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High Level Architecture Model of a Small Hydropower System: Modeling the Failure of the Control Gate and Proposing Solutions to Such Failure

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Abstract: ***This paper shows the High-level system architecture model of a small hydropower system with a relatively small capacity of about 150kw of power primarily for use in small neighbourhoods, villages, remote areas, companies and anywhere applicable. The inspiration came from the current lack of sufficient power situation in Nigeria. This paper demonstrates the benefit of using system architecture to model and view a system in a holistic manner so as to easily detect problems and provide solutions to those problems without causing any form of complete system shutdown. The main objective is to study a small hydropower system to check for possible failures and to propose solutions to those failures. In this paper, the focus will be on failures that could arise from the control Gate and solutions will be offeredto get the best possible total generation capacity and effectiveness of the whole system. The control gate subsystem controls how much water is going into the system and subsequently how much power can be generated and hence forms an important subsystem in the hydropower system. The paper will also show what happens within the hydropower system during peak and off-peak periods by using systems Architecture modelling to analyse the system to anticipate or totally prevent any failure and be completely prepared to counter such failure. The system architecture will be modelled using Unified Modelling Language (UML) diagrams drawn with the aid of Sparx Enterprise Architecture Tool.***

Keywords: Control Gate, Enterprise Architecture Tool, Hydropower, Systems Architecture, Systems Failure, UML, UML sequence diagram

1. Introduction

Hydropower is the energy generated by the force of water in motion. Hydro means water. This means of power generation started over 2000 years ago when the ancient Greeks used water wheels to grind grains. The first hydroelectric power plant was built on the Fox River in Appleton WI in 1882. Many more hydro plants were built in subsequent decades [1, 2].

The proposed system in this paper is a small hydropower system in-cooperating the use of a small dam and reservoir. The proposed system is to be built to averagely generate about 150Kw of power to a neighbourhood of about 10 – 12 houses assumed to consume about a maximum of 12Kw each of power. The system could generate more or less of 150kw depending on the demand during any period. The neighbourhood is assumed to have a river right behind it with an average flow rate of 249m$^{3/}$s and the system will be built on that river [3]. This neighbourhood will also be assumed to be independent of the national grid based on the fact that the power supply is quite epileptic and not sufficient, to begin. Therefore, the system needs to be as reliable and efficient as possible so that they are not totally blacked out. Measuring power effectiveness is by equating demand and supply i.e. the system is effective when supply is very close to the request.

Hydropower was picked as a case study for this paper because;

- The system is relatively simple,
- It is a form of renewable energy,
- The operation and maintenance costs are low,
- It is environmentally friendly,
- It has a long lifetime,
- Unscheduled breakdown is not frequent, and if they do happen, they do only for a relatively short period because of the simplicity of the system [4].

1.1 Mode of operation of hydropower systems

The flowing river has much force which can be harnessed to generate power in hydropower generation plants. The concept of hydropower generation is quite simple.

The flowing water is first stored in a reservoir created by a dam built on the river. Passing the water through a dam is essential to raise the water level so that it can create enough pressure while it is falling. Water from the reservoir flows through an intake and a control gate into a tunnel called the penstock. The water builds up pressure while it is falling through the penstock and this force is then used to turn a turbine that generates mechanical energy. The turbine which is coupled via a shaft to a generator turns the rotor of the generator and magnetises the coils of the stator to generate electrical energy. The voltage of the generated electricity is stepped up by a transformer and transmitted through power lines to the end user. The water exits the system to join the river downstream to continue its course of natural flow after completing its purpose of turning the turbines [5, 6].

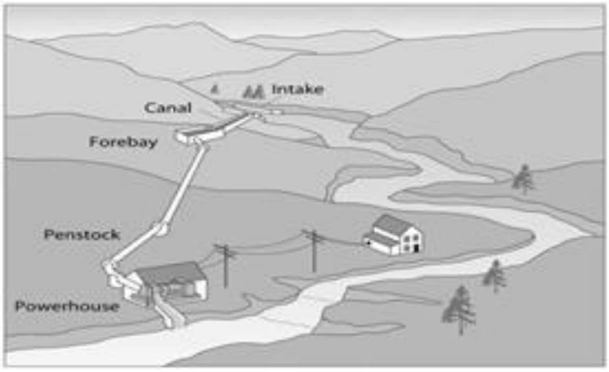

Figure 1: Layout of a Hydropower plant (From: Microhydro-power systems. [Online]. ENERGY.GOV, 2012. [Viewed 31/05/2015]. Available from: http://energy.gov/energysaver/articles/microhydropower-systems

Problem Statement

A neighbourhood that is off the national grid and generating its power with a small-scale hydroelectric generation plant needs its system to have redundant features and to be highly efficient, how can this be achieved?

Aim and Objectives

The aim of this paper is to show the system architecture of a small-scale hydropower system to be used to power a small neighbourhood. The objectives include to;

1. Show the system architecture of a small hydropower system, how it works using UML sequence diagrams and to check for possible failures and propose solutions to those failures.
2. Show how the system can control the output power during peak and off-peak periods so as to save power and not overwork the turbine.

2. Architecture Model of the Small Hydropower System

Logical statement: The River is diverted into a Reservoir via a dam which stores some of the water. Some water flows through the penstock and then turns a turbine. The turbine which is coupled with the generator generates electrical energy. The transformer which is connected to the generator steps up the generated voltage and transmits to the power lines which in turn transmit the power to the users. The water flows back to the river after turning the turbine and repeats the cycle (feedback loop). The users can access the river.

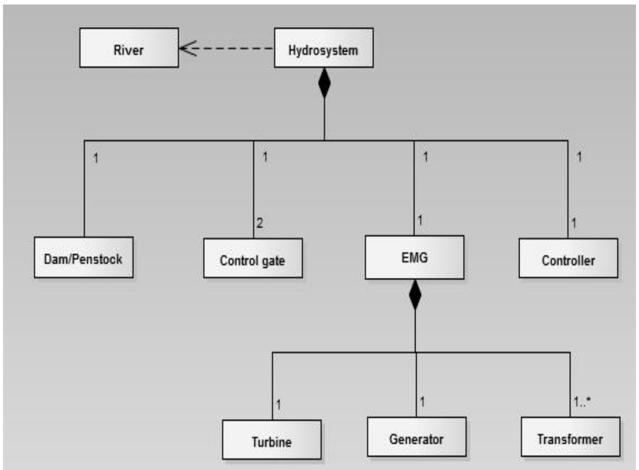

Figure 2: Meta model of the Small Hydropower system

Fig. 2 shows that the “Hydrosystem” is composed of the Dam/penstock, Control gate, EMG (Electromechanical and Generation) and a controller. Also, the EMG consists of the turbine, generator and the transformer. The number notations on the diagram represent the number of that component within the system. i.e. the “Hydrosystem” is composed of “1 controller” and “2 control gates”. “1.*” simply means 1 or more. So, the EMG consists of 1 or more transformers.

2.1 Subsystems (Description of components)

2.1.1 Dam/Penstock

Dam (Reservoir): this is a structure built on the river to divert and store some of it for usage to generate power. It will have a height of about 4m. Usually, micro hydro systems do not require dams, but we propose that it is important to use in this scheme’s structure. There will be periods when the river will have less flow rate than required and so in that case, the dam would compensate for the river by creating some height for the water so that it can gain some kinetic energy while falling into the penstock. Using the dam in this system will only make the system more reliable and efficient, and this is vital since the neighbourhood is off the grid.

Flow Sensor: this is a device that senses and measures the flow rate of the river at certain time-based intervals. It is in constant communication with the controller system. It updates the value of the flow rate measured at any instance.

Penstock: this is a tunnel that directs water flow to the turbine; designed in such a way that it enhances the water flow. In this system, it will be sloping downwards so that the acceleration due to gravity can strengthen the movement of the water to the turbine.

2.1.2 Controller

The controller is a digital automatic control system that includes a computer programmed with the features needed to run the hydro system. It constantly receives feedback from the flow sensor, control gate and the electromechanical & generation system. It continually checks its status to compare the power demanded to power generated and ensured that they match. It stores the data from the operating activities in its memory whichare collected and analysed [7].

2.1.3 Electromechanical and Generation System (EMG)

This subsystem consists of the turbine, generator and transformer and is classified in this paper as EMG just for simplicity. The turbine and generator are connected via a shaft, and they rotate at the same speed. Their speed is constantly being measured using electronic feedback by a sensor called the governor. The generator and turbine are housed in a structure called a powerhouse. This is just to protect the components from damages.

Turbine is electromechanical equipment that is rotated by the force of water to enhance the shaft in the generation of mechanical energy. The choice of turbine depends on the pressure and the flow rate of the water. There are two main types; Impulse and Reaction Turbines. Reaction Turbines are usually used in systems that generate enormous power and so the Impulse type turbine with an efficiency of about 80 - 90% should be employed in this system since the generated power is relatively small [8].

The generator is electromechanical equipment that converts the mechanical energy produced by the turning motion of the turbine to electrical energy. The generator of this system shall have a capacity of 200kw. In fact, only 150 of the 200kw is needed, but it is important to have a spinning reserve. The spinning reserve is the terminology used to describe the extra generating capacity available to a generator (that is connected to a power system) by increasing its power output. It can be accessed by increasing the speed of the turbine to increase the energy generated. Therefore, the spinning reserve of the generator is 50Kw. The idea of a spinning reserve for this system is a more futuristic and preventive plan as;

- Two more houses could be added to the network comfortably without having to change the generator.
- In the case that some houses start to use more than the calculated 12kw, the system can still cater for the modification (unforeseen load).
- It prevents overload and subsequent damages to the generator and hence the overall system.

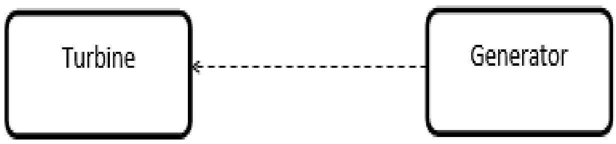

Figure 3: Turbine and Generator relationship

Calculations:

For this paper some basic values shall be assumed;

Average flow rate of river B = 249m3/s
P = HQgn [9].Where;
P avg = power to be generated = 150KW (12KW for 12 houses each)
H = height of dam = 4m
g = acceleration due to gravity = 9.8m/s
n = efficiency of small turbine = 85%
Q = required flow rate of river
Solving for Q;
Qavg = P/Hgn = 150/(4 x 9.8 x 0.85) = 4.5m3/s, this is the required flow rate for the system.
Pmax = Possible maximum power that can be generated = 200kw
Qmax = P/Hgn = 200/(4 x 9.8 x 0.85) = 6m3/s
Percentage of river needed = 6/249 x 100 = 2.4%

Only 2.4% of the river needs to be diverted for maximum usage in the hydropower system.

Transformer: when the power is generated, the voltage is usually not high enough so the transformer steps up the voltage so that it can be transmitted through the power lines and to the houses for usage.

2.1.4 Control Gate

This is the inlet to the system. The gate controls how much water is going into the system. For this system, a butterfly valve which is electrically and manually controlled as the gate will be used as an example. In most cases, the gate is usually permanently opened or permanently closed, but this system should be designed in such a way that the gate will constantly be in motion. This is so because it will be used to control how much power to be generated i.e. opening the gates more leads to more power being generated and closing will automatically mean less will be produced.

The gate will have a position sensor installed which will constantly measure its position and feedback to the controller.

Figure 4: Electrical and manually controlled Butterfly valve

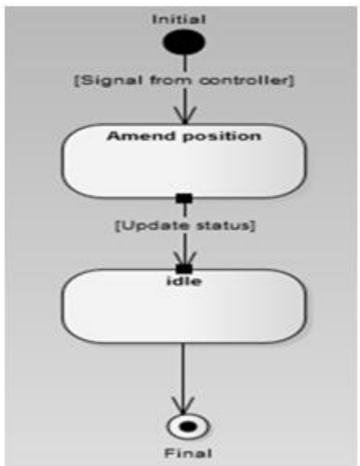

Figure 5: Electrical and manually controlled Butterfly valve

3. How Does the System Work?

The users demand power and the flow sensors in the river constantly updates the controller with flow rate information. The controller then analyses the collected information and used to determine the adequate position of the control gate to generate the required power. So, the demand and the river's flow rate determines how opened the gate will need to be. Higher demand will mean the gate will be in a more opened position and lower demand will mean vice versa. On the other hand, when the flow rate is high, the gate may need to be closed more.

After the gate is positioned appropriately, the water goes in to turn the turbine and to generate electricity which is transmitted to the users.

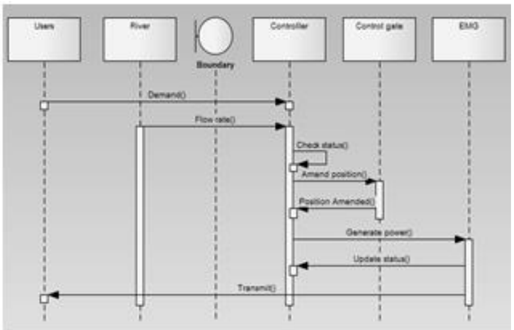

Figure 6: System in normal working condition

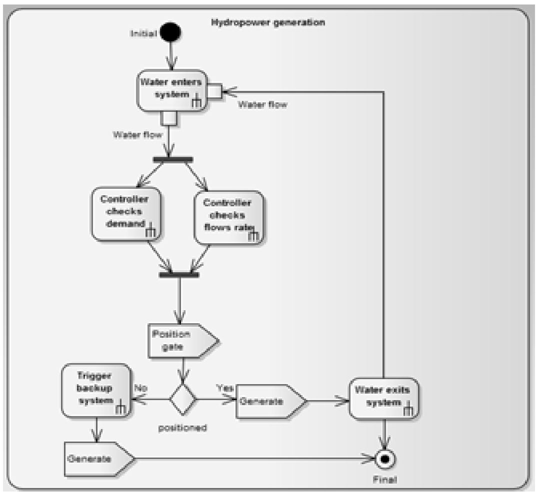

Figure 7: Activity diagram

In the "open condition", it is required for the gate to be opened to some certainly determined position to undergo normal operating activities. While in the "close condition", it is necessary for the gate to be fully closed for system maintenance. Therefore, the output power of the system will be 0 watts in which case the backup system generates the power.

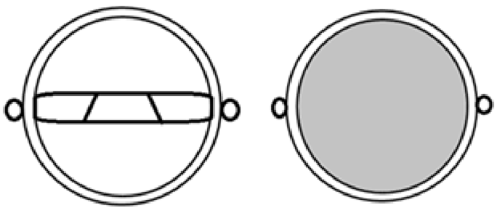

Figure 8: Gate in open position and Close position

3.1 System failure

In this paper, the failure of the control gate will be concentratedon. This component is vital to the system, however; it is prone to failure at some point.

The gate is said to have failed when it has either refused to close when it is required to or has declined to open when it is required. These failures shall be referred to as "close failure" and "open failure" for clarity.

3.1.1 Close failure

This situation occurs when the gate is required to open but remains closed. If this situation occurs, the system will be unable to resume normal operation hence there will be no output power generated (0kw).

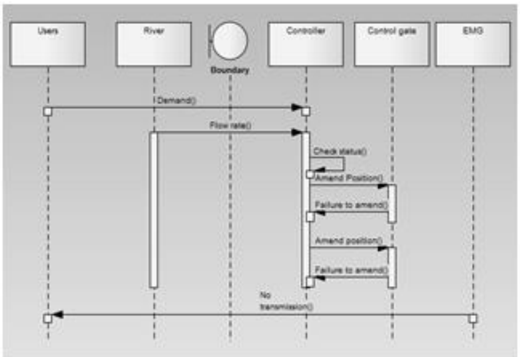

Figure 9: Sequence diagram: Close failure

3.1.2 Open failure

This failure occurs when the gate is required to close but remains open. Usually, the gate either needs to be closed for maintenance purposes or if a fault has been identified in the system. If it refuses to close, maximum power will be generated which will mean extreme voltages (surge) will be transmitted to the users. This causes damages to the households for example; it can start a fire as well as damage their electrical appliances.

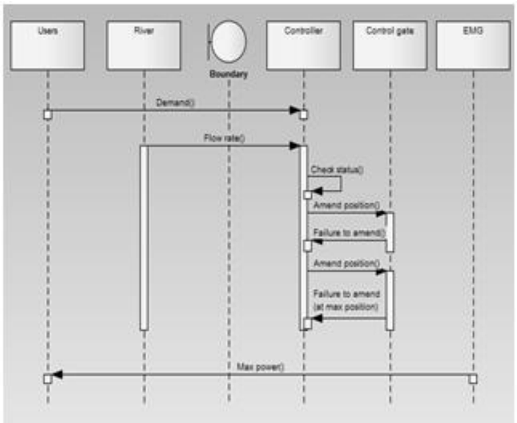

Figure 10: Sequence diagram: Open failure

3.2 Proposed solutions

3.2.1 Two control gates arranged in parallel

A second control gate is installed in parallel to the first. This second gate shall become active when the first gate has failed to open. This solution is put in place to compensate the system when a close failure situation occurs. The diagram below illustrates this scenario. The following sequence diagram shows what happens within the system when this solution is adopted.

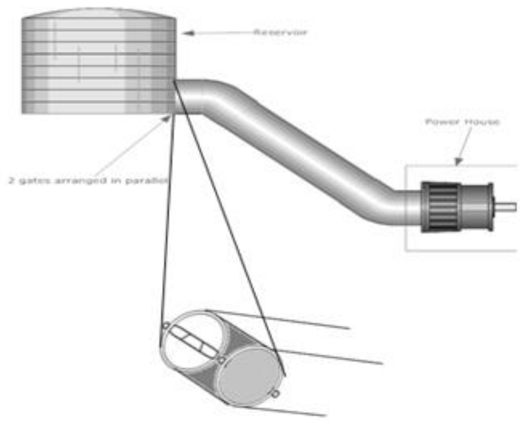

Figure 11: Two Control Gates arranged in parallel (One operational)

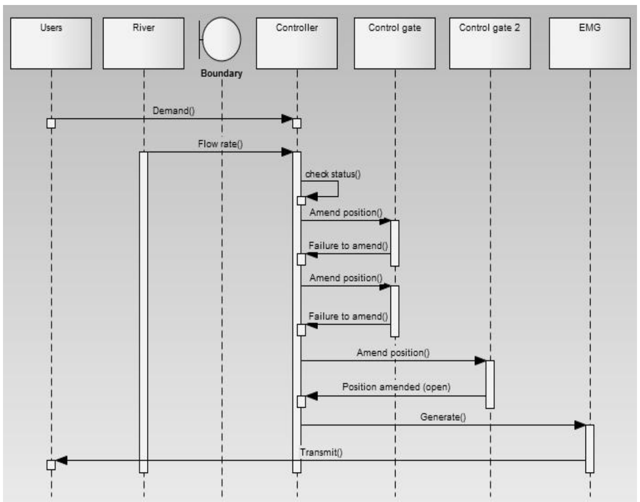

Figure 12: Sequence diagram: 2 gates in parallel

3.2.1 Backup Inverter system

This is a backup scheme for the system. It can be used when the hydropower system has a fault or is being maintained. It could have a capacity of 200kw, and its batteries will be charged by the hydro system when it (the hydro system) is in service. When the gate has refused to close and excess water is coming into the system, it is safer to take the load off the hydro system completely and put it on the inverter system to prevent damages. However, the inverter can also be used during a close failure period. This solution is adoptable since in this context the hydropower system is to generate a relatively low capacity (150kw). In the case where larger capacities are involved, this solution may become very difficult to implement.

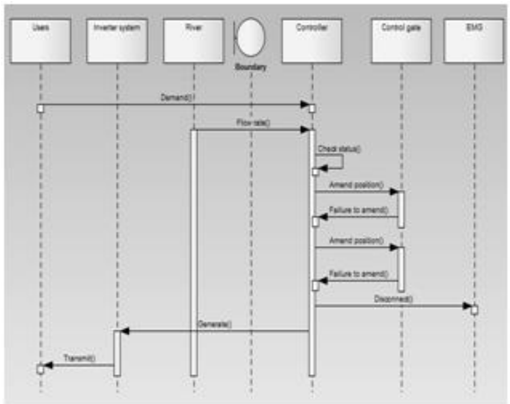

Figure 13: Sequence diagram: Inverter system solution

4. Conclusion

The control gate is a critical part of a hydropower system, and different scenarios have been considered to ensure its continuous operation at all times. This paper has shown that the system does indeed need to have redundant components, referring to the problem statement. This is because if the plant fails in any way, the neighbourhood is entirely blacked out. Drawing out the architecture diagrams gave a clearer picture of what exactly is going on within the system and what exactly would happen if the system failed at any point. The simple principle of parallelism was capitalised on in this paper. Parallelism as in when two of the same component are arranged in parallel, they are both independent of each other and so when one fails, the other can compensate. Moreover, as shown if this principle is adopted it can serve as a viable solution to an otherwise serious problem in this context. This solution will be capital intensive seeing as the gate and penstock arrangement would need to be restructured in an already existing hydropower station. Hence it will be more applicable for new stations where the solution could be factored into their design before they are put in place.

Redundancy was achieved by designing the system with an extra control gate and a backup inverter system so that at any failure period, there is a backup plan to support the system to prevent total lack of power from occurring. Also, small subcomponents like the flow sensor and the position sensor which are also crucial, have redundant associates.

It is important in this system to ensure optimum effectiveness because the neighbourhood is off the national grid and as such the hydropower system is their only source of power.

The proposed system above is overall, simple and reliably effective and also shows that *Redundancy reduces the likelihood of failure.*

Acknowledgment

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References

[1] J.S. Bridle, BREEZE, P. Power Generation Technologies. Oxford, UK: Newnes, 2005.

[2] HAIDAR, A.M., SENAN, M.F., NOMAN, A., and RADMAN, T. Utilization of pico hydro generation in domestic and commercial loads. Renewable and Sustainable Energy Reviews, 2012, 16(1), pp. 518 – 524.
[3] CROWDER, D. W., and VERNON KNAPP, H. Effective discharge recurrence intervals of Illinois streams. Geomorphology, 2005, 64(3-4), pp. 257-276.
[4] EMOVON, I., ADEYERI M.K., and KAREEM, B. Power generation in Nigeria; Problems and solution. In: The 2011 International Conference of Nigerian Association for Energy Economics (NAEE), Abuja, Nigeria, 2011.
[5] INTERNATIONAL TECHNOLOGY AND ENGINEERING EDUCATORS ASSOCIATION. Is hydroelectricity green? The Technology Teacher, 2009, 68(4), pp. 6.
[6] Microhydropower systems. [Online]. ENERGY.GOV, 2012. [Viewed 31/05/2015]. Available from: http://energy.gov/energysaver/articles/microhydropower-systems
[7] Powerful Hydroelectric Control Solutions. [Online]. Emerson Process Management, 2011. [Viewed 31/05/2015]. Available from: http://www2.emersonprocess.com/siteadmincenter/PM%20Power%20and%20Water%20Documents/pws_002704.pdf
[8] COBB, B.R., and SHARP, K.V. Impulse (Turgo and Pelton) turbine performance characteristics and their impact on pico-hydro installations. Renewable Energy, 2013, 50, pp. 959-964