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Micro turbine by using air compressor for generating Power i standalone system

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Abstract - This project relates to power generation using pneumatic motor feed fromcompressor. This type of energy generation is clean , eco-friendly & portable. The plant size depends on the rating of power generation . This plant is equivalent to pumped hydro power plant here instead of water ambient air is used. This technology does not release any byproduct, also it can be operated all days & nights without any running cost in all seasons. Compressed air pneumatic motor operated.This invention relates to a Compressed Air Turbine-Generator, or CAT-G that will enable the ability to manage energy gathered from ecologically friendly sources, such as solar and wind power. Compressed Air Energy Storage, (C.A.E.S.), is a promising mode of clean energy storage. A major challenge facing this technology is the need to efficiently convert the compressed air energy into electricity. Conventionally, high-pressure air is used only to improve the efficiency of a conventional jet powered turbine generator.

I. INTRODUCTION

The focus herein is on a new technology that efficiently converts the energy stored in compressed air directly into electrical power without producing greenhouse byproduct gases or other pollutants. This new capability will add important flexibility to the optimization of ecologically friendly energy systems

1. Energy storage technologies. As a result of such studies, the CAES system was not considered an attractive option in several market pricing strategies and different wind penetration levels. However, these results were obtained because the CAES system and combined
heat and power (CHP) plant had limited capacity. The main difference in a wind based hybrid power system (HPS) for an isolated application in comparison to a grid connected hybrid power system is the origin of the available excess energy for storage. In a grid connected hybrid power system (HPS), the le renewable energy. storage system consumes the electricity that has been produced by power plants by burning fossil fuels and might not be financially attractive option, as is shown in [10]. On the other hand, the maintenance cost after installing energy harvesting equipment is the only expense required by a RES based power system. It can benefit from a vast amount of free energy to compensate for its lower efficiency in comparison with other technologies. This enhancement can be more attractive considering the environmentally friendly nature of the CAES system, and its high durability. Proper design, along with developing suitable control strategy considering the physics of energy conversion in a CAES system, can result in the improved performance of a RES-based power system. In this paper after presenting a brief overview of energy storage system and current comparison methods, the anatomy of a wind based hybrid power system is explained. Following this, a new criterion based on the limited storage capacity of storage systems is developed. This concept is then used for the control and performance assessment of a small-scale wind-based hybrid power system (HPS) for possible application in a remote community.

2. Brief Survey of Typical Energy Storage Systems:

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There are different types of energy storage systems, based on various physical principles, and each of these technologies is well suited for a specific power or energy range [8]. Flywheel [13], hydrogen [8], pumped hydro [9], compressed air energy storage (CAES) [13], electrochemical double layer capacitor [11,15], batteries [11], superconducting magnetic energy storage (SMES) [11,15] and virtual energy storage systems [15], are some examples of available energy storage systems. The performance of these storage systems can be evaluated by considering a variety of factors such as the capability of the storage system to provide energy for a long or short time, efficiency, energy density, life cycle, cost (including initial, operational and maintenance costs), depth of discharge, self-discharge rate, reliability, environmental aspects, and energy/power rating. Some applications require specific characteristics of the storage system to meet technical constraints such as high energy density for limited space conditions or transportability for portable applications, power/energy rating and cost. Two main comparison approaches can be considered in the choice of a storage system for a given application. In the first approach, the storage system may be selected based on its capability to provide energy for a long or short time. Such a comparison is shown in Figure 1. The second approach is based on the efficiency and life cycle comparison of energy storage systems. This approach is suitable for economic evaluation of the possible options, special application with limited available energy source and a high number of cycling requirement. Such a comparison is shown in Figure 2. In this illustration, energy storage systems are arranged based on increasing efficiency. Considering the storage capacity of different storage systems shown in Figure 1, an appropriate energy storage system may be selected using a comparison chart based on efficiency and life cycle, as shown in Figure 2. Flywheels and batteries are highly efficient, while CAES and pumped hydro storage systems can be used in applications that require high energy with reasonable efficiency and significant life cycle. The energy storage capacity of each storage system can be calculated using a steady state representative of the energy conversion procedure. Based on their energy

conversion process, four main categories for energy storage systems can be considered for the following technologies: Batteries, Flywheels, Pumped Hydro

, and CAES. These energy storage technologies have been chosen in this paper in order to develop the novel comparison criterion based on their energy harvesting capacity. In order to compare their energy storage capability, the required equations to describe the storage behavior of each energy storage system will be provided in the next part of this overview.

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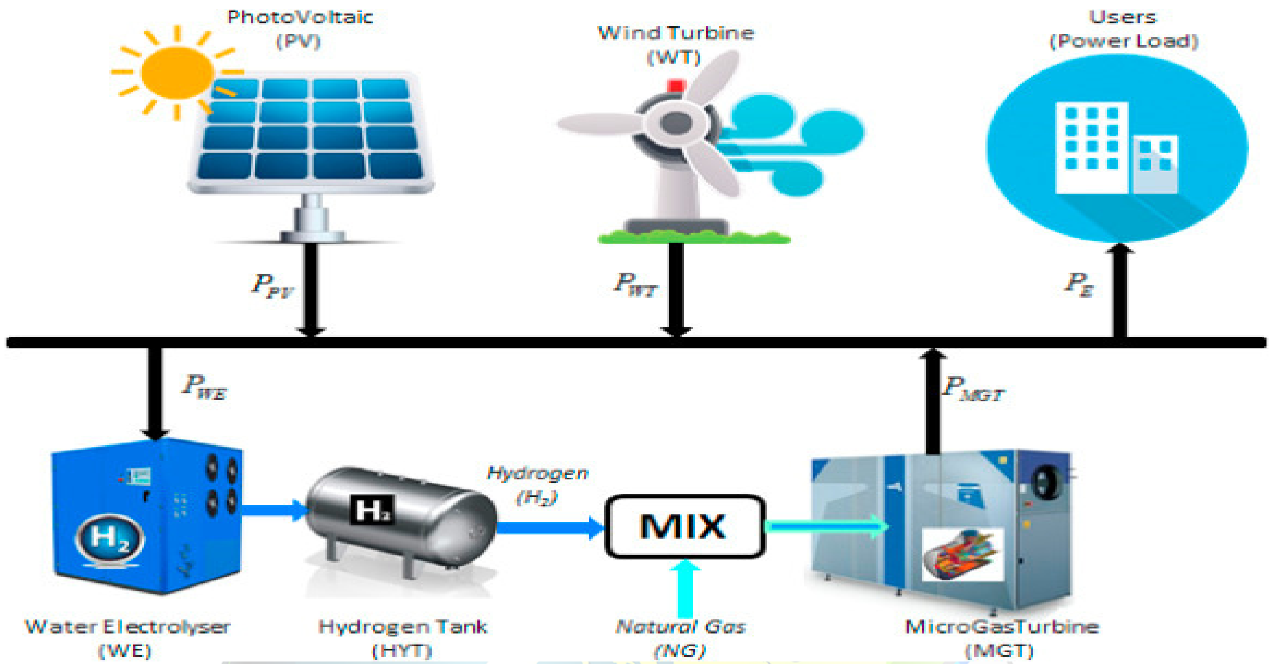

3. Energy storage systems with different storage Capacity:

The energy capacity of a battery is usually defined based on the cell voltage product to its nominal discharge current rate known as ampere-hours (Ahr), which is provided by the manufacturer. The charge and discharge characteristics of a battery can be examined utilizing a mathematical model. A comprehensive model of a typical battery comprises three sub-models: a thermal sub-model to represent the electrolyte temperature based on the thermal properties of the material and battery losses; the charge and capacity model to depict the state of the charge (SOC) and depth of discharge current (DOC); and an equivalent circuit to simulate the dynamic performance of the battery [18]. Although utilizing this model results in an accurate battery model, it requires a large number of parameters, for which obtaining their exact value can be a complicated and time consuming procedure. On the other hand, a generic battery model that represents a battery's performance during charging and discharging procedures can be satisfactory in studies, and this only requires steady state analysis [19]. where itsparameters can be directly obtained from the manufacturer's datasheet. The exchanged electrical charges during charge and discharge cycles can be obtained by integrating its current. The battery capacity can be considered steady during the discharge hours by neglecting discharge effect on temperature and output voltage characteristics. In a flywheel energy storage system, the excess energy is stored in a rotating mass in kinetic energy form. This system, based on its fast energy conversion mechanism, is appropriate in applications that require high power capability.

where mf is the rotating mass of the flywheel in kg and V is the circular velocity of the flywheel in m/s. The pumped hydro energy storage system is the oldest energy storage technology in the world. This system includes a pump-turbine, a higher reservoir and a lower reservoir. During low demand periods, the excess energy is applied to pump water to a higher reservoir. The stored water will be released to a lower reservoir while the stored energy is delivered to the customers utilizing the turbine. Based on required infrastructures in such an energy storage system, pumped hydro storage is more

suitable for utility scale energy storage systems. The mass power output of a pumped hydro energy storage

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system. where ρ is density of water in kg/m3 , g is acceleration due to gravity in m/s2 , Q is discharge through the turbines in m3 /s, H is effective head in m and ηP is efficiency of the pump. The delivered energy of a pumped hydro storage system can be determined by the product of the output power obtained in Equation (4) and the time duration. In a CAES system, energy can be stored as high pressure air in a high pressure reservoir by applying work to the compressor. The energy storage procedure in this technology follows the thermodynamic law of energy conversion for air. The stored energy depends on reservoir volume, pressure, temperature, and its energy conversion process, which can be isothermal, adiabatic, or isentropic. The amount of work, in a polytropic process, is expressed as [2,20]: W = (n/n − 1) P1 V1 [(P2/P1) (n-1/n) − 1] where n is the polytropic exponent (cp/cv), P1 and P2 are the atmospheric and the tank pressure in a compression cycle respectively. These energy equations assemble all the limiting parameters in each energy storage capacity. Considering the energy capacity representative of each energy storage technology, it can be concluded that each storage system has physical limitations on the maximum storage capacity. For example, the volume of the reservoir in a pumped hydro system or the rotational speed and mass of a flywheel is limited. This maximum capacity can be considered as a criterion for storage capability assessment of energy storage technologies, which is critical in a wind based energy system. Consequently, this constraint on energy storage capacity is the core focus of this paper in the evaluation of the performance of the selected energy storage technologies.

4. Proposed Criterion for Energy Storage Capability and Control Performance Assessment:

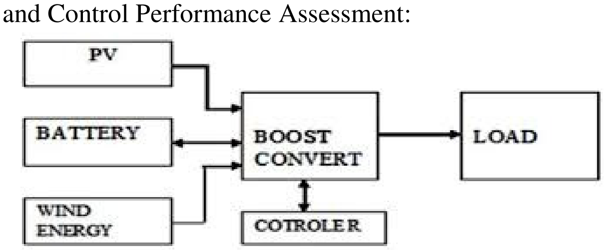

Fig.1. Hybrid power System

In a wind-based energy system, the general design of the system is focused on increasing the wind energy share in energy production in a cost effective manner. The random nature of the wind speed highlights the necessity of an energy storage system to solve the wind integration issues. While a storage system can smooth the energy output characteristics of a wind farm, the wind penetration rate can only be increased by storing a large quantity of wind energy during overproduction periods and restoring it during underproduction regimes. The wind penetration is directly related to the amount of the stored energy, and as a result, energy storage systems with higher storage capacity have higher impact on the wind penetration in a wind-based HPS. In addition, the storage system capability in storing energy is limited by its energy conversion rating. In order to have a reliable energy source with maximum RES share, overdesign of the storage system can increase the wind penetration in electricity generation; however, this might not be a proper approach. In addition, having a huge storage capacity does not guarantee that the storage system can harvest the available excess energy in a limited duration of time due to its limited converted energy transfer capacity. When a storage system is charged to its nominal capacity, it is not possible to store more available excess energy from a wind farm. In this study, rejected energy is considered to be the amount of energy that a storage system cannot harvest from an RES due to its limited capacity. In a fixed blade wind turbine, this extra energy is usually applied to a dump load to maintain the power system stability. In a fully controlled wind farm the wind turbine blades are controlled in such a way that the energy production is limited to the load demand and power system stabilizer capacity. In other words, sometimes the energy system cannot extract the full capacity of available wind energy. This condition can be more significant when a large amount of energy is available in a short time duration as a result of high wind speed, and the storage system is not able to capture this energy due to either its limited.To ensure a continuous and reliable supply of electricity to the isolated community, it is assumed that the existing diesel generators can be utilized for backup purposes. The main purpose of using the diesel generator as a backup is to support the unreliable wind based power system and

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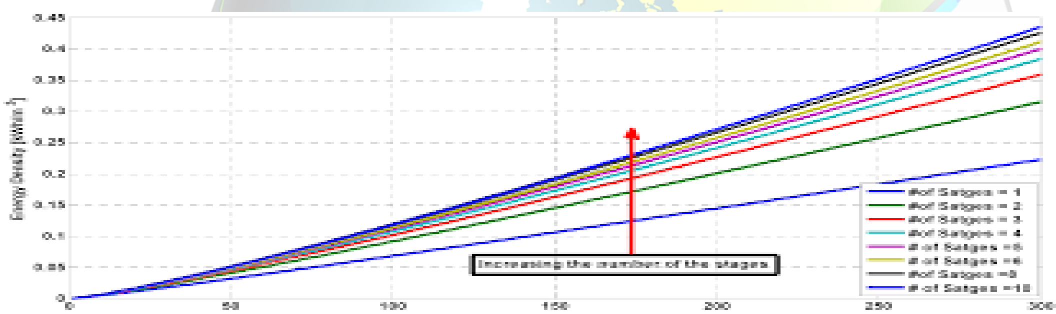
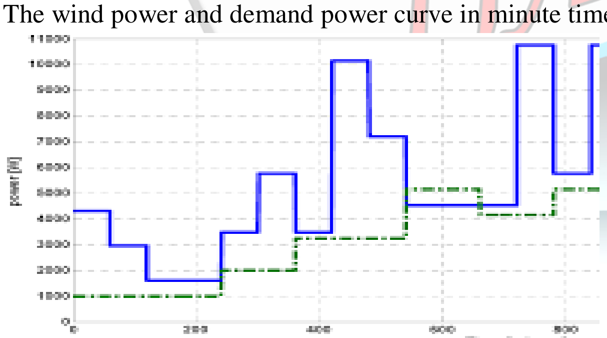
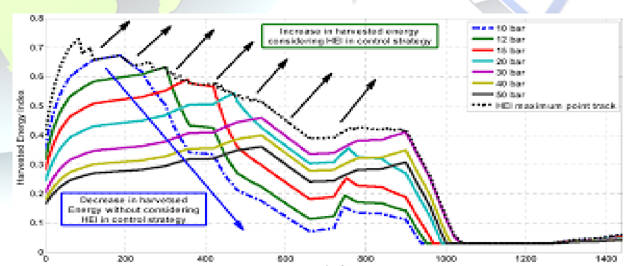
guarantee the reliable operation of the HPS. The diesel generator operates when the total output power of wind turbine and storage system is not sufficient to meet the power demand. On the other hand, in order to retain the stability of the power system in high wind regimes when the storage system is fully charged, a dump load will be connected to the wind turbine output. Consequently, the proposed hybrid system includes the existing diesel generators, wind turbines, an energy storage system, dump loads, and a control unit for dynamic energy management. The objective of such an implementation is to reduce the diesel generator's total fuel consumption. Two different mode of operation can be considered for the diesel generators in a wind based HPS: Standby and On-Off mode of operation. In an On-Off mode of operation, an energy storage system eliminates the no load operation of the diesel generator and results in more economical operation of the diesel generator. On the other hand, the standby mode of operation requires more fuel consumption as a result of no load fuel consumption.where Cp is the wind power coefficient, Ar is the cross section area swept by rotor and Vw is the wind speed. The air density ρ can be taken as 1.225 kg/m3 . In this study, the Bergey Excel-S 10 kW wind turbine is chosen, based on the available average wind speed and demand. Considering the power curve provided by the manufacturer, the Cp value can be considered as a function of wind speed,

Energy density variation as function of number compression stages and pressure:



The wind power and demand power curve in minute time scale:





A comparative study, based on efficiency, life cycle,cost (including initial and operational costs), and energy/power rating, as well as simplicity of implementation and its expandability [8,10,14], leads to the selection of the CAES as the most suitable energy storage system for application in a remote community power supply. A typical CAES plant includes the following components: power system including expander(s), compressor(s) and generator; control equipment including supervisory control unit, switchgear, cooling and heating system; and high pressure reservoir with airflow piping. Considering Equation (5), the stored

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energy in a fixed volume is related to the pressure ratio, and by increasing the pressure ratio both the stored energy and energy density of a CAES system can be increased. The energy density of the storage system is a critical parameter. The efficiency of CAES systems has been considered as the main drawback in many studies [8,9,11]. Low efficiency for single-stage compression and expansion is the limiting factor of a very high pressure system. However, an efficient design of such a system can lead to an enhanced performance of a CAES system. Highly efficient heat exchangers for after compression cooling and pre heating between expansion stages can be utilized to overcome this limitation. In addition, compressing air in multi-stages instead of one stage can improve the overall energy conversion efficiency (see Figure 6). For example, changes in efficiency of the compression cycle with higher compression stages are shown in Figure 7. As the Figure illustrates, the efficiency can be increased using more compression stages. As a result, the challenge will be to compromise between the performance, complexity and the total cost of a CAES system.5. Using the Harvested Energy Index in CAES Systems:To show the effect of the proposed performance index on the overall design of a wind based hybrid energy system, the Harvested Energy Index (HEI) for different energy storage systems and different capacities is calculated. The analysis of the proposed HEI in performance assessment of an energy storage system can be done through a case study. The challenges in this analysis are to design a storage system with proper sizing. In addition, an optimum control strategy should be developed in order to harvest the maximum energy from the available wind source. Using Equation (6), the harvested energy indices for different energy storage capacities are calculated and shown in Figure 8 over a minute time scale during a day. According to this result, increasing the size of the storage system will result in more captured energy fromwind.Harvested Energy index for different energy storage capacity. The required power of compressors can be calculated by derivation of the work equation with respect to time. All the working parameters of a compressor, except flow rate (Q), can be considered constant (assuming an efficient heat exchange with the environment). The power of the compressor can be obtained from Equation (5) as:Pcompressor = (n/n – 1) P1 Q [PR(n-1/n) – 1]where PR is the ratio of the compressor output pressure to its input pressure (P1). Assuming a polytropic process for both compression and expansion, the polytropic exponent of air for the compression process can be considered 1.45 for compression and 1.36 for expansion [14]. The pressure of the tank will increase depending on the amount of the entered air mass to the reservoir based on Equation (11), where the change in air mass can be calculated using Equation (12):

$$P\,V n = mRT$$

$$m = \rho \int Q\, dt$$

where R is the gas constant and T is the working air temperature. The change of the compressed air stored in the reservoir can be calculated and it depends on the available power for the high pressure compressor. The change in stored energy is formulated using presented equations (5) and (7 to 12). The available wind power output defines the working condition of the other components o
f the hybrid power system. Based on this value, the following scenarios was considered for the HPS:

1- The charging cycle: This condition happens
2- when the output power of the wind turbine is more than the load, and the storage system hasavailable storage capacity. In this condition, the excess power is applied to the compressor and the output flow rate of the compressor is
3- calculated using Equation (10). The total air
4- mass entered to the high pressure tank can
5- be obtained using Equation (12) and the tank pressure can be obtained using Equation (11). The tank pressure will continue to increase as long as the excess power is available and the tank pressure is lower than its nominal value.
6- 2- The rejection cycle: In this cycle, the energy storage is charged to its maximum capacity and any additional power cannot be stored. Considering the fixed blade configuration for the wind turbine, this rejected power will be consumed by the dump load in order to maintain the system stability.
7- 3- The discharge cycle: The storage system starts to deliver power to the load, when the

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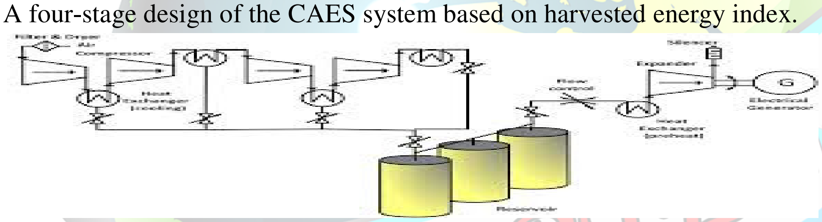
output power of the wind turbine is not sufficient to meet the demand. This cycle will be terminated when the storage system is fully discharged or the wind speed increases and the wind turbine output power is sufficient for the load.

8- 4- The shortage cycle: Diesel generator will operate in this mode in order to compensate the wind turbine output power. In this situation, the total power of the wind turbine and storage system is less than the required power for the load. The fuel consumption of the diesel can be calculated by using its power-fuel consumption equation

At the beginning of the storage cycle, the compressors can work in parallel mode with small pressure ratios to increase the storage speed and flow rate into the reservoir. Based on the pressure increment in the tank, the compressors can be switched to a series-parallel combination to increase the compression ratios. The working pressure of the compressor will change when the reservoir is fully charged to the optimum pressure based on the maximum HEI. This adjustable configuration of the multistage compressors enables the storage cycle to operate in variable capacity condition to increase the HEI. Compressing a certain amount of air to a high pressure can be done using gradually increasing working pressure to achieve an efficient energy conversion process. It takes less energy and time to compress air at low pressures compared to high pressures. Based on this, it is suggested to store energy in reservoirs at low pressure and gradually increase the working pressure of the compressors.

A four-stage design of the CAES system based on harvested energy index.



In order to show the effectiveness of the proposed control method, the utilization impact of such a control strategy on the fuel consumption of the diesel generator is investigated. In this assessment, systems with different set of constant working pressures are compared to two systems with controllable working pressures based on the HEI concept. At the first control strategy and based on the proposed maximum HEI tracking control strategy, the working pressure of the compressor is increased in 25 steps of 2 bar to the final working pressure of 50 bar. Although this control strategy increases the accuracy of the maximum HEI tracking, its complexity and cost might result in an impractical option for the control strategy. Therefore, a four stages compression unit with controllable valve is considered a practical option for the HEI implementation. The second system has a four-stage configuration with compression ratio of 3 for each stage. Each compression stage will become online after connecting to the previous compressor, when each stage reaches the maximum working pressure (in this case 3, 9, 27, and 81). Figure 12 shows the change in pressures for the compression system.

II. AIR MOTOR:

Air motors harness the safe, reliable power of compressed air to generate torque and rotational motion.Several different designs are available to serve a wide variety of applications.

Air motors are used to produce continuous rotary power from a compressed air system. They boast a number of advantages over electric motors:• Because they do not require electrical power, air motors can be

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used in volatile atmospheres.
• They generally have a higher power density, so a smaller air motor can deliver the same power as its electric counterpart.
• Unlike electric motors, many air motors can operate without the need for auxiliary speed reducers.
• Overloads that exceed stall torque generally cause no harm to air motors. With electric motors, overloads can trip circuit breakers, so an operator must reset them before restarting equipment.
• Air motor speed can be regulated through simple flow-control valves instead of expensive and complicated electronic speed controls.
• Air motor torque can be varied simply by regulating pressure.
• Air motors do not need magnetic starters, overload protection, or the host of other support components required by electric motors.
• Air motors generate much less heat than electric motors.

As one would expect, electric motors do possess some advantages over air motors:• If no convenient source of compressed air exists for an application, the cost of an air motor and its associated support equipment (motor-driven compressor, controls, filters, valves, etc.) will exceed that of an electric motor and its support equipment.
• Air motors consume relatively expensive compressed air, so the cost of operating them will probably be greater than that of operating electric motors.
• Even though electronic speed controls escalate the cost of electric motor drives, they control speed more accurately (within ±1% of desired speed) than air motor controls do.
• Air motors operated directly from a plant air system are susceptible to speed and torque variations if system flow and pressure fluctuate.

III. DC MOTOR :

A DC motor is any of a class of rotary electrical machines that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor.

DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys, and appliances. The universal motor can operate on direct current but is a lightweight motor used for portable power tools and appliances. Larger DC motors are used in propulsion of electric vehicles, elevator and hoists, or in drives for steel rolling mills. The advent of power electronics has made replacement of DC motors with AC motors possible in many applications.

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A coil of wire with a current running through it generates an electromagnetic field aligned with the center of the coil. The direction and magnitude of the magnetic field produced by the coil can be changed with the direction and magnitude of the current flowing through it.

A simple DC motor has a stationary set of magnets in the stator and an armature with one or more windings of insulated wire wrapped around a soft iron core that concentrates the magnetic field. The windings usually have multiple turns around the core, and in large motors there can be several parallel current paths. The ends of the wire winding are connected to a commutator. The commutator allows each armature coil to be energized in turn and connects the rotating coils with the external power supply through brushes. (Brushless DC motors have electronics that switch the DC current to each coil on and off and have no brushes.)The total amount of current sent to the coil, the coil's size and what it's wrapped around dictate the strength of the electromagnetic field created.

IV. Conclusion

In order to show the effectiveness of the proposed control method, the utilization impact of such a control strategy on the fuel consumption of the diesel generator is investigated. In this assessment, systems with different set of constant working pressures are compared to two systems with controllable working pressures based on the HEI

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