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Reliable Energy Storage in Micro Grid

T. Yuvaraja*
Research Scholar, Department of EEE
Meenakshi Academy of Higher Education & Research, Chennai City, India

G. Sundar
Professor, Department of EEE
Arulmigu Meenakshi Ammam College of Engineering, Kanchipuram, India

S. Arumugam
Principal
GRT Institute of Engineering & Technology, Tirutani, India

Abstract
Storage devices can be used in a power grid to store the excess energy when the energy production is high and the demand is low and utilize the stored energy when the produced energy cannot meet the high demands of the consumers. This proposed work represents a micro grid consisting of a standardized synchronous generator, and connectional renewable energy sources, in order it has to be investigated as the effective energy flow control and transient stability improvement by employing thermal storage. Thermal storage, unlike electrical one is more users friendly and has longer life span. The effectiveness in power flow is much more effective. The proposed work contains storage capable on stability effects in micro grids which are evaluated. A suitable model is developed for the thermal storage and the grid's stability analysis is adopted by using conditional methods. Subsequently the optimal controller for the storage the stability of the micro grid is improved as verified through the simulations.

Keywords*: Energy storage, Synchronous generator, Distributed generator.*

****Author for correspondence*** yuvaarajastr@gmail.com

1. Introduction

Micro grid is a power supply network in which a cluster of small on-site generators provide power for a small community such as homes, parks, and office buildings. The increasing interest in micro grid is changing the dependency on the conventional centralized power system. In a centralized power system, power is transmitted from a large source to several utilities through a transmission line and a centralized control and hence can create shortcomings in the efficient power supply. By contrast, by employing localized power grid or micro grid such incidents can be prevented. During disturbances, the generation and the loads of a micro grid can separate from the main distribution system to isolate the loads from the disturbance and thereby maintain the continuity and reliability of the service without harming the main transmission grid [1]. Modern micro grids are regarded [2, 3] as small power systems that confine electric energy generating facilities, from both renewable energy sources and conventional synchronous generators, and customer loads with respect to produced electrical energy. It has been connected to the main grids or operated as isolated power systems [3]. In the micro grids, alternative energy sources such as renewable can be integrated with local consumptions [3] and are more efficient and initiate less environmental issues. This, in turn, enables performance optimization and enhances the supply reliability [4]. Furthermore, since micro grids are to be on or near the site which they are to supply, the loss during the transmission of electricity are reduced, which often the grid to effective [5]. Finally, micro grids can be modified according to the needs of the site it will be servicing. For example, it can be used only for lighting purpose or for working on big machinery.

As discussed earlier, micro grid encourages the use of renewable energy sources. Although renewable energy resources, classifies as wind and solar which enhance the production capability of a micro grid and address the environmental concerns [6], they impose economic operation and stability challenges to the micro grid due to their un-assumed nature. So the power variations are caused by intermittent nature of the renewable should be smoothed to serve the demand more appropriately and competently. The lack of correlation between the mentioned renewable energy sources' generation trends and that of the consumption challenges the economic operation of the power grid. Some cases of the complications due to renewable are that the wind energy is mostly available during nights when the consumption is at its lower level. And also, the peak energy from solar cells is obtained in the middle of the day, which is usually not the maximum load time and no solar energy is available on cloudy days. Hence, stored energy must be utilized to compensate for calmer periods (in case of wind energy) and for the loss of sunlight (in case of solar energy).

2. Energy Storage

The use of energy storages can improve the balance between generation and demand trends, and thus, will have a significant impact on the grid's economic operation. On the other hand, the grid's dynamics and its stability rely on the amount of stored energy in the micro grid. In a conventional power system with a large number of synchronous generators as the main sources of energy, the mechanical energy in the generators' rotors, in the form of kinetic energy, serves as the stored energy and feeds the grids in the event any drastic load changes. In micro grids, energy storage the stabilizing effects on the system due to the low kinetic energy stored in the micro grid's generators such as wind turbines and small synchronous generators. Consequently, the effective dynamic power flow control and stabilizing mechanisms, which engage energy storage, are of paramount importance.

Accordingly, the rising problem of imbalance between energy production and demand presented by the sporadic nature of solar and wind resources can be resolved using energy storage [7]. Storage devices can be used to store the excess energy when the production is high and the demand is low, and utilize the stored energy when the produced energy cannot meet the high demands of the consumers. Various storage technologies have emerged to fill the gap and accommodate the net demand variability [4]. The addition of storage technologies such as ultra-capacitors, conventional batteries, and heat storage can improve the economic as well as the environmental appeal of a micro grid's distributed energy resources [8]. Storage devices tend to make the net demand profile flatter and improve reliability. Among the various storage devices, the most common ones are electric and thermal energy storage. The popular electrical storage devices are batteries and ultra-capacitors. Batteries have higher specific energy than ultra-capacitors, and thus, can provide an extra energy for a longer period of time [9, 10]. The thermal storage, on the other hand, temporarily stores the thermal energy in the form of a hot or cold medium for later use. Electric storage has attracted much attention recently due to their technological improvements and economic advantages [11]. In most proposed micro grid operation strategies, electric storage such as batteries is used to store energy when there is extra generation, then at peak times the stored energy is instilled to the grid through power electronic inverters [12]. This will help make the generation trend flat which contributes to the use of the reserve generation capacity more economically. However, a major portion of the stored electric energy is normally converted back to thermal energy due to significant thermal energy demand [13] and hence thermal energy storage can play an important role in meeting consumer's needs for more efficient and environmentally friendly energy use.

A. Micro Grid Modeling and Thermal Storage

Recently, micro grids have earned numerous research interests because they can provide high quality, uninterrupted power supply to the consumers. Micro grids that are connected to the grid or independent are feasible and highly beneficial. Figure 1 shows the micro grid seen together with the main transmission grid [5]. Currently several research groups around the world are investigating the feasibility and benefits that micro grids may provide. There might be some issues related to micro grids such as harmonics associated with the system, however this paper does not attend such problems, but concentrates only on modeling of the system for the investigation at various conditions such as fault and sudden load change. The first micro grid under study in this paper is an isolated system as depicted in Figure 2 and is comprised of a conventional synchronous generator powered by a steam turbine, constant and variable loads, energy storage, and renewable sources of energy (wind and solar) which are connected to the grid via power electronics. The renewable sources operate at maximum available power (from wind or solar) to save costs of extra control mechanisms such as pitch control as well as to exploit the maximum natural energy.

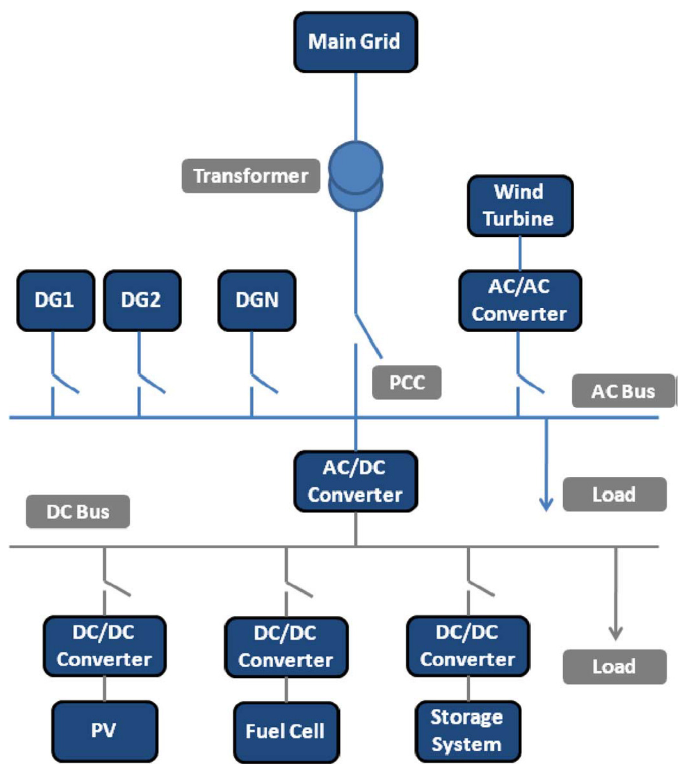

Fig.1: Micro grid Distribution Structure

Thus, their power is subject to change as the ambient energy fluctuates. Micro grid can be represented by a set of differential and algebraic equations to be solved simultaneously where the differential equations represent the synchronous generator dynamics and the algebraic equations describes the power balance in the micro grid.

B. Simulation Results

For validation of our theory, two power system topologies are considered. In both cases the simulations are performed for various conditions in this section to evaluate the effectiveness of the storage and the proposed controller design. The micro grid is considered to be a city or a few neighborhoods in a large city powered majorly by a local power plant and are depicted in Figure 2.

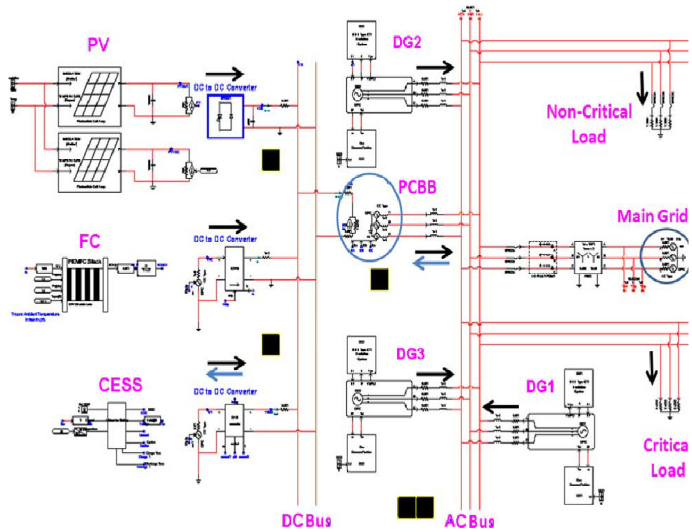

Fig. 2: Isolated Micro grid structure

C. Simulation Analysis

For our first simulation, the system in Figure 3 is designed. The system is

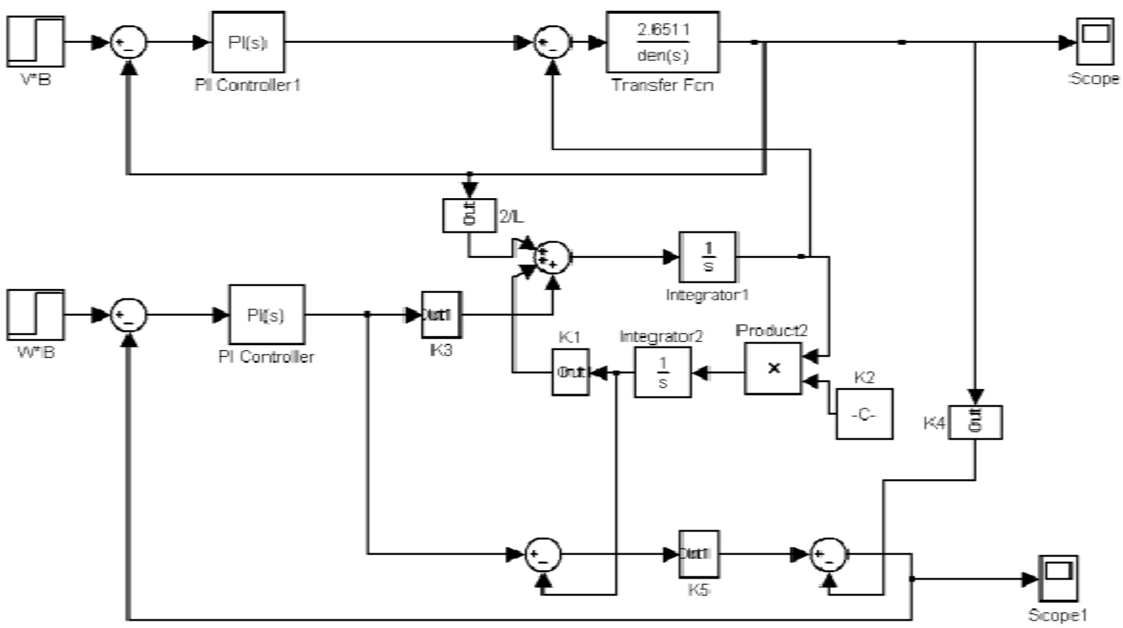

Fig. 3: Simulation structure on Energy storage conception in Micro grid

built in MATLAB/Simulink and consists of a 600MW synchronous generator to provide power at 22 kV. The generator models either a single large generator or an aggregation of a few small generators in a station in the city or in a close neighborhood. A Y-Y transformer steps down the voltage to 1.5 kV which is the voltage at which the loads (distribution network on consumers' side in the micro grid) operate. The loads in are represent the residential and commercial customers whereas the entire thermal under Energy storage devices, including residential and commercial are modeled as a lumped thermal storage in the simulation. Moreover, the renewable sources in simulate the distributed renewable sources in the micro grid. The renewable energy sources are modeled as the current source with resistance in parallel and they provide powers at constant phase angle. Although it is conventional to ignore the stator dynamics in transient simulations; that is, using synchronous generator one-axis or two-axis models, here we simulate the generator using a more detailed model including stators dynamics. However, the controller employs the generator one-axis model, as proposed in to provide the storage control signal. The goal of the control in this paper is to employ the storage's active power as a means of power flow control and improving the micro grid stability, and thus, provide a damping controller to smooth the power oscillations when disturbances occur due to fault or load change or renewable energy fluctuation. The controller design is obtained through linearization technique. In order to design the controller with linearization techniques, the sate space representation is used to model the power systems and their control inputs.

The simulations are performed with resistive-inductive loads in the system. Reactive loads are more practical type of loads in the system with considerable number of induction motors used in residential and commercial appliances. The loads used in the simulation have a power factor of 85%. The simulation results are studied to observe the improvement in the behavior of the power system dynamics due to resistor type thermal storage over the power system stabilizer and governor (PSS+governor) after a fault, after a sudden load change in the system, and during unpredictable changes of renewable sources' generation. Also, each result is compared with the outcome obtained using a battery storage in the system instead of the thermal storage using the same optimal controller to control the power of the battery. In order to simulate the battery, a similar model to the thermal storage is utilized as the used model will eventually alter the power of the storage; however, the rate of absorbed power is restricted in battery storage as batteries possess lower absorbed power rates than the thermal storage. The absorbed power rates are higher in thermal storage than batteries by a factor of 40% whereas these devices show the same power when giving power back to the system (injection power.) The injection power of the thermal storage can be interpreted as the portion of rated capacity that can be withdrawn from storage. In our simulations, in case of thermal storage and battery, the original power system stabilizer and governor are retained. The optimal controller with both thermal and battery storage employs for the LQR controller to increase the frequency damping effect. In all simulations, the thermal storage has an initial (steady-state) power, which is equal to the thermal power delivered to the buildings, and thus, no energy is stored in or extracted from the storage. During the disturbances, the power is different from the steady state and energy is stored or extracted from the thermal storage, and thus, the stored energy level is changed.

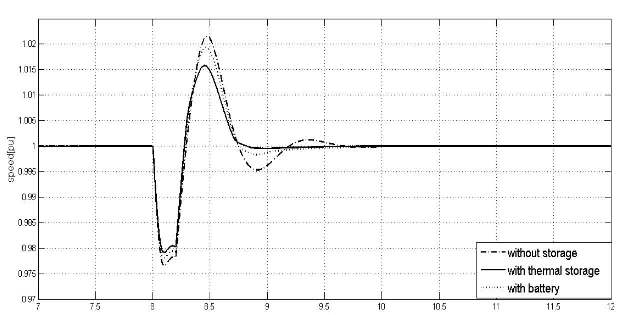

Fig. 4a

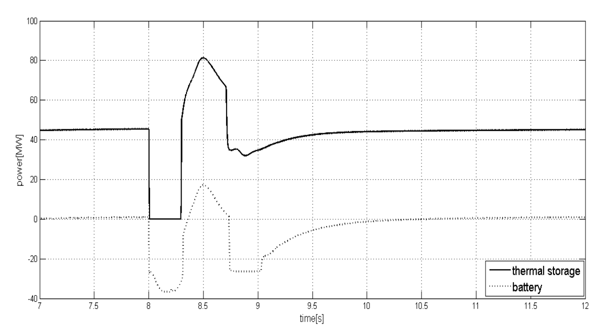

Fig. 4b

Figure 4 (a) Frequency oscillations of the micro grid under disturbance with no storage, with thermal storage, and with battery; (b) Active power absorbed by the thermal storages and battery (negative absorbed power in battery shows an injection or discharge of power to the micro grid)

D. Three-phase Fault

In this part, first, the frequency oscillations in the micro grid right after a fault is investigated with and without using thermal storage. Figure 4 compares the damping effects of the PSS and governor with and without the thermal storage or battery, which shows that damping behavior is improved by operating the thermal storage. The absorbed/delivered power by the storage before and after the fault (steady-state) as well as during the fault (transients) is depicted. Comparison of the performances of the thermal storage with the battery in Figure 4 demonstrates that although the battery can stabilize the system, the thermal storage still works better, which is due to higher absorbed power of thermal storage. The charging (absorption) power of the battery is normally 40% of absorption power of the thermal storage with the same capacity; however, their discharge (injection) powers are the same. In the simulation, hard limits are set on the battery power, accordingly, to limit its absorption power. Here the maximum discharge power level of the battery is set equal to the thermal storage maximum absorption power (about 40MW). Moreover, since battery has no steady-state power consumption, the battery power stays at zero during steady-state operation.

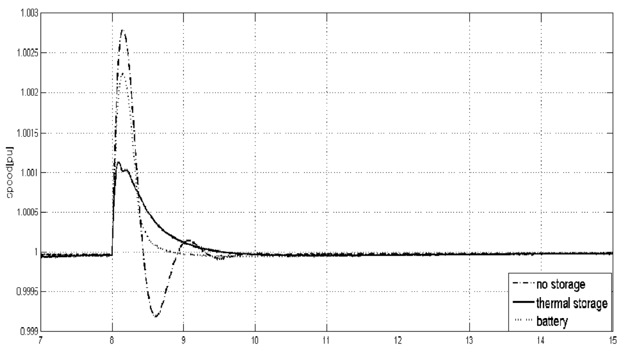

Fig. 5a

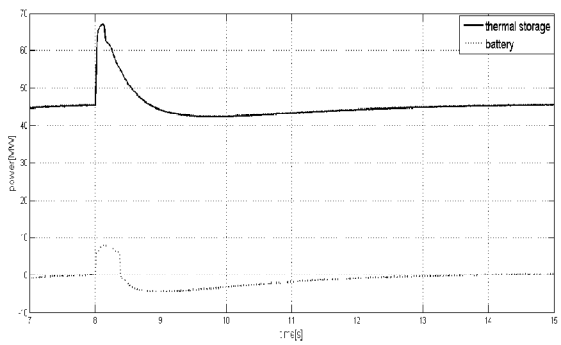

Fig. 5b

Figure 5 (a) Frequency oscillations of the micro grid under 20% load change in the load with no storage, with thermal storage, and with battery; (b) Active power absorbed by the thermal storage and battery.

E. Sudden Load Change

Next, the effect of a sudden change in the load is investigated in the micro grid. Figure 5 shows the case when total load in the system suddenly decreases by 20%. The thermal storage offers a rapid power compensation to improve the dynamic stability of the micro grid while the absorbed power of battery tends to exceed its maximum as seen in Figure 5(b). Also, as seen in Figure 5, the designed controller is robust and works even when the 20% load change in the system.

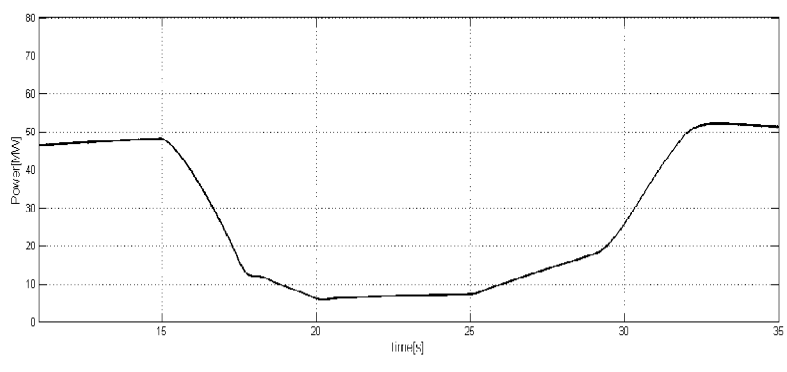

Fig. 6: Change in the power generated by renewable sources

F. Renewable Energy Fluctuations

Finally, the effect of sporadic nature of renewable sources in the micro grid is investigated and the demand response through power adjustment in the storage is observed.

G. Change in the Renewable Source Power

Here, the total generated power of the renewable is subject to change as shown in Figure 6 as a result of a change in the ambient energy. For instance, when a solar source is present, clouds in the sky will decrease the power generated by the solar energy source. Similarly, a wind source produces less power when the speed of the wind decreases. After introducing the change in the renewable power source, the responses of the micro gird with and without storage are simulated.

As shown in Figure 7(a), upon occurring the renewable power variations, frequency variation observed is not as significant with or without the battery and resistor type storage. However, as observed in Figure 7(b), in the case when only PSS and governor try to stabilize the system the voltage drop is substantial compared to the case when thermal storage or a battery is working with the grids.

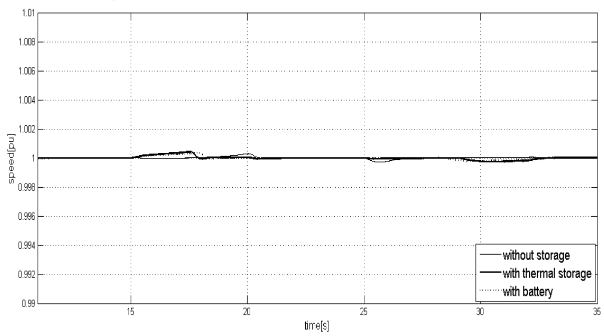

Fig. 7a

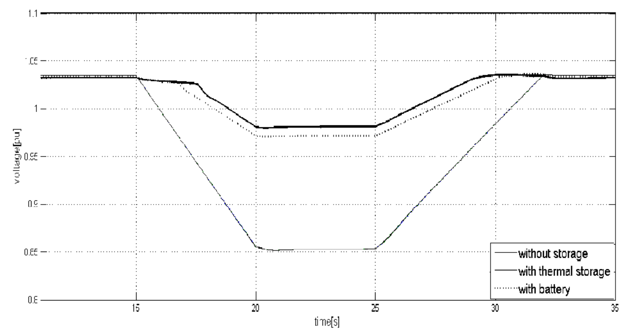

Fig. 7b

Fig. 7: (a) Frequency oscillations of the micro grid caused by the intermittent renewable source with no storage, with resistor type thermal storage, and with battery; (b) Voltage profile at a selected bus in the micro grid in the absence and presence of storage and battery.

Hence, the power absorption by the thermal storage and the battery is rapidly adjusted to the changes of the ambient energy to mitigate the voltage drop in the micro grid caused by variable generation and to prevent power changes in the synchronous generator (demand response). Although Figure 7(b) depicts the voltage of only a selected bus, a similar behavior was be seen in other buses as well. The heat pump thermal storage can adapt to the intermittent slow changes (in the range of a few seconds and longer) of the renewable sources' generated power. Thus, it is expected that voltage variations due to intermittent renewable sources are mitigated by heat pump thermal storage, which is displayed in the figure 8 compares the voltage profile at a selected bus with and without a heat pump and as indicated, the voltage drop has notably improved when a heat pump is used than the case when only PSS and governor are working to stabilize the system.

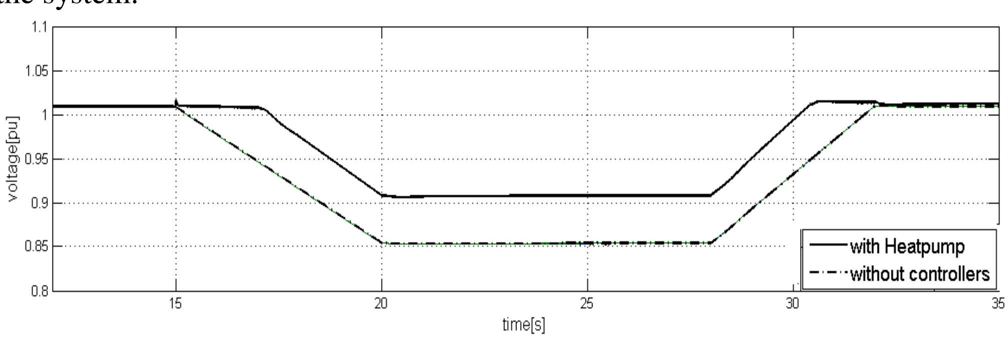

Fig. 8: Voltage profile at a selected bus in the micro grid in the absence and presence of heat pump

H. Random Change in the Renewable Source Power

The change in the power generated by the renewable source is usually not as smooth. The generation of power follow erratic path not easily recorded. Hence, to confirm that thermal storage is a better option in the micro grids in either case, one more simulation is performed assuming that the power produced by the renewable source is as random as shown in Figure 8. Thus, for the final part of the simulations in the first case, the renewable sources powers in the micro grid are subject to change as shown in Figure 8. The Figure shows the irregular power generated by the renewable sources in the system that can increase or decrease depending on the various factors. As seen in Figure 7 above, the thermal storage and battery work in a similar manner to establish flatter trend in the grid. Hence, in this segment the result of battery is not shown. Similar to the previous case, Figure 9(a) displays that no considerable frequency oscillation is observed in the system when only PSS and governor are working. However, as suggested in Figure 9(b) the voltage profile improves substantially when thermal storage is used in addition to PSS and governor.

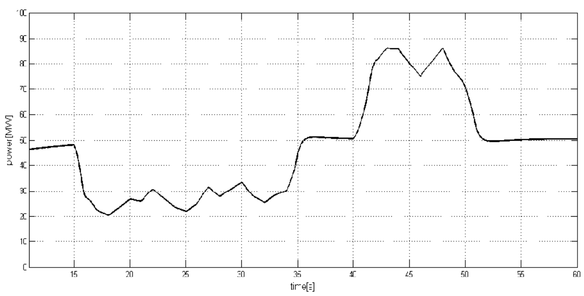

Fig. 9a

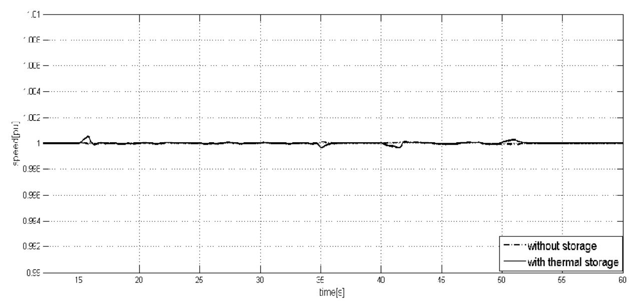

Fig. 9b

Fig. 9: (a) Frequency oscillations of the micro grid caused by the intermittent renewable source with no storage and with resistor type thermal storage (b) Voltage profile at a selected bus in the micro grid in the absence and presence of thermal storage.

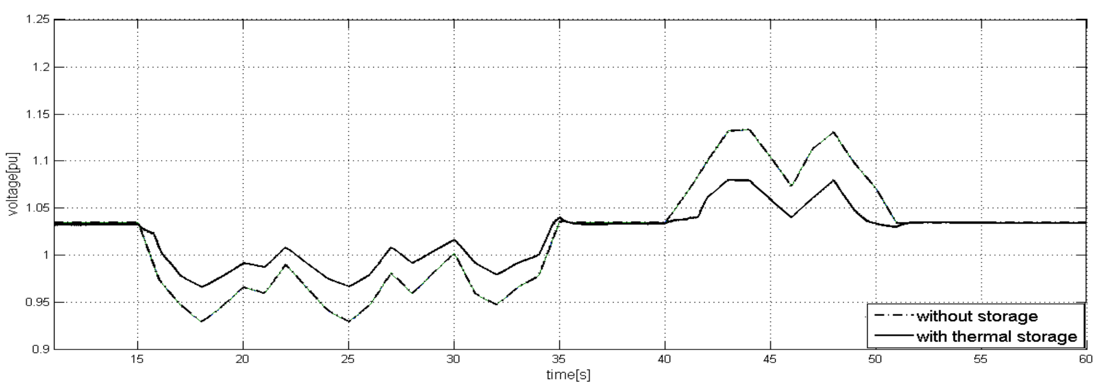

Fig. 10: Intermittent changes in the power generated by renewable sources

3. Conclusion

This paper presents a model of a micro grid and employs the thermal, battery, and heat pump storage under various circumstances to improve the micro grid stability and demand response. Firstly, a power system with a synchronous generator, renewables, and storage is modeled with a set of differential and algebraic equation. Secondly, the equations are linearized to establish a linear system. Thirdly, an optimal LQR controller is designed using the dynamic states produced with and without the observers. Finally, the effectiveness of the controller to dampen the oscillation is examined for various case scenarios such as three-phase fault, sudden load change, and the sporadic nature of the renewables. The results obtained with the controllers are compared with the results attained with just the PSS and governor of the generator to dampen the disturbances. The proposed model and the simulations demonstrate that by using storage along with a proper controller in a micro gird the following can be achieved.

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