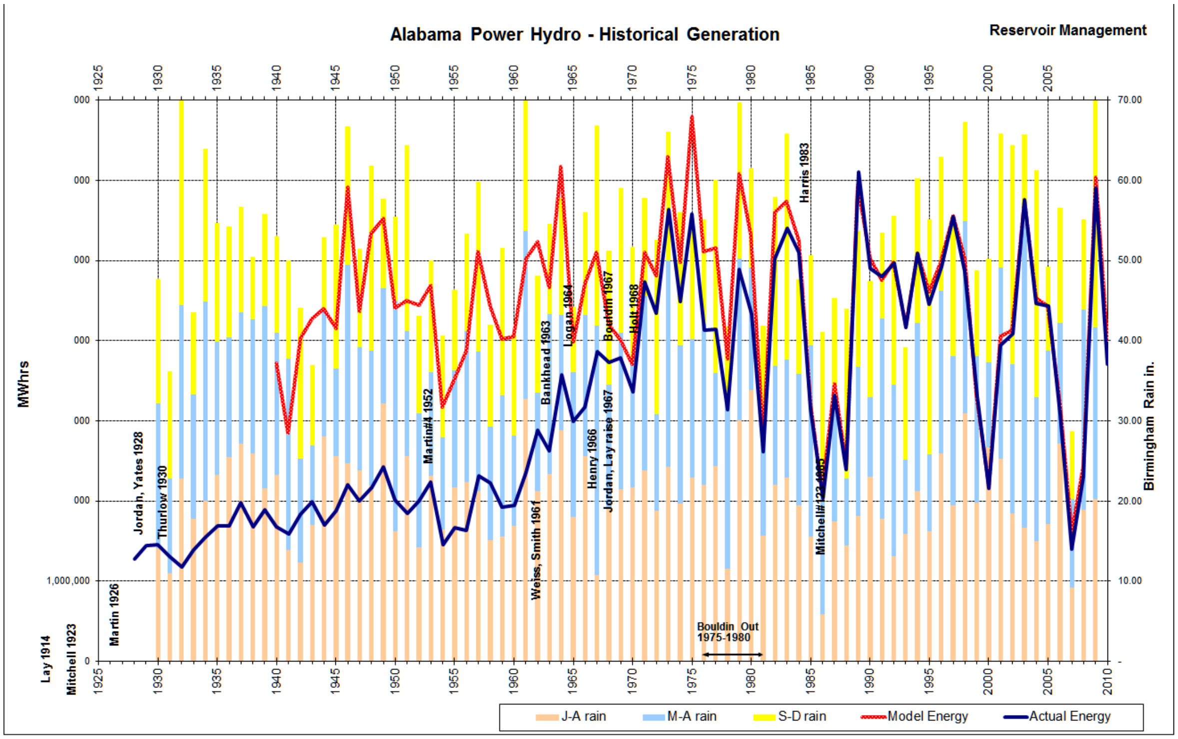
Unit	Resulting Energy Increase (%)
Lay Unit 1	**13.2**
Lay Unit 4	**7.9**
Bouldin Unit 2	**11.6**
Jordan Unit 4	**10.8**

Average resulting energy increase per unit: 10.9%

The resulting energy increase percentages shown in the **Table 1** were determined using Alabama Power's proprietary Hydro Energy Model (HEM) to compare the pre-upgrade performance (baseline) to the post-upgrade performance. The HEM is an analytical daily model for the determination of power production by simulating actual reservoir operations. The parameters for the HEM include generating capacity, turbine discharge ratings and efficiencies, generator efficiencies, head loss, and regulated operating guidelines.

By using the HEM rather than actual generation records for deterministic performance, Alabama Power has developed an accurate estimate of annual generation under baseline conditions to which alternatives can be compared. The HEM assumes that all current hydroelectric projects are in place for the entire 1940 to 2010 period of record, regardless of their actual in-service dates. As the number of new hydroelectric projects came into service over the period of record, and as their actual energy was incorporated into the data set, the modeled energy more accurately replicated the historical energy. This gives great confidence in the modeled energy results and, therefore, the associated energy increase percentages due to the turbine upgrades. **Figure 1** shows the performance of the modeled energy generation to the actual energy generation for the 61-year period of record. FERC has recognized the validity of the HEM approach to estimating annual generation by accepting this method in the context of Alabama Power's recent relicensing efforts.

Fig. 1. Alabama Power Hydro – Historical Generation



A. <u>Delays / Challenges</u>

Although the upgrades were ultimately successful, resulting in average performance-tested energy increases exceeding those initially expected, the project did face a small number of issues, mainly impacting delays to the project schedule or additional work items to address discovered issues. In many of the cases described below, these delays were either unanticipated or uncontrollable, such as weather delays, change of vendor ownership, or additional work that could not be detected from the outset.

First, the award of the contract for the vendor chosen to perform the Jordan Unit 4 Turbine Vendor (Weir American Hydro Corporation) was delayed. The initial vendor (American Hydro Corporation) changed ownership during negotiations, and the contract terms had to be re-negotiated with the new ownership (Weir American Hydro). Therefore the project completion date was extended considerably beyond the originally planned date.

Second, following inspection of embedded turbine components for the two Lay units, extensive additional field machining was recommended and authorized. This task added approximately three months to the field completion schedule for each project. However, this additional work could not have been foreseen until disassembly when the embedded turbine components could be inspected.

The Bouldin disassembly work also experienced considerable delays with the bottom ring removal. Extensive additional field machining was required for the Bouldin unit, adding approximately four months to the field completion schedule. The Bouldin progress was further delayed by unacceptable outside shop refurbishment being returned for re-work. Furthermore, the project experienced additional delays when shims were left out of the wicket gate mechanism and had to be retro-fitted back in. Finally, the unit experienced leakage at the head-cover interface with the stay ring flange during initial water-up of the draft tube. Extensive measures were required to seal the leakage.

The Jordan project was delayed approximately three weeks due to unusually heavy rain events. Flood conditions prevented the operational baseline pre-disassembly vibration testing. These tests must be conducted at or very near the normal head conditions, in order to be compliant with industry standards. As was experienced at Lay and Bouldin, the anticipated extensive field machining of embedded components added approximately two months to the completion schedule. Heavy rains during early January 2014 caused flood conditions, which delayed progress with the reassembly for several weeks.

Finally, performance testing of the Lay, Bouldin, and Jordan units presented many unanticipated challenges. Alden Research Laboratory was selected to measure the post-upgrade unit flow. Alden Research Laboratory is recognized as a world-wide leader in testing. Alden determined that both Lay and Jordan were best suited for current meter flow testing, while the Bouldin intake configuration was a better candidate for dye-dilution flow testing. The Lay flow tests had to be supplemented with computational fluid dynamics (“CFD”) modeling to identify a portion of the flow not being measured by the current meter arrangement. This additional work required considerable time to achieve accurate results. The performance testing problems encountered at Lay had a major negative influence on progress of testing activities for Jordan. Custom flow deflectors had to be fabricated and installed with the assistance of divers, which required considerable time. In addition, Jordan also experienced a problem with the headgate lifting chains and eyes, which required correction, prior to beginning any performance testing activities. The initial Bouldin test results were considered inaccurate, as a portion of the test curve deviated from expected behavior. A second test had to be performed at a later date, which produced accurate results.

B. Accomplishments

As outlined in the objectives for the project, the upgrades achieved at the Lay, Bouldin, and Jordan developments did indeed result in improvements in capacity, efficiency, and energy, as further delineated below. In addition, many intangible benefits emerged from the upgrades — benefits that sometimes tend to be given less accolades. For example, each of these units had experienced considerable years of service. As with any machine, various components had become worn, out of adjustment, out of industry tolerances, and less reliable. These major hydro unit upgrades afforded the opportunity to perform a complete unit disassembly, inspection, and a refurbishment overhaul. Embedded components were thus able to be inspected both visually and with NDE devices, and problems were able to be corrected. Cracks which could have jeopardized the integrity of the unit were able to be repaired. Bushings could also be replaced, which will prevent unwanted clearance and excessive movement and wear.

In summary, a major upgrade on a hydro unit provides the owner with essentially a new unit. The four upgraded units should now provide more reliable service and reduced maintenance for a significant number of years. The range of actual performance data is provided below, and is presented as a "before / after" upgrade comparison showing the range of increases in efficiency, output, and flow at the selected units.

Table 2. Range of Performance Results for the Upgraded Units (Lay, Bouldin, Jordan)

Units	Before Upgrade	After Upgrade	Difference
Maximum Unit Efficiency	**77% – 87.40%**	**77.7% – 88.90%**	**0.70% – 1.50%**
Generator Output at Max Efficiency (MW)	**28.8 – 77.6 MW**	**30.78 – 85.3 MW**	**1.98 – 7.70 MW**
Unit Flow at Max Efficiency (CFS)	**3900 – 8590 CFS**	**4300 – 9250 CFS**	**400 – 660 CFS**
Gate Opening at Max Efficiency	**72% – 87%**	**71% – 100%**	**-1% – 13%**

V. CONCLUSIONS

In conclusion, the upgrades to the four units on the Lay, Jordan, and Bouldin developments were clear successes, resulting in the installation of more modern technology and producing increases in capacity, efficiency, and energy. This resulted in an average energy increase of 10.9%, which exceeded the 7.3% average increase expected in the application. In keeping with the goals of the FOA and the ARRA, the upgrades to Alabama Power's hydro units enabled the units to provide more reliable and effective service with reduced maintenance for a significant number of years.

VI. RECOMMENDATIONS

This project was a successful example of DOE partnering with the private sector to accelerate the development of renewable energy in ways that are cost-effective and that preserve reliability. Alabama Power's program was nearly shovel-ready due to the advanced state of its regulatory review, but the ARRA funds enabled the company to accelerate the upgrade project and thus begin producing increased efficiency, capacity, and energy at a sooner date than it otherwise would.

Alabama Power has been a leader in the hydroelectric industry since the turn of the 20th century when Captain William Patrick Lay founded Alabama Power in 1906 to build Lay Dam to "be developed for the service of Alabama." Alabama Power recommends that DOE continue to explore additional opportunities to partner with private industry to continue to modernize the thousands of existing hydropower facilities to leverage additional clean energy throughout the country in ways that are cost-effective and preserve reliability.

VII. PROJECT PHOTOS

A. Pictures of Lay Dam Project

Fig. 2. Aerial View

Fig. 3. Installation of Turbine – Picture #1

Fig. 4. Installation of Turbine – Picture #2

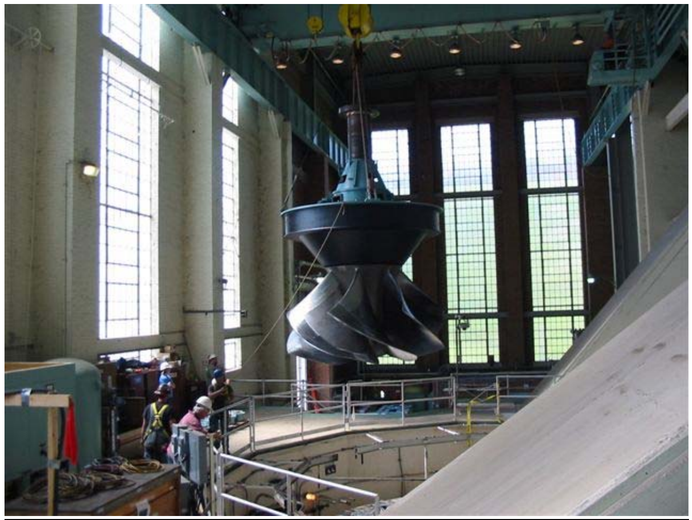


Fig. 5. Installation of Turbine, Inner Head Cover, and Bearing Housing

Fig. 6. Generator Stator with Rotor Removed

Fig. 7. Upper Bearing Bridge Installation

Fig. 8. Wheel-pit Assembly

B. Pictures of Jordan Dam Project

Fig. 9. Aerial View

Fig. 10. _Old Turbine Being Removed

Fig. 11. Field Machining Tool Being Installed

Fig. 12. Distributor Section in Shop for Refurbishment

Fig. 13. Upper Bearing Bridge Ready for Installation

Fig. 14. Installation of New Turbine

Fig. 15. Installation of Generator Rotor

C. Pictures of Bouldin Dam Project

Fig. 16. Aerial View

Fig. 17. Wheel-pit Components Ready for Removal

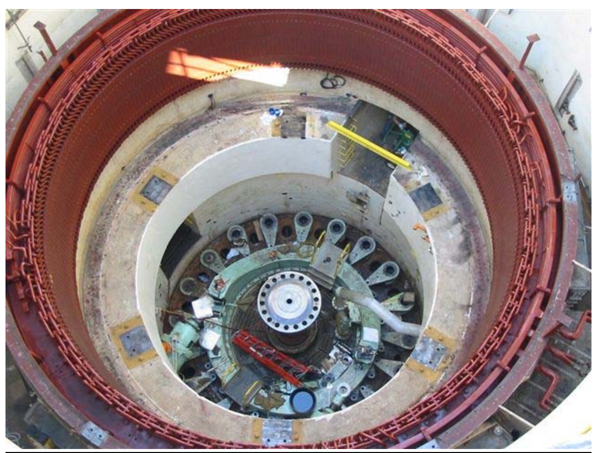


Fig. 18. Old Turbine Components Ready for Removal

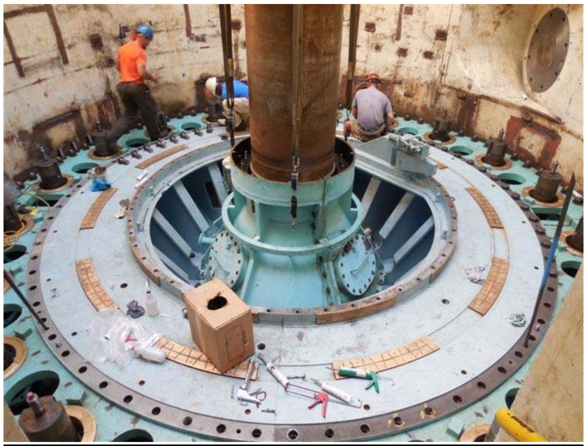


Fig. 19. Removal of Old Discharge Ring

Fig. 20.   Refurbished Wicket Set in Bottom Ring

Fig. 21. Thrust Bearing Being Set

Fig. 22. Installation of New Turbine