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Optimization of Electrical Efficiency of Micro- Hydro Power Plants

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Abstract: *The study intends to find energy efficiency and optimization system for Cameron, with better political and social ability to overcome such mega projects on need basis. Cameroon boasts of a huge hydropower potential pegged at 115,000 GWh/year, and only 4% of it has been harnessed so far. Study investigates more efficient and reliable plan for another 10 to 15 years. Micro Hydro-Power plans are in more need and required energy can be met with production efficiency to build and expedite the procedure. Cameron, 6,000 mega watts hydropower potential has been identified through the country's rivers and waterfalls. Micro-hydro-electric power is both an efficient and reliable form of clean source of renewable energy. It can be an excellent method of harnessing renewable energy from small rivers and streams. The researcher used SIMULINK to study the electrical efficiency of the micro hydro power plant that was designed. SIMULINK allows the researcher to build the simulation model in a systematic way starting from simple sub-models.*

Keywords: *OPTIMIZATION, SIMULINK, MICRO HYDRO ELECTRIC*

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I. Introductions

Cameroon lying at the junction of western and central Africa, its ethnically diverse population is among the most urban in western Africa. The capital is Yaoundé, located in the south-central part of the country. Political and economical stability of the country had lead to development in infrastructural project on private and public level. Domestic production and indicators of economy are flourishing and promising for the country, average increase of 4% GDP in annual per capita measurement has made remarks on the landscape of Cameroon and demand of energy and electricity for projects and development increased on vast level. Government of Cameroon has perpetual planning to meet energy demand by installing different onshore and offshore projects. By 2035 government intends to comply with all planning modules and enable the prosperity to hike to achieve utmost development in the country and facilitate the business man.

Cameroon boasts of a huge hydropower potential pegged at 115,000 GWh/year, and only 4% of it has been harnessed so far. The country's total electricity consumption was about 7,852 GWh last year and is expected to increase by around 6.5% annually. That is why the development of hydropower plants has to be expedited to meet this growing energy demand.6,000 (MW) hydropower potential has been identified through the country's rivers and waterfalls, focusing mainly on the following big rivers: the Sanaga River to increase the capacity of the two existing big power plants, another two-plant cascade with more than 400 MW on the Nyong River, and almost 300 MW on the Ntem River.

North side of the country also provides the great opportunity for the hydropower development and project initiation of the country. Law Environment Act introduced in 2005 (Hydro News, 2019) has allowed lots of project management schemes and investments influx into the Cameroon by direct investment and foreign direct investment into hydro power plant and energy projects

II. Background

Energy production into electricity is the most versatile option for any country to boost into the economical adventures through enacting the new projects and infrastructural demands of the country. Pollution free environment is subject to hydro plant for energy conversion and object of Cameroon to install the energy conversion plants with non-polluting environment. New and innovative methods are adopted all over the world for enhancing the capacities of energy conversion into electricity especially in PV/Thermal/Hydro hybrid plants which are enabling countries to compete on research based innovative applications and approaches to establish a system of conversion at low cost. Weightless, easy to transport and distribute wind, water and sunlight is used to enhance the conversion process and capacities for better systematic acquisition of energy. Cameroon as an upcoming industrial economy needs to introduce a system meeting the energy requirement and controlling the use of energy in industrial and non commercial sectors is striving to meet the demands and generate energy at lowest cost since last 5 years. Energy of such mega usage for country like Cameroon can be achieved through renewable production including hydro, enhancing efficiency in production of fossil-fuel-based generation, including carbon capture, and advanced nuclear power. Another way of using the electricity efficiency in reduction of 30% usage for short term and for longer supply of energy in development sectors, longer research based approaches are applied by government agencies to adopt control mechanism in rates of supply for industrial usage and development sectors.

Statement of Problem

Problems identified in research are the efficiency of production and side effects in production applies for the maximum production of the energy and maximizing emission

(International Electro technical Commission, 2019) stated a greater concern in efficiency definition of the energy conversion and usage of the reduced electricity in the sectors. Greater concerns are emphasized on the usage of electricity in commercial sectors that can be reduced as to provide leverage to industrial sectors.

This study will concentrate solely on the challenges of achieving electrical efficiency in hydro-power plants specifically on micro-hydro power plants. This study aims to do the following:

1. Provide a micro-hydro plant design to maximize the output efficiency of energy conversion
2. Simulate the design and find out the specifications where optimization is achieved;
3. Application of the MHP on the rivers and waterfalls of the Cameroon as per the capacity of energy production.

Limitations

Micro-hydro power plants are subject of experiments in this study as the primary object of the investigation. Electrical efficiency in all the means is the basic factor addressed in the study and investigated through derivations. Optimum solution is the acquired through the design of the MHP system and installation. Furthermore, study focuses on the capacity generated through the hydro management of the Cameroon rivers and waterfalls, cannot be used in other parts of the word without integrated adjustments in design

III. Literature View

This literature review will discuss the evolution of micro- hydroelectric power systems and the advantages of using hydropower to generate electricity. Then it will present current designs being used by different micro- hydro power plants all over the world. Each of these designs will be described and the researcher will simulate which of these designs would be able to achieve optimum electrical efficiency for the micro power plants in Cameroon.

The Evolution of Micro-Hydro Electric Power

Large-scale hydro-electric plants supply 16% of the world's electricity as stated by the International Energy Agency (IEA), with greater challenges and problems associated within the system. Large cost, large Dams, Large tracts and greater control is required which sometimes is impossible for small sized countries less developed. Usually water control is hard due to the mountain people and old tribes living in the area claiming environmental hazards and creating obstacles for such huge projects (Singh, 2009). Alternative solution for such problems is small installation of energy plants called Micro-hydro-Electric plants of energy generation ranging generation between (5) and (100)KWs of Power, good enough to support a controlled area installing across rivers and canals, acting as battery to store the electricity in the water.

In particular, the advantages that micro-hydro-electric power plant has over its same size wind, wave and solar power plant counterparts are as follows:

- Its high efficiency (70-90%), by far the best of all energy technologies;
- Its high capacity factors (> 50%) compared with 10% for solar and 30% for wind power plant;
- Its slow rate of change; the output power varies only gradually from day to day not from minute to minute; and
- A study between small-hydro-electric power plants (up to 10 MW capacity) and micro-hydro-electric power plants (up to 100 KW capacities)

It concluded that larger one is more capital and brainstorming intensive projects where as smaller and micro are easier to handle and install with same capacity of generation in distributive areas. Political starting up MHP are much more easier than large system installations for the country like Cameroon, Many of these systems are “run-of-river" which does not require an impoundment. Instead, a fraction of the water stream is diverted through a pipe or channel to a small turbine that sits across the stream. Scope for harnessing the micro-hydro-electric power plant and capacity generation is higher are identifies the potential of installing such activities in the socio-economic and political systems of the country Properly designed micro-hydro-electric power plant causes minimum environmental disruption to the river or stream and can coexist with the native ecology (Nasir, 2014).

IV. Methodologies:

Design Procedure of Micro-Hydro Power Plant

MHE is excellent and less effort required way of generating and harnessing electricity energy and its control mechanism. MHE is more efficient and befitting of harnessing and storing energy from river and canals. One of its feasible forms is the micro-hydro project designed to be a run -of-river type, as it does not require higher capacity of storing to power the turbine. The flowing water will just run straight through the turbine and back into the river or stream to use it for the other purposes. Local ecosystem and environment hazards are less effective and impact oriented in such a way as to install the MHE and let the water be used for original purpose of cultivation r drinking.

MATLAB Simulink computer program is used to design the MHE; that will calculate all the design parameters and implementation of those phases required in installation. Sit-head and flow rate will define the choice of designed parameters and turbine type. TP and speed is directly proportionate to the Site head with specific high and low speed as per the flow of water through turbine; variation in water flow will define the power and speed of turbine.

The head losses in the penstock could range from 5 to 10 percent of the gross head, depending on the length of the penstock, the quantity of the water flow rate and its velocity. The turbine efficiency could range from 80 to 95 percent depending on the turbine type, and the generator efficiency about 90 percent.

Study investigates optimization of efficiency in electricity generation of MHE design and implantation phase and construction of the MHE is feasible for the project site and there aren't going to be major problems during the design and implementation stages of the micro-hydro-electric power plant station will show that construction of the micro-hydro-electric project is going to be feasible for the project site and there aren't going to be major problems during the design and implementation stages of the micro-hydro-electric power plant (Nasir, 2014).

Modeling of the SHPP components, such as synchronous machine, turbine and its governing system is compulsory to make a breakdown of the power system response, in order to achieve higher optimization in MHE project, no disturbance is intended while system is designed. The performance of the power system is going to be affected by the dynamic characteristics of the hydraulic turbine and its governor system during any disturbance, such as the presence of a fault, harmonics on the network, or a rapid change of load and loss of a line. Simulink blocks contained in the Sym Power Systems block set are used for modeling SHPP system. In this simulation model, the position speed gesture is going to be obtained from the kinetic energy of the falling water through the penstock. Is compares with synchronized reference speed signal and fed back of river water to attain the higher capacity. The speed deviation produced by comparing reference and synchronous generator speed is going to be used as an input for PID based speed governor. PID is used as turbine governor because this control has a simple structure, stability, strong robustness and non-steady state error. The governor produces the control signal, causing a change in the gate opening. The turbine in turn produces the torque, driving the synchronous machine that generates the electrical power output. The speed governor constantly checks speed deviation to take action (Nanaware, et al., 2012).

V. Simulation & Results

Synchronous Machine Model

Simulink/MATLAB is used to simulation model of three-phase p-poles synchronous machine. Figure 1 below shows a synchronous machine model. Synchronous machine model

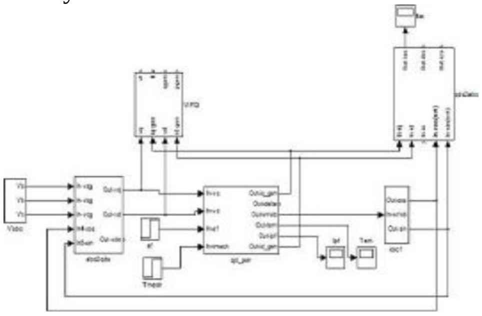

Figure 1 *Synchronous machine model*

The synchronous generalized model is going to be used to simulate a three-phase. P-pole, symmetrical synchronous machine in rotating q-d reference frame. Dependence of the inductances on the position of the rotor is taken out by the d-q model. In achieving it, magnetic saliency possession systems are coordinated to enables faster output which is the rotor for synchronous generators.

The d–q model is going to show the rotor as well as the stator equations using the coordinates of the rotor, aligning it with the d and q axes of the rotor. This is because without magnetic saturation, the two axes won't be coupled. Along the d and q axes, the rotor windings Q, D, and f have already been aligned. Moreover, the flux linkages ΨA, ΨB, ΨC, the currents IA, IB and IC, and the stator voltages, VA, VB, VC, need to be transformed to rotor orthogonal coordinates. The Park transform which refers to the transformation of coordinates ABC to d–q-0 holds true as well for flux linkages, currents and voltages, as follows:

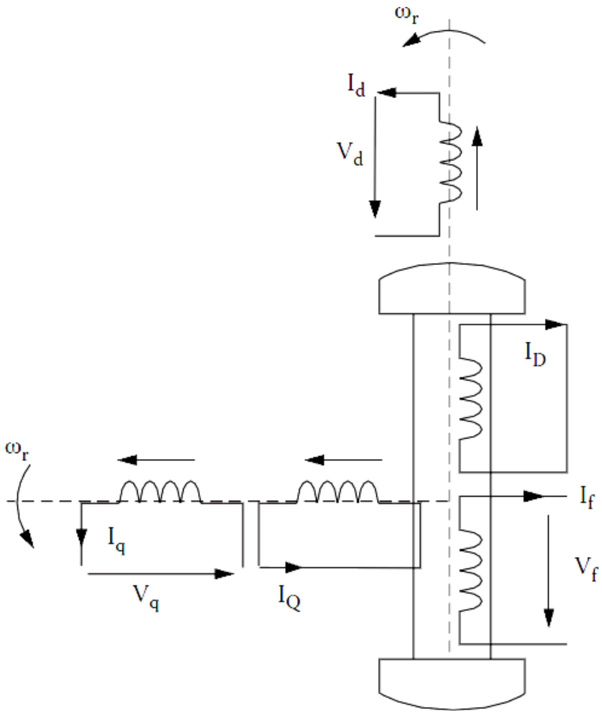

Figure 3 *d-q Model of a Synchronous Machine*

Voltage Equations of the Synchronous Machine

P-pole, symmetrical synchronous machine voltage equation is than presented in the rotating q-d reference frame. Figure 2 below presents the equivalent circuit of synchronous machine in their respective q-d axises. It illustrates the inductances and the resistances in the q and d equivalent circuits of synchronous machine -

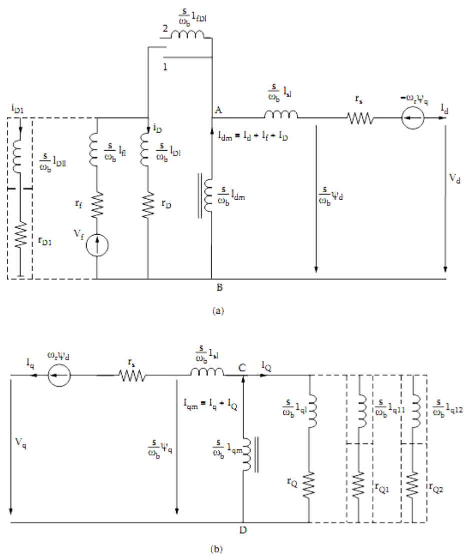

Figure 3 *q and d equivalent circuits of Synchronous machine*

The next sets of equations describe the general model of a synchronous generator.

1. $\Psi d = lsl\ Id + \Psi dm$; $\Psi q = lsl\ Iq + \Psi qm$
2. $\Psi dm = ldm\ (ld + lD + lf)$; $\Psi qm = lqm\ (lq + lQ)$;
3. $\Psi f = lfl\ If + \Psi dm$; $\Psi D = lsl\ ID + \Psi dm$
4. $[\ r0 + (s / \omega b)\ l0\ ]\ i0 = V0$
5. $[\ rf + (s / \omega b)\ lfl\ ] - Vf = -(s / \omega b)(\Psi dm)$
6. $[\ rD + (s / \omega b)\ lDl\ ]\ Id = -(s / \omega b)(\Psi dm)$
7. $[\ Q + (s / \omega b)\ lQl\ ]\ IQ = -(s / \omega b)(\Psi Qm)$
8. $[\ rs + (s / \omega b)\ lsl\ ]\ Id + Vd - \omega r \Psi q = -(s / \omega b)(\Psi dm)$
9. $[\ rs + (s / \omega b)\ lsl\ ]\ Iq + Vq + \omega r \Psi d = -(s / \omega b)(\Psi qm)$

Where;

a) Ψq, Ψd is the flux linkages in the d and q axes;

b) Ψqm, Ψdm is the mutual flux linkages in the d and q axes;

c) Iq, Id is the q and d currents;

d) ΨQ, ΨD is the flux linkages of the damper coils in the d and q axes;
e) IQ, ID is the currents of the damper coils among the q and d axes.

Torque Equation

Equating the inertia torque to the accelerating torque:

$$J\ (d\omega rm / dt) = Tem + Tmech + Tdam$$

Where J is the inertia torque of the rotor, Tem is the electromagnetic torque, Tdamp is the externally- applied torque in the direction of the rotor speed and Tdamp is the damping torque in the direction opposite to rotation. The value of Tmech will be negative for the motoring condition.
The electromagnetic torque is given by as:

$$Tem = (3/2)\ (p / \omega b)\ (\Psi ds\ tqs - \Psi qs\ tds)\ N.m.$$

Hydraulic Turbine Model

Characteristics of a hydraulic governor affect the power system in the process. Such as a rapid change of load, the loss of a transmission line or an occurrence of a fault is usual disturbances covered through turbine systems of the process. it is essential to have an accurate modeling of these hydraulic governor-turbines in response of any emergency of disturbance occurrence. What can be done is to model these simple hydraulic systems which are operated by proportional-integral controllers and proportional-integral-derivative. This particular model checks their transient responses to disturbances by simulating it in MATLAB. Figure 3 below shows the block diagram of the hydraulic governor-turbine system.

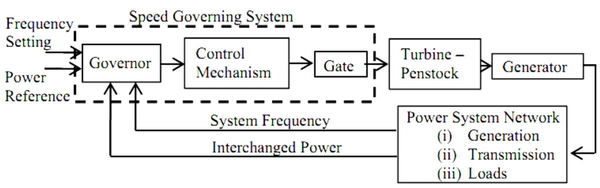

***Figure 3** Block diagram of the hydraulic governor- turbine system*

System Converts as shown in the block diagram the kinetic energy of the water in to mechanical energy which becomes the primary source of the electricity. Consumer receives the converted electricity from mechanical energy generated by synchronized generators of the system. Depending on the input signals of the deviations of both the interchanged power and the system frequency with respect to the reference settings, the speed of the generator is adjusted by the speed governing system. By doing so, the generator is able to operate at or near nominal speed throughout its operation.

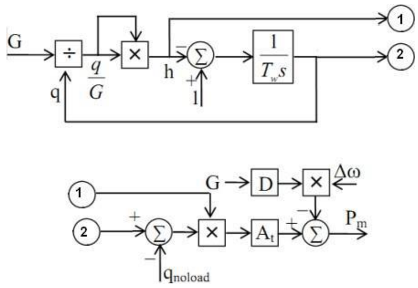

Figure 4 *Block diagram of the hydraulic turbine*

Excitation System Model

Excitation system model is focus of the further discussion and elaboration. DC excitation system has no or less saturation and commutator is used as the source of power, enabling functionality of DC generator.

Figure 3 above, shows the block diagram of the model represents the field-controlled DC commutator exciters that has voltage regulators that operate at all times.

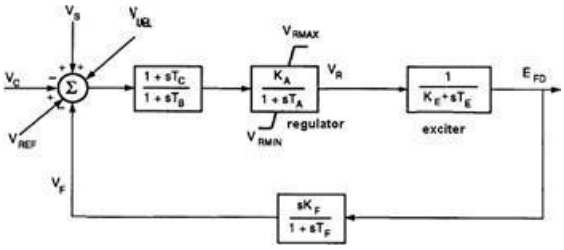

Figure 5 *Excitation system block diagram*

The most important input to DC model is the Output VC from the terminal voltage transducer and load compensator model. At the summing junction, terminal voltage transducer output, VC, is subtracted from the set point reference, VREF. The stabilizing feedback, VF, is subtracted, and the power system stabilizing signal, VS, is added to produce an error voltage. In the steady-state, these last two signals are zero, leaving only the terminal voltage error signal. The resulting signal is amplified in the regulator. The major time constant, TA, and gain, KA associated with the voltage regulator. These voltage regulators utilize power sources that are essentially unaffected by brief transients on the synchronous machine or auxiliaries buses. The time constants, TA and TB may be used to model equivalent time constants inherent in the voltage regulator; but these time constants are frequently small enough to be neglected, and provision should be made for zero input data. The voltage regulator output, VO, is used to control the exciter.

$$V_R/E_{FD} = 1/K_E + {}_ST_E$$

A signal derived from field voltage is normally used to provide excitation system stabilization, VF, via the rate feedback with gain, KF, and time constant, TF.

Simulation results

The d–q model of synchronous machine

This D-Q model of a synchronous machine will be used along with a hydraulic turbine model and an excitation system model that were discussed earlier. Using these three models, the researcher can then simulate the performance of a hydro power plant. It will be important to discuss the hydraulic turbine model and the excitation system models first before simulation is done.

To start with the results, Table 1 shows the synchronous machine parameters.

Sym.	Qual.	Value
VA	Stator voltage	1 sin (100*¶*t)
f	Frequency	50 Hz
Xls	Inductance of stator coils	0.08
Rs	Resistance of stator coils	0.03788
Xmd	Mutual inductance on d axis	2.16
Xmq	Inductance of damping coils among d axis	0.3085
X'lkd	Inductance of damping coils	0.05281

R'kd	Resistance of among d axis	Damping coil
R'kq	Resistance of among q axis	Damping Coil

Table 1 *Synchronous Machine Parameters*

The following figures show the simulation results of normal operation mode, where Fig.5 shows stator currents and voltages and excitation voltage, while Fig.4 shows rotation speed and output mechanical power of the turbine. All quantities are per unit, and the horizontal axis is always the time in second.

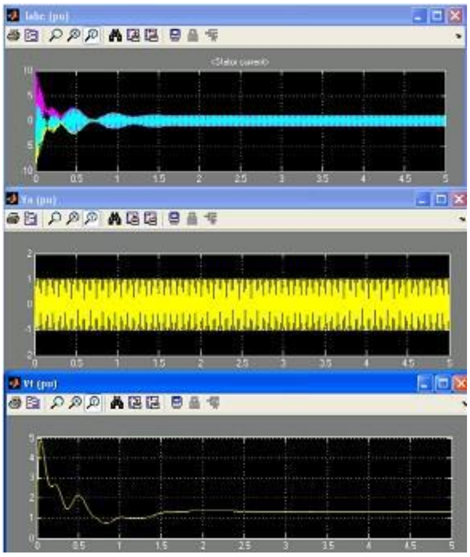

Figure 6 *per unit stator currents Iabc, Vs, excitation voltage Vf*

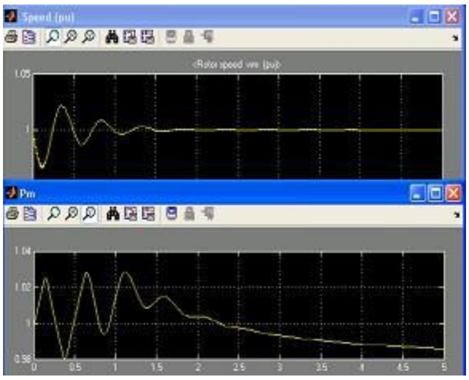

Figure 7 *per unit speed, output mechanical power of the turbine Pm*

Figure 6 and Figure 7 show the system response for three phase fault at the generator terminals in time 2 to 2.2, while Figure 8 shows the stator voltages and currents before, during and after the fault. Finally, Figure 9 shows the mechanical power and speed changes because of the fault.

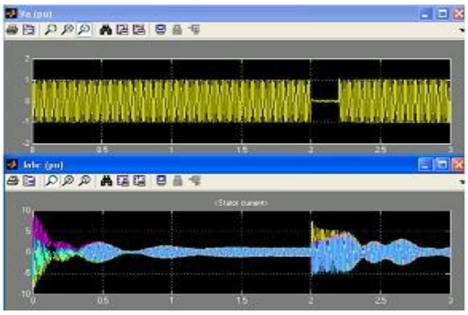

Figure 8 *Stator voltage Va, stator currents Iabc*

VI. Conclusions

Major concept of the paper is to understand the efficiency of the micro-hydro power system instead of large hydro plants; paper used SIMULINL to investigate the efficiency output and usage of electricity. Software allowed the simulation for the researcher and reader build a model from scratch and sub-models. Simulated design of MHE allowed using several operating conditions and test applied to the model presented the results desired by researcher. Real life event were replicated in design for simulating and achieving the real results by adding many faults and uneven operating conditions as per the environment of the Cameroon, variables were applied and investigated through this model. Mathematical equations proved the systematic implementation of the Micro Hydro Plant Units in rivers and waterfalls of Cameroon as the test site. Different real time operating conditions were tested through mathematical model. Dynamic system integration were gained through requisite equations and unknown variables that may change as per the site and water ranges. Differential equation discussed set of variables and enhancing capacity models for electricity generation efficiency of MHE. Moreover, the most important non-linear factors in the governing system like the backlash, rate limiting saturation and the dead-zone were considered and then applied to the designed model. Reliability of the MHE was hence proved, based on SIMULINK simulation and real time variables computed physical quantities of design mode. The pressures, rotation speed, active power and guide vane opening performed up to par and the results were also compared to the simulation done on other laboratory set-ups. Load rejection, the normal operation, the no-load operation and the start up; as the in service differentials and quantities were positioned beneath different control modes, focusing on power feedback, power efficiency, the openings and the designated frequency.

Error consideration and point out of the power efficiency, conditionally with each mode was applied thus in final MHP/MHE model passed through crucial analysis on real time factors and consideration, transit process and SIMULINK simulation has approved efficiency production of electricity and usage control as per the small unit without disturbing the nature and echo-system of Cameroon

Further studies of micro HPPs is further recommended as quick testing is needed to lower the time needed for tuning of system parameters and control settings. This micro hydropower plant model has successfully been applied effectively in scientific studies and in the analysis done by other consultants.

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