DEVELOPMENT OF MINI SCALE COMPRESSED AIR ENERGY STORAGE SYSTEM

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***Abstract* - Nowadays, we know about the problem of decreasing the source of natural gas fuel, makes the higher fuel cost for Gas Turbine power plant usage. Because of that, the new technology called the Compressed Air Energy Storage system is created. The main concept of this system is use off-peak power to pressurize air into an underground reservoir, which is then released during peak daytime hour to power Gas Turbine for power production. This project is to design in small scale system where it can use off-peak electricity to switch on the air compressor to compressed air. Then the compressed air produced will store in high pressure cylinder tank replace the airtight underground caverns. When the air is released from the high pressure tank, the air expands through a micro-turbine which connected single shaft with generator rotor. Then the micro turbine run and rotate generator rotor that convert mechanical energy to electrical energy. Output voltage then will convert from dc to ac voltage.**

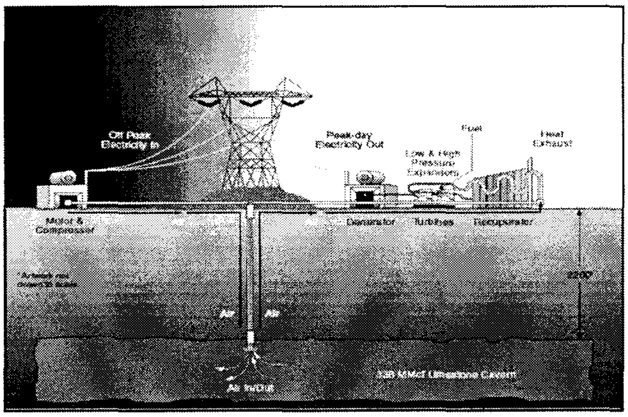

Figure 1: Conceptual representation of large scale CAES system

Key Words – Mini scale, Compressed air energy storage (CAES), compressor, air turbine, DC motor.

I. INTRODUCTION

The "Analysis on Mini Scale Compressed Air Energy Storage (CAES) characteristic for power generation" is the study case project base on hardware development approach that studied and analyzed on each main parts characteristic of the system.

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This project involves the development of the mini scale with the same concept on the large scale system as show in Figure 1. The analysis was focusing on the output pressure from the Air Compressor unit which it can use to generate the electricity at the generator. The variable output air pressure will be tested to show how much electricity was generated. The results of the output generated voltage were record and analyzed. So, the characteristic, performance and efficiency of the overall CAES system were being finding. These project flows as block diagram in Figure 2 with the several methods to complete the system. There are four main parts of system consist of Air Compressor unit, Micro-turbine, DC Electric Generator, and DC-AC Converter Circuit.

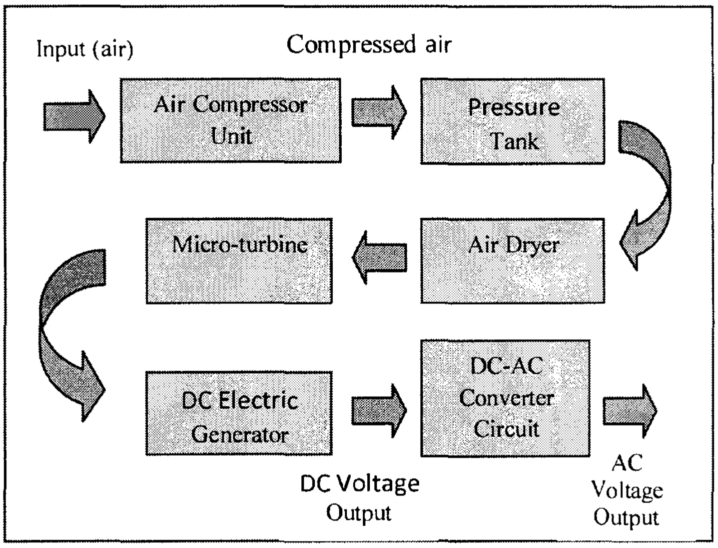


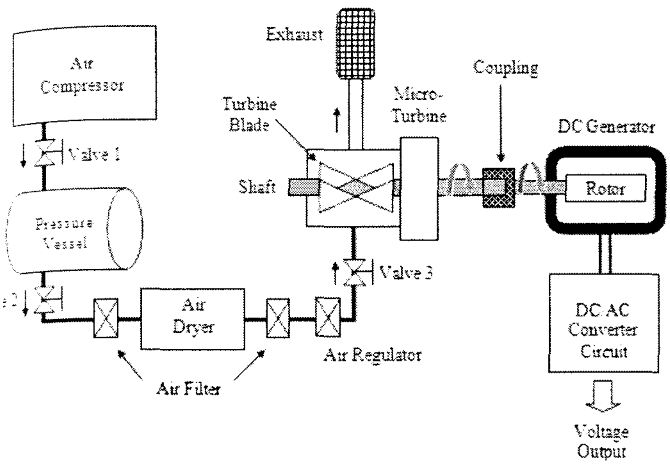
Figure 2: CAES System Block Diagram

II. DEVELOPING PART OF HARDWARE

A. Project Design

Project design is function to design the structure of the mini scale CAES system based on the selected requirement shown in Figure 4. This system must have four main parts to fully operate. If do not have one of the main parts, the system cannot properly operate. In other hand, each of main parts is related and has relationship with each other. The air compressor functions to compress the air and store it in the high pressure cylinder maximum 8bar. When it release, the compressed air then flow through inlet micro-turbine and expand to the turbine blade. Then, the micro-turbine blades rotate about 800rpm the single shaft that connected the generator rotor rated 24VDC. The generator then converts mechanical energy to electrical energy and produce electricity. The expected

12VDC voltage output from generator then will convert to



12VAC voltage output after flow through DC-AC converter circuit.

Figure 4: Mini scale CAES system design

The finding of the main part is the process include in developing part of hardware. There are four parts consists of the Air Compressor, Micro-turbine, DC Electric generator and DC-AC Converter circuit.

B. Project Construction

Project construction is the process of assembling, implementation and the installation of the main parts to complete the system. The process is start with assemble all the main parts. The combination of the each part is important to make sure the system complete and can operate properly. The micro-turbine divide by a section consist of static and moving part. The moving part includes turbine blades which function to rotate the single shaft that hold the turbine blade. The moving part is operating when the compressed air at high pressure flow and expands through the micro-turbine blades. The rotation speed of the turbine blade depends on the air pressure level.

The next is the installation process. The connection between micro-turbine and generator can be done with installation a single shaft and coupling unit. The coupling unit is function to connect one part with another part. The balancing process must be done to make sure that the system can run smoothly and solve the vibration problem. After finish the installing the all main parts, the next process are project testing process.

III. PROJECT TESTING AND MODIFICATION

Project testing is process to check the condition of the system after the system is complete construct. The testing process is start with test run the system at lower air pressure flow. This is because to make sure the system is not damage the parts of the system. The testing on the project must be done in many times. Besides that, the test run also to check the vibration of the system and make sure the system smoothly operate.

The project modification is method to solve if the problem occurs at the system. For example if there have vibration on the generator, it must be repair with doing balancing on the system. After the modification on the system has done, the system must to test first before the system consider in good condition. Then, the system already can operate properly.

A. Collecting Data

The data of the experiment is collect and fill in the table. The mini scale CAES system will be running for a many times to take the average values. The tables consist of a parameter that has been measure includes number of test, input air pressure, output air pressure, speed of micro turbine, and voltage output from generator.

The data result are collected from two methods consist of Method I and Method II. The method will be explained in this chapter. Then, from this data result the characteristic will be analysis in next chapter. The hardware development and progress also will be discussed.

B. Analysis On Output Air Pressure

In general the small CAES system that has been developed as show in Figure 5 can operate properly. The system is start operate with Air compressor that supply with three phase 415V and 3hp to produce compressed air. Then the air compressor run and compress 8bar (116psi) compressed air. It can store the compressed air in Compressor tank and it automatically cut-off if fully complete stored.

The valve 1 then will open and compressed air can flow to the pressure vessel. The function of the pressure vessel is as medium storage with large capacity. The maximum capacity is 16bar (230psi). To reach the target output 12VDC, the pressure vessel is set to store only 8bar (116psi) compressed air. The valve 2 next will open and compressed air flow through air filter to separate oil and vapor from pressure vessel. A clean compressed air then flow through air dryer to produced dry compressed air. Air dryer is supply with single phase 240V to operate.

Then it will flow through air regulator. Air regulator is use to set at certain pressure of the compressed air before flow into inlet micro-turbine. An air entry into the micro-turbine is influenced by the amount of voltage output produced.

Figure 5: Completed small CAES system

C. Expected Result

The expected result is the small CAES system can smoothly operate and make the better output result. So the analysis about the characteristic of the system can be done. The three main characteristic include output air pressure, speed of micro-turbine and output voltage produce are related.

The Air Compressor will compress the maximum value of air pressure at 8bar and stored it in pressure vessel. To analysis the characteristic of the system, input air pressure to micro-turbine can be variable at range 1bar to 8bar. The target result is at level air pressure (8bar) can run the micro-turbine blade at range 700 rpm which connected generator rotor to produce the output voltage of 12VDC. Then, the output voltage will convert from to 12VAC after flow through the DC-AC Converter circuit.

IV. RESULT ANALYSIS

There are two methods of test that use to collect the data on the small CAES system. The method used is different in procedure when doing testing. The method of test is consisting of method I and method II. The purpose of both methods is to show the comparison between results in each method. Besides that, the comparison can show the characteristic of the small CAES system that have been developed.

A. Analysis on time period between method I and method II

The Figure 6 show the graph plotted between the time period for tank to empty (sec) versus input pressure to inlet micro-turbine (bar) using method I. In method I, the air pressure is release from 8bar to 1bar air pressure and each level of air pressure is taken time usage the compressed air. At the 8bar to 7bar air pressure the system used 5.42 second, 7bar to 6bar is 6.3 second, 6bar to 5bar is 7.62 second, 5bar to 4bar is 8.64 second, 4bar to 3bar is 12.56 second, 3bar to 2bar is 17.86 second, and 2bar to 1bar is 30.12 second. This result shows that when the level of pressure is increase, the time of usage the compressed air is shorter time period.

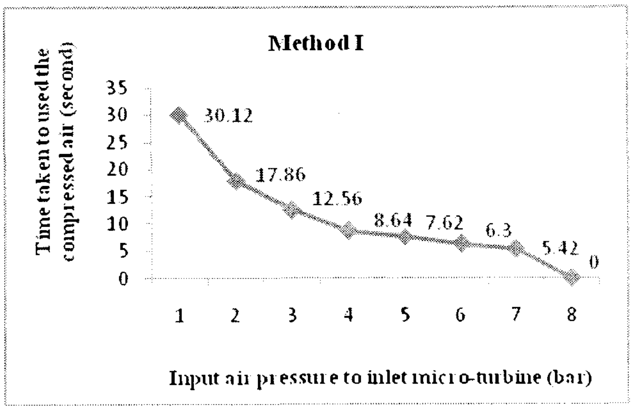


Figure 6: Graph of input air pressure to inlet micro-turbine (bar) versus time taken to used the compressed air (second)

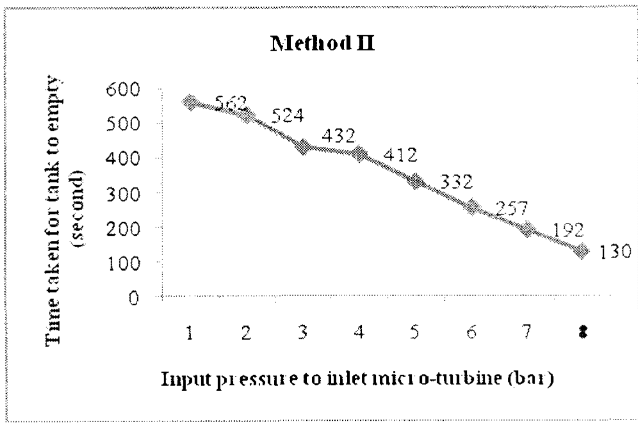


Figure 7: Graph of time taken for tank to empty (second) versus input air pressure to inlet micro-turbine (bar)

The Figure 7 show the graph plotted between time taken for tank to empty (second) versus input pressure to inlet micro-turbine (bar) using method II. In method II, air pressure is release from 8bar until a tank is empty and the time usage a compressed air has been taken. The measurement of time usage a compressed air is start from 1bar to 0bar is 562 second, 2bar to 0bar is 524 second, 3bar to 0bar is 432 second, 4bar to 0bar is 412 second, 5bar to 0bar is 332 second, 6bar to 0bar is 257 second, 7bar to 0bar is 192 second, and 8bar to 0bar is 130 second. From the graph in figure 12, the curve of graph shows that when input pressure applied is increase cause a time taken for pressure vessel to empty is decrease.

From analysis on the time taken by the system to use compressed air between both methods show that the patern of increasing value of time taken are quite different. There are having comparisons on time period to usage the compressed air between method I and II. According to Figure 6, by using method I, at lowest air pressure 1bar, system was using compressed air for 30.12 second and at highest air pressure 8bar is 0 second. By refer to method I procedure, at highest air pressure, the system is fully air compressed and starting to operate, so the initial time is 0.

According to Figure 7, by using method II, at lowest air pressure 1bar, system was using compressed air for 562 second and at highest air pressure 8bar is 130 second. The comparison is the different in time period because of different method that have been used. By using method I, the system only use short time period to use the compressed air. Different by using method II, the system use long time period to use the compressed air. From the analysis, it show that time period of the system used the compressed air is depends on the input air pressure that have been applied to Micro-turbine. It means when increasing of applied air pressure cause decreasing of time period of system to use the compressed air.

B. Analysis on speed rotation between method I and method II

The Figure 8 shows the graph plotted between Micro-turbine speed (rpm) versus input pressure to inlet micro-turbine (bar) using method I. In method I, the air pressure is release from 8bar to 1bar air pressure and each level of air pressure is taken the Micro-turbine speed. From the graph, when input pressure from pressure tank is 1bar, rotation per minute (rpm) that created by Micro-turbine is 183.8 rpm, 2bar is 293.4, 3bar is 343.4 rpm, 4bar is 388.8 rpm, 5bar is 434.4 rpm, 6bar 475.6 rpm, 7bar is 539.8, and 8bar is 551.2 rpm. This graph shows that Micro-turbine speed are increasing when the input pressure are increase.

The Figure 9 show the graph plotted between Micro-turbine speed (rpm) versus input pressure to inlet micro-turbine (bar) using method II. In method II, air pressure is release from 8bar until a tank is empty and the micro-turbine speed has been taken. From the graph, when input pressure from pressure tank is 1 bar, rotation per minute (rpm) that created by Micro Turbine is 186 rpm, 2 bar is 297 rpm, 3bar is 344 rpm, 4bar is 389 rpm, 5bar is 435 rpm, 6bar is 478 rpm, 7bar is 540 rpm and 8bar is 550 rpm. This graph shows that Micro-turbine speed are increasing when the input pressure are increase.

From analysis on the speed rotation of Micro-turbine between both method I and method II shows that the patern of increasing value of speed are sligtly the same. By reffer to graph of method I and II, the maximum speed is at 551.2 rpm and 550 rpm respectively after the system is release 8bar air pressure. The maximum continuous speed of micro-turbine is 800 rpm when it supplied with 8bar air pressure as Micro-turbine specification in Appendix. By using method I and II, the micro-turbine is rotate 68.9% and 68.75% respectively of maximum continuous speed. So, the micro-turbine is not operate at 100% maximum continuous speed. This problem occur maybe cause by loses in pipeling between pressure tank and micro-turbine. From the analysis, the speed rotation of the micro-turbine depends on the output air pressure from pressure tank. It means the speed rotation is proportional with the air pressure applied.

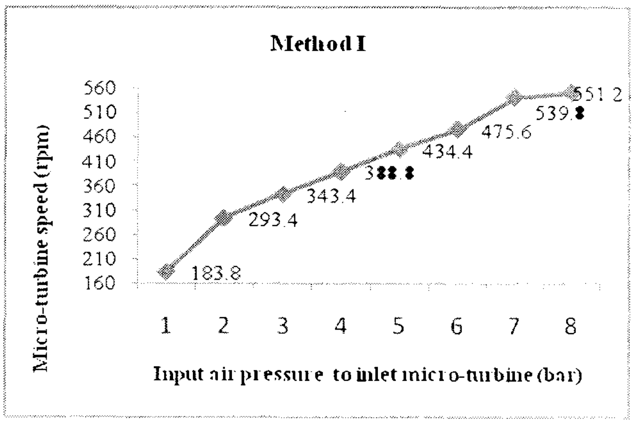


Figure 8: Graph of micro-turbine speed (rpm) versus input air pressure to inlet micro-turbine (bar)

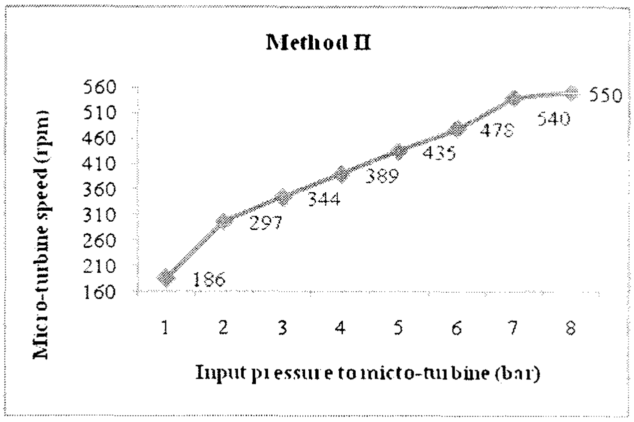


Figure 9: Graph of micro-turbine speed (rpm) versus input air pressure to inlet micro-turbine (bar)

C. Analysis on output voltage between method I and method II

The Figure10 shows the graph plotted between output voltage produce (Vdc) versus input pressure to inlet micro-turbine (bar) using method I. In method I, the air pressure is release from 8bar to 1bar air pressure and each level of air pressure is taken output voltage produce by DC generator. From the graph, when input pressure is 1bar, output voltage that produced is 1.65 Vdc, 2bar is 2.71Vdc, 3bar is 3.39Vdc, 4bar is 3.82Vdc, 5bar is 4.31Vdc, 6bar is 4.83Vdc, 7bar is 5.13Vdc and 8bar is 5.35Vdc. This graph shows that the output voltage increase when the input pressure applied is increase.

The Figure 11 show the graph plotted between output voltage produce (Vdc) versus input pressure to inlet micro-turbine (bar) using method II. In method II, air pressure is release from 8bar until a tank is empty and the output voltage produce has been taken. From the graph, when input pressure is 1 bar, output voltage produce is 1.65Vdc, 2bar is 2.74Vdc, 3bar is 3.40Vdc, 4bar is 3.89Vdc, 5bar is 4.30Vdc, 6bar is 4.82Vdc, 7bar is 5.12Vdc and 8bar is 5.38Vdc. This graph shows that the output voltage produce is increase when input pressure applied is increase.

From analysis of the output voltage produce between method I and II shows that the patern of increasing output voltage for both method are quite same. The generator used in the system is the type of DC generator with nominal voltage output of 24Vdc as DC generator. The target result is when the air pressure applied at 8bar the generator can produced 12Vdc. From the graph plotted that using both methods, it show the system not reach the target output voltage. By using method I and II, when the air pressure is applied at 8bar make DC generator produced 5.35Vdc and 5.38Vdc respectively. This problem may cause by not sufficient of air pressure to inlet Micro-turbine. According to both the graphs, it shows the output voltage produce is depending on the speed rotation of micro-turbine blades and air pressure that applied to the system. Both parameters are varying to output voltage produce.

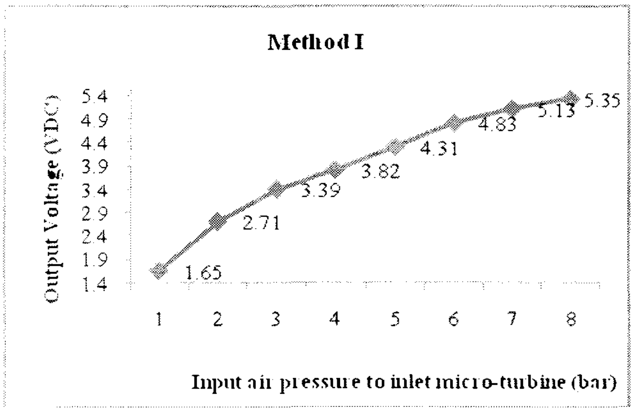


Figure 10: Graph of output voltage (V) versus input air pressure to inlet micro-turbine (bar)

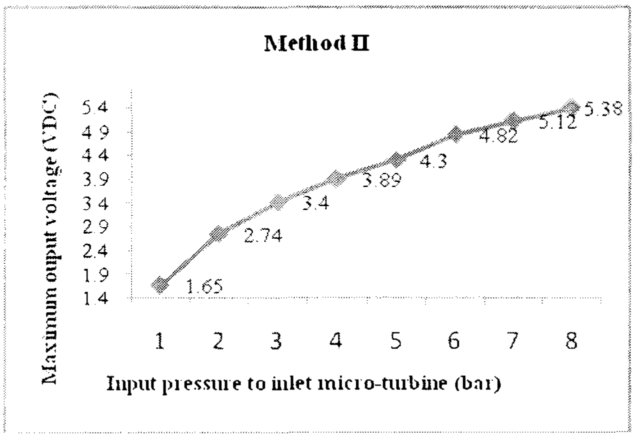


Figure 11: Graph of maximum output voltage (V) versus input air pressure to inlet Micro-turbine (bar)

V. CONCLUSION

As conclusion, this project on title "Analysis on Small Compressed Air Energy Storage (CAES) system characteristic for power generation" is about to develop and analysis the characteristic of each of components for power generation. Before the analysis is done, the development of the small CAES system hardware must be done first. The system is design with selected specification of the each component to achieve the target result. The system is completed after each main component has already assembled and test running have been done.

The understanding on the parts parameter and all method are involved in develop the small CAES system hardware. In order to ensure this project is successful, process to do is planned well and done systematically. The study and research must always be done to know detailed information about the CAES system. The combination four main parts of the system is needed in order to make sure the system completed and can be smoothly operated. Thus, the analysis on the characteristic of the system can be done.

The analyzed on characteristic are involved includes the time taken for system to use a compressed air, speed rotation of Micro-turbine and output voltage produce by DC Generator by collecting data result in two methods. The characteristic of the small CAES system focusing on the Air Compressor is fully discover after finish analyzed the results that have been collect by using two methods. This conclusion are made base on full system testing with different methods but same purpose.

In analyzing the time period, it show that the time taken to fully compressed air is take longer time period compare to time usage the compressed air. It shows that small CAES system that has develop is not efficient due to time to produce output voltage. This system must to improve with give the shorter time period to fully compress the air pressure. In analyzing the speed rotation shows that the Micro-turbine speed is depend on applied air pressure to the system. When the air pressure increase makes the speed rotation also increases. It means that, the air pressure is directly proportional with speed of rotation.

In analyzing the output voltage produce show that the system must to use more air pressure in order to produce more output voltage. Base on the input pressure from the Air Compressor and rotation of Micro-turbine shaft, output DC voltage is generated. If the air pressure is applied with small amount make the small output voltage produced. Same with the speed parameter, the air pressure is directly proportional with output voltage produced.

The overall performance of the small CAES system that have been developed which use the energy storage concept can be improved to achieved the target output and for the future research.

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