# Performance Testing of The Robert Moses Niagara Power Plant and Sir Adam Beck Generating Station

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**ABSTRACT**

*The Robert Moses Niagara Power Plant and Sir Adam Beck Generating Station are international hydroelectric power plants located on the Niagara River, which flows from the Lake Erie to Lake Ontario. The Robert Moses Niagara Power Plant is located in the state of New York, USA, and it consists of one generating station (13 units), and a pump-generating station (12 units). The Sir Adam Beck Generating Station is located in the province of Ontario, Canada, and consists of two generating stations (total of 26 units), and a pump generating station (6 units). Construction of the Sir Adam Beck Generating Station # 1 began in 1915-1929, the construction of Station # 2 began 1953 and Robert Moses Niagara Power Plant construction began 1958. Turbines at Sir Adam Beck and Robert Moses Niagara Power Plant are of the Francis type.*

*The Niagara River flow is shared equally between U.S. and Canada. The New York Power Authority owns and operates the U.S. side of the power project and Ontario Power Generation owns and operates the Canadian side. Both companies are upgrading the generating units for higher efficiency and to maximize the utilization of the water resource. Historically, both utilities agreed to utilize the same methods of measuring unit flow through the generating units in order to establish equal sharing of river flows.*

*An analysis was undertaken to select the best-suited performance test methodology to measure the turbine/unit efficiency. The analysis consisted of a comparison between the different test methodologies and their applicability to the unit configuration; conformance the IEC-41 and ASME PTC 18 test codes; and the test cost. From this comparison, The Pressure Time Method using the Gibson Instrument. Initially, the generating units were tested in 1923 to 1961 using the Gibson method.*

*In 1992, the Pressure Time Method using the Gibson Instrument was selected to carry out the turbine/unit performance testing and to measure the unit flows, which consists of the same Gibson Instrument that was used for the station commissioning. A test procedure was developed and statistical samples of 25 % of each type of unit are being tested by the Gibson Method and all other units are being tested by the Index method to evaluate unit performance similarity. This presentation describes the similarity evaluation procedure and the results achieved.*

*The final results were used to develop new operating rating tables for both utilities to accurately determine the split of river flows.*

## HISTORICAL BACKGROUND

The Robert Moses Niagara Power Plant is located at Lewiston, New York, USA, on the east side of the Niagara River, and Sir Adam Beck Generating Station is located on the west side of the Niagara River at Niagara Falls, Ontario, Canada.

The Robert Moses Niagara Power Plant consists of 13 turbine-generating units that were built in the early 1960's, The Sir Adam Beck Generating Station consists of two stations Sir Adam Beck I which consists of 10 units which were built in 1920's and Sir Adam Beck II which has 16 units which were built in 1950's. The Niagara River flow available for power generation is shared equally between the two power entities. The International Niagara Committee has the controlling authority over the water management of the river. The outflow from the power project is determined on a weekly basis by representatives of the International Niagara Committee based on the outflow; the power entities manage their share of the water to operate the turbines for electricity production.

One type of turbine was initially installed at the Moses Power Plant. The Sir Adam Beck I have three types of turbines and Sir Adam Beck II has one type of turbine. During the unit commissioning, representative units of each turbine type were field tested to determine the actual installed turbine and unit performance. Average performance characteristics were then developed from the field tests for each turbine type. The utilities issued comprehensive reports to the International Niagara committee detailing the unit performance test results based upon the Gibson method of flow measurement.

Ontario Power Generation Sir Adam Beck II station, upgraded 10 of the turbines to Alstom turbine design and four of the Sir Adam Beck I station turbines were upgraded to GE Hydro design.

At present, New York Power Authority has upgraded 8 of the turbines to the Voith turbine design.

Subsequently, revised comprehensive reports for each type of turbines were submitted to the International Niagara Committee detailing the revised unit performance based upon the Pressure Time method of flow measurement using the Gibson Instrument.

## DESCRIPTION OF WATER SUPPLY PASSAGES AND TURBINE RATING

Thirty-nine fixed-Francis type turbines are installed; twenty-six in the Canadian side and thirteen in the United States side. The water supply passages to each turbine consist of two short rectangular reinforced concrete supply intakes and a steel penstock to a full scroll casing. (Figure 1)

The units operate at normal rated head of 90 m (300 ft) and the head varies from minimum of 85 m (285 ft) to maximum 93 m (315 ft). The total flow varies from 2,800 $m^3$/sec (100,000 $ft^3$/sec) to 3,000 $m^3$/sec (110,000 $ft^3$/sec). Total output varies from 4,000 MW to 5,000 MW.

## REVIEW OF POSSIBLE TEST METHODS OF FLOW MEASUREMENT

The following selection criteria for the appropriate test method was established:

1. Expected accuracy
2. International test code acceptance
3. Suitability of unit geometry (test code requirement relative to actual unit configuration)
4. Economical factors (Unit outage, test set-up cost, test cost, and test equipment removal)
5. The safe operation of the unit.

All test methods that are recognized by the test codes were considered and the test requirements were compared to the unit configuration.

The Pressure Time Method using the Gibson instrument was selected because it is one of the most suitable methods for the unit configuration and it is the same method that was used in the original unit commissioning and it is economical for this type of unit.

## SELECTION OF THE PRESSURE TIME METHOD USING THE GIBSON ISTRUMENT TO MEASURE TURBINE FLOW

The Pressure Time Method using the Gibson instrument was used in the initial rating tests for both plants. The Gibson test is suitable to be used at these plants due to the unit configuration. The penstock length and the distance between the upper and lower Gibson piezometer taps are suitable for the test code requirements

It was determined that the Pressure Time Method using the Gibson Instrument of measuring unit flow would be the most accurate and repeatable method to measure flow, according to international standards for all field performance tests at the Robert Moses Niagara Power plant (RMNPP) and Sir Adam Beck Stations (SAB). (See IEC, ISO and ASME test codes).

The Pressure Time Method using the Gibson Instrument was selected for measuring flow on the following basis:

1. The expected test accuracy (+2.25%) is acceptable and it is economical relative to other alternative test methods.
2. The pressure time method using the Gibson instrument is approved by the International Test Code IEC-41 test code and is suitable for the unit configuration (see Figure 1).

3. Suitability of unit geometry (test code requirement relative to actual unit configuration)
4. Economical factors (Unit outage, test set-up cost, test cost, and test equipment removal)

## FIELD UNIT PERFORMANCE TESTS

The objective of the performance test program was to conduct sufficient field tests on each of the turbine types to yield a representative average performance curve on which to base the new rating tables.

It was decided to test Four (4) units from Moses Niagara Power Plant and Four (4) of Sir Adam Beck II generating Station by the Pressure Time method using the Gibson instrument. All other units would be tested using the Index method to verify unit performance similarity.

The field performance tests involve measurement of key parameters, including generator output, discharge, wicket gate opening, gross head, net head and differential pressure across the Winter-Kennedy piezometer taps installed in the scroll case of each unit.

The performance tests were carried out in accordance with International Standard IEC 41 third edition dated 1991 and ASME PTC 18, and ISO 3354. The tests were carried out for each unit using the same test methodology, the same test procedure, the same test equipment, the same test instruments and the same test team.

The unit efficiency performance results of the tests are shown in Figures 2, 3, and 4. A comparison of the average curve for each type of turbine is shown in Figure 5, 6.

## PRESSURE TIME METHOD USING THE GIBSON INSTRUMENT - TEST PROCEDURE

Site inspection was carried out before the field test. The piezometers used for the test were flushed to ensure they were clear of any obstructions. Piezometers used during the test were periodically flushed to eliminate any trapped air. The field metering section width and height were obtained from construction drawings. The dimensions were checked on-site before the test.

Temporary stilling wells were installed to measure the static water level of the unit headwater and tailwater. The wells were made of 2.0 inch diameter steel pipes and were sealed at the bottom with the exception of a 0.1875 inch diameter hole. The wells were fixed to the concrete wall. Temporary benchmarks were established on the top of each well. One well was installed in each intake, while two wells were installed in each tailrace.

With the exception of power and flow, all instruments were calibrated on site prior to the start of the test. The power meter and current meters were calibrated off-site. The test was conducted with the trashracks installed

The performance test consisted of 40 to 45 test runs covering a range of wicket gate openings from 20% (speed-no-load) to 100 % of full servomotor stroke. Turbine flow was measured and computed using the Pressure Time method using the Gibson instrument. The test runs were made at 20-minute intervals. At the beginning of each run the wicket gates were set at a fixed opening. About 5 minutes were allowed for conditions to stabilize.

During the remaining 15 minutes, the data acquisition system measured all parameters simultaneously at a rate of 100 scans/minute.

> Station headwater elevation, Unit headwater elevation, Station tailwater elevation, Unit tailwater elevation, Pressure elevation at the scroll case entry, Scroll case differential pressure (Winter-Kennedy), Generator output, Servomotor stroke

Turbine flow was calculated by the Pressure Time Method using the Gibson Instrument as follows:

The turbine flow was measured by the pressure-time method using the Gibson instrument. Flow is calculated using the following formula:

$$Q = ((K \times A_{GIBSON}) / (S \times F)) + Q_{LEAKAGE}$$

Where:

K = Gibson Instrument Constant

= $(g / 12) \times (M - 1) \times (R + 1)$

**CALCULATION OF HEAD**

All headwater and tailwater elevations used to calculate head were referenced to Benchmark Great Lakes Datum 1985 (IGLD 1985).

A temporary benchmark was established at the scroll case entrance measuring station (net head) using closed loop leveling from the reference benchmark Power (IGLD 1985).

Headwater (forebay) measurements were made using precision pressure transducers installed in gauge wells on individual unit intake piers and at the station intake gauge wells. Tailwater elevations were similarly measured at the unit tailwater, and the station tailwater well. Scroll case differential pressure was measured at the Winter Kennedy taps on each unit for the purpose of relative flow measurements (index tests).

The gross head is the head that is used for the rating tables. The gross head equals station headwater minus the station tailwater.

To convert from the net effective head upon which the turbine manufacturers' model test curves are based, the head loss due to friction between the forebay and scroll case entry and the residual velocity head in the tailrace were established. The friction loss between the forebay and scroll case entry was derived from field measured values on all units tested. The residual velocity head in the tailrace was computed from the cross-sectional area of the tailrace immediately downstream from the draft tube of each unit and the discharge through the unit.

## HEADWATER AND TAILWATER ELEVATION

Station headwater and tailwater levels (to determine gross head) were measured by a linear depth pressure transducer installed in the permanent headwater gauge stilling well. (Figure 1).

Three linear depth pressure transducers installed in three separate temporary stilling wells measured unit headwater level. Two temporary stilling wells were located in the emergency stoplog slots of each intake. The third temporary stilling well was located on the nose of the pier between intakes. The unit tailwater elevation (to determine net head) was measured by two linear depth pressure transducers placed in two temporary stilling wells. The wells were located on the east and the west side of stoplog openings of the draft tube exit on the tailrace deck (see Figure 1 for details).

## PRESSURE AT SCROLL CASE ENTRY

The pressure elevation (to determine net head) at the scroll case entry was measured using a linear pressure transducer. The transducer was connected to the manifolded piezometers at the scroll case entry.

## WICKET GATE SERVOMOTOR STROKE

Wicket gate opening was measured by means of a linear displacement transducer on the servomotor piston rod and an angle positioner mounted on the wicket gate stem of each unit tested. Full servomotor stroke was calibrated over the entire operating range. The wicket gate angle was measured during calibration of the servomotor stroke linear displacement transducer to an accuracy of $\pm$ 0.5 degrees.

The wicket gate angle may be calculated using the following equation:

$$Ang = c0 + c1 \times (SMS) + c2 \times (SMS)^2 + c3 \times (SMS)^3 + c4 \times (SMS)^4$$

## POWER OUTPUT

Generator output was measured by means of a high accuracy three-phase watt-hour meter (Yokogawa watt/watt-hour transducer). The same watt-hour meter was used for all tests. In addition generator output (3 phase 2 element) was measured using a Scientific Columbus watt/watt-hour transducer. The instrument and the transformers were calibrated to ensure the measurement accuracy. Generator performance in terms of efficiency for various percentages of rated output was taken as the average of the generator manufacturer guarantees. The generator efficiency was determined from data supplied by the generator manufacturer at unity power factor.

## INDEX PIEZOMETER TAPS CALIBRATION (SCROLL CASE DIFFERENTIAL PRESSURE)

The scroll case differential pressure was measured by a linear differential pressure transducer connected to the Winter-Kennedy piezometer taps located in the scroll case. The low-pressure tap is located between the guide vanes. The high-pressure tap is located in the outside of the scroll case opposite the low pressure tap.

The Winter-Kennedy scroll case differential pressure relationship was calibrated using measured differential pressures and corresponding measured flows. The least squares method was used to determine the calibration constant and exponent, n, of the standard Winter-Kennedy relationship.

$$Q = k \times (DP)^n$$

where:

Q = flow (m3/sec)

DP = scroll case differential pressure (psi)

## CONCLUSION

The Pressure Time method using the Gibson Instrument was an effective and accurate means of measuring flow at The Robert Moses Niagara Power Plant's turbine-generating units and at Sir Adam Beck II. The Gibson Instrument proved to be very useful in achieving accurate test data on turbine unit performance and to provide the baseline data to derive the rating tables used for water sharing of the Niagara River.

The Index method proved to be very useful to prove unit similarity and to show the unit that is not similar. (See figure 5 and 6)

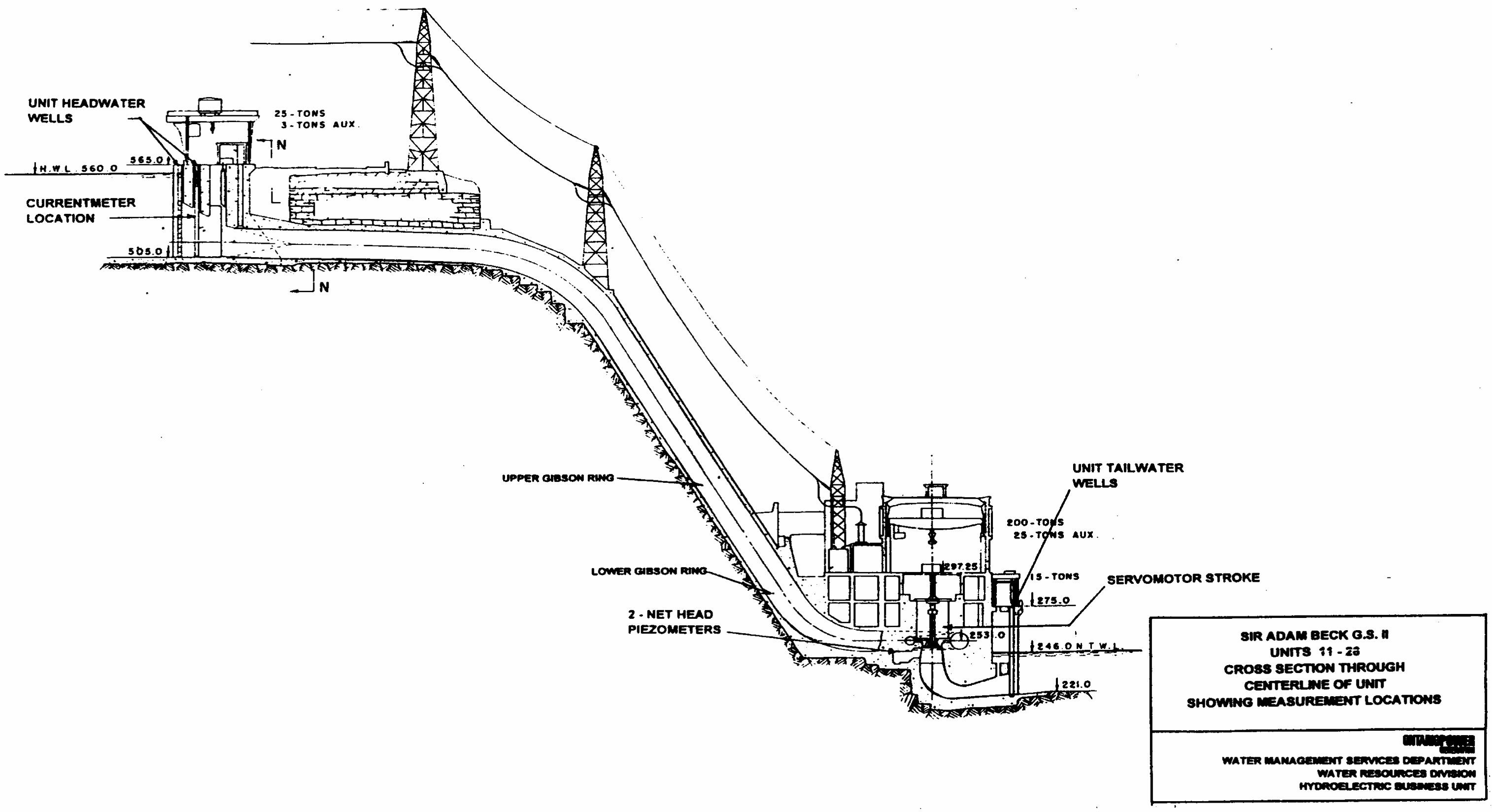


FIGURE 1 UNIT CROSS SECTION

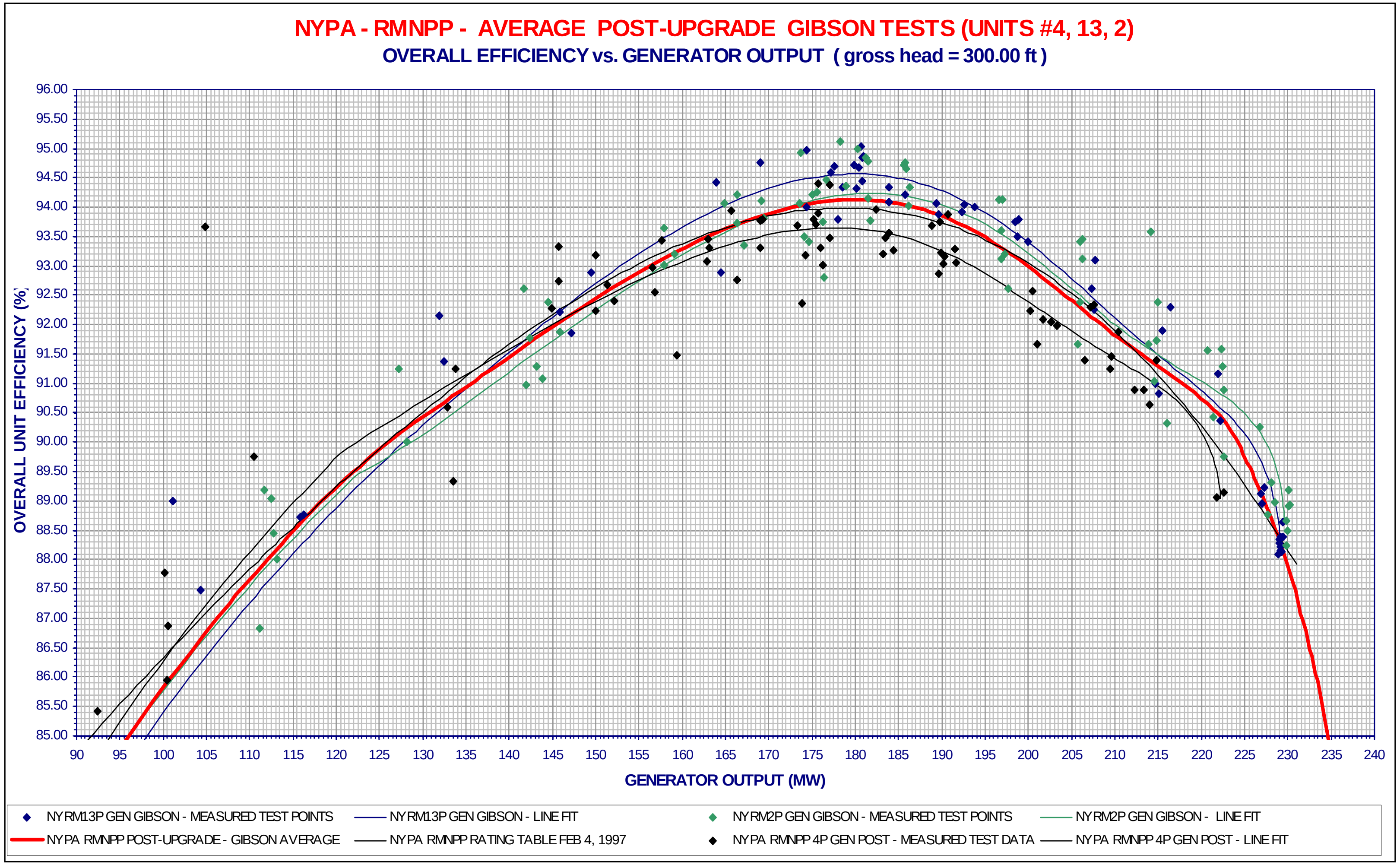


FIGURE 2 NYPA – ROBERT MOSES NIAGARA POWER PLANT - AVERAGE UNIT RESULTS

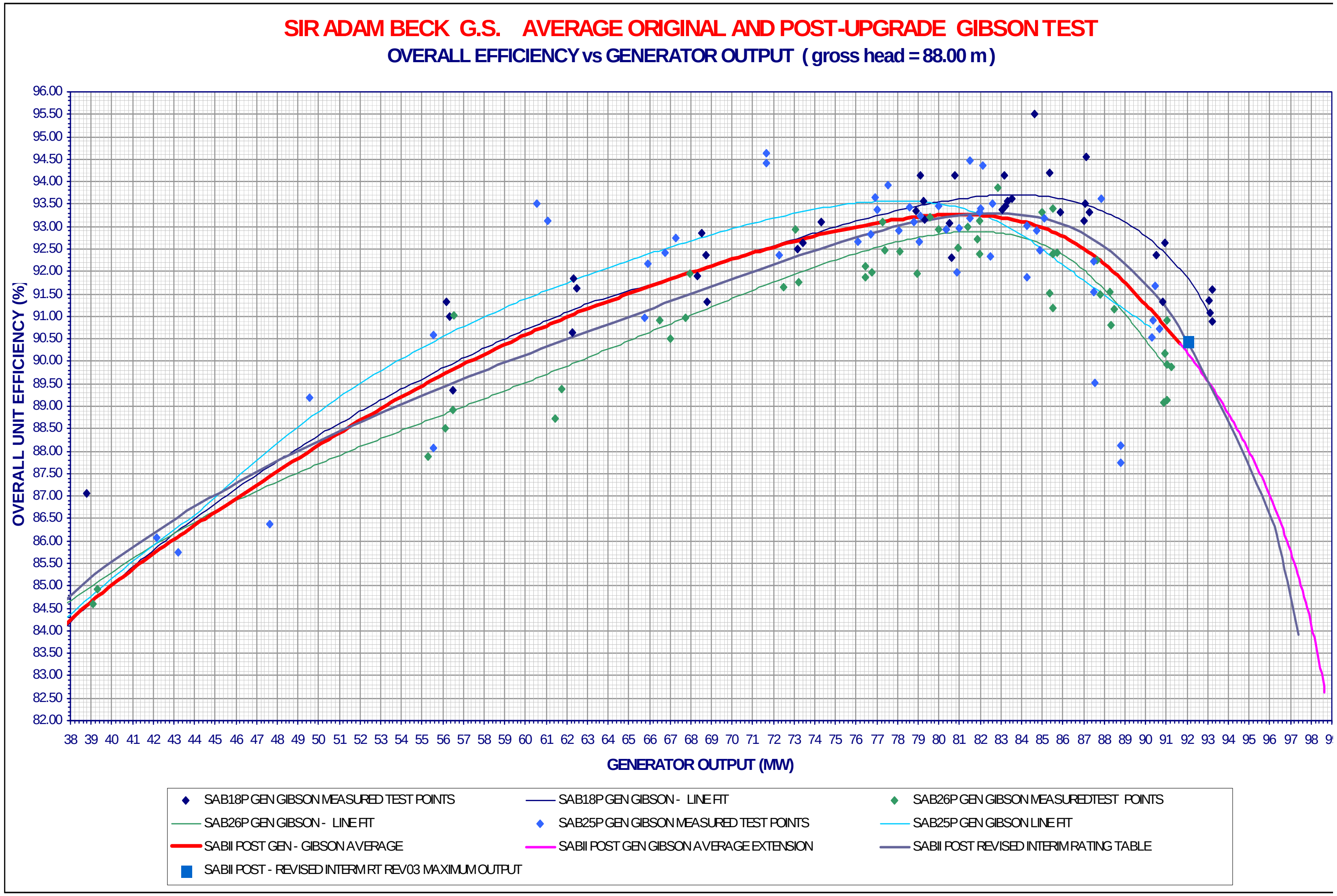


**FIGURE 3 OPG – SIR ADAM BECK II - AVERAGE UNIT RESULTS**

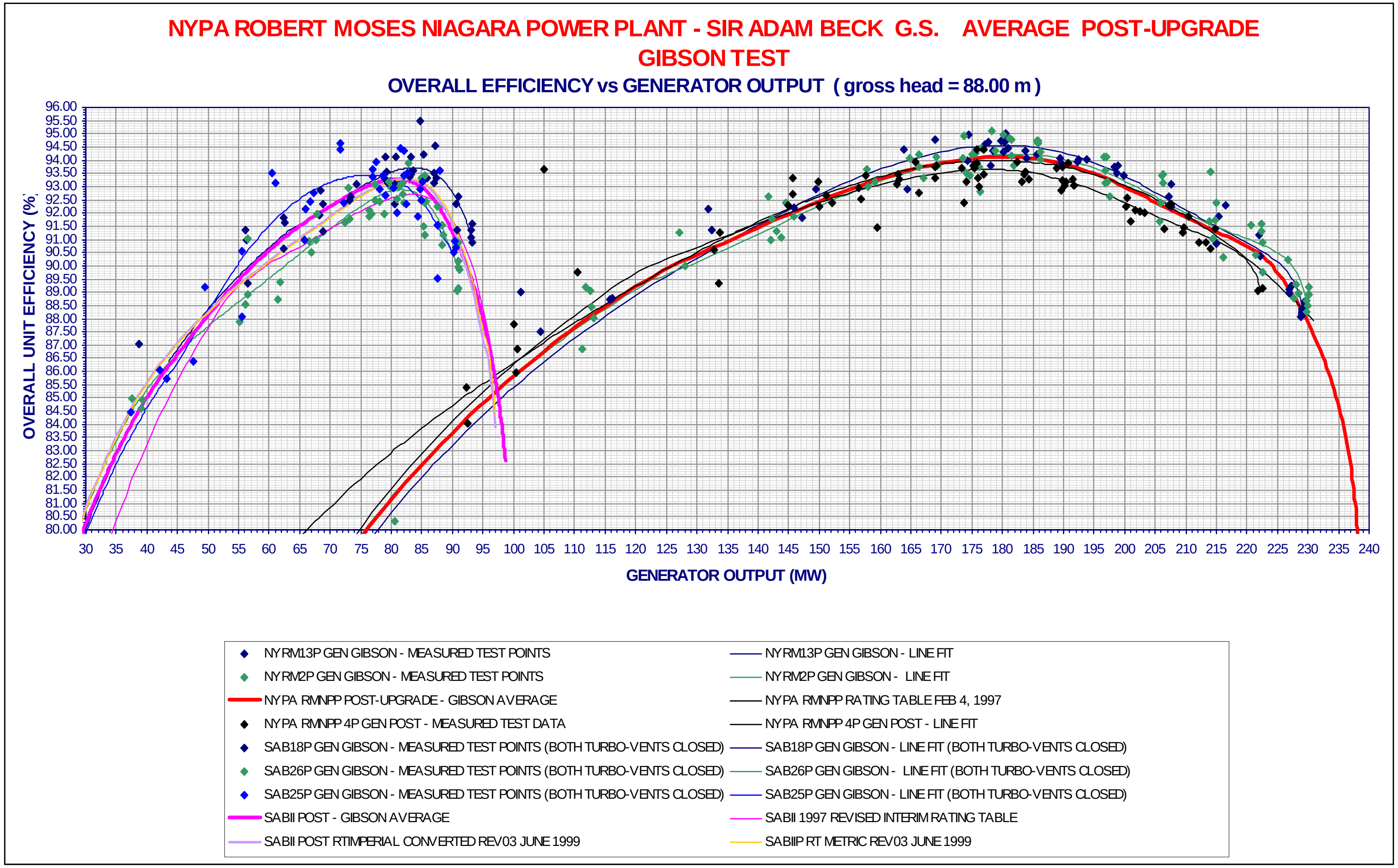


**FIGURE 4 NYPA RMNPP AND OPG - AVERAGE TEST RESULTS**

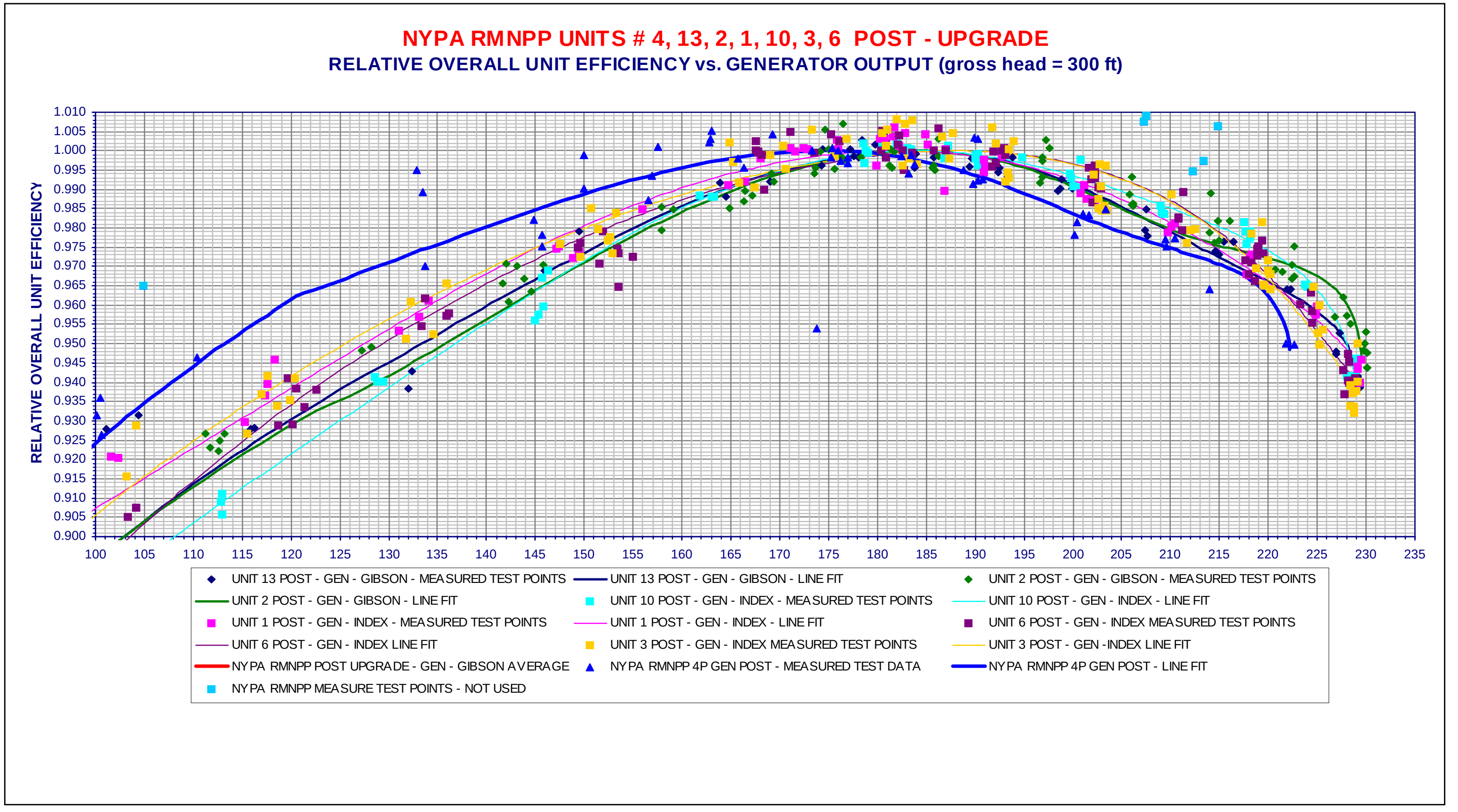


**Figure 5 NYPA RMNPP INDEX TEST COMPARISONS**

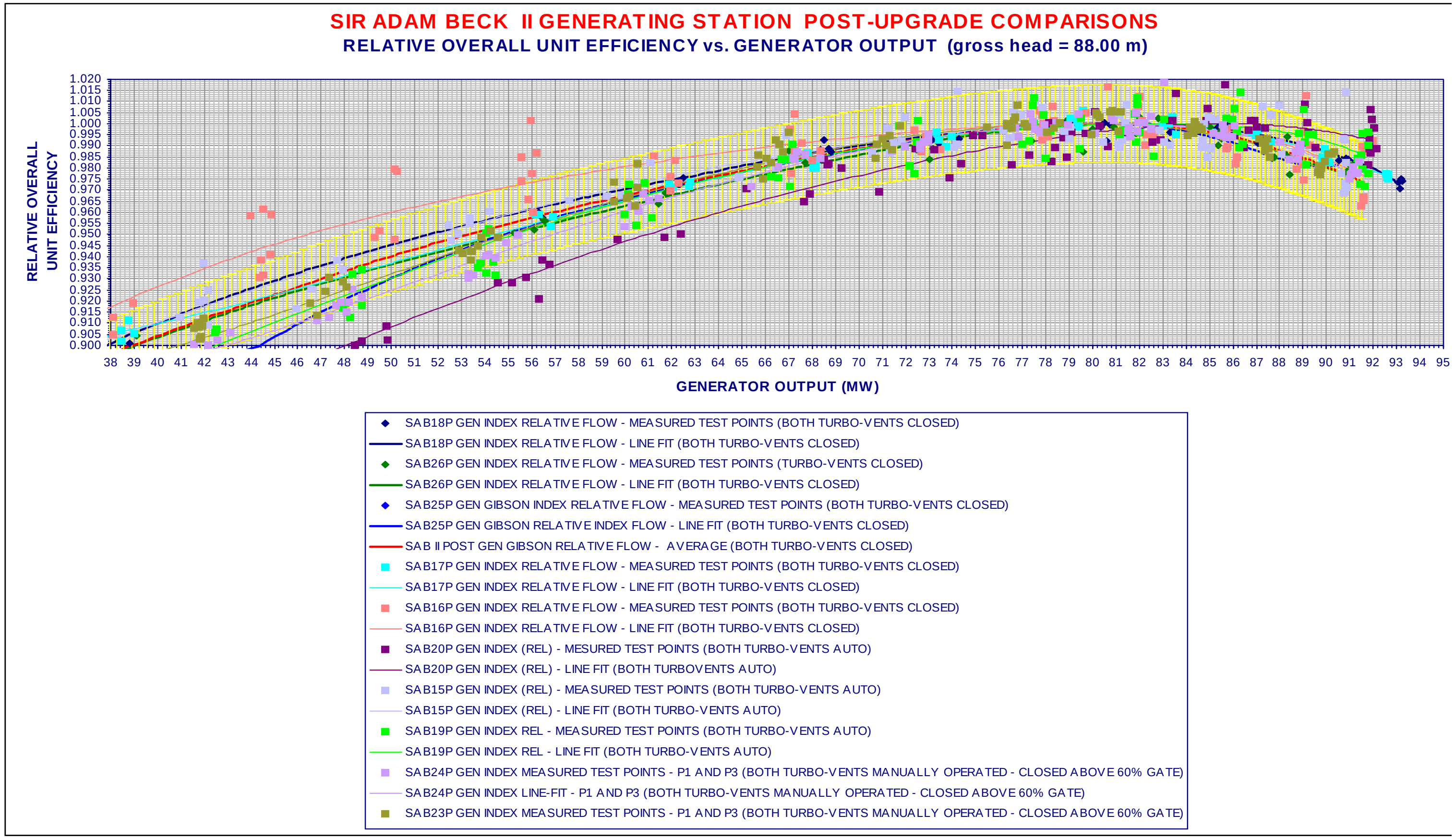


**FIGURE 6 SIR ADAM BECK II INDEX TEST COMPARISONS**