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Simulation of Electrification of Railway Lines using Microgrids

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ABSTRACT

In order to increase the utilization rate of regenerative braking energy, reduce the operation cost and improve the power quality of traction power supply system in high-speed railways, this system proposes an economic process of energy storage by hybrid renewable energy sources in the train. The planned train station design makes use of solar and wind power, as well as batteries for an efficient storage system. The solar system provides voltage to the inverter through BUCK-BOOST converter. An energy management approach is suggested to control the DC bus by voltage and the buck-boost converter by current. The WECS with DFIG, AC-DC conversion takes place with the aid of PWM rectifier and the control of rectifier is carried out with a PI controller. The output of converter is fed to the grid through a 3Φ VSI, which converts the DC voltage into AC voltage. The LC filter is employed to enhance the output of the inverter. The control outputs are the output power of the PV input power sources as well as AC power injected into the power grid. The obtained results indicate that the proposed approach delivers better performance with enhanced efficiency and minimal harmonics. The entire system is validated through a MATLAB simulation.

Keywords: Microgrid, WECS, Photovoltaic, DFIG, Regenerative Braking, Bi – Directional Converter

1 Introduction

The Indian electric railway system is one of the largest and highest-consumption of power in terms of end users. Under the background of an environmentally concerned economy, it is crucial to reduce the railway energy consumption. One energy-saving technique is to introduce renewable energy (such as photovoltaic (PV) and wind energy) to construct an electric railway microgrid system (ERMS). The introduction of renewable energy can significantly reduce the railway energy consumption and reduce the depletion of nonrenewable energy resources. Thus, the construction of the railway smart microgrid system is crucial for realizing energy conservation and emission reduction and thus enhancing the eco-friendliness of the railway. However, locomotive traction loads and renewable energy sources both have strong stochastic volatility. For example, the traction energy of the locomotive varies over time and is easily affected by various emergencies, and the power generation of renewable energy is affected by the weather and cannot be controlled. These energy fluctuations affect the stability of the railway power-supply system. To solve this problem, an energy-storage system (ESS) is added to the ERMS as a buffer hub for each energy system. Additionally, given that the ERS generates large amount of regenerative braking energy (RBE), it is necessary to use the ESS to store surplus energy. Thus, the installation of a railway microgrid system is crucial for maintaining railway grid stability and realizing energy utilization.

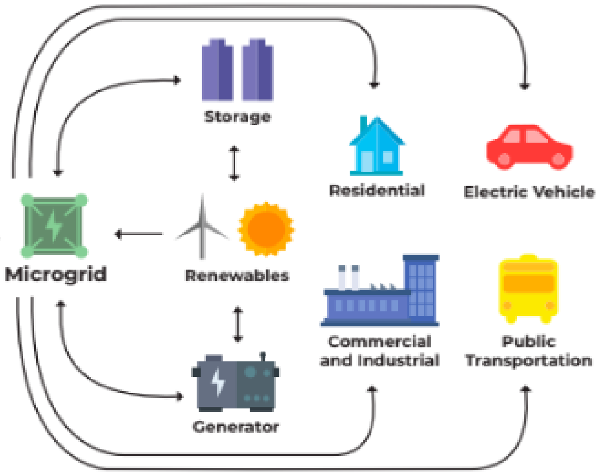


Figure 1: *Movement of energy in microgrid*

However, the ERMS differs from the traditional microgrid system. In the ERMS, the load power is high and has strong randomness. If the ESS is adopted only as an energy-transfer station to store and release renewable energy and the RBE is adopted to supply locomotive traction energy, the ESS must be configured with a sufficient capacity and with fast response, which places a large burden on the ESS. Therefore, it is better to adopt measures to reduce the operating pressure on the ESS, which will also improve the stability of the railway grid.

There is a distributed load in railway stations, e.g., lighting, air conditioning, elevators, and escalators. Therefore, injecting the renewable energy and RBE into the distribution grid in railway stations via regenerative inverters will relieve part of the operating pressure of the ESS.

2 Existing System

The high-speed locomotives generate a large amount of regenerative energy during braking, which can be transferred to other locomotives in the vicinity. However, in most cases, the RBE surges back to the power grid via reversible substation when there is no powering locomotive in the feeders belonging to the same feeding section, which causes a great disturbance to the upstream utility grid and increases the dispatch difficulty of the power system. In addition, there is also no evidence to show that the back-flown RBE is effectively utilized because it will cause three-phase unbalance and finally be dissipated as heat at the bearings of rotating machines or consumed as circulating current at the delta windings of power transformers. At present, regarding the existing methods for RBE utilization, there are three major alternatives:

1) Energy optimization method
2) Energy feedback method
3) Energy storage method

The energy optimization method refers to that, by harmonically controlling operation of other locomotives, the RBE is consumed by the locomotives at the same power supply arm to reduce the total energy consumption. This method can effectively utilize the RBE in some way, but it has disadvantages such as low energy utilization rate and poor flexibility. In the energy feedback method, the RBE is fed back to the power network of train station then reused by elevators, exhaust fans and other electric equipment. However, the RBE contains abundant harmonic and negative sequence components causing serious threats to the electric equipment. The energy storage method is that the RBE is stored to relevant storage media (flywheels, batteries, super capacitors, etc.), and then the stored energy is supplied to the traction loads subsequently this approach can achieve high energy utilization and high flexibility, which has become a research hotspot in recent years. There are many kinds of available energy storage schemes, such as flywheel energy storage system (FESS), battery energy storage system (BESS), superconducting magnet energy storage (SMES) and Super capacitors (SC). The SC possesses the ideal characteristics of long service life, high power density, and fast response, etc. Hence, the SC is the most suitable candidate for the events like regenerative braking that requires large power in a short while.

Railway static power conditioner (RPC) is considered as a most promising power quality compensation device in electrified railway, as it transfers active power from one feeder to another to rebalance the power consumption at each feeder, and independently compensates reactive power for both sections.

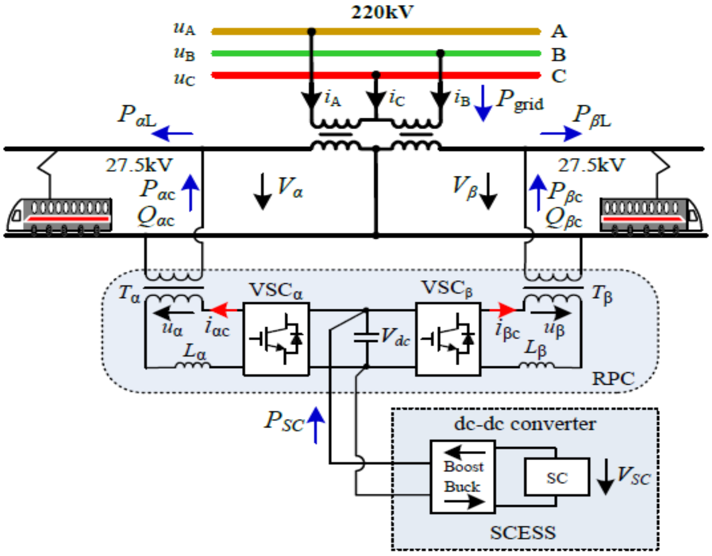


Figure 2: *Existing System Block Diagram*

In this existing system, to utilize energy more efficiently, a Super capacitors based energy storage system (SCESS) integrated railway static power conditioner (SCESS-RPC) is presented. The drawbacks of this system are:

- Uninterrupted energy supply is not guaranteed in this system.
- Harmonics exist in output voltages.
- High cost and also absences of renewable energy sources.
- Super capacitors need over charge and over discharge protection.

3 Proposed System

Distributed power generation utilizing renewable energy source such as solar, wind, fuel cell, and biomass can help to alleviate the pressure of energy shortage and to reduce environment pollution. Direct Current (DC) microgrids are attracting interest for their ability to easily integrate modern loads, renewable sources and energy storage and transportation systems is one of the interested domains. In this system a microgrid based Railway Station is considered, where the energy utilization is more efficient compared to a normal railway station thanks to the presence of solar energy, wind energy, recovery braking systems and storage devices to supply the local loads. A dedicated DC microgrid is treated, where the regeneration of the train braking energy is seen either as an important possibility to recycle electric power, due to the fact that it is naturally available when the train uses electric brakes to slow down its engines instead of using mechanical brakes, but either as a problem for voltage stability and power quality, due to its intermittent high peaks of power.

Therefore, a dedicated power management controller able to provide optimal reference values to the local controllers of the devices composing the DC microgrid is needed, to reach the target to recycling the train braking energy in a railway station while assuring its power flow and keeping voltage inside operation bounds. The dedicated power management model for a Railway Station able to store the regenerated energy in a battery as energy buffer while keeping a correct power balance among framework in a power flow scheme. In recent years, a lot of research has been carried out in terms of control strategies for optimal management of the regenerative energy in microgrids but there are still not yet contributions on power management models dedicated to DC microgrids with different kind of Energy Storage Systems (ESS).

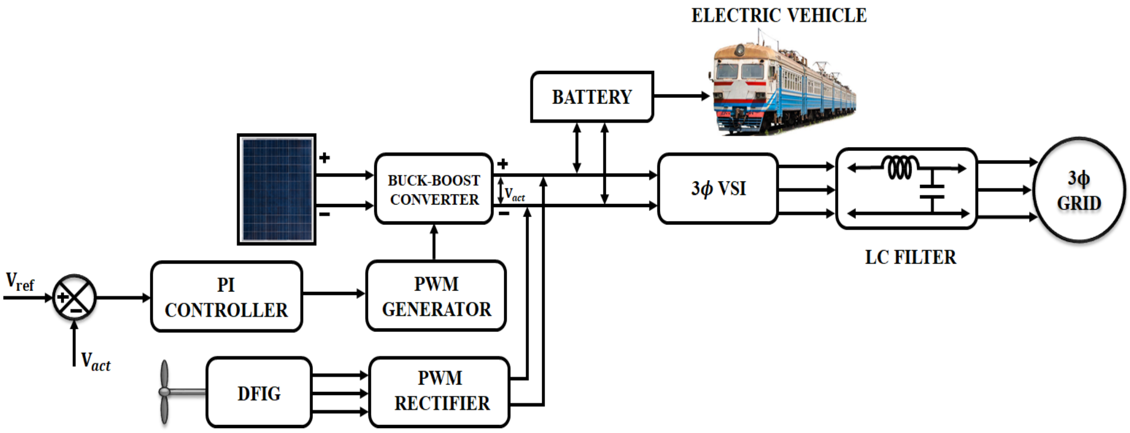


Figure 3: *Proposed system block diagram*

In this proposed system an innovative method for energy storage in the train employing ESS with the goal of lowering energy usage. The planned train station design makes use of solar and wind power, as well as batteries for an efficient storage system. The grid synchronization of renewable energy source applications like PV source is performed. The PV voltage is insignificant and generally gets influenced by the impacts of climate variations including irradiation and temperature. A DFIG based Wind energy conversion system and a diesel generator, provides the necessary DC supply through a PWM rectifier. A PI Controller is employed which is robust and does not demand information regarding the actual model. The optimal DC voltage extracted from the PV panel using PI Controller is injected into a BUCK BOOST converter, which helps to improvise the dc voltage. The battery act a bi-directional system which enhance the DC power stored in the battery is fed into the train to drive the system and as also supply a power to the grid. A power output obtained from a PV panel is fed into the BUCK BOOST converter and the enhanced output from the converter is converted to AC through a 3Φ VSI, which is injected to the grid after proper synchronization. A PI controller is implemented to maintain the constant voltage of the DC link and increase the grid's performance. The PWM generator is employed in this study to generate the proper pulses. The harmonic present in VSI is rectified using LC filter, thereby the current has been safely injected into the grid.

3.1 PV System

The sun is an eco-friendly and everlasting reliable energy source. The energy radiated from sun is received directly for power generation by way of photovoltaic. One of the significant methodologies utilized from solar power is photovoltaic (PV) which is capable of converting sunlight into electricity using photovoltaic effect. The basic building block of photovoltaic modules which produces electricity from the light energy by photovoltaic effect is a Solar cell. The PV module efficiency relies on the tangible utilized in photovoltaic cells and the technique used to form a module by placing the solar cells. Efficiency of solar module is about 12-29 % in conversion of sunlight to electric energy. Among which gallium Arsenide solar cells have 29% of maximum efficiency, whereas solar cell with silicon have 12-14% of efficiency. The performance of PV module may also drop due to temperature in PV module and load conditions. Hence to increase the derivation of power from PV module, optimal power point operation of module is important. To accomplish this controller called maximum power point tracker is necessary. PV cells are manufactured from different materials.

Mono-crystalline and polycrystalline are the popular techniques of silicon. Conventional solar cell gives less than 2W near to 0.5V hence to obtain a required voltage as output a number of cells are linked in series to make a solar panel. Hence the panels are integrated into an array. The series connection of an array results in high output voltage. During the process if PV cell have no solar radiation it functions as a p-n junction diode. When solar radiation falls on the PV cell due to the interaction between incident photons and cell atom, pairs of electron holes are produced. The electric field produced by the junction of cell divides the photo generated electron-hole pair with electrons and holes drifting to n region and p region of the cell. This movement causes a photo current which rely mainly on intensity and wavelength of solar irradiation. As mentioned above if solar radiation is not falling on PV cell it becomes inactive and functions as a p-n junction diode. In this condition PV cell does not generate current or voltage. However, when cell is linked with an external large supply than cell voltage it produces a current$I_D$which is called dark current.

The PV system used for power conversion consists of several series and parallel combination of PV modules the tracking controller and power converters like DC-DC converter and inverter. Hence the generated DC voltage can be amplified using DC-DC converter and converted to AC by using the inverter. The PV panel should be selected as per the rating of the load.

The total current I is the difference of the light generated current I_{ph}, diode current I_d and current through R_{sh}

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

Diode current I_d and Shunt Resistance current I_{sh} is presented by Equations (3.2) and (3.3)

$$I_d = I_0 \left\{\exp\left[\frac{q}{mkT_c}(V + IR_s)\right] - 1\right\} \tag{2}$$

$$I_{sh} = \frac{V+IR_s}{R_{sh}} \tag{3}$$

m= Idealizing factor
K= Boltzmann constant
T_c= Absolute temperature of cell
q= Charge of electron

V= Potential across cell
I_0= Cell reverse saturation current
By utilizing Equations is shown below

$$I = I_G - I_0 \left\{exp\left[\frac{q}{mkT_c}(V + IR_s)\right] - 1\right\} - \frac{V+IR_s}{R_{sh}} \tag{4}$$

Usually shunt Resistance R_{sh} in PV cells is high hence $\frac{V+IR_s}{R_{sh}}$ is eliminated Hence,

$$I = I_G - I_0 \left\{exp\left[\frac{V+IR_s}{A}\right] - 1\right\} \tag{5}$$

Where A=curve fitting parameter

$$A = \frac{mkT_c}{q} \tag{6}$$

Determination of phase current I_{ph} According to Figure, output current at standard test condition is

$$I = I_{ph} - I_0 \left[exp\left(\frac{V}{a}\right) - 1\right] \qquad 7)$$

When PV cell is short circuited

$$I_{sc} = I_{ph} - I_0 \left[exp\left(\frac{0}{a}\right) - 1\right] = I_{ph} \tag{8}$$

Only in ideal case Equation (8) is valid. Hence the equality is not accurate. Equation (9) is written as

$$I_{ph} \approx I_{sc} \tag{9}$$

The photocurrent depends on both irradiance and temperature

$$I_{ph} = \frac{G}{G_{ref}}\left(I_{ph} + \mu_{sc}.\Delta T\right) \tag{10}$$

G=irradiance
G_{ref}=irradiance at standard testing conditions
The following Figures show the IV and PV curves of single solar panel for different irradiance.

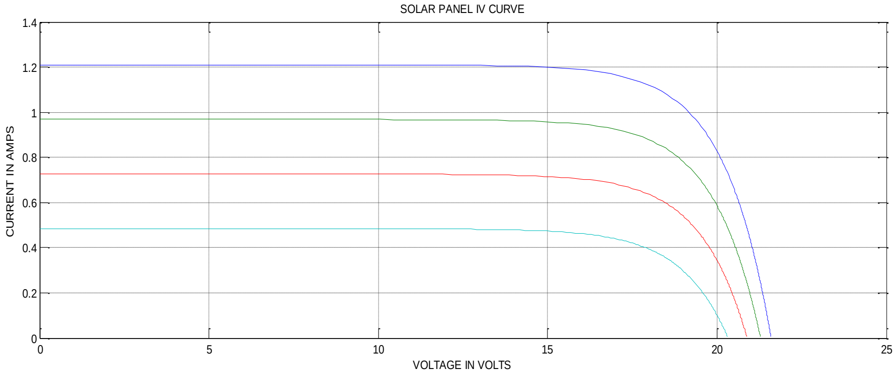


Figure 4: *Single solar module IV curve*

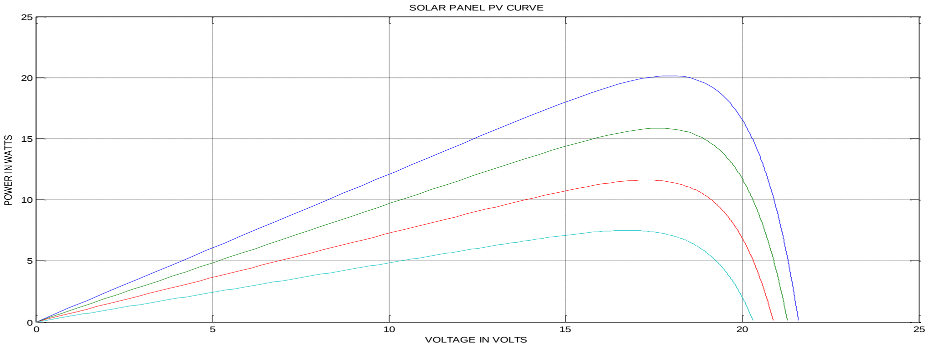


Figure 5: *Single solar module PV curve*

3.2 Wind Energy Conversion Systems

Wind energy conversion systems (WECS) are designed to convert the energy of wind movement into mechanical power. With wind turbine generators, this mechanical energy is converted into electricity and in windmills this energy is used to do work such as pumping water, mill grains, or drive machinery. Since the wind is the intermitted source of energy, the output voltage and frequency from generator will vary for different wind velocities. The variable output ac power from the generator is first converted into dc using the rectifier. The available dc power is fed to the grid at the required constant voltage and frequency by regulating the modulation index of the inverter.

The wind power system contains wind turbine that exchanges wind’s kinetic energy as rotating motion, then turbine speed is equated to the generator speed by using gear box, a generator that changes mechanical energy into electrical energy, the rectifier that transforms ac voltage into dc, manageable dc-dc converter is used to suggest the maximum power point.

The airs kinetic energy is transferred by wind turbines (i.e. wind power) as mechanical power which are utilized to operate the machine else generator directly. The shape of blades, pitch angle, speed of rotation, and rotor radius are used to associate the power from the blades of the turbine. Generated power is represented as,

$$= \frac{1}{2}\,\rho A v^3 C_p(\lambda,\theta) R^2 V^3 \tag{11}$$

In which, P_m– Power taken through wind turbine; ρ–Air density; θ –Pitch angle; R–blade radius; V– Wind speed;
And λ is the ratio of tip-speed and it is denoted as,

$$\lambda = \frac{\Omega R}{V} \tag{12}$$

In which, R is rotor speed; C_p is expressed with function of tip-speed ratio

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_1} - 0.4\beta - 5\right) e \left(\frac{-16.5}{\lambda_1}\right) \tag{13}$$

$$\lambda_1 = \frac{1}{\frac{1}{\lambda+0.089} - \frac{0.035}{\beta^3+1}} \tag{14}$$

In this C_p is the power coefficient of wind turbine; λ can be expressed as tip speed ratio; λ_1 as constant
Wind turbine is directly implemented as Cp–TSR characteristic, TSR as tip-speed fraction represented as:

$$TSR = \frac{\omega_m R}{V} \tag{15}$$

R, ω_m are turbine radius with mechanical angular speed, individually. Power coefficient contains high value in optimal value from tip-speed ratio TSR_{opt} that ends with optimum regulation from wind turbine yet detain of highly obtainable wind power with turbine.
As in (15), high power of various wind speed produced by various rotor speeds. Hence, turbine speed must be monitored to track optimal tip-speed ratio. Utilization of absorbing speed control from system sketch is attained by activate rotor in high wind at high speed also with low wind at low speed. By rotational speed authority from turbine grants TSR as managed by power coefficient is reduced.
Based on (15), the estimated rotor optimum speed is

$$\omega_{opt} = \frac{TSR_{opt} V}{R} \tag{16}$$

The output torque corresponds to maximum power is

$$T = \frac{1}{2}\frac{\rho A C_{Pmax}}{\omega_{opt}}\left\{\frac{R\omega_{opt}}{TSR_{opt}}\right\}^3 \tag{17}$$

The wind turbine shaft is automatically fixed with the generator rotor shaft, thus the developed mechanical power through wind turbine (through kinetic energy towards mechanical energy transformation) that transferred towards rotor shaft and the construction of rotor contains rotor winding (both field else armature). By this, the roaming conductor is obtained at stationary magnetic field else stationary conductor at roaming magnetic field. However, the principle of generator is used to generate the electric voltage.

3.3 Buck Boost Converter

The buck-boost converter is another significant member from the family of DC-DC converters. The ideal equivalent circuit of the fundamental buck-boost converter topology is presented. Similar to the boost converter, the buck-boost converter is also operated in CCM and DCM. The two stages of operation in CCM are as follows,

Stage 1

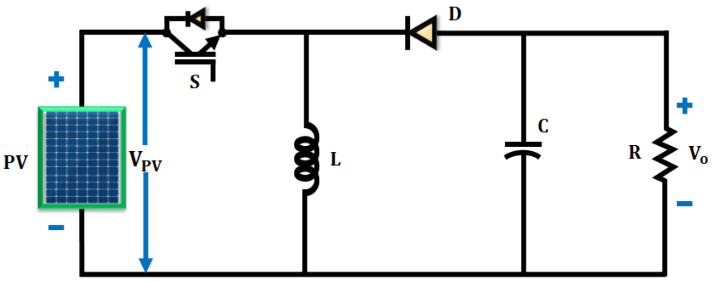
Time Interval ($0 < t \leq DT$): The power switch is in ON state during this sub-interval, resulting in the increase in value of the inductor current, since the input is placed across the inductor and the diode is reverse biased. Figure 6(b) represents the equivalent circuit for this sub-interval. The output capacitor discharges and supplies to the load in this stage. The voltage across the inductor is equal to the input voltage, which is given by,

$$V_L = V_{PV} = L\frac{di_L}{dt} \tag{18}$$

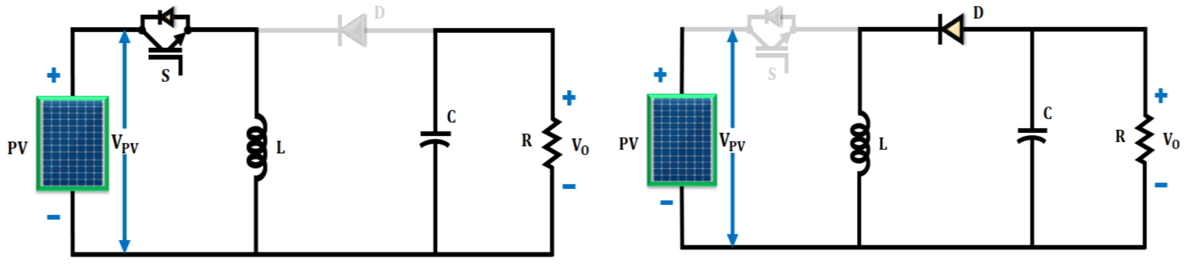
Stage 2

Time Interval ($DT < t \leq T$): During this sub-interval, the diode is in ON state and the power switch is in OFF state. The charging of capacitor in addition to the discharging of the inductor takes place. The inductor current linearly decreases and flows through the diode. The buck-boost converter power stage for stage 2 is presented in Figure 6(c). The voltage gain equation is,

$$\frac{V_O}{V_{PV}} = \frac{D}{1-D} \tag{19}$$



(a)



(b) (c)

Figure 6: *Buck-Boost converter (a) Circuit Topology (b) Stage 1 Operation and (c) Stage 2 Operation*

Where D is the duty cycle, which is given as,

$$D = \frac{V_O}{V_O - V_{PV}} \tag{20}$$

The value of inductance and capacitance is given as,

$$L = \frac{R(1-D)^2}{2f} \tag{21}$$

$$C = \frac{D}{Rf\Delta V_O/V_O} \tag{22}$$

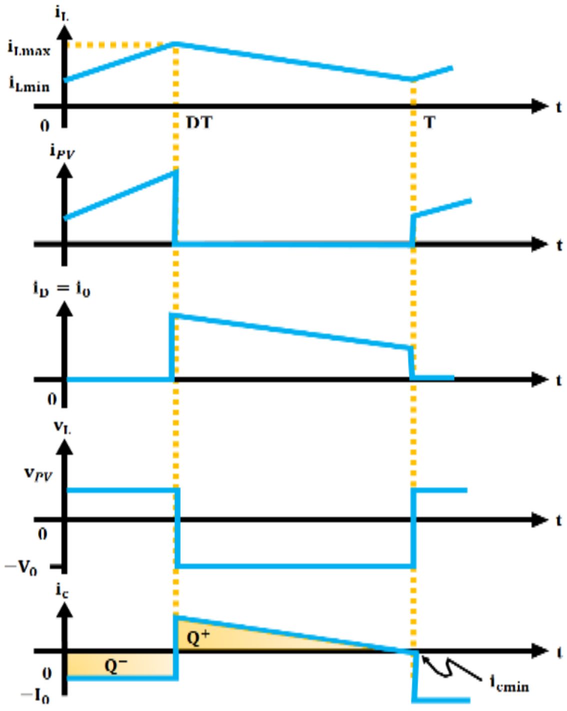


Figure 7: *Buck-Boost Converter Waveforms*

The choice of power switch relies on maximum inductor current and maximum input voltage, whereas, the diode is selected on the basis of ability to handle load voltage and load current.

3.4 Three Phase Voltage Source Inverter

Rectifier fed inverter system has two stage converters. In this research inverter side control is described. Rectifier side control is used to find out duty cycle. Most inverter applications require a means of voltage control. This control may be required because of variations in the inverter source voltage and regulation within the inverter. It can be grouped into three categories,

- Control of voltage supplied to the inverter
- Control of voltage within the inverter
- Control of voltage delivered by the inverter

It is often possible to include inverter output voltage control without significantly adding to the total number of circuit components. A single-phase pulse width control technique is discussed here to illustrate the important principles of this means of controls. By properly gating the inverter controlled rectifying device it is possible to vary the amplitude of fundamental component of inverter output voltage. With this method of control, it is possible to substantially reduce or eliminate lower frequency harmonics. Therefore, with a minimum filtering a good output waveform is obtained over a wide inverter voltage control range.

4 Result and Discussion

The proposed work is implemented in MATLAB simulation and the following results are obtained.

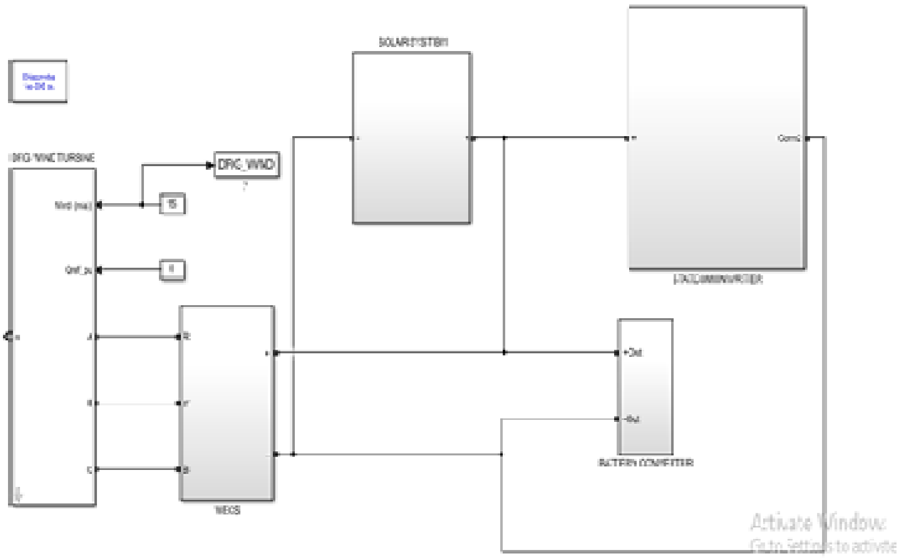


Figure 8: *Simulation Diagram*

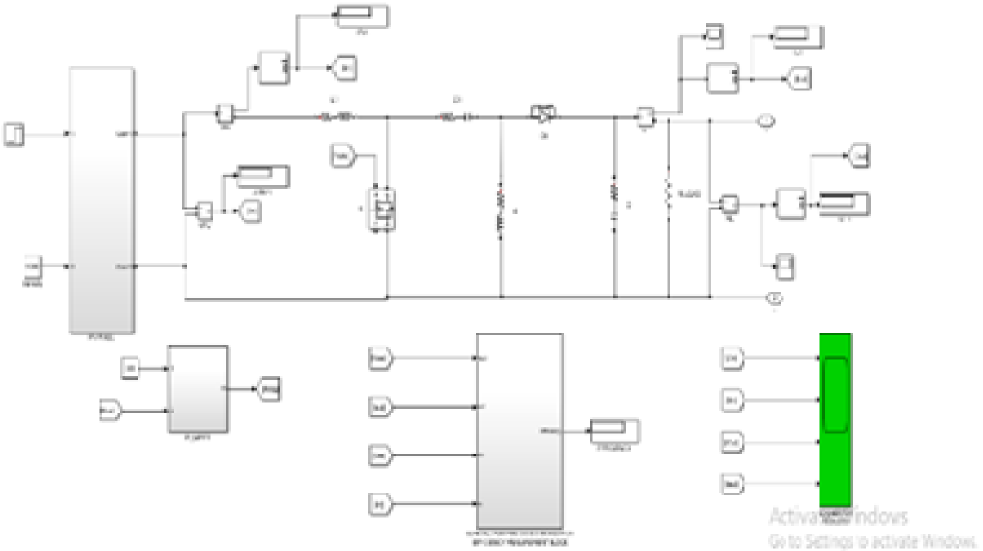


Figure 9: *Simulation Diagram for solar with converter*

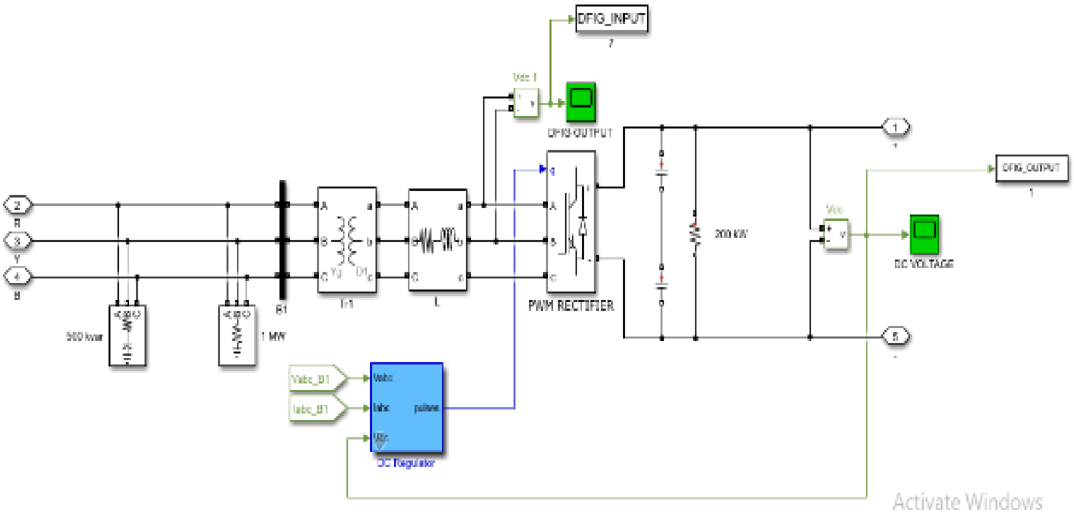


Figure 10: *Simulation Diagram for WECS*

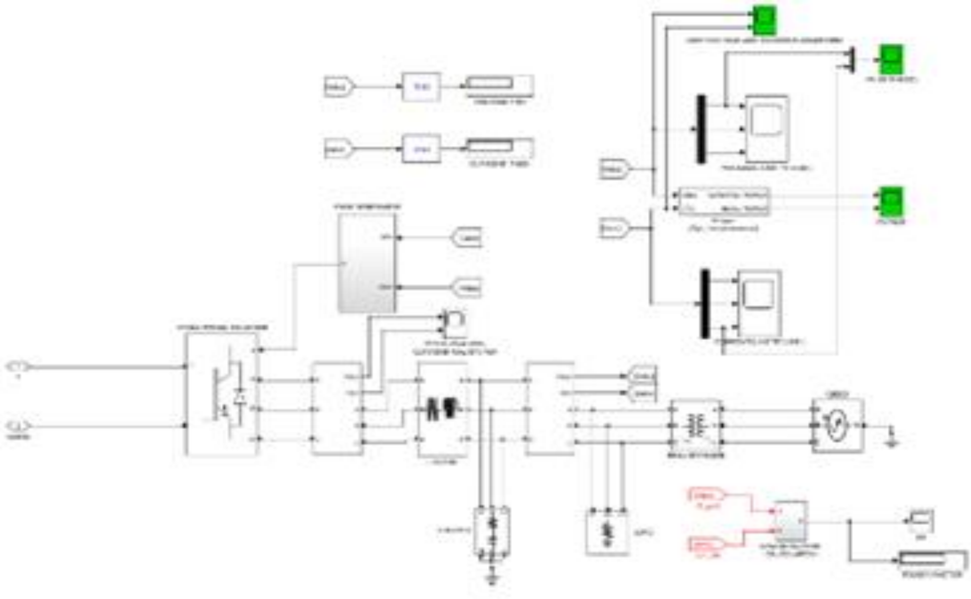


Figure 11: *Simulation Diagram for STATCOM inverter*

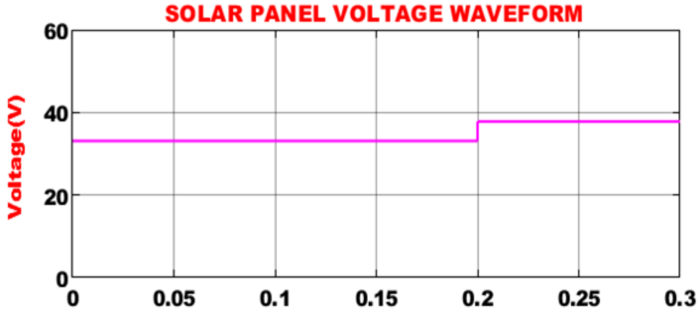


Figure 12: *Converter Input voltage waveform*

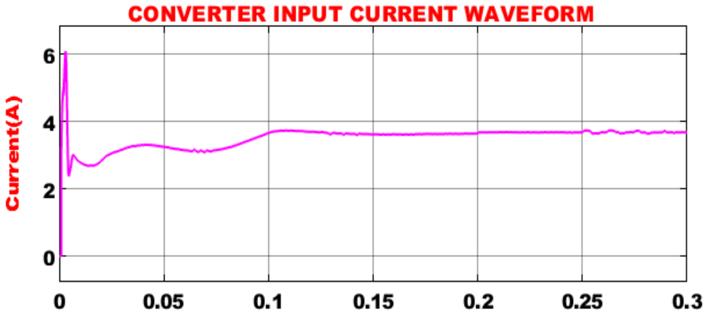


Figure 13: *Converter Input Current waveform*

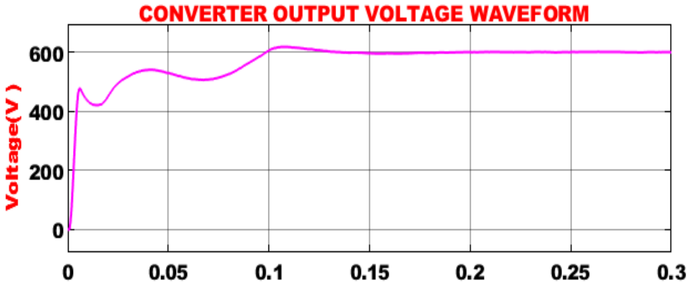


Figure 14: *Converter Output voltage waveform*

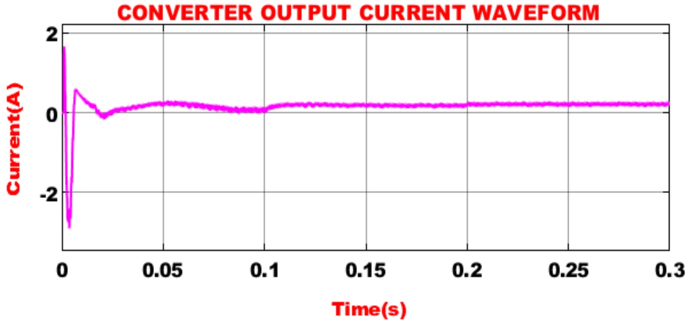


Figure 15: *Converter Output current waveform*

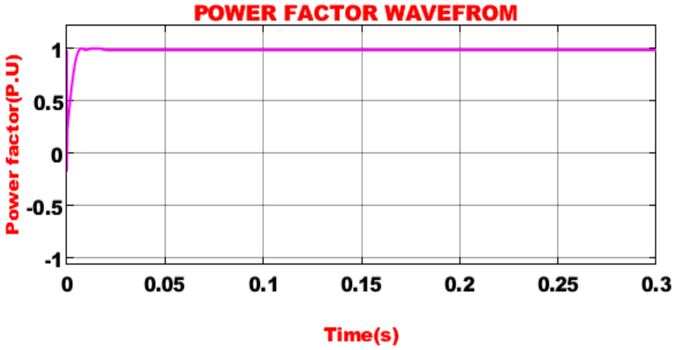


Figure 16: *Power factor Waveform*

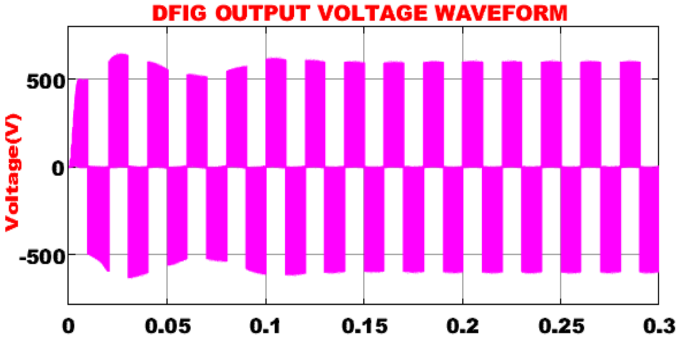


Figure 17: *DFIG output voltage waveform*

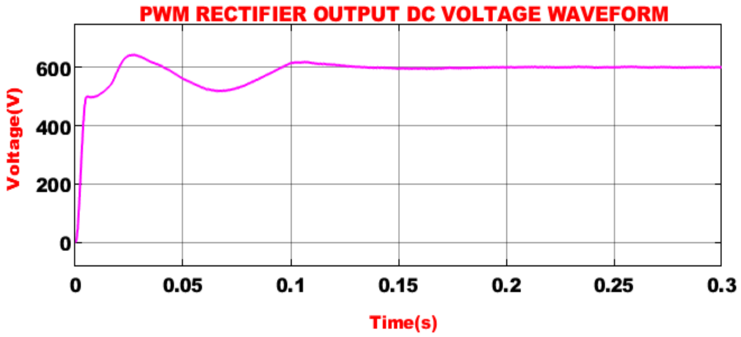


Figure 18: *PWM Rectifier Voltage Waveform*

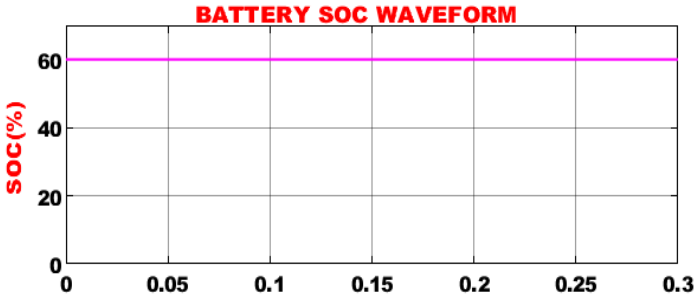


Figure 19: *Battery SOC Waveform*

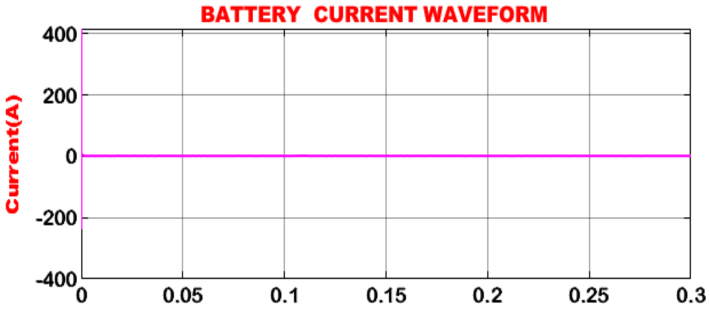


Figure 20: *battery current waveform*

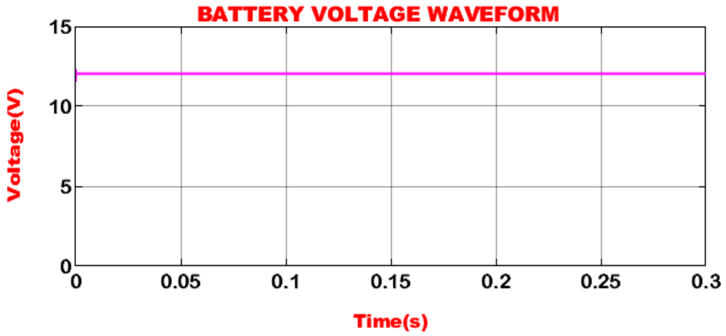


Figure 21: *battery voltage waveform*

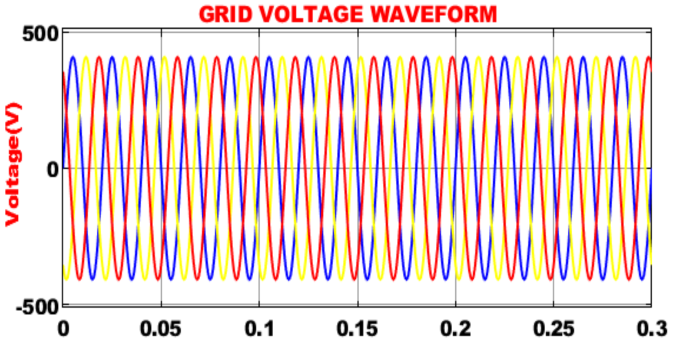


Figure 22: *Grid voltage waveform*

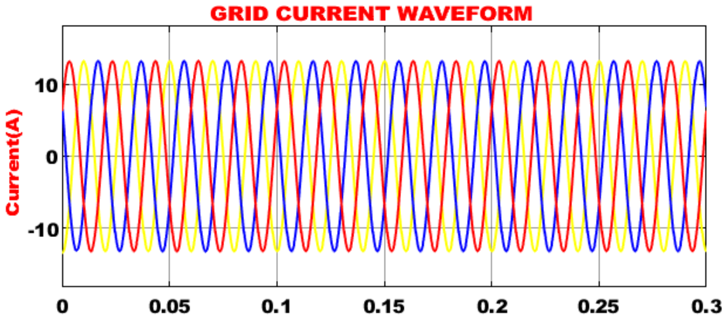


Figure 23: *Grid current waveform*

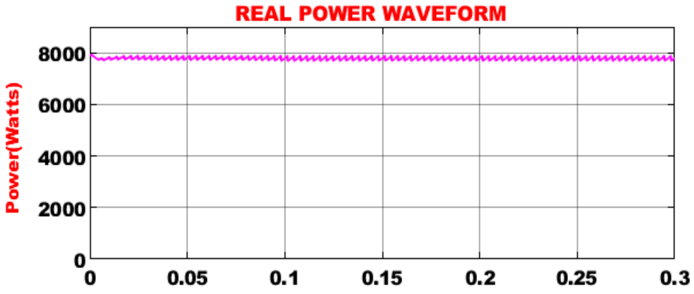


Figure 24: *Real Power waveform*

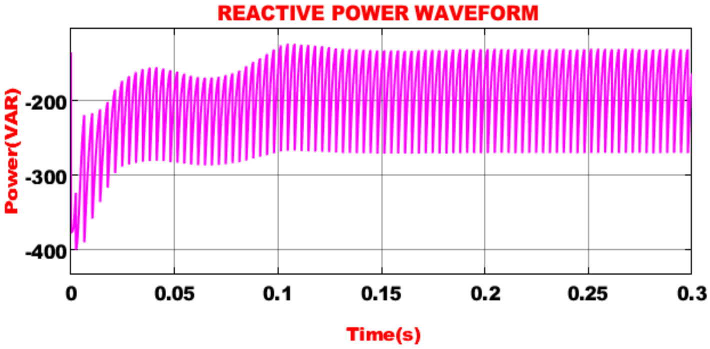


Figure 25: *Reactive Power Waveform*

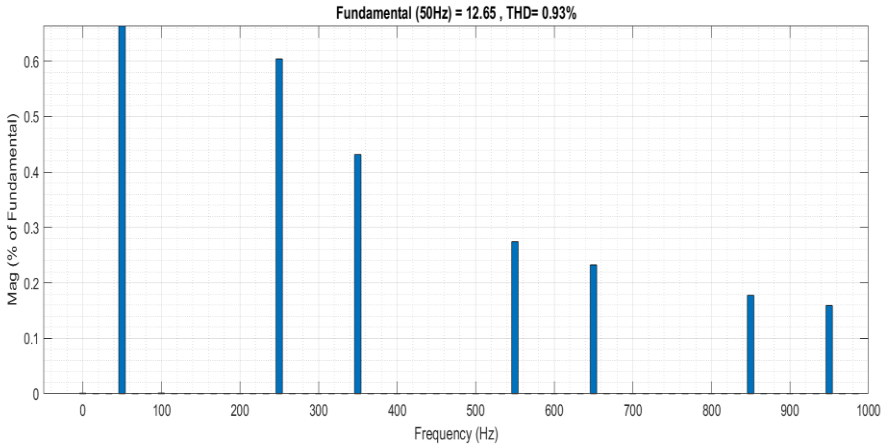


Figure 26: *THD waveform*

5 Conclusion

In this proposed system deals that the efficient and control management of railway stations with BMS based on microgrid stations to meet the limitations of rail transportation systems in terms of energy saving. In this project, the planned train station design makes use of solar and wind power, as well as batteries for an efficient storage system. The output voltage generated by the PV system is not efficient hence it is fed to a buck boost converter which delivers a boosted output of similar polarity of the input voltage. The converter operates neglecting the variation of irradiance level and offers improved voltage gain with minimized switching losses. A battery converter is incorporated with the PV system and WECS system to meet the growing power demand and to provide an uninterruptible supply to railway stations. The battery converter also provides power to the three phase grid acted as a bi directional converter. A 3ϕ VSI is exploited for converting fixed DC voltage to variable frequency AC voltage. An LC filter is employed for the attenuation of the harmonics of switching frequency. Thus, the projected system provides improved power quality with grid synchronization along with minimized distortion. A hybrid module was modelled in MATLAB/Simulink and the results are observed.

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