Design a Novel Controller for Stability Analysis of Microgrid by Managing Controllable Load using Load Shaving and Load Shifting Techniques; and Optimizing Cost Analysis for Energy Storage System

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Abstract System stability is one of the most imperative requirements in a Microgrid designing to have an efficient, secure, and sustainable performance using renewable energy sources. In this paper, as a cardinal objective, the voltage and frequency stability is achieved by power balancing technique using load shaving and load shifting method. In particular on this occasion, controllable load is the only manageable load by which we can optimize cost using those two techniques and therefore the cost can be greatly reduced; thus saving substantial amounts of money to reduce electrical power consumption during peak/mid-peak hours. Moreover, the capacity of designed power system can be optimized by the same token. This paper proposes a novel controller to handle the frequency and voltage stability based on the generation and load; it can also track down the optimal cost line to facilitate the entire distribution policy. An energy storage system has also been proposed to manage those peak hours/loads in case of insufficient/surplus of the net generation and sub-sequential cost analysis has been presented as well. The feasibility of this method has been authenticated very meticulously by Matlab/Simulink verification

Keywords Algorithm Based Controller Design, Voltage and Frequency Stabilization, Load Shaving and Load Shifting, Cost Optimization, Energy Storage Sizing, Peak Controllable Load.
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1. Introduction

Microgrid, a small scale power supply network, is designed to provide power supply for small community that enables local power generation for local loads [1]. Compared to the conventional grid system, the microgrid technology, consisting of miscellaneous generating sources, administers much robust, consistent, and efficient performance as the power provider system. Employing the microgrid system, after a painstaking research on renewable energy over a decade, now it is possible to curtail the cost of supply energy into a large extent. Moreover, the power quality and reliability is greatly enhanced by the implementation of microgrid technology. Beside these conveniences, it effectively reduces the system emission as well. Here, the renewable energy resources in the form of distributed generation (DG) are being progressively integrated in power systems specially in microgrid arrangement to increase power generation, provide grid support and reduce carbon dioxide emission[2]. Using of distributed generations in the microgrid systems is becoming popular gradually to provide a reliable source of electricity to critical as well as non-critical loads [2-3]. Occupying these several distributed generation units, a microgrid can create a compact and robust system by using local information at each generator. It offers a number of lucrative advantages over the conventional grid including better efficacy; lesser energy is wasted in the form of heat. Microgrid can be the most reasonable answer of the world's energy crisis as the transmission loss is highly reduced. But, on the other hand, there are several types of disturbance that can lead to power imbalance which results certain instability of the frequency and the voltage. Compared with the conventional grid system, stability issues are more prevalent in the microgrids arrangement because power and energy ratings are much lower relating to the traditional load. If the load of the system is abruptly increased, the frequency and the voltage can become unstable. As a salient feature, microgrid system has backup energy storage option that provides the backup power in the case of power failure or any kind of disturbance and fault. This storage system with high charging and discharging rates is literally able to provide adequate energy to load when no continuous power supply is available there [4]. Shaving and shifting the peak controllable load, as the electricity price is high during peak time, helps to stabilize the entire system and to make the system economically justifiable for the consumer. Apart from this particular strategy, to regain the stability and bring the normal and stable operation, various kinds of controller are used for the power management after being subjected to unexpected changes into the load [4-14]. In a small system, frequency stability might be a great concern for any disturbance causing a significant loss. To mitigate the unwanted disturbances, various energy storage systems can be used to scale down the frequency fluctuation. Furthermore, as the peak hour tariff is much more than the mid-peak and off-peak hour, so the net cost can be reduced effectively by shaving the loads during on-peak time or shifting the load from on-peak time to off-peak time or mid-peak time depending on the load condition. Besides this, the voltage and frequency stabilization is also possible by shaving and shifting the load employing a controller that will manage the controllable load during peak hours, and thus will reduce the cost and improve the stability limit as well. In this paper, to meet the very particular objective mentioned above, an algorithm based controller is proposed which incorporates with the voltage, frequency as well as the net expense of the microgrid system. To obtain the stability, load shaving method is used by shaving the peak controllable load to retain the voltage and frequency at desired level. Besides this, to minimize the overall cost, a comprehensive analysis of the energy storage capacity as well as the energy storage cost optimization is illustrated to facilitate the consumers.

Some research work is held to improve the stability of the microgrid and make the system cost effective for the consumers. Tianjun , Huanna.,Jiangbo [5] proposed a system - energy managing state which is able to balance the energy in autonomous state and capable of managing the power in grid connected state under time-of-use pricing. In advance of the research, Logenthiran,, Srinivasan, Khambadkone[6] introduced a multiagent system which maximizes the power generation and minimizes the operational cost of the microgrid system. In another research, Rahimi, Zarghami, Vaziri,[11] provided a simple and effective scheme for peak-load shaving problem from a utility's perspective where a BESS system can potentially improve the voltage profile during the peak hours. Apart from this, Alam, Muttaqi ,Sutanto.[9] developed an intelligent strategy to control the local peak load shaving using a PEV battery.This paper proposes such a conctroller which incorporates the stability issue and cost issue at the same time.

In this paper, section II deals with the load side management analysis of the microgrid system. In like manner, section III presents peak load shaving strategy for voltage and frequency stabilization, section IV shows the cost analysis of power for summer and winter, section V deals with the energy storage capacity analysis for specific loads and section VI manifests the energy storage application and its cost optimization. In the later part, section VII presents the proposed controller to optimize the energy pricing and the load management based on three parameters such as frequency, voltage and costing respectively to increase the system stability. To verify all the cases and results, section VIII and IX are dedicated for the simulation and discussion with detail theoretical explanation.

The contribution of this paper is as following: this paper focused on the three cardinal parameters of the microgrid system economy such as frequency, voltage, and overall cost. Keeping these three parameters under consideration, a controller has been designed which will take care the microgrid stability issue as well as reduce the overall cost by implementing load shaving or load shifting technique depending upon the on peak, off peak, and mid peak period.

2. Load Side Management of Microgrid

Load management which is commonly known as Demand Side Management (DSM) possesses a vital role in microgrid operation. The peak demand can be easily minimized by controlling the energy demand which helps to reshape the load profile. As a result it increases the grid sustainability to a greater extent by reducing the overall cost and carbon emission level [6]. Many DSM and energy efficiency efforts are used for reducing total cost of meeting energy demand.. For proper understanding of the DSM Hamed Mohsenian[15] proposed a theory named as game theory where he established a demand side management strategy. The fundamental purpose of the microgrid management is to optimize the local production in the islanded as well as grid connected mode of operation. DSM has been using since early 80's and is massively used for load shaping techniques in order to firmly distribute the electricity [16].Logenthiran and Srinivasan[9] employed a strategy named as Heuristic optimization strategy where they proposed a demand side management strategy incorporating load shifting method specified for smart grid system.Apart from this many researchers have proposed many management system strategy[17] All household and commercial loads are mainly divided into two groups: critical load and controllable load. Critical loads are mainly the loads which can't be altered autonomously, so can't be controlled. This kind of load is more important than the controllable load which includes emergency life supports, financial transactions, elevator service etc. Another kind of load is the controllable load which can be controlled autonomously without remarkable effect on the consumer's life. Controllable loads are those loads whose usage can be shifted to some other point of time owing to the lack of generation [7]. This type of loads includes water heater, heat pump, air conditioning, pluggable electric vehicle etc. So active power p_k and reactive power q_k of load can be controlled by active current i_{pd} and reactive current i_{qd} respectivly and can be expressed as

$$p_k = v_{pd} i_{pd} + v_{qd} i_{qd} \quad (1)$$

$$q_k = v_{qd} i_{qd} - v_{pd} i_{pd} \quad (2)$$

The controllable load can be easily altered by changing the load current.

A microgrid consists of various kinds of loads as well as source. The conventional microgrid diagram with diverse sources and loads is given below

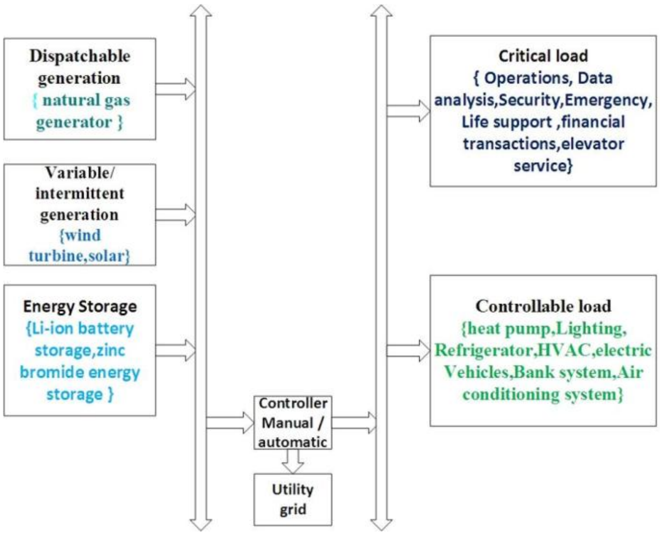

Fig. 1: Schematic Diagram of Conventional Microgrid Including Controller,Utility Grid as well as Diffrent Sources and Loads

The management system can decrease the output power of the controllable micro sources if there is a shortage of energy in order to maintain the frequency and voltage stability of the microgrid [6]. For maintaining the stability steps are taken to decrease the power demand at peak hours or to shift some power demand to off-peak hours which also makes the system cost effective. As the critical loads must run on the system, the controllable loads are mainly shaved and shifted to adjust the voltage and frequency[18].

Reducing the peak period demand and minimizing the total amount of power bought from the utility grid is a potential way to maximize the economic benefit of the system which helps to maximize the use of the renewable energy resources. The problem is mathematically depicted as a minimization problem and can be expressed as follows.

Minimize

$$\sum_{t=1}^{N} (P_{Load}(t) - P_{Objective}(t))^2 \quad (3)$$

[5]

Where $P_{Objective}(t)$ represents the value of the objective curve at time t [8] and $P_{Load}(t)$ represents the load power consumption at time t, which can be depicted by the following equation:

$$P_{Load}(t) = P_{Estimate}(t) + P_{Connect}(t) - P_{Disconnect}(t) \quad (4)$$

[5]

Where $P_{Estimate}(t)$ is the estimated load power consumption at time t and $P_{Connect}(t)$ and $P_{Disconnect}(t)$ are mainly the amounts of load can be connected and disconnected as desired at time t at the time of load shifting [6]. $P_{Connect}(t)$is divided into two parts: the amount of load increment at time t due to the connection times devices shifted to time t and amount of load increment device connections which were scheduled for times that precede , which can be depicted by the following expression:

$$P_{Connect}(t) \sum_{i=1}^{t-1} \sum_{j=1}^{M} X_{jit} P_{1j} + \sum_{k=1}^{t-1} \sum_{i=1}^{t-1} \sum_{j=1}^{M} X_{ji(t-1)} P_{(1+k)j} \quad (5)$$

3. Load Shaving Strategy for Voltage and Frequency Stabilization

Voltage and frequency has a drastic effect with power. When the load increases the frequency as well as the voltage decreases and when the load decreases the frequency as well as the voltage increases. Peak load shaving has become a great interest to utilities as the demand for power has grown with the increase in population, commerce, and industry [10]. As the stress in the distribution grid varies depending on the pattern of the peak period load profile, the value of peak shaving would not be the same throughout the whole peak period. Peak shaving would be most useful during the occurrence of the maximum load demand, whereas it would be comparatively less useful during the periods before and after the occurrence of the maximum load demand. Therefore, it would be more useful to establish a variable peak-shaving strategy [11].The fluctuation of voltage and frequency with the power and the recovering of power within a safety margin is given below in the following figures.

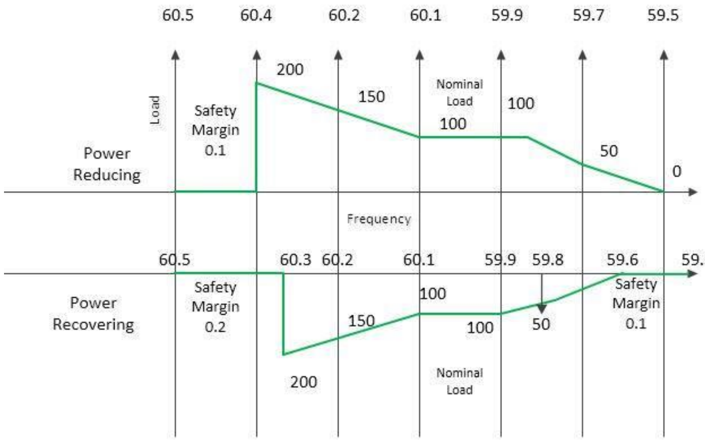

Fig. 2: Frequncy Stabilization Technique by Managing Controllable Loads Maintaining Safety Margin

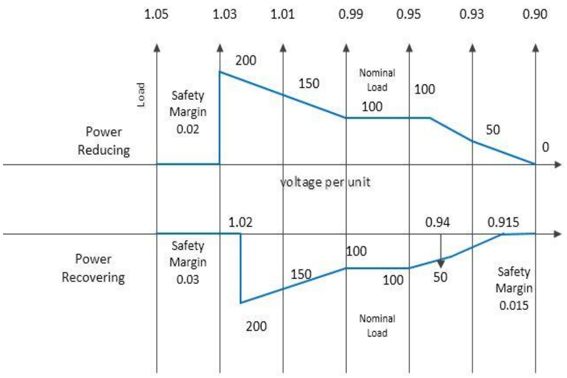

Fig. 3: Voltage Stabilization Technique by Managing Controllable Loads Maintaining Safety Margin

Here, as the source power is decreasing, so frequency is also reducing. Henceforth, a certain amount controllable load is cut out to maintain frequency stability of the regarding system. Here, it can be observed that the load power is 200 kW at the frequency of 60.4 Hz. The frequency reduces to 60.1 to 59.9 Hz, since the source power decreases consistently and so load is reduced to 100 kW at certain stage and after some periods the frequency reduces to 59.7 Hz load and the load power is shaved to 50 kW by further shaving of the controllable load and at frequency 59.5 Hz all the controllable load is cut down, to maintain frequency stability. On the other hand, when power is recovering and the frequency comes to 59.8 Hz; 50 kW controllable load is added. Here safety margin is 0.1 Hz. When the frequency comes to the range between 59.9 to 60.1 Hz all the nominal load are added to the system. Similarly when the frequency increases to 60.2 Hz another 50 kW load is further added to maintain the frequency stability and when it goes to 60.3 Hz another 50 kW e.g. total 200 kW load is added to the system. In this case safety margin is 0.2 Hz. In this way the frequency stability is maintained. All the loads are shaved and added are controllable load.

The Voltage curve is reduced in the same way so did the frequency as power is reducing and in the same way controllable load is cut out to maintain stable voltage across the load. When the voltage is 1.03 pu ,the system contains 200 kW load and 50 kW is shaved off when the voltage is 1.01 pu. When the voltage is reduced to 0.99 per unit the controllable load is reduced to 100 kW and it remains in this nominal value until the voltage reaches to 0. 99 per unit. When the voltage becomes 0.93 per unit the load is shaved to 50 kW and when it reaches to 0.90 per unit all the all controllable loads are cut out to maintain voltage stability.

When power is recovering we add load at 0.94 PU voltage for example 50 kW load at that point. In this system, we have considered safety margin is 0.015. Similarly, at voltage level 1.02 PU, we add 200 kW load where here safety margin is 0.03 PU. High voltage or frequency is more damageable to the system that is why we keep more safety limit at higher voltage side. Thus the reliability is maintained.

4. Cost Analysis of Power for Load Shaving and Shifting

Electricity consumption fluctuates quite a bit within the day. More loads are used during peak time and less load is used during off peak time. Time of use pricing is an important phenomenon which depicts the seasonal total charge for energy used depending on the specific time of a day as well as the current season the energy is used. Time of Use (TOU) pricing is an electricity pricing and billing mechanism that charges more or less for electricity based on the real cost of the power at that time. Generally electricity bill is determined by the using period and the amount of electricity used. Time of use pricing is classified in to three different categories according to the various parts of a day such as On-Peak, Mid-Peak and Off-Peak.The charge for using load during on-peak is not same as the off-peak. Peak power generation is much more expensive than off peak often twice as much and sometimes much more. Loads increase substantially in the hot summer due to the use of the seasonal load such as air conditioners and extra use of electric heaters during the coldest days of the winter; those are the times when the most expensive, extra electricity producing units are needed. The use of these "peaking units," in turn, makes the electricity produced at these times the most expensive. If it is possible to shave or shift the on peak load then cost can be minimized easily during summer as well as winter season. Time of use pricing is an efficient way for the consumers who use electricity late at night or at weekend. If consumers are not capable of shifting the energy use to off-peak periods it won't be much effective. The following figures depict the corresponding cost per kWh for on-peak, mid-peak and off-peak during summer as well as winter season.

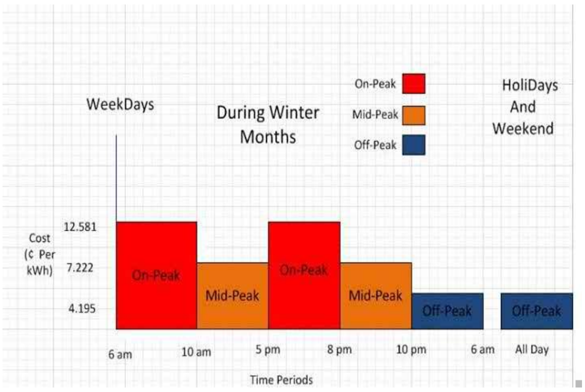

Fig. 4: TOU (Time of Use) Pricing during Winter Months

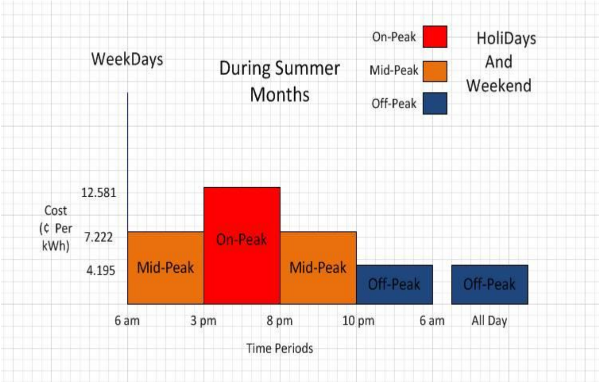

Fig. 5: TOU (Time of Use) Pricing during Summer Months

The following figure shows that, during winter season, the on peak TOU period is from 6am-10am and from 5pm-10pm, total 7 hours; for mid peak, the TOU period is from 10am-5pm and from 8pm-10pm; total 9 hours and for the off peak, the TOU period is from is 10am-6pm total8 hours. On holidays and weekend the all the loads are off peak load. In the same way during summer the on peak TOU period is from 3pm-8pm which is total 5 hours; for mid peak the TOU period is from 6am-3pm and from 8pm-10pm which is total 11 hours; furthermore for the off peak the TOU period is from 10pm-6am which is total 8 hours. On holidays and weekend all the loads are off peak load like the winter season. For the on peak load the demand for electricity is high and the consumers have to pay the highest price per kWh. The price for the on peak load is assumed to be 12.581 ₵/kWh. During mid-peak time the demand for electricity is between on peak and off peak and assumed to be 7.222 ₵/kWh. Demand for electricity is lowest for off peak time and assumed to be 4.195 ₵/kWh.Then the total cost for on-peak, mid-peak and off-peak load for winter and summer season for both the weekend and without weekend is given in the following table

Table1: Energy and Cost of the On-Peak, Mid-Peak and Off- Peak Period during summer and winter including Weekend

Time	Energy(kWh per Month)		Cost(($)	
(Without Weekend)	Winter	Summer	Winter	Summer
On-Peak	194.43	28.93	24.46	3.63
Mid-Peak	249.98	249.98	18.05.	18.05.
Off-Peak	221.79	221.79	9.30	9.30

Table 2: Energy and Cost of the On-Peak, Mid-Peak and Off- Peak Period during Summer and Winter excluding Weekend.

Time (With Weekend)	Energy(kWh per Month)		Cost($)	
	Winter	Summer	Winter	Summer
On-Peak	265.12	189.38	33.35	23.83
Mid-Peak	340.86	416.63	24.62	30.08
Off-Peak	302.97	302.97	12.71	12.71

The 3D plot of the energy and cost with regard to the on-peak, mid-peak and off-peak time is given below

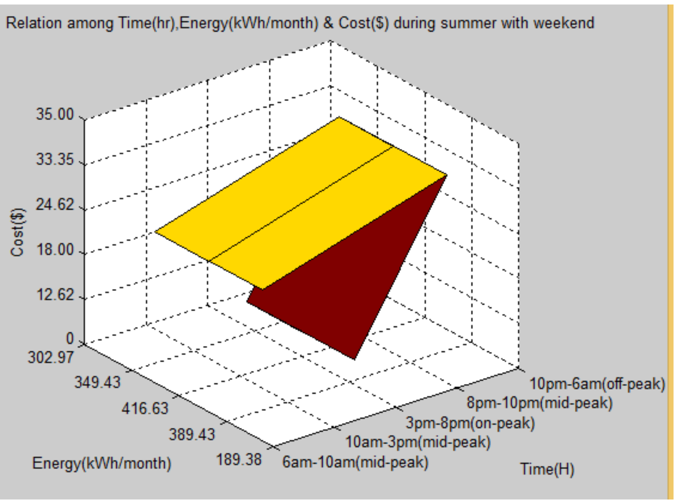

Fig. 6: Relation among Time, Energy and Cost during Summer with Weekend

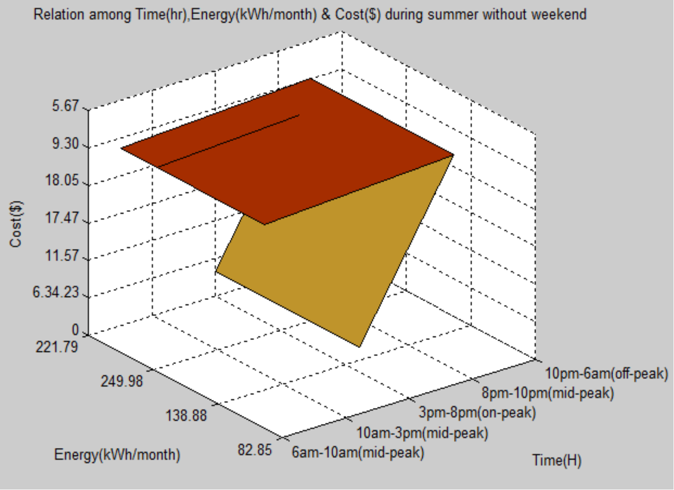

Fig. 7: Relation among Time, Energy and Cost during Summer without Weekend

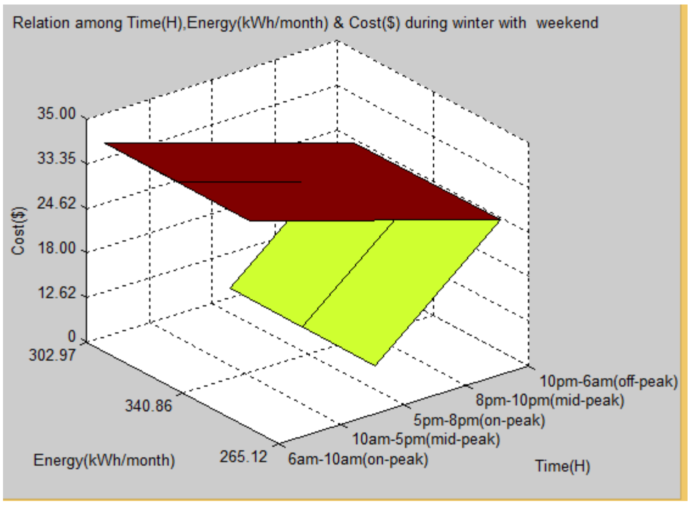

Fig. 8: Relation among Time, Energy and Cost during Winter with Weekend

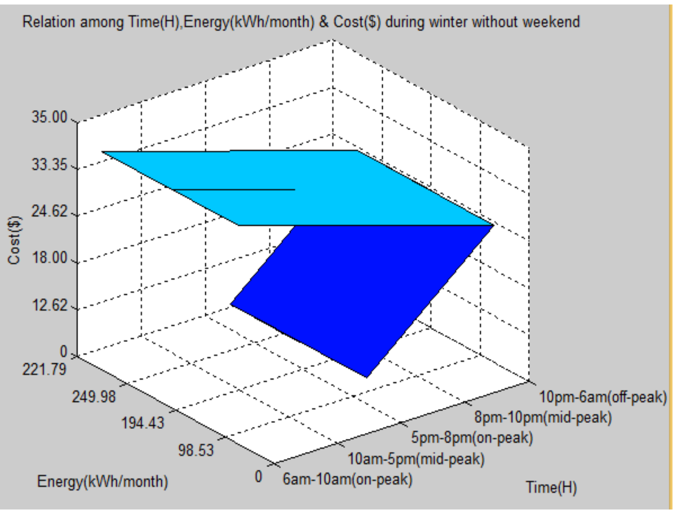

Fig. 9: Relation among Time, Energy and during Winter without Weekend

5. Energy Storage Capacity Analysis:

The usage of energy storage system (ESS) is getting more popularity now a days and it will be a potential micro source for the future microgrid network .Since using ESS is better than importing electricity from utility grid it is economically justifiable to be employed in power systems [15]. Power generation shortage Utilizing the ESS, generation shortage owing to outage, line fault or any kind of disturbances of main units and intermittency of renewable units can be solved easily by ESS system. Therefore ESS satisfies the microgrid reliability criterion [15]. If it is possible to implement a practical and accurate ESS model in microgrid system it is quite feasible to improve and enrich the operation of the system from both security as well as economic point of view. Excess electricity generated from the sources can be either exported to the utility grid or stored in energy storage. To diminish the intermittencies of the renewable sources, mismatches of the load, are some major problems to be solved since it affects the stability of the system. Usage of the energy storage system to store electrical energy when there is a surplus in generation and re-dispatch it properly when it is desired is a potential solution to the specified problem. [16]. Analysis of the capacity of the energy storage is to be undertaken first when considering ESS in the microgrid [16]. Energy storage capacity analysis is very important to know the potential capability of the energy storage to be used as backup to run certain load during off peak period [17-18]. It is a potential way to minimize the peak demand by encouraging the usage of off-peak electricity which assists to optimize energy efficiency and it is mainly referred as Load side management system [17]. Moreover, at off peak period when the generation is greater than the demand, the energy storage can be charged with the additional onsite generation and can be discharged at peak period to run the peak load when the demand is higher than the generation [18]. The state of charge (SOC) of an ESS is observed at all times and when it reaches 20%, the battery is prevented from discharging and when it goes

100% then it is prevented from charging and rest of the surplus will be sold out or and be used in another application. Efficiency of the charge and discharge cycle is controlled by the SOC at any given period [18-21]. Generally an ESS system performance is measured by observing some parameters such as voltage across cell, maximum discharge current, maximum charge current, total no of cell connected in series, maximum capacity of the cell, total no of batteries connected in parallel, higher capacitance acceptable limit, lower capacitance acceptance limit [18-21]. Sizing a stationary battery is important to ensure that the loads being supplied or the power system being supported are adequately catered for by the battery for the period of time (i.e. autonomy) for which it is designed. Since Improper battery sizing can lead to poor autonomy times, causes permanent damage to the cells due to over-discharge, causes over load voltages or low load voltages; the analysis of energy storage capacity is important. Moreover energy storage capacity analysis is essential to ensure that load being supplied can be supported by the specific energy storage. So, ESS needs to be optimally sized and hence the decreased operating costs validate the investment on ESS.

Charge and Discharge equation of energy storage is shown in eqn

Discharge: $S(t+1) = S(t) - \Delta t P_{ES,dis}/\eta_d$ (9)

Charge: $S(t+1) = S(t) + \Delta t P_{ES,cha}/\eta_c$ (10)

Here, $P_{ES,dis}$ is the power discharged by the energy storage and $P_{ES,cha}$ is the power charged by the supply to the energy storage and $S(t)$ the energy stored in the battery [15-22].

Mostly battery satisfies the following equation

$$\frac{dE(t)}{dt} = S(t) \qquad (11)$$

Here E(t) is the amount of energy stored at time $t$and S(t)is the charging or discharging rate. If S(t)>0 then energy storage in charging mode and if S(t)<0 then energy storage in discharging mode. The battery charging/discharging rate ought to satisfy $S(t)_{min} \leq S(t) \leq S(t)_{max}$. where , $S(t)_{min}$<0 is the highest battery discharging rate , e.g. the energy storage needs to be charged and$S(t+1)_{max} \geq 0$ is the maximum battery charging rate e.g energy storage needs to discharge .[23-25]

During the time of ESS installation, the minimum size for the ESS need to be considered while operates at islanded mode. Sizing a appropriate battery bank, in terms of its power and energy rating, might assist in shaving the peak demand as well as store the surplus energy and supply it in case of insufficient generation [16]. The overall cost of generating or importing electricity at particular peak periods as well as the cost of the energy storage system during peak power shaving should be associated and with the ESS rating (kWh) rather than the power rating (kW) in order to compare the two costs [16]. Therefore a small discharge period is preferred if it is possible. When the peak shaving is done the minimum energy supplied by ESS

$$E_{dis}^{min} = \int_0^T (P_{Load}^t - P_{generation}^{t,max})\delta t, P_{Load}^t \geq P_{generation}^{t,max} \qquad (12)$$

where is T is the time period, it is mainly assumed to be one day , δt is the interval of time which is assumed to be one hour , P_{Load}^t is the system load at time t and $P_{generation}^{t,max}$ maximum power generation by all the generators in a microgrid system. When

the generation of power by micro resources is more than the total amount of load , it can be used to charge up the ESS. Then the minimum energy charged to ESS is expressed as

$$E_{cha}^{min} = \int_0^T (P_{generation}^{t,min} - P_{Load}^t)\delta t, P_{generation}^{t,min} \geq P_{Load}^t \qquad (13)$$

Here, $P_{generation}^{t,min}$ denotes the minimum supply power by the micro sources.

Lastly the minimum value of ESS rating can be determined by

$$E_{BESS}^{min} = \max(\frac{E_{dis}^{min}}{\eta_d}, \eta_c E_{charge}^{min}) \qquad (14)$$

Here η_d and η_c is the discharge and charge efficiency and $\frac{E_{dis}^{min}}{\eta_d}, \eta_c E_{charge}^{min}$ are the minimum discharge and charge energy respectively.

In order to avoid the physical damage of ES due to deep discharge and high charge/discharge currents, the state of charge (SOC) and charge/discharge power should be limited to reasonable bounds

Now if $P_{ES,dis}{}^{max}$ is the maximum discharge power and $P_{ES,cha}{}^{max}$is the maximum charge power then the power limits [15-22].

$$0 \leq P_{ES}(t) \leq P_{ES,dis}{}^{max}$$
$$-P_{ES,cha}{}^{max} \leq P_{ES}(t) \leq 0 \qquad (15)$$

State of Charge (SOC) is an essential factor that identifies the state of energy storage discharge state as compared to the fully charged state.

And the SOC limit of the ES must be

$$SOC_{min} \leq SOC \leq SOC_{max} \qquad (16)$$

Where SOC_{min} the minimum is limit of SOC and SOC_{max} is the maximum limit of SOC

In most of the cases, the maximum discharge current is associated with the capacity of the

energy storage, If C/5 used where C is the capacity of the energy storage presented in Ah (this indicates that, if a 100 Ah energy storage is used , then the maximum discharge current supposed to be 20 A)[18-19]. This is suggested to permit a suitable battery lifetime (high C-rate discharges produce poor lifetimes). An analogous restriction (C/10) is placed on the maximum charge current which helps to protect the battery and enhances the 'charge efficiency' (high C-rate charging is not efficient). A lower limit of 20% is placed on the SOC in order to keep the battery safe from deep discharge ESS follows the analogous charge and discharge cycle every day. Because of the specified restrictions, an essential factor affecting lifetime is the collective energy (in kWh) stored by the energy storage. Hence the model suggests that a 250 Ah e,42 V energy storage will have an identical performance to a 500 Ah, 21 V energy storage (i.e. both energy storages have 10.5 kWh of electrical storage). Moreover, if these two energy storages' possessed different discharge rates(e.g. first one with C/5 and the second one with C/10), then the energy storage with the lower discharge rate will possess longer lifetime. Jenkins and Fletcher [19] using their proposed algorithm determined the appropriate specifications of parameter for an ideal energy storage A simple table of energy storage sizing for specific capacity and voltage is given below.

Table 3: Summary of chosen battery specifications of the given parameter to measure the performance of energy storage

Energy Storage Size(kWh)	Capacity (Ah)	Voltage Across Battery	No of Cells	Maximum Discharge Current(A)	Maximum Charge Current(A)
5.3	250	21	50	50	25
10.5	250	42	100	50	25
21	500	42	200	100	50
42	1000	42	400	200	100
63	1500	42	600	300	150

The energy capacity of energy storage must be able to meet the difference between the highest nergy and lowest energy. Now if $E_{acu} = \frac{P_{ES} \cdot T_{ES}}{3600}$ is the accumulative energy and P_{ES} is the power in kW by considering the SOC limits, the energy capacity of ES can be determined as follows

$$E_{ES}^{CAP} = \frac{E_{acu}^{max} - E_{acu}^{min}}{SOC_{max} - SOC_{min}} \qquad (17)$$

Where E_{ES}^{CAP} is the energy storage capacity and $E_{acu}^{max} - E_{acu}^{min}$ is the estimated energy variation of the accumulated energy of the system in kWh

6. Energy Storage Application and Cost Analysis:

In most of the cases energy storage is used as a backup system in microgrid e.g. when the load demand is comprehensively high than the generation .In some cases energy storage is more preferable to use rather than buying electricity from the utility grid [27] .It is possible to use the energy storage to run dc load and to run the load during peak demand and minimize the cost. Apart from this energy storage has some other application as well. It is depicted in the following table.

Table 4: Various application of energy storage

Category-1 Electric Supply	**Category-2 Ancillary Service**	**Category-3 Grid System**	**Category-4 Utility Customer**	**Category-5 Renewable Integration**
Electric Energy Time Shift	Load Flowing	Transmission Support	Time of Use(TOU) Energy Cost Management	.Renewable Energy Time Shift
Electric Supply Capacity	Area Regulation	Transmission Congestion Relief	Demand Charge Management	Renewable Capacity Firming
	Electric Supply Reserve capacity	Transmission and Distribution System	Electric Supply Reliability	.Wind Generation Grid Integration
	Voltage Support	Substation on Site Power	Electric Service Power Quality	

Cost Optimization is a very essential thing for any kind of system. The cost of the microgrid can be reduced in three ways. Firstly shaving the on peak and mid peak load since during on peak and mid peak hour the cost per unit is the highest; secondly, shaving the load from on-peak period to off- peak period as off hour possess lowest cost per unit and thirdly, using energy storage during peak hours instead of buying electricity from the utility grid. Main cost components ESS are the storage unit ($/kWh) and the power conversion unit ($/kW). The Cost Calculation of the Energy Storage is given below

$$Cost_{total}(\$) = Cost_{pcs}(\$) + Cost_{storage}(\$) \qquad (18)$$

Here $Cost_{pcs}$ is the cost of the Power Conversion System, $Cost_{storage}$ is the cost of the energy that is stored in the energy storage. Cost of the Power Conversion System (PCS) is mainly proportional to the rating of the power system. PCS is mainly used to tune the current, voltage, and other power characteristics of the storage based system. PCS is divided into two separated units in order to charge and discharge with different characteristics. [24-28].

$$Cost_{pcs}(\$) = Unit\ Cost_{pcs}(\$/kW) \times P\ (kW) \quad (19)$$

The storage unit cost is mainly proportional to the amount of energy stored. As all system has some efficiency then this equation can be modified as

$$\mathrm{Cost_{storage}}\ (\$) = \mathrm{Unit\ Cost_{storage}}\ (\$/\mathrm{kWh}) \times (\mathrm{E\ (kWh)}\ /\eta) (20)$$

Here E is the stored energy capacity

A system's Cost is mainly calculated by summing up the cost of the storage unit as well as the power conditioning system. Most of the cases the subsystems are treated distinctly as they provide different functions and being priced by diverse ratings. Most of cases power equipment's are priced in $/kW and energy storage units are priced in $/kWh. Because of this, costs of the individual subsystem are necessary, however they are often difficult to separate from purveyor system prices. Zakeri and Syri [24] suggested a framework of energy storage cost analysis. They divided the cost into two parts. 1. TCC (Total Capital Cost) and 2. LCC (Life Cycle Cost).TCC includes all the cost such as purchase cost, installation cost, PCS cost, BOP (Balance of Power) cost etc. PCS cost has been described before. BOP is mainly the additional cost required for power balancing. TCC can be easily calculated by summing up the storage cost,BOP cost and PCS cost[24].It can be expressed as

$$Cost_{TCC} = Cost_{PCS} + Cost_{BOP} + Cost_{Storage} \ (21)$$

On the other hand LCC is measured by yearly basis. LCC mainly includes operation and maintenance cost. To calculate LCC it is required to annualizing LCC cost since LCC is carried out by annual cost of energy [24-27]. It is done by a term [21] called Capital Recovery Factor (CRF)[24] which is the ratio of constant annuity that converts a present value in to stream of equal payment over a specified time.

$$Cost_{TCC}^{annual} = TCC \times CRF \quad (22)$$

Where $CRF = \frac{i(1+i)^P}{i(1+i)^P-1}$ (23)

So total Life Cycle Cost

$$Cost_{LCC} = Cost_{TCC}^{annual} + Cost_{Operation\ \$Maintenence}^{annual} + Cos$$

$$Cost_{Recycling}^{annual}$$

(24)

After considering all of this Susan [25] optimized the cost and performance of different energy storage system, is given below

Table 5: Energy Storage Cost .Efficiency and life cycle for different energy storage.

Energy Storage Model	Power Subsystem Cost $/kW	Energy Storage Subsystem Cost $/kWh	Round Trip Efficiency	Cycle
Advanced Lead-Acid Batteries	400	330	80	2000
Lead-Acid Batteries with Carbon Enhanced Electrodes	400	330	75	20000
Sodium-Sulfur Batteries	350	350	75	3000
Zinc/Bromine Batteries	400	400	70	3000
Lithium–Ion Batteries	400	600	85	4000

The 3D plot of the subsystem cost. Efficiency and life cycle as well as the Energy storage cost, efficiency and life cycle is given below which is drawn by the matlab

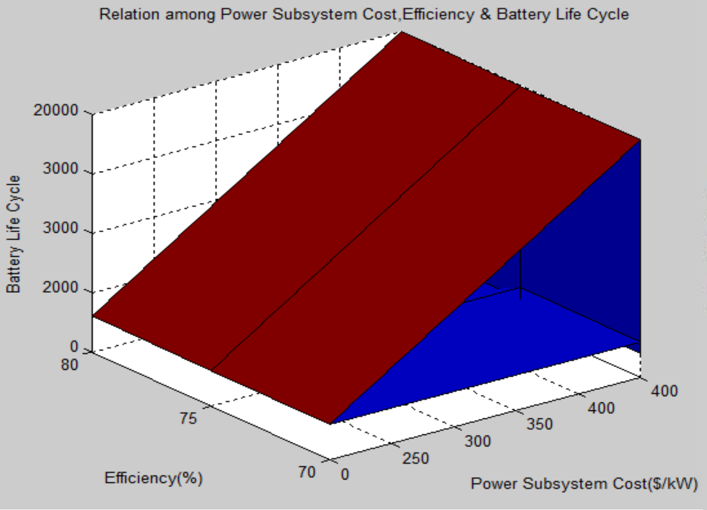

Fig. 10: Relation among the Power Sub System Cost, Efficiency and Battery Life Cycle

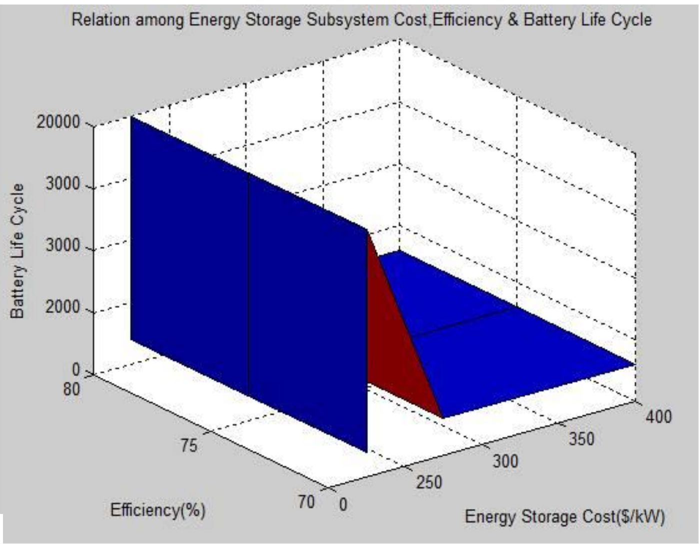

Fig 11: Relation among the Energy Storage Subsystem Cost, Efficiency and Battery Life Cycle

The 3D plot depicts that if the cost of the system is sufficiently large, then to support the system higher efficiency energy storage is required. However for higher efficiency energy storage; the energy storage must have a longer life cycle. . If it is possible to design a robust control system to maintain the frequency ,voltage and cost at the same time[34]. Moreover a comprehensive analysis of the energy storage along with the cost analysis makes the system more feasible [35-37] to theconsumers

7. Proposed Algorithm

Considering three parameters frequency, voltage and cost of the power an algorithm is proposed here to make the system stable as well as reliable for the consumers in terms of cost. The algorithm is given below.

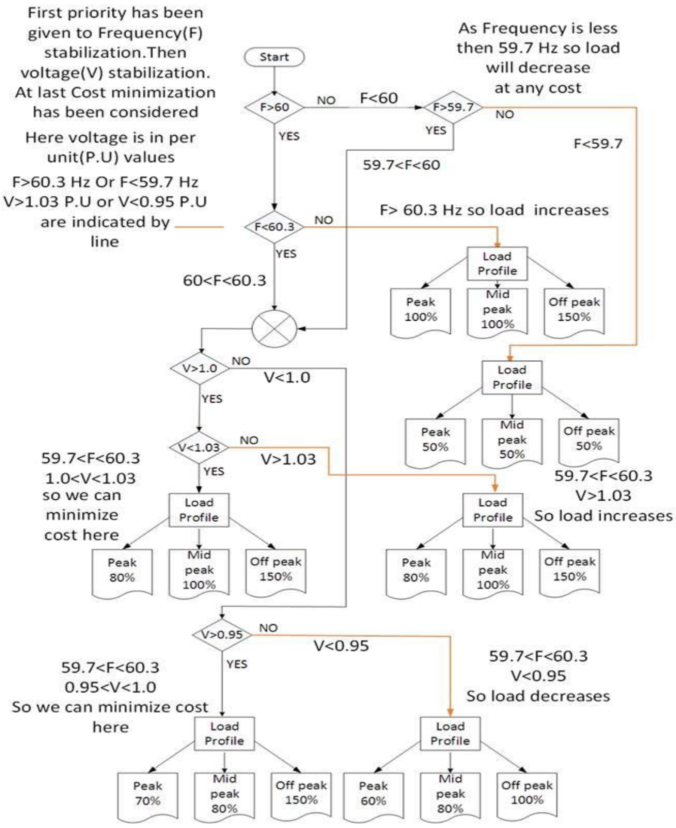

Fig. 12: Proposed algorithm controller in terms of frequency, voltage and cost

In this flowchart, first priority is given to the Frequency (F) Stabilization, then the Voltage Stabilization and lastly to the Cost of Energy. ere, the load power varies with the variation of frequency and voltage. When the frequency and voltage are in the Stability Range i.e. 59.7< F< 60.3 and 0.95< V< 1.03 respectively, the cost can be minimized easily. In this situation, the peak load can be shifted as desired depending on the frequency and the voltage to reduce the cost. During mid-peak or off peak period more load can be used as compared to the on peak period since mid-peak and and off-peak load are less costly than the on peak load. If F>60.3 Hz then the load is increased at any cost because if load is not increased system may become unstable. In this algorithm it is shown under this condition 100% ,100% and 150% load can be used in on-peak ,mid–peak and off-peak period. But if the frequency does not exceed 60 Hz only 50% load can be run on the system as if more loads is used frequency can exceed the stable range. Since frequency is the first priority so the cost is generally ignored where reduction of frequency is necessary to maintain stability Here a point to be noted that highest value of frequency in stable region is 60.5 Hz. But in this case load is altered up to 60.3 Hz for maintaining the safety margin .Similarly load are changed up to 59.7 Hz for maintaining the safety margin although lowest value of the safety region is 59.5 Hz. When V>1.03 p.u the more load must use in the system to maintain voltage stability so 80% on- peak load, 100% mid-peak load and 150% off-peak load can be used on the system without fluctuating the voltage and cost can be kept in to the optimal cost line as well. used during mid-peak and off –peak period but only 80% load can be used during on. When V<0.95 p.u. more load must be decreased so that Voltage will not reduce and cross the range. In this algorithm under this condition 60% on-peak load, 80% mid –peak load and 100 % off-peak load has been used to keep the voltage in the stable range. The voltage can be reduced to its lowest value which is 0.90 p.u . But the load is kept at 0.95 p.u for ensuring the stability. By using this controller it is possible to control the frequency, voltage and the cost of the microgrid system .As microgrid is an emerging technology [38-42] the proposed controller can be used in the microgrid system to make it more acceptable and for future practical usage throughout the world.

8. Simulation Result and Discussion

In this section, cardinally, the theoretical pedagogy and the conceptual consequences have verified in virtual platform such as MATLAB/Simulink through some rigorous simulation results. In addition, in the later part of this section, the advantages and the comparative conveniences of employing this proposed controller have been discussed reasonably. Here, for simulation work, the MATLAB function block has been used to execute the proposed algorithm along with the electrical network using Simulink platform. With a MATLAB Function block, it is facilely possible to write a MATLAB function for using in a Simulink model. It literally allows adding MATLAB functions to Simulink. In Simulink model, the controllable sources and controllable loads have been adopted. To visualize the entire arrangement, the Simulink diagram has been shown below.

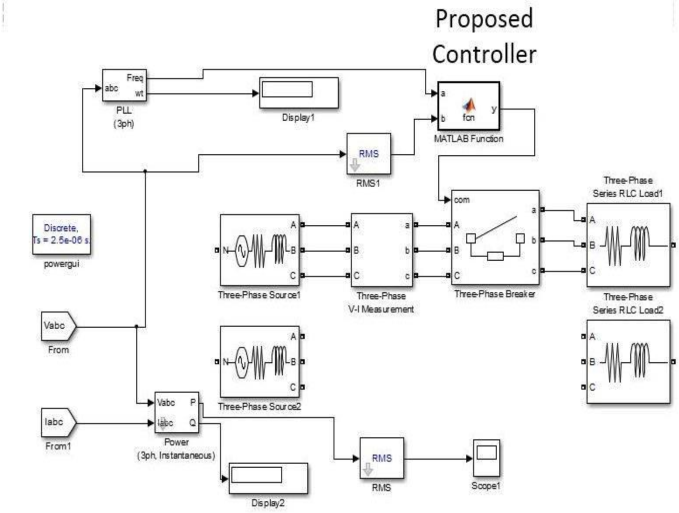

Fig. 13: Electrical network of the microgrid along with the MATLAB function block containing proposed algorithm

Here, from the network depicted above, it can be observed that the proposed controller is used in the MATLAB function block. In this controller, different numerical values of the frequency and the voltage can be taken as input. Then, based on the proposed algorithm, this controller controls the source and load power precisely with the application of a circuit breaker i.e. at specific time, the circuit breaker can be opened or closed by the command sent to it by the proposed controller. In this manner, it regularly controls the load by determining how much load should run on the on the system. We already know that a microgrid system necessarily deals with four key parameters: source power, load power, voltage and frequency. Since the controllable sources and controllable loads are used in Simulink; the voltage and frequency fluctuates with respect to the source power and load power . The specification of these parameters used in Simulink is given below.

platform

Table 6: Specification of various parameters used inSimulink

Time(s)	Source(kW)	Load(kW)	Voltage(V)	Frequency(F)
0	80	1	480	60.05
1	100	80	450	60.15
2	150	130	440	60.15
3	200	180	425	60.15
4	250	230	412	60.15

The simulink results are given below

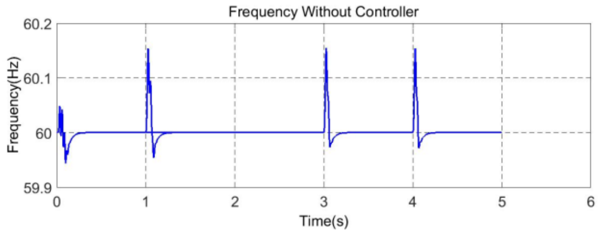

Fig. 14: Microgrid System Frequency When no controller is connected to the system based on Table 6

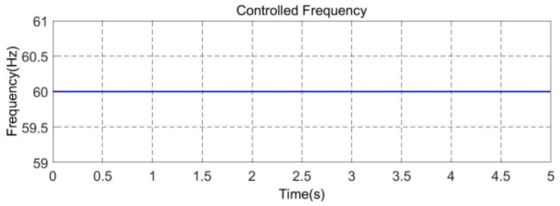

Fig. 15: Microgrid System Frequency when controller is connected based on Table 6

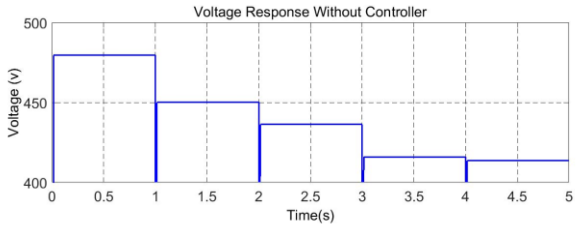

Fig. 16: Microgrid System Voltage When no Controller is connected to the System Based on Table 6

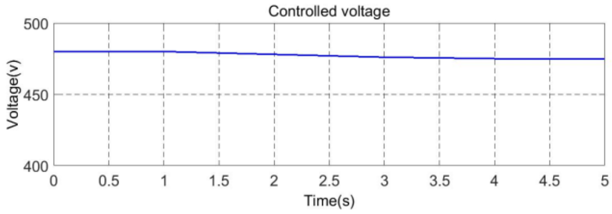

Fig. 17: Microgrid System Voltage when controller is connected to the System Based on Table 6

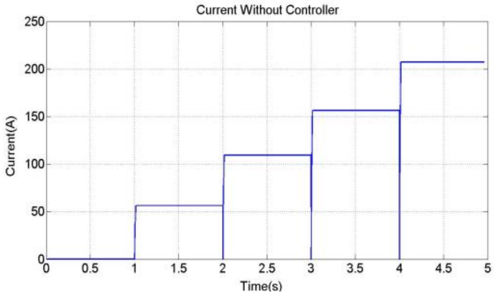

Fig. 18: Microgrid Load Current When no Controller is connected to the System Based on Table 6

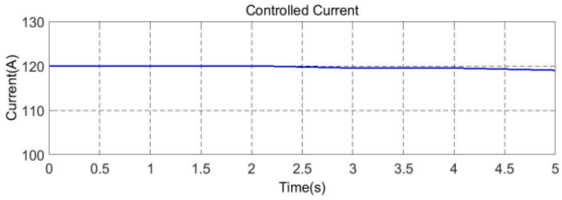

Fig. 19: Microgrid Load Current when Controller is Connected to the System Based on Table 6

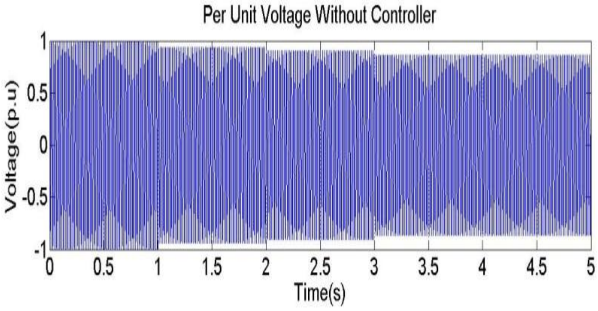

Fig. 20: Microgrid System Voltage at Per Unit When no Controller is Connected to the System Based on Table

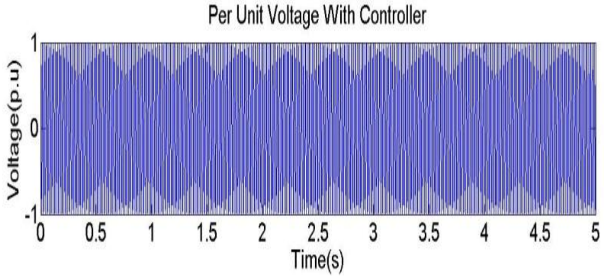

Fig. 21: Microgrid System Voltage at Per Unit when controller is is Connected to the System Based on Table 6

From the simulation, it is found that, in the elementary stage, as the power reduces, the frequency also reduces. Then, using the proposed controller, the load is firmly adjusted into the system to retain the frequency stable. The controller operated with a particular algorithm senses the differences between the actual frequency output and the desired frequency. After that, it varies the input and output power in a felicitous way to keep the frequency stable. In the same token, since the source power reduces, so the voltage across the load reduces reasonably. In a certain position, the voltage traverses the stable region and the system becomes unstable consequentially. In that case, the controller readily senses the differences between the actual voltage output and the desired voltage. After correlating these two values, it justly varies the input and the consequent output power to hold the voltage stable. Employing this controller, it is also feasible to execute the same function for the conventional p.u. consideration of the voltage. Here, to comprehend the case, per unit value of the voltage with controller and without controller is also depicted above.

9. Conclusion

In a nutshell, in this paper, a novel controller is introduced for the stability analysis of microgrid system by administering the controllable load. To regulate the controllable load, load shaving and Load shifting techniques are adopted to attain the desired stability. Besides the stability issue, a specific analysis is delineated on Cost Optimization employing the energy storage system with some rigorous simulation verification and authentic data in a tabular fashion. To present the proposal in a comprehensive manner, here, the load side management is described with a theoretical detail. After that, the load shaving strategy is specifically outlined for the desired voltage and frequency stabilization. Employing the load shaving and load shifting, the scope of cost optimization is analyzed to facilitate the consumer of the microgrid technology. After analyzing the energy storage capacity, its application and the system implementation cost, the algorithm that operates controller function is presented distinctly. All the regarding cases and the consequent results regarding the proposal are verified by the MATLAB/Simulink authentication. To conclude with firm promise, this proposed controller and techniques can be considered as a robust solution in instability issue with a reasonable cost cut in electrification.

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