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Procedia Technology 21 (2015) 139 – 146

Procedia Technology

SMART GRID Technologies, August 6-8, 2015

Design and Analysis of a Sustainable LV Residential Microgrid

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Abstract

In the present scenario, power cuts are daily occurrences in many parts of the world. People all over the world would like to avoid these unscheduled power cuts and have a reliable, secure and clean electricity. For an affordable energy usage, sustainable power generation with renewable resources are highly recommended for environment friendly generation of energy with lower carbon footprints. They are isolated from the utility grid in case of any power outage or power blackouts. The key objective of this work is to model a self-sustained microgrid from the existing Indian distribution feeder, which means a small scale interconnected, centralized single controllable system where the particular arena is supplied with distributed energy resources like solar and wind instead of the main grid. The existing system of a particular region supplied with 42 bus system layout connected with 100 KVA transformer. Wind and the solar sources are designed individually and this hybrid energy is interconnected with the layout model to make up a small, modern self-sustained grid called the microgrid. The results are obtained in PSCAD software package with several case studies.
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Keywords: Microgrid; Renewable Energy; Solar and Wind.

1. Introduction

Conventional sources performance is deteriorating everyday and it has detrimental effects on the environment. Some other technical drawbacks include voltage fluctuations, voltage drops, poor conversion efficiency and fossil fuel depletion. Three possible solutions for an effective electrical system are highlighted.

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doi:10.1016/j.protcy.2015.10.081

First one is the generation. As the demand for power increases, the generation needs to be increased as well. Second one is the economy. Saving the costs develops complexity in creating awareness among the individuals and does not seem to be a wise option. The third one is the sustainable power generation. In order to have most economic operation and ensure optimum utilization, it becomes necessary to operate various distributed generation located in a region into an integrated system, which provides sustainable power generation. For this purpose, distributed energy resources like wind and solar are combined together to supply the utilities. This organization is centrally supervised and controlled. This type of efficient network is called as Microgrid (MG).

Self-sustained generation is accomplished by MG. One such MG is the Residential MG and the implementation of residential MG for transient analysis model is proposed in [1]. As the demand for power increases, MGs are expected to grow in the nearby future. It concentrates on application of MG for residential purpose in islanded mode of operation. MG system includes fundamental power system component models, two renewable energy sources models such as wind and solar and one energy storage source model. [1] and [2] elucidates the electricity obtained from photovoltaic cell with appropriate equations and descriptions. Beyond the fundamental models, MG also deals with modern inverters [3] and energy monitoring systems [4]. The authors [3] proposed the three-phase four-leg voltage sourced inverter based load unbalance compensator including its control algorithm. It focuses on the improvement of the power quality of standalone MG. The energy monitoring system [4] was developed with energy management system. Control board developed by DSP + CPLD that provides remote start and shutdown control for each internal MG. In order to achieve maximum amount of power sharing between the MG and the utility, the intelligent controllers are developed in the project. The optimal power flow controller is developed [5] for a utility connected MG based on a real-time self-tuning method. The controller scheme includes an inner current control loop and an outer power control loop which is based on a synchronous reference frame and the conventional PI regulators. Particle Swarm Optimization is an intelligent searching algorithm that is applied for real-time self-tuning of the power control parameters. [6] Represents the development of a table-top MG control system with the help of multi-agent systems. For efficient data communication in the multi-agent system, microcontrollers and Zigbee wireless communication technology are implemented in the hardware-in-the-loop simulation framework. MG stability is another essential parameter to be considered. [7] Simulates the dynamic performance of MG during and subsequent to islanding process. The model contains a solid oxide fuel cell, a single shaft micro turbine, a flywheel, two photovoltaic panels and a wind generator system. [8] Brings out the idea of reducing multiple reverse conversions in an individual AC/DC grid and also makes connections to various renewable AC/DC sources and loads easier. [9] Explores the significant use of DC MG to enhance the energy access. It focuses on the benefits of solar DC MG development in India. Various emerging trends like MG, suffer from economic constraints as their major drawback in developing countries. [10] Deals with financial analysis to implement MG power generation in rural settings. It gives different decision strategies to attain the appropriate solution for sustainable energy management.

With the inference of the review on MG, it shows that there is very little work required for restructuring of MG from the real time feeders. This work proposes the Design and Development of the self sustained MG for small group of residential consumers with their existing electricity board distribution system. The proposed model is simulated in PSCAD with the modelling of Wind Turbine and Solar System. The analysis of the system stability is done through the several case studies.

2. Existing Distribution System

The transmission system of an area is known as a grid. Each grid operates independently, though power can also be exchanged between the grids. This paper considers the layout of a particular region in an Indian distribution feeder. The Grid capacity is 11 kV. Step down transformer is used to step down this voltage to 440 V and is distributed to the consumers through the main bus. This main bus is connected to two feeders. For convenience, these two feeders are named as A and B .Feeder, which is to the right side of the main bus is named as Feeder A and to the left side of main bus is named as Feeder B. Feeder A comprises of 12 number of buses and Feeder B comprises of 30 number of buses. First bus on the Feeder A is located 400 meters away from the main bus. Bus number 4 on the Feeder A is connected to bus number 5 and 6. Bus number 6 is a point of common coupling for three buses namely, bus numbers 7,8 and 9. All the loads in Feeder A are domestic loads. First bus on Feeder B is located 50 meters away from the main bus. There is a minimum of 50 meters distance between each buses. Bus number 9 on Feeder B feeds two small feeders. Bus number 16 is split into two feeders vertically, top and bottom.

The loads are connected in such a way that they form a straight line from top to bottom. On Feeder B, bus number 24 is connected to agricultural load and bus numbers 6 and 7 are other loads and remaining loads are domestic loads. Assuming that all the loads are operating in 3 phase supply, load specifications are given in the Table 1.

Table 1: Specifications of the loads.

Type of the load	Feeder A	Feeder B
Domestic loads in KW	31	44
Agricultural loads in HP	0	5
Other loads in KW	0	6

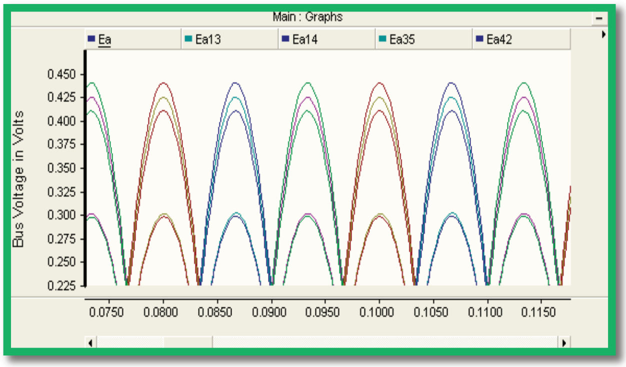


Fig. 1. Feeder B voltage decrease from first bus to last bus

In Fig. 1, it is clearly shown that the voltage is reduced from the first bus (Ea) to last bus (Ea42). Voltage profile of all the buses on both the feeders A and B are depicted in Fig. 2(a) and Fig. 2 (b).

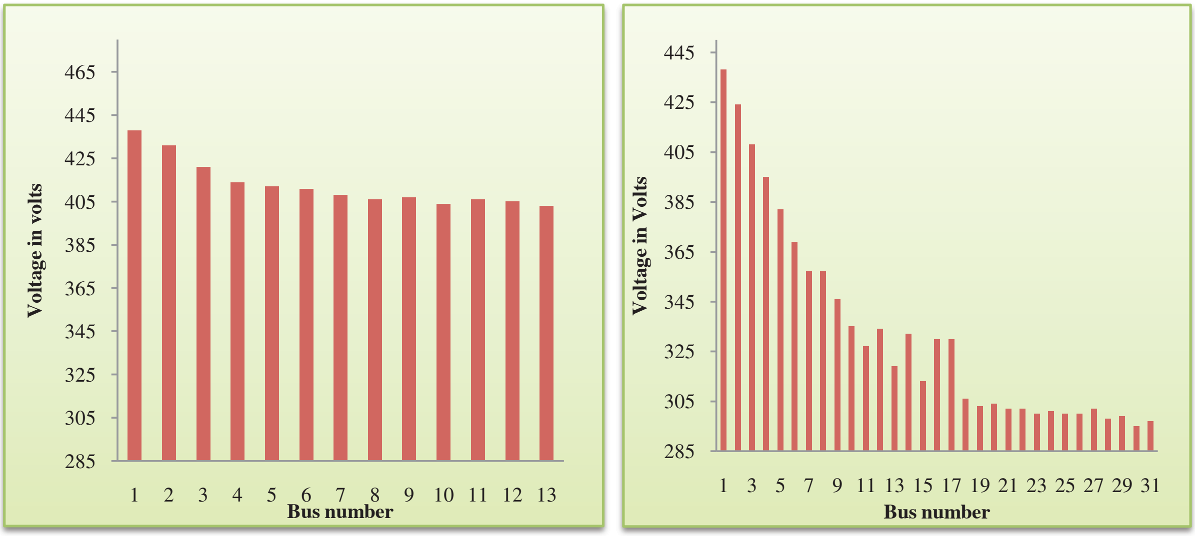


Fig. 2 (a) Feeder A voltage profile; (b) Feeder B voltage profile

The graphical result indicates the instability of the existing system. This will be overcome by the proposed MG feeders.

3. Modeling Overview

In this section, the distributed energy sources like wind and solar are modeled and analyzed using PSCAD.

3.1 Modeling of Wind Source

Availability of the wind is the primary concern to be noted in modeling the wind source model. The kinetic energy in the wind is converted to mechanical energy with the help of blades and it is further converted to electrical energy with the help of generator. In this way, power from the wind is extracted and used efficiently. For a typical three blade, MOD-2 wind turbines are used. The generator used here is permanent magnet synchronous generator.

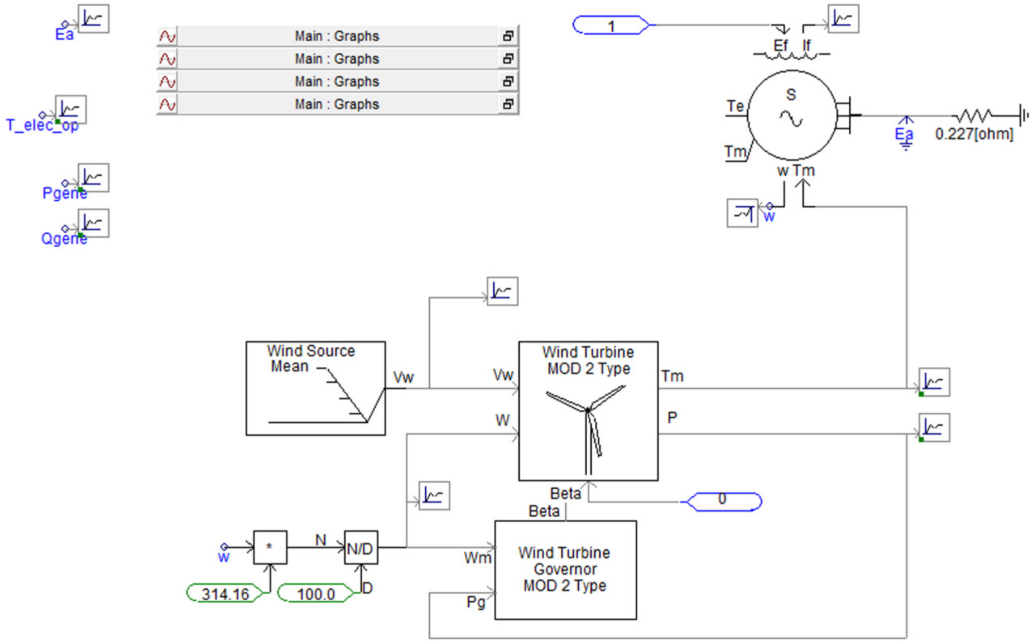


Fig. 3 Wind model

The output from the generator is 2.67 MW for a mean speed of 13 m/s. The wind power increases as the wind speed increases. Wind speed below 4 m/s is called as the cut-in speed. Speed below cut-in will not rotate the generator. The modeled system shown in Fig. 3 was tested under various load conditions.

3.2 Modeling of Photovoltaic Module

Modeling of PV source consists of three parts, a PV array module, DC-DC converter and an inverter. The PV model is shown in Fig. 4.

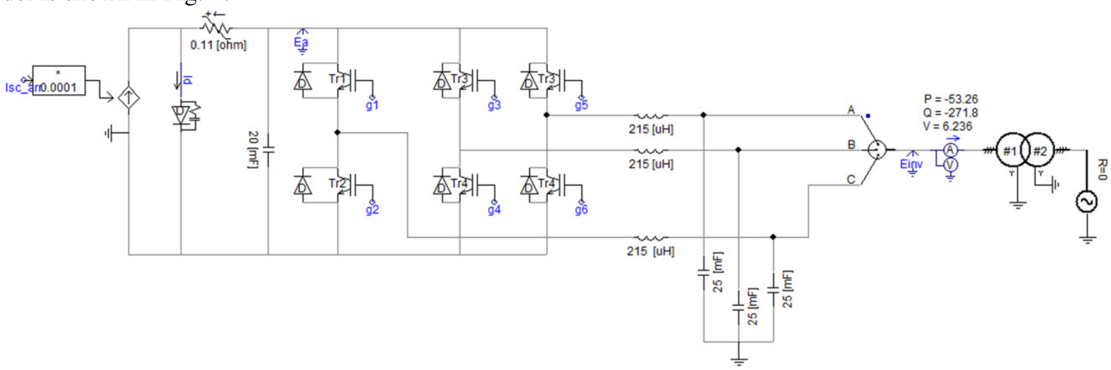


Fig.4 Solar model

The output of the PV model is DC. In order to tie the output of the PV model with the utility grid system, it is necessary to convert it to AC. In order to maintain constant voltage between the converter and the inverter, P and Q regulation is performed. The output from the P regulation in addition components with the phase shift of 120 and -120 is fed into the modulator along with the triangular wave carrier signal obtained from the trigger circuit .These two signals are compared in the comparator and generates 1 when the modulating wave amplitude exceeds the carrier wave. The trigger pulses obtained from the comparator are gt1, gt3 and gt5. Since the semi conductor devices are connected complementary to each other in the inverter, gt2, gt4 and gt6 are obtained from gt1, gt3 and gt5 respectively.

4. Reconstructed into MG

In this case, the entire layout is separated into three MG namely, MG1, MG2, MG3. Feeder A is taken as MG1. Feeder B is separated into two MG namely, MG2 and MG3. Each MG is provided with various renewable resources such as wind and solar. The inhabitants of each MG were given a clear description of the work and the government subsidies. Depending upon the total load calculated in that particular arena, available power from the wind turbine and the solar panel, the number of wind turbine and the solar panels are determined for each MG. MG1 has a total load of about 31kW and has 12 buses. Similarly, MG2 has a total load of about 26kW and has 12 buses; MG3 has a total load of about 28.75kW and has 16 buses. The residents of respective bus numbers have accepted to mount solar panels or wind turbines on their rooftop. Therefore, MG1 is powered with wind energy, MG2 is powered with wind energy and MG3 is powered with solar energy.

4.1 Isolated MG

Feeder A is taken as MG1 supplied with wind source. Feeder B is divided into two MGs. MG2 is supplied MG2 is supplied with wind source and MG3 is supplied with solar source. Fig. 5, Fig. 6 and Fig. 7 clearly depict that the MGs generate better results than the existing system.

4.2 Interconnected MG

Fig 14 shows the structure of interconnected MG. Interconnected MG is the case where the utility grid is not connected to the MGs. This structure elucidates the power sharing between the MGs. In other words, if power failure occurs in any one of the MG, then power shared from the remaining two MGs. From the Fig. 8, it can be understood that the voltage at different buses in the interconnected MG surpasses the voltage at different buses in the isolated MG. In case of power failure in all the MGs, then the necessity for grid connected mode appears.

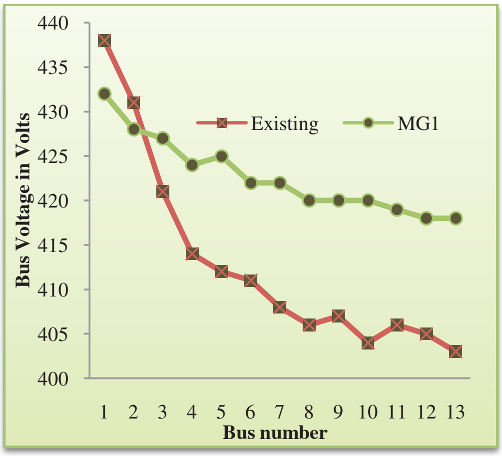


Fig. 5 Existing system Vs MG1

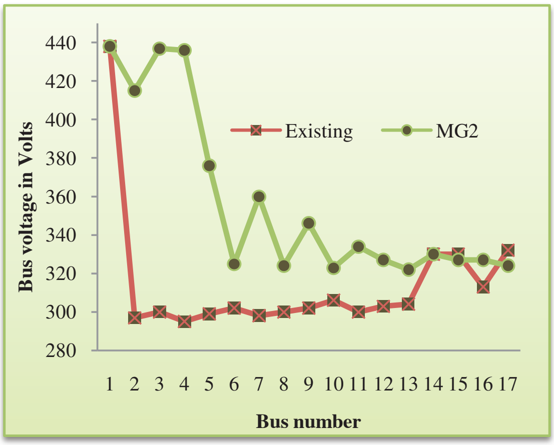


Fig.6 Existing system Vs MG2

4.3 Grid connected mode

In Fig. 15, it is clearly shown that the MGs are interconnected and supplied with both the renewable sources and the utility grid. This determines the switching operation between the renewable energy sources and the utility grid. For a clear understanding, switching operation for one MG is described in this section. The supply is provided from both the renewable sources as well as the utility grid. There are breakers connected in between them. Breaker 2 is connected between the main bus and the utility grid. Breaker 3 is connected between the main bus and the wind energy source, Ea. Ea is the output voltage obtained from the wind energy source model. Under normal operating conditions, the supply comes from the wind, the breaker 3 is closed allowing the supply to flow through the node Ea to the load. At the same time, the breaker 2 connected to the grid remains open. In case of power failure in the wind supply or in case there is no wind available in the particular site, then grid connected supply comes into action. In this case, breaker 3 is opened so that faulty system is isolated from the healthy one. The supply to the load is provided from the utility grid by closing the breaker 2. In this way, reliable supply is given to the loads. Similarly, the above mentioned description applies to other two MGs as well. Fig. 8 gives a comparative look on all the three cases. Interconnected MG gives better performance than the isolated MG. However, grid connected MG stands best among all.

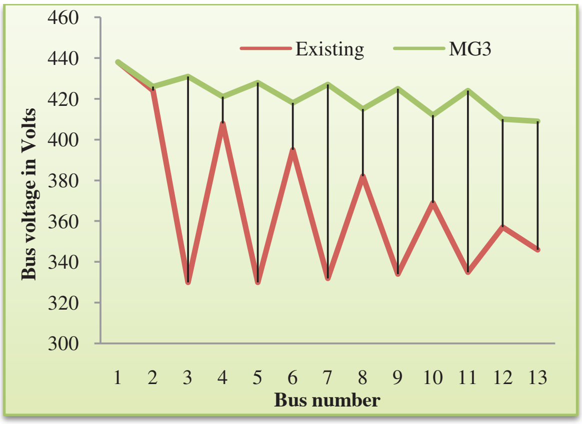


Fig.7 Existing system Vs MG3

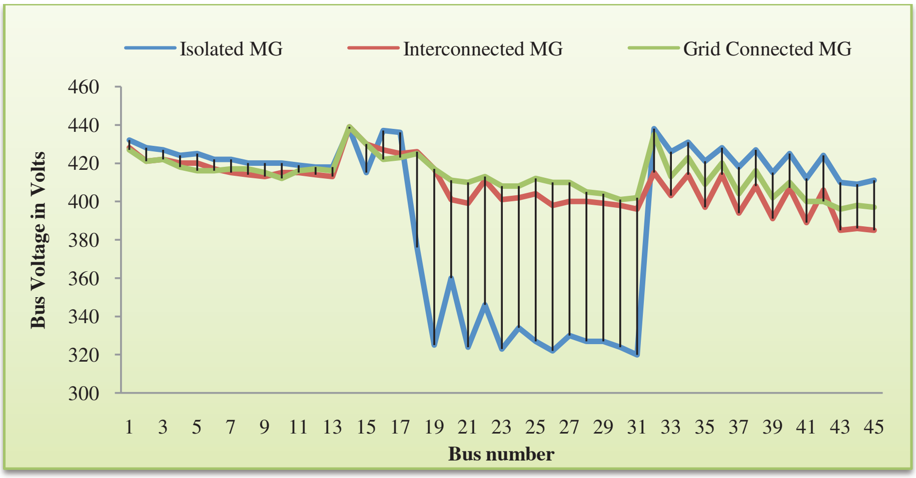


Fig.8 Interconnected MG Vs Isolated MG Vs Grid connected MG

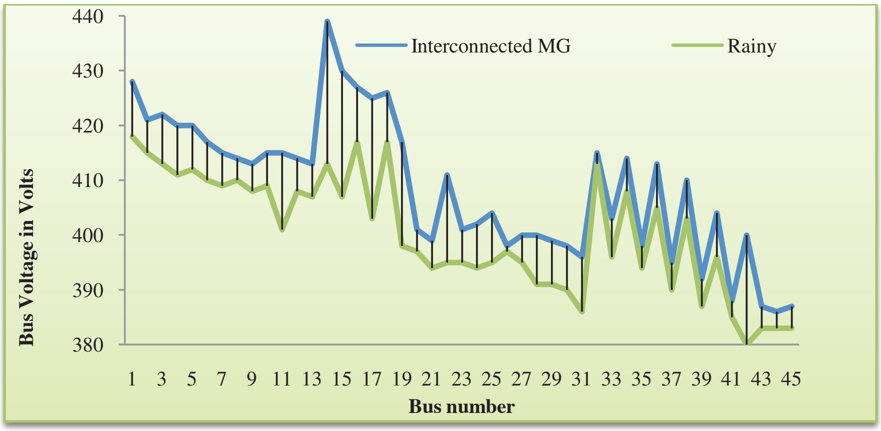


Fig.9 Interconnected MG Vs Rainy Season

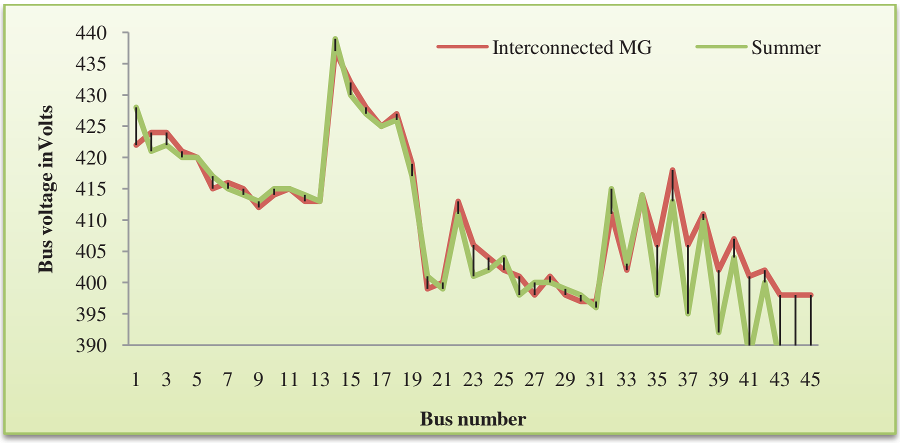


Fig. 10 Bus voltage at various buses in summer season

5. Case Study Analysis

5.1 Analysis of various bus voltages in the rainy season

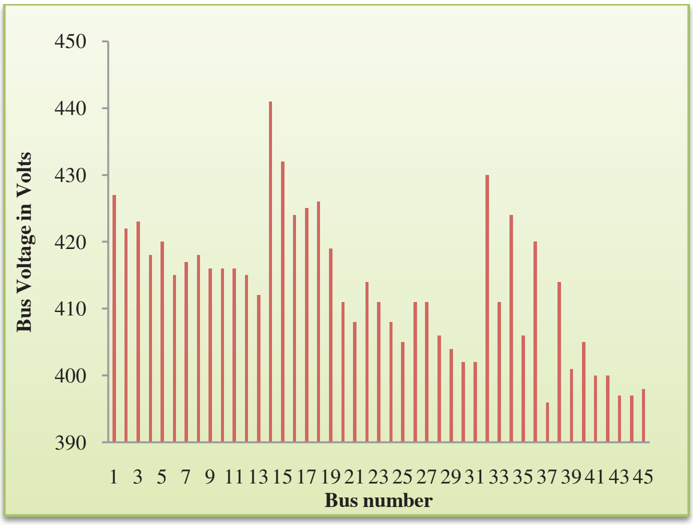
In this case study, various bus voltages are analyzed when the rainy season is taken into account. From this condition, it can be inferred that the output from the solar source is very low and hence can be neglected. The entire MGs are powered by wind source and hence obtained the results as shown in Fig. 9.

5.2 Analysis of various bus voltages in the summer season

In this case study, various bus voltages are analyzed when the summer season is taken into account. All the loads are increased by 25 percent compared to the existing system. The results are obtained as shown in Fig. 10.

5.3 Fault Bus Analysis and cost estimation

In this case study, voltages at various buses are analyzed under fault condition. Fig. 11 shows the variation in the output voltage when a fault occurs at one of the bus. Fig.12 shows a graph plotted between Investment and Pay Back Period for each MG.



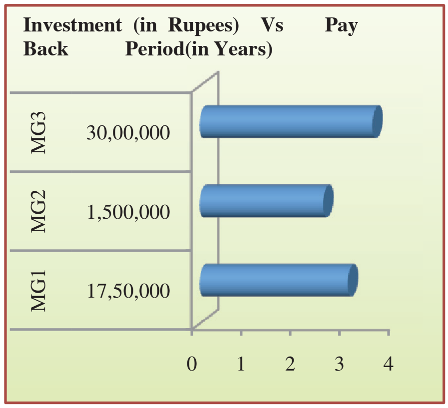


Fig.11 Bus voltages at various buses under fault condition

Fig.12 Cost Estimation

6. Conclusion and future work

A MG simulation model is developed in PSCAD/EMTDC software. The MG system model includes the renewable energy sources. Two DER units are modeled in this work, a wind energy source and a solar energy source. Though the results obtained in this work substantiate that it is better than the existing generation system in India, it slightly lacks in grid stability and there is also variations in the voltage levels. Grid stability and reduction of the fluctuations occurring in the voltage levels can be achieved by using optimal controllers, energy storage batteries and filters, which will be carried out in the future work. Apart from that, the MGs are ready to be implemented in the Indian Distribution Feeder.

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