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STABILITY IMPROVEMENT OF DC POWER SYSTEMS IN FUZZY LOGIC

Mrs.S.PAVITHRA, Dr.P.SELVAN

Abstract— The capacity of all-electric ships (AES) increases dramatically, the sudden changes in the system load may lead to serious problems, such as voltage fluctuations of the ship power grid, increased fuel consumption and environmental emissions. In order to reduce the effects of system load fluctuations on system efficiency, and to maintain the bus voltage, we propose a hybrid energy storage system (HESS) for use in aess. The HESS consists of two elements: a battery for high energy density storage and a superconducting magnetic energy storage (SMES) for high power density storage. A dynamic droop control is used to control charge/discharge prioritization. Manoeuvring and pulse loads are the main sources of the sudden changes in aess. There are several types of pulse loads, including electric weapons. These types of loads need large amounts of energy and high electrical power, which makes the HESS a promising power source. Using Simulink/Matlab, we built a model of the AES power grid integrated with a SMES/battery to show its effectiveness in improving the quality of the power grid.

I. INTRODUCTION

AS the world trending to be electric, ship technology is no exception. In the past, ship design did not depend mainly on the electrical power system because ships were propelled mechanically by connecting the steam engines or turbines directly to the propellers. However, the introduction of ships that were propelled electrically opened the door for the increased inclusion of electrical design in shipbuilding. To encourage the trend to electrification, the concept of all-electric ship (AES) was proposed by the U.S. Navy. As the capacity of the AES is expected to reach hundreds of megawatts in the near future, a high-performance power system with multiple power sources is required to meet such huge power demands. The AES has different types of loads, including propulsion loads, ship service loads and pulse loads, such as electrical weapons. Electrical weapons rely on stored energy to attack targets, which need a high amount of power in a short period. On the AES design, one of the most important features is the ramp-rate of the generators.

The ramp-rate is the increased or decreased rate of the output power per minute and usually in MW/minute. The ramp-rate of ships generators, such as gas-turbine generators are in the range of 35 to 50 MW/minute, whereas the pulse loads required a 100 MW/second ramp-rate, which is significantly higher than the ramp-rate of the genera-tors. If the changes in the loads are faster than the ramp rate of the generators, unbalanced power between loads and generators occurs, which leads to instability in the power sys-tem. Because the ramp-rate of the ship’s generators is not high enough to maintain the power demanded by electrical weapons, the need for an integrated power system (IPS) architecture is inevitable.

The IPS is intended to provide the total amount of power required by the AES by using common set of sources. Missions that require high power support, such as a weaponry system and improve the efficiency of propulsion, which are some of the advantages of the use of an IPS in ships. IEEE 1709 recommends the use of medium-voltage DC (MVDC) in shipboard power systems, which improves the reliability, survivability and power quality of the system. The hybrid SMES/Battery has been proposed for railway substations by using fuzzy control. The use of the SMES was proposed in a hybrid vehicle in which a cryogenic tank al-ready existed.

A SMES/Battery hybrid energy storage sys-tem (HESS) was integrated into microgrids to mitigate the influence of the renewable generations.

The implementation of a HESS for AESs has been proposed to supply both the peak and pulsed loads. Several studies were performed to mitigate the effects of the pulse loads on shipboard power system by using HESS. A super capacitor and batteries were combined to supply pulse loads and support grid stability with different control schemes. A flywheel energy storage system was added to the system to maintain the health of the ship’s power systems by maintaining the propulsion motor speed and the generator speed during pulse load periods. propose the use of the superconducting magnetic energy storage (SMES)/battery HESS in AESs.

Mrs.S.Pavithra., Department of Electrical and Electronics and Engineering, Erode Sengunthar Engineering College, Erode.
(Email ID : pavi.vkr@gmail.com)
Dr.P.Selvan ME., Ph.d. , Head of the Department, Associate Professor, Department of Electrical and Electronics and Engineering, Erode Sengunthar Engineering College, Erode.
(Email ID : selvan_14@rediffmail.com)

Compared with super capacitors, flywheels, and other energy storage devices, SMES devices have higher power density, faster time response and unlimited charge and discharge life cycles. Because the battery has a relatively low power density, it cannot respond quickly in supplying the high transient current that is needed for the pulse loads.

In this model, SMES works as a high power density device and a battery as the high energy density device. A dynamic droop control is used to co-ordinate the charge/discharge prioritisation between the SMES and the battery. The ultimate goal of the HESS, based on dynamic droop control, is to supply the power demanded by the pulse loads and to maintain the main DC bus voltage within the targeted range.

II. REVIEW OF LITERATURE SURVEY

1) Li, Jianwei, et al. "Design and test of a new droop control algorithm for a SMES/battery hybrid energy storage system." Energy 118 (2017): 1110-1122.

The High capacity energy storage units are desirable to maintain power system stability in the presence of power disturbances produced by renewable energy sources and fluctuating load profiles. Battery energy storage systems may be used to smooth power flow, however, the frequent, deep charge and discharge cycling required dramatically reduces battery service life. A hybrid energy storage system (HESS) using battery energy storage with superconducting magnetic energy storage (SMES) is proposed to mitigate battery cycling while smoothing power flow. A HESS power sharing control method based on the novel use of droop control is proposed.

This is able to control charge/discharge prioritization and hence protect the battery from high power demand and rapid transient cycling. A sizing strategy is proposed for the battery and SMES which overcomes the oversizing problem. A hardware implementation is used to assess the control and SMES sizing methods for short time scale HESS operation. A dynamic off-grid sea-wave energy conversion system is simulated to assess the performance of the HESS over a longer time scale. A battery lifetime model which takes into account both battery life cycles and discharge current rate is used to estimate battery lifetime extension. A lifetime increase of 26% is obtained for the HESS design example investigated.

2) Li, Jianwei, et al. "Analysis of a new design of the hybrid energy storage system used in the residential m-CHP systems." Applied Energy 187 (2017): 169-179

The energy balancing problem is the main challenge for the effective application of micro combined heat and power (m-CHP) in a residential context. Due to its high energy density and relative robustness, the lead-acid battery is widely used for power demand management to compensate the mismatch between the m-CHP electrical output and domestic demand.

However, batteries are not suited to respond effectively to high frequency power fluctuations, but when coupled to the m-CHP, they experience frequent short-term charge/discharge cycles and abrupt power changes, which significantly decreases their lifetime. This paper addresses this problem by hybridising the lead-acid battery storage with superconducting magnetic energy storage (SMES) to form a hybrid energy storage system (HESS) that is coordinated by a novel sizing based droop control method. The control method for the first time considers both the capacity sizing of the HESS technologies and the droop control method of the battery and the SMES.

A hardware in the loop test circuit is developed coupling with the real time digital simulator (RTDS) to verify the performance of the HESS with the new control algorithm. The experimental results show that control method is able to exploit the different characteristics of the SMES and the battery to meet the mismatch of m-CHP power generation and domestic demand. In addition, the lifetime analysis is implemented in this paper to quantify the battery lifetime extension in the HESS, which further proves the validity of the proposed control strategy.

3) Nie, Z., Xiao, X., Hiralal, et al. "Designing and Testing Composite Energy Storage Systems for Regulating the Outputs of Linear Wave Energy Converters." Energies, 10(1) (2017), p.114.

Linear wave energy converters generate intrinsically intermittent power with variable frequency and amplitude. A composite energy storage system consisting of batteries and super capacitors has been developed and controlled by buck-boost converters. The purpose of the composite energy storage system is to handle the fluctuations and intermittent characteristics of the renewable source, and hence provide a steady output power. Linear wave energy converters working in conjunction with a system composed of various energy storage devices, is considered as a microsystem, which can function in a stand-alone or a grid connected mode. Simulation results have shown that by applying a boost H-bridge and a composite energy storage system more power could be extracted from linear wave energy converters. Simulation results have shown that the super capacitors charge and discharge often to handle the frequent power fluctuations, and the batteries charge and discharge slowly for handling the intermittent power of wave energy converters. Hardware systems have been constructed to control the linear wave energy converter and the composite energy storage system. The performance of the composite energy storage system has been verified in experiments by using electronics-based wave energy emulators.

4) Hussein, M., Senjyu, , et al. "Control of a Stand-Alone Variable Speed Wind Energy Supply System. " †. Applied Sciences, 3(2) (2013)., pp.437-456.

This paper presents a simple control strategy for the operation of a variable speed stand-alone wind turbine with a permanent magnet synchronous generator (PMSG). The PMSG is connected to a three phase resistive load through a switch mode rectifier and a voltage source inverter. Control of the generator side converter is used to achieve maximum power extraction from the available wind power. Control of the DC-DC bidirectional buck-boost converter, which is connected between batteries bank and DC-link voltage, is used to maintain the DC-link voltage at a constant value. It is also used to make the batteries bank stores the surplus of wind energy and supplies this energy to the load during a wind power shortage. The load side voltage source inverter uses a relatively complex vector control scheme to control the output load voltage in terms of amplitude and frequency. The control strategy works under wind speed variation as well as with variable load. Extensive simulation results have been performed using MATLAB/SIMULINK.

5) M. Cupelli, et al. "Power Flow Control and Network Stability in an All-Electric Ship," in Proceedings of the IEEE, vol. 103, no. 12, pp. 2355-2380, Dec. 2015

The concept of an all-electric ship, while offering unprecedented advantages from the point of view of efficiency and flexibility of operation, has introduced new challenges in terms of stability and power flow control. The advent of a full power electronics power system has raised new questions from the point of view of system dynamics, particularly when dealing with the new medium-voltage direct current distribution. The overall goal of guaranteeing a secure operation of the power system has brought researchers to consider two main approaches: reducing the dynamics of the large load to operate in a range of dynamics compatible with traditional generation systems, or making the generator set smarter through its power electronics interface. This paper compares these approaches to stable operation, focusing on the latter considered more in line with the progress of technology and in general more appealing.

III. PROPOSED SYSTEM:

The implementation of a HESS for AESs has been proposed to supply both the peak and pulsed loads. Several studies were performed to mitigate the effects of the pulse loads on shipboard power system by using HESS. A super capacitor and batteries were combined to supply pulse loads and support grid stability with different control schemes. A flywheel energy storage system was added to the system to maintain the health of the ship's power systems by maintaining the propulsion motor speed and the generator speed during pulse load periods. propose the use of the superconducting magnetic energy storage (SMES)/battery HESS in AESs. Com-pared with super capacitors, flywheels, and other energy storage devices, SMES devices have higher power density, faster time response and unlimited charge and discharge life cycles. Because the battery has a relatively low power density, it cannot respond quickly in supplying the high transient current that is needed for the pulse loads. In this model, SMES works as a high power density device and a battery as the high energy density device. A dynamic droop control is used to co-ordinate the charge/discharge prioritisation between the SMES and the battery.

ADVANTAGES

- ❖SMES works as a high power density device and a battery .
- ❖high energy density device
- ❖SMES devices have higher power density, faster time response and unlimited charge and discharge life cycles.

IV. BLOCK DIAGRAM

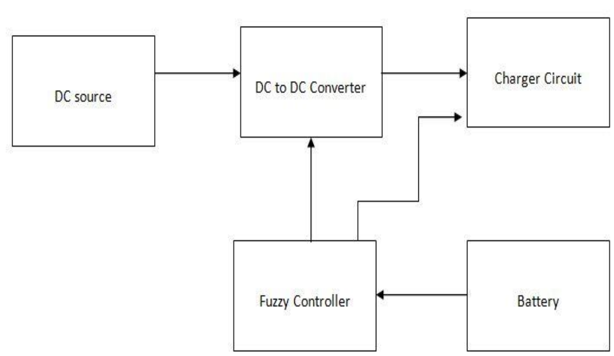


Figure 1 : Boost Converter

Switched mode supplies can be used for many purposes including DC to DC converters. Often, although a DC supply, such as a battery may be available, its available voltage is not suitable for the system being supplied. For example, the motors used in driving electric automobiles require much higher voltages, in the region of 500V, than could be supplied by a battery alone. Even if banks of batteries were used, the extra weight and space taken up would be too great to be practical. The answer to this problem is to use fewer batteries and to boost the available DC voltage to the required level by using a boost converter. Another problem with batteries, large or small, is that their output voltage varies as the available charge is used up, and at some point the battery voltage becomes too low to power the circuit being supplied. However, if this low output level can be boosted back up to a useful level again, by using a boost converter, the life of the battery can be extended.

The DC input to a boost converter can be from many sources as well as batteries, such as rectified AC from the mains supply, or DC from solar panels, fuel cells, dynamos and DC generators.

The boost converter is different to the Buck Converter in that it's output voltage is equal to, or greater than its input voltage. However it is important to remember that, as power (P) = voltage (V) x current (I), if the output voltage is increased, the available output current must decrease.

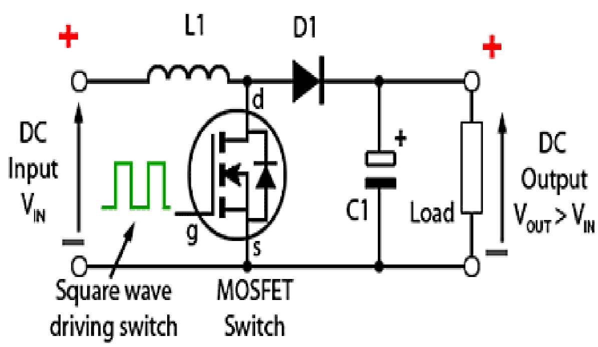


Figure 2 : Basic Boost Converter Circuit

A. Boost converter Operation

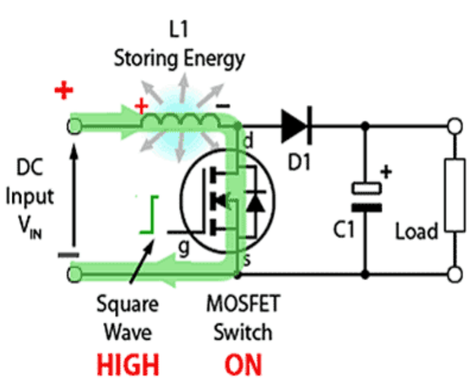


Figure 3: Boost Converter Operation at Switch On

Fig 3 illustrates the circuit action during the initial high period of the high frequency square wave applied to the MOSFET gate at start up. During this time MOSFET conducts, placing a short circuit from the right hand side of L1 to the negative input supply terminal. Therefore a current flows between the positive and negative supply terminals through L1, which stores energy in its magnetic field. There is virtually no current flowing in the remainder of the circuit as the combination of D1, C1 and the load represent a much higher impedance than the path directly through the heavily conducting MOSFET.

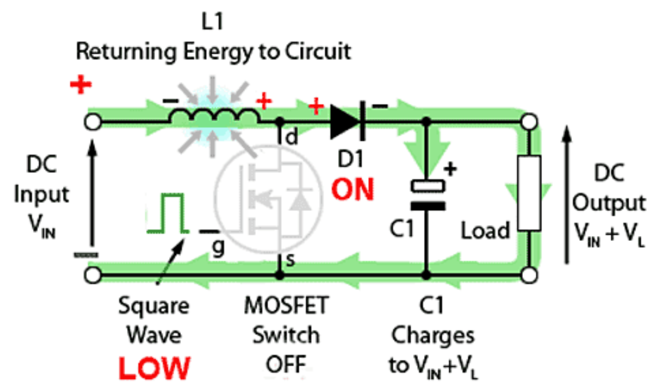


Figure 4: Current Path with MOSFET Off

Fig. 4 shows the current path during the low period of the switching square wave cycle.

As the MOSFET is rapidly turned off the sudden drop in current causes L1 to produce a back e.m.f. in the opposite polarity to the voltage across L1 during the on period, to keep current flowing. This results in two voltages, the supply voltage V_{IN} and the back e.m.f.(V_L) across L1 in series with each other.

This higher voltage (V_{IN} +V_L), now that there is no current path through the MOSFET, forward biases D1. The resulting current through D1 charges up C1 to V_{IN} +V_L minus the small forward voltage drop across D1, and also supplies the load.

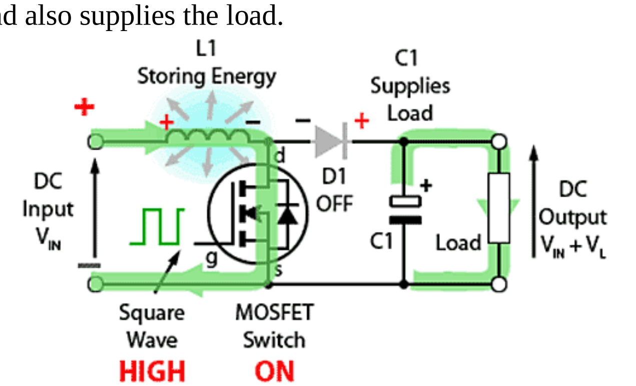


Figure 5 Current Path with MOSFET On

Fig. 5 shows the circuit action during MOSFET on periods after the initial start up. Each time the MOSFET conducts, the cathode of D1 is more positive than its anode, due to the charge on C1. D1 is therefore turned off so the output of the circuit is isolated from the input, however the load continues to be supplied with $V_{IN} + V_L$ from the charge on C1. Although the charge C1 drains away through the load during this period, C1 is recharged each time the MOSFET switches off, so maintaining an almost steady output voltage across the load.

The theoretical DC output voltage is determined by the input voltage (V_{IN}) divided by 1 minus the duty cycle (D) of the switching waveform, which will be some figure between 0 and 1 (corresponding to 0 to 100%) and therefore can be determined using the following formula:

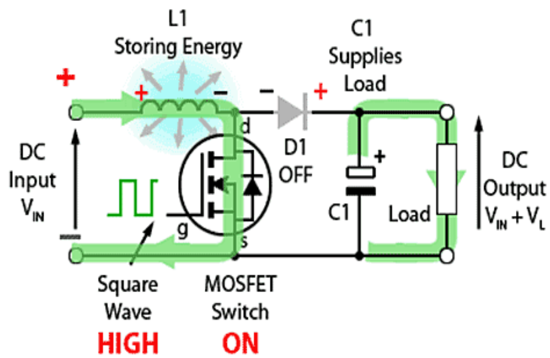


Figure 6: Current Path with MOSFET On

B. MOSFET with Working MOSFET as a Switch

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits.

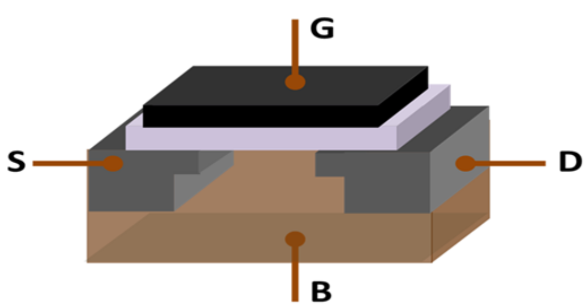
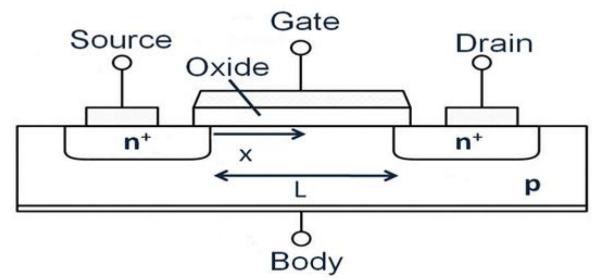


Figure 7 : MOSFET SWITCH

The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity present in the device is the main part



The MOSFET can function in two ways

- ❖Depletion Mode
- ❖Enhancement Mode

1) Depletion Mode:

When there is no voltage on the gate, the channel shows its maximum conductance. As the voltage on the gate is either positive or negative, the channel conductivity decreases.

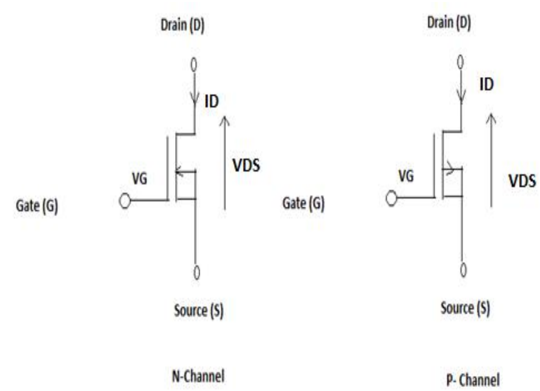


Figure 8: N Channel and P Channel

2) Enhancement mode:

There is no voltage on the gate the device does not conduct. More is the voltage on the gate, the better the device can conduct.

V. Working Principle of MOSFET:

The aim of the MOSFET is to be able to control the voltage and current flow between the source and drain. It works almost as a switch. The working of MOSFET depends upon the MOS capacitor. The MOS capacitor is the main part of MOSFET. The semiconductor surface at

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the below oxide layer which is located between source and drain terminal. It can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively. When we apply the positive gate voltage the holes present under the oxide layer with a repulsive force and holes are pushed downward with the substrate.

The depletion region populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source, the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage , a hole channel will be formed under the oxide layer.

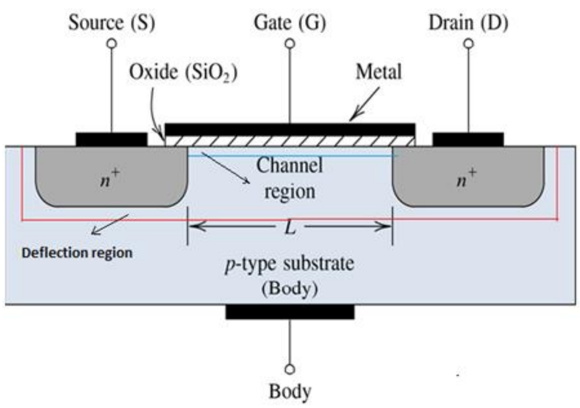

Figure 9 : MOSFET Block Diagram

1) P-Channel MOSFET:

The P- Channel MOSFET has a P- Channel region between source and drain. It is a four terminal device such as gate, drain, source, body. The drain and source are heavily doped p+ region and the body or substrate is n-type. The flow of current is positively charged holes. When we apply the negative gate voltage, the electrons present under the oxide layer with are pushed downward into the substrate with a repulsive force.

The depletion region populated by the bound positive charges which are associated with the donor atoms. The negative gate voltage also attracts holes from p+ source and drain region into the channel region.

2) N- Channel MOSFET:

The N-Channel MOSFET has a N- channel region between source and drain It is a four terminal device such as gate, drain , source , body. This type of MOSFET the drain and source are heavily doped n+ region and the substrate or body is P- type. The current flows due to the negatively charged electrons. When we apply the positive gate voltage the holes present under the oxide layer pushed downward into the substrate with a repulsive force.

The depletion region is populated by the bound negative charges which are associated with the acceptor atoms. The electrons reach channel is formed. The positive voltage also attracts electrons from the n+ source and drain regions into the channel. Now, if a voltage is applied between the drain and source the current flows freely between the source and drain and the gate voltage controls the electrons in the channel. Instead of positive voltage if we apply negative voltage a hole channel will be formed under the oxide layer.

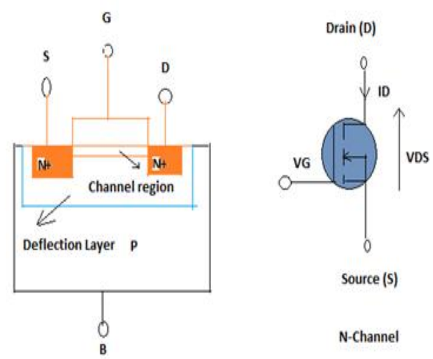

Figure 10 : Enhanced mode

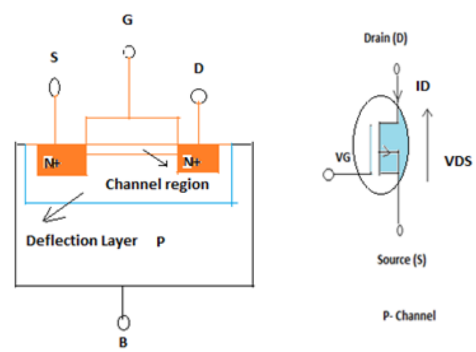

Figure 11 : Depletion Mode

3) MOSFET SWITCH

In this circuit arrangement an enhanced mode and N-channel MOSFET is being used to switch a sample lamp ON and OFF. The positive gate voltage is applied to the base of the transistor and the lamp is ON (V_{GS} =+v) or at zero voltage level the device turns off (V_{GS}=0). If the resistive load of the lamp was to be replaced by an inductive load and connected to the relay or diode which is protect to the load. In the above circuit, it is a very simple circuit for switching a resistive load such as lamp or LED. But when using MOSFET to switch either inductive load or capacitive load protection is required to contain the MOSFET device. We are not giving the protection the MOSFET device is damage. For the MOSFET to operate as an analog switching device, it needs to be switched between its cutoff region where V_{GS} =0 and saturation region where V_{GS} =+v.

VI. SIMULATION RESULT

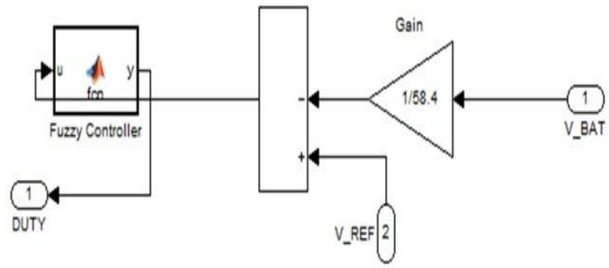

Figure 12 : Stability Improvement Dc Power

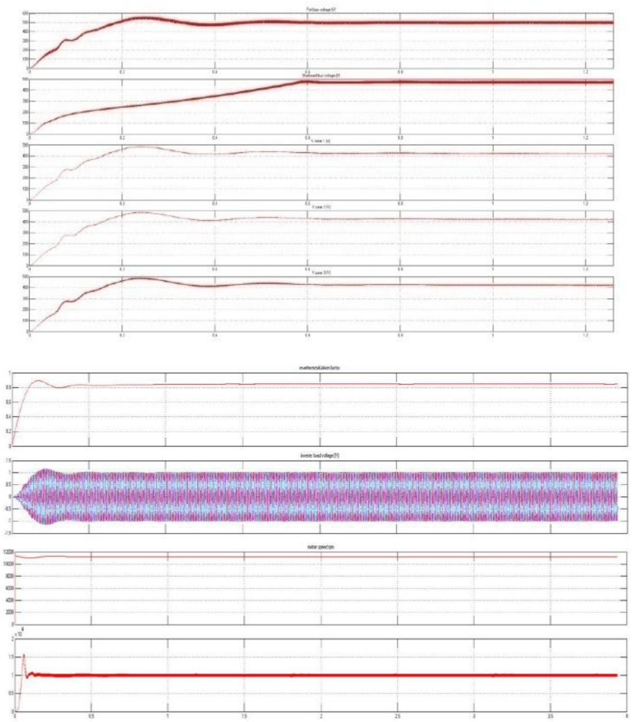

Figure 13 : Output MATLAB Simulation for Stability Improvement Dc Power

VII. CONCLUSION

The use of SMES/battery HESS based on the dynamic droop control in the AES to mitigate the effects of the sudden load changes on the system's stability. The AES including SMES/battery was built in the SimPowerSystems™ environment to test the system's behaviour with and without HESS. The HESS based on dynamic droop control showed good performance during the pulse load periods. By supplying the pulse loads from the HESS, the system maintained the voltage at the targeted level, keeping the motor at the required speed and maintaining constant generation output power both with and without pulse loads. To further investigate this approach, an experimental system containing a SMES and battery HESS will be constructed and tested in our laboratory. An optimization study for the SMES size and the battery life will also be performed.

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