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Smart Direct Current Nanogrid – A New Ray of Hope

[1]S. P. Jolhe, [2]Dr. G. A. Dhomane and [3]M. D. Karalkar

[1]Department of Electrical Engineering, Government College of Engineering, Nagpur, India

[2]Department of Electrical Engineering, Government College of Engineering, Amravati, India

[3]Department of Electrical Engineering, Priyadarshini J. L. College of Engineering, Nagpur, India

Email id: spjolhe@gmail.com[1], gadhomane@gmail.com[2], minalkaralkar@gmail.com[3]

ABSTRACT

The demand of the electric power supply is increasing day by day very sharply. This increases burden on the centralized power grid several times. The consumers expect an uninterrupted, reliable power supply and high-power quality. Power companies expect -increase in efficiency within the national grid, Pollution control demands - reduction in carbon emissions and remote communities expect power supply. This increase in expectations open the new area for the power systems research and design to develop new structures to meet these demands. This has shown the way to find the alternatives to centralized power generation and transmission(Grid System); which will be more reliable; prone to outages (due to long distance transmission), has very less transmission losses for increase in efficiency, which is a substantial contributor for reduction in global carbon emissions and more practical solution when supplying remote communities. The solution to above problem is "Nanogrid". Nanogrid is small structure which produces power closer to its point of consumption (Transmission line cost and transmission losses are reduced, hence more efficiency can be achieved), often utilizing carbon neutral, renewable energy (RE) sources (sun, wind). To maximize the efficient use of Distributed generation (DG), control structures are used to balance the intermittent RE power production with consumer power consumption. This paper explores the current research in nanogrid; it studies the existing nanogrid and uses the knowledge to give a brief definition of a nanogrid. The different techniques are discussed, which ensure the efficient operation of a small-scale DG system.

Keywords: *Distributed generation, Microgrid, Nanogrid, Renewable energy and Smart grid*.

1. INTRODUCTION

In The centralized power generation and transmission system (power grid or now "Smart Grid" [1-11] are currently facing a number of difficulties. The long-distance transmission lines delivering power from large central generators to consumers is the major problem. This has disadvantage of high structural and maintenance cost and more transmission losses which lead to lower efficiency [12-14]. The long-distance transmission lines are more prone to costly power outages due to heavy rain/snow or wind storms and long trees (e.g. bamboo tree) collapse and non-environmental condition like equipment failure due to age [15-17]. The centralized power generation can able to generate huge power but it requires fossil fuel to run, which produces 30.8 billion tons of carbon dioxide each year. This has not only polluting air but water also. These are all steam generator which uses the river water as its basic requirement. This produces other class of the problem for the world. Coal, oil and natural gas are the main fuel for the electric power generation in world [18]. Till date 47.5% of people living in the India as well as 1.2 billion people globally do not have access to electricity or continuous electric supply [19-20]. The main reason is their location either very far from the central grid, hilly area or dense forest where extending the grid is often considered uneconomical and unpractical also [21, 22].

The partial solution for above mention problem is Distributed Generation (DG) [23, 24]. If electric power is supplied to the remote location or to whom, who do not have access will have following advantages

A. Social
B. Economical
C. Environmental
D. Lifestyle improvement
E. Increase in GDP of nation
F. New business and market formation,
G. Employability

DG often utilizing carbon neutral, renewable energy (RE) sources (sun, wind). These sources are environmentally friendly and available in plenty amount, as well as free of cost. DG has advantage that it can form the power system which is close to the point of use. This has following advantages [25-26]

a. Reduces the construction and equipment cost for long distance transmission
b. Reduces the maintenance cost
c. Reduces break-down time
d. Increase efficiency.
e. Increase in reliability
f. Increase in stability of system
g. High power quality

The centralized power generation has ability to produce huge and continuous electric power with high power quality than the DG but it cannot be put near to load and requires huge investment. DG uses the renewable sources like wind and solar which have much low power capacity, this make it

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adaptable power solution to individual or bunch of people [27]. DG can be used in following configuration

1. Standalone
2. Grid connected

1.1 Standalone system

Fig 1 shows the structure of the standalone system. Normally it consists of single source of generation [21] with or without battery.

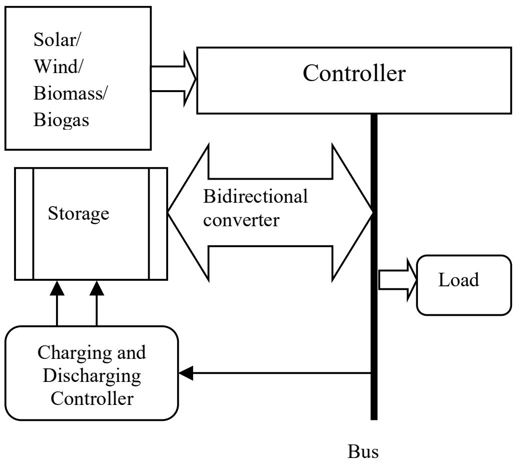

Fig 1. Standalone Power System Block Diagram

This is very popular in residential module. In individual residential module solar is general choice of source. This has many disadvantages as renewable sources are stochastic in nature. To overcome above mention disadvantage and make the renewable sources compatible to use and increase the reliability - hybrid system will be used in Nanogrid. Nanogrid uses the combination of different renewable and non renewable sources to satisfy the power demand of the consumers (small communities, university campuses and hospitals etc) and utilize the maximum capacity of renewable source. Different control strategies make the Nanogrid flexible and controllable system which can be connected to main power grid or operate individually (standalone) [28-32].

In Fig 1, if more than one source is connected, it is hybrid standalone power system. It may be renewable or non renewable generator. The best choice of the renewable resource for the hybrid system is solar, wind, biogas and biomass. The non renewable sources are diesel generator and fuel cell.

1.2 Grid connected

Fig 2 shows the structure of grid connected distributed generation. In this system power is utilized in priority wise. First priority is consumer own load and second, if additional power produce or no load then power is given to the grid. It requires special type of the energy meter to measure the power taken from the grid and power supplied to the grid. Government is also giving promotion to this activity [33]. This directly increases the generation of the nation, although with very little fraction.

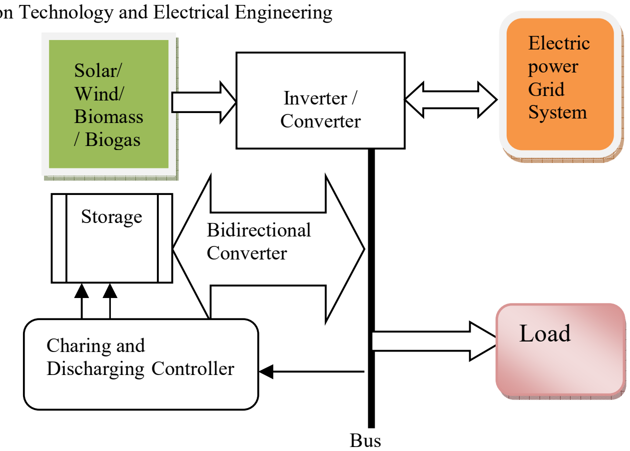

Fig 2. Grid Connected Power System Block Diagram

2 SMART GRIDS

Global warming is the main cause for climate change, which is the one of major challenges faced by the world; other challenges are security of energy supply and after the accident in Fukushima of Japan, serious concerns about the safety of nuclear power is re-emergence. This encouraged many countries to develop smart grids (SGs) [1-11] as a component of their energy policy portfolios.

Smart Grid has following major objectives [1]

a. the secure operation of large power grids under disturbances, the minimization of the risk of blackouts, and enhanced resilience;
b. the seamless accommodation and efficient utilization of vast amounts of distributed energy resources (DERs);
c. the facilitation of an advanced electric power market and demand response; and
d. The provision of electric power with high reliability, high quality, and high efficiency for a digital society.

The smart grid is huge power capacity structure which will be further distributed in small power capacity grid called as microgrid. For integrating and taking the advantages of renewable energy this microgrid further distributed in small power capacity grid called as Nanogrid, generally with 2-20KW[34]. These additions of distributed generation will create the problem of power quality [36, 37].

3 NANOGRID

3.1 Definition

Nanogrid can concise define as -A Nanogrid is a small power capability distribution system for a single house/small village/ small building/ small community, with the ability to operate standalone or with utility grid by connecting or disconnecting it from other power entities via a gate way. It consists of local power production powering local loads, with the option of utilizing energy storage and/or a control system [35].

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3.2 Components/structure of a Nanogrid

Basic structure of the Nanogrid is shown in Fig 3, it consist of following components

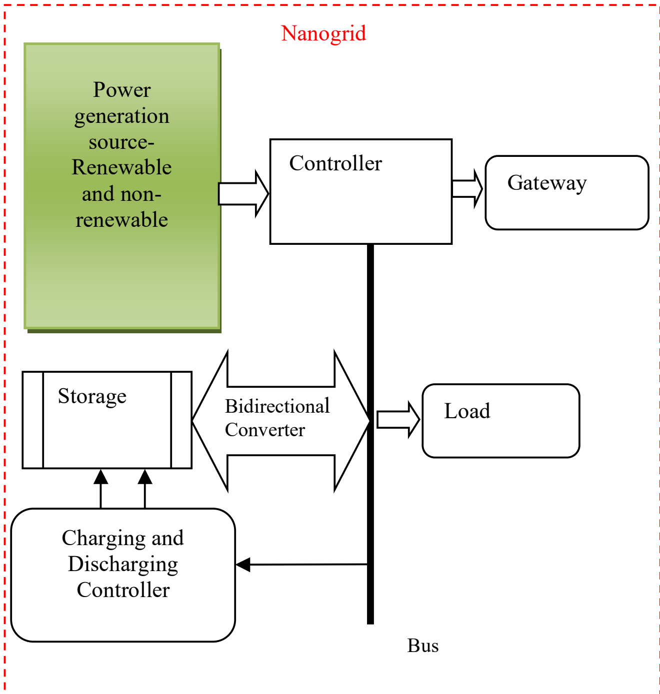

Fig 3. Components/structure of a Nanogrid

- **Power generation at /or very near to load - .** Nanogrid requires at least one power generation unit in the system. It may be renewable or non-renewable power supply [34]. The typical renewable energy sources are solar and wind, whereas the non-renewable may be sources such as diesel generators or fuel cells [39]. One of the main features of a Nanogrid is that it can have required sized distributed generation which can inject power in power grid.
- **Load** – Residential or commercial loads like lighting, water pump, etc are connected to local generation [39-41]. In grid connected Nanogrid system excess power generation can be given to the grid or store in suitable storage system. The first priority of Nanogrid is to supply local load.
- **A gateway** – For connecting Nanogrid with other Nanogrid/ micro grid / power grid a bidirectional switch is required which is called as a gateway. In power grid connected Nanogrid system power can be sold to or purchase from the power grid. This increases the financial benefit of owning distributed generation. Gateway's main function is to communicate with other power entities and convey the power requirements of the Nanogrid. Other function is protected / disconnects the Nanogrid from other external power entities in case of fault or as per requirement of system and to operate Nanogrid in standalone mode [42-44].
- **Storage devices** – In a Nanogrid structure Storage devices are optional. These are used to increase the reliability of supply, as the renewable sources are stochastic in nature. This will add in stability of system and effective utilization of renewably generated power. It is not need in case of non renewable generation unit. General choice and most suited storage device for the Nanogrid is battery [45-55].
- **Nanogrid Controller** – This is the main component in the nanogrid. This is decision maker unit. There are different controlling techniques used like single phase control, three phase, demand response, hybrid control etc. [34, 38, 39, 43, 56 -58].

The technological development in the field of the power electronics has made revolution. Because of this, renewable energy power sources like solar and wind, which have continuously changing, can be used for the generation of the power. Although generation is very small with regards to power grid but it is sufficient to small community, small village, island, hospital or even single house also. Power load is now changing due to development in electronics and communication system like LED lights, smart television (TV), mobile, etc. which can operate on AC and DC both. As the Nanogrid can operate in standalone mode and also in grid connected mode as well as some Nanogrid can form a little cluster to make microgrid and feed of smart grid [35]. Fig. 4 shows multiple Nanogrids connected together for forming microgrid and connected to the electric power grid

3.3 The difference between Nanogrid and microgrid

This distinction should be made for the following reasons:

- Microgrid can be formed by connecting multiple Nanogrids together as shown in Fig 4. The power rating of the Nanogrid is very less than the Microgrid.
- Microgrid and Nanogrid have different potential market. As the power rating is less in Nanogrid, cost investment is also less than that of Microgrid and hence profit also. But this attracts small investors/small business owners or even common person to invest in this.
- Nanogrid structure has small power rating, so its control strategies and equipments are different from the microgrid.

4 SYSTEM DESIGN

The model is for the Solar Photovoltaic (PV) home system which forms the Nanogrid with DC load. The simulation model uses a 60 Wp solar panel and a battery with charging /Discharging control. Only DC load is considered. The system uses the 230V DC.

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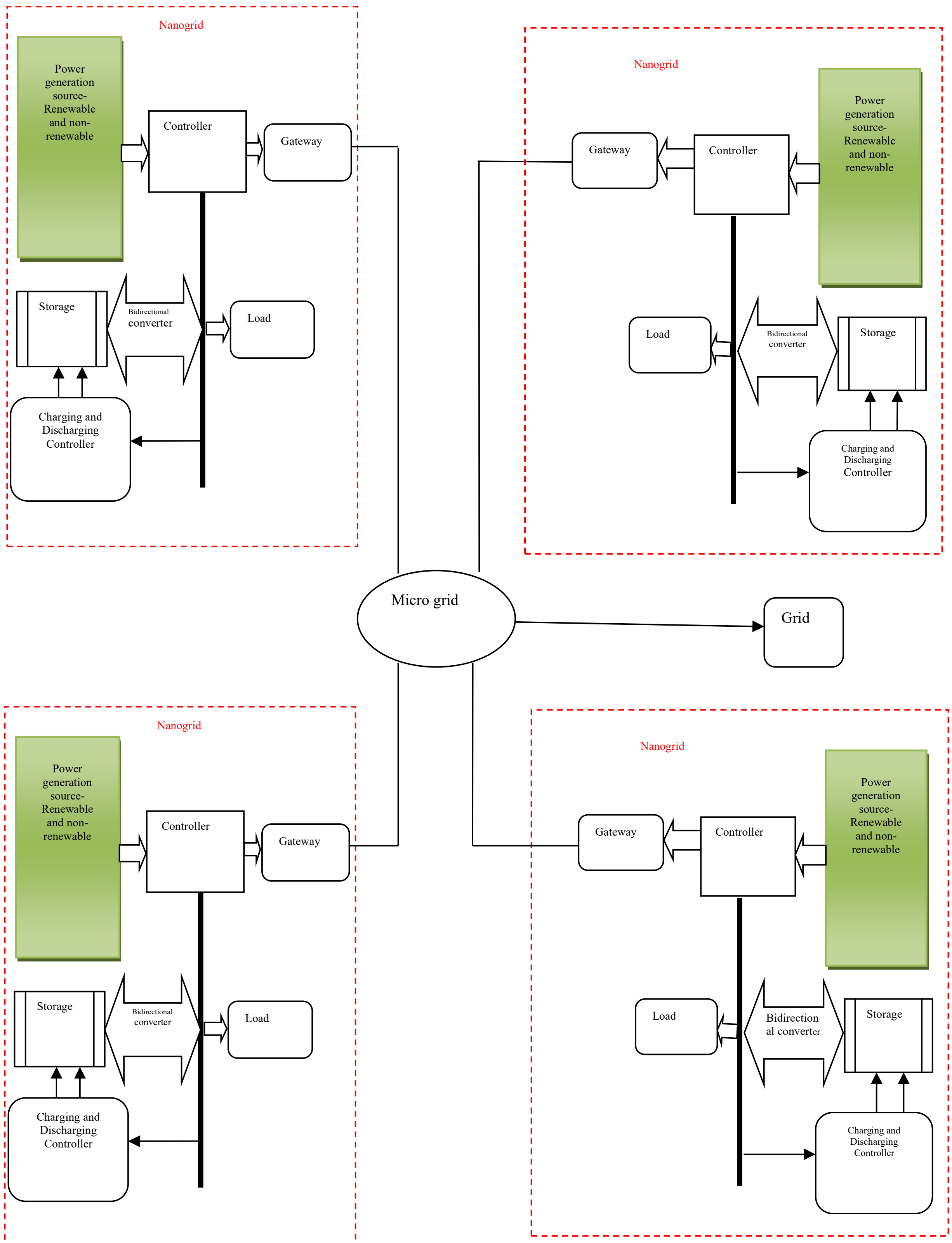
Fig 4. Difference between Nanogrid, Microgrid and Grid



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4.1 Solar Panel:

The model uses 60 Wp solar PV panel. Details of the respective component modelling are as follows.

Table 1 Parameters used in the PV module model

SN	Parameter at standard test conditions (STC)	Value
1	Maximum number of cell	36
2	Maximum Power Pmax	60W
3	Voltage at Pmax	17.1 V
4	Current at Pmax	3.5 A
5	Open Circuit Voltage Voc	21.1 V
6	Short Circuit Current Isc	3.8 A
7	Temperature Coefficient of Voc	-0.38 %/oC
8	Temperature Coefficient of Isc	0.065 %/oC
Model Parameter (defined)		
1	Band energy Eg	1.12 eV
2	Ideality factor A	1.2
3	Shunt resistance Rsh	1000 ohm
4	Coefficient Ks	0
Model parameter(calculated)		
1	Series resistance Rs	0.008 ohm
2	Short circuit current Isc0	3.8 A
3	Saturation current Is0	2.16e-8 A
4	Temperature coefficient Ct	0.0024 A/K

The model inverter is designed to operate on 60V (input) and 230V DC (Output). To satisfy the requirement of the inverter, three solar panels are connected in series, as the individual cell Open Circuit Voltage (Voc) is 21.1V. The Open Circuit Voltage of the solar panel will be now21.1 * 3 = 63.3 V. Voltage at Pmax of the individual solar cell is 17.3 V.

4.2 Storage

In this model; Battery is taken as a storage device. Although there are many option are available now a days like super capacitor, flywheels, etc. To protect battery from over charging or over discharging, the protection is provided. The battery is charged during no load condition or small partial load. Battery is connected through the bidirectional converter. The voltage of the battery is equals to the load rated voltage i.e. 230V.

4.3 Load

Real data on the usage pattern was not available, so literature values are used and combined to form a synthetic load duration curve. The load in typical homes in underdeveloped or developing country is as given in Table 2 [59]. According to UNFCCC, the load on the system is not constant. So charging and discharging period may be different for the storage device. In this simulation, maximum demand is taken into consideration for the longer duration. Although according to the literature an aggregate load of 43 W per day is used in 3 and 4 h, which means daily energy consumption of a typical home, will be 162 Wh.

In literature, some authors have argued that daily energy consumption will be up to 5 h per day. This leads to higher demand of power [60]. According to that longer usage hours of the devices and additional devices are also considered. This reflects as the rise in the maximum demand, 240 Wh/d (Table 3).

In the simulation, loads are modeled as a variable resistor. The simulation model is design to operate on the maximum demand for entire duration.

SN	Appliance	Unit	Watt	Usage (h/d)	Demand (Wh/d)
1	CFL light	5	6	5	150
2	TV	1	10	5	50
3	Radio/ cassette player	1	5	2	10
4	Mobile Charger	2	3	5	30
Total					240

Table 2 Daily load (UNFCCC 2012)

SN	Appliance	Unit	Watt	Usage (h/d)	Demand (Wh/d)
1	CFL light	6	5	4	120
2	TV	1	10	3	30
3	Mobile Charger	1	3	4	12
Total					162

Table 3 Longer Usage Hours

The system is designed to operate in three stages
i) No-load
ii) Full load
iii) Maximum load

5 RESULT

i) No-Load condition:

The system is not having load up to 5s. In this period power generated by the solar is 180W, storage system (Battery) will take the charging current during this period (Up to battery get fully charged) Figure 6 shows three color lines ; blue for DC load power, red for battery charging and discharging power and green line is for the power generated by the solar power.

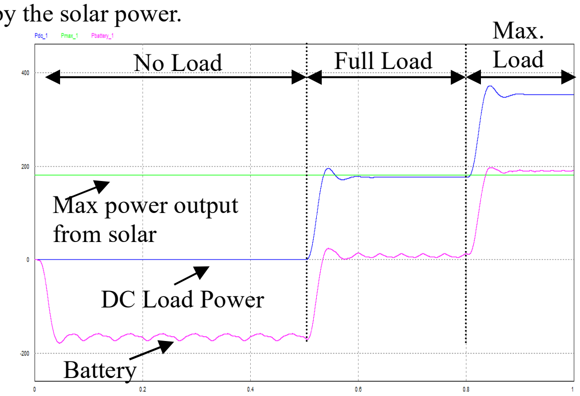

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Fig 5. Maximum power, DC load power and power taken/ given by battery

ii) Full Load condition:

The system is on full load i.e. 180W. This is full load condition for the system, as solar PV panel will generate that much power for this system design. In this condition entire power generated by solar PV panel is taken by the load. Battery is not charging as well as not supplying power to the load.

iii) Maximum Load condition:

Normally system is designed to operate at the 25% more than its full capacity. In this paper that limit extend to double of the full load. The simulation result shows the proper results. Battery and the solar PV panel generation are same and the load is fed up to its double capacity.

a) DC voltage across the load:

The load voltage value for this simulation is taken as 230V. The system is on no-load up to 5s; in this period battery is getting full power i.e. only battery is getting power from the supply. As the battery get fully charged it get detached from the system. As nothing is connected to the circuit in this case the voltage will be somewhat higher than load voltage. Figure 7 shows the same phenomenon.

%regulation = (full load voltage – no load voltage)/no load voltage)*100

= (236-230)/236

= 2.54%

The variation from no-load to full load voltage is very less i.e low regulation and high power quality in this case.

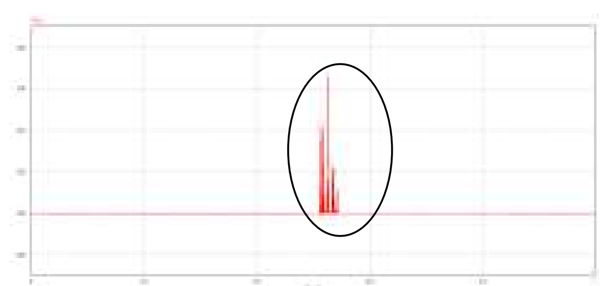
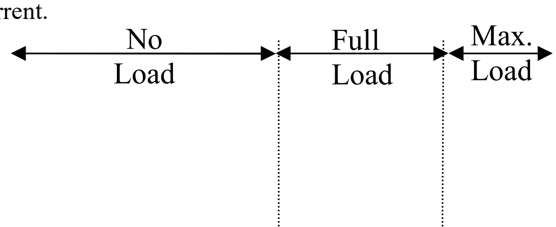


Fig 6 DC voltage across the load

b) DC current:

The load in this simulation is considered as the constant for the particular timing. As mention above, the load is switched on in three steps. Load current is increased as the load is increasing. When load is more than 180W, battery current is also going to supply the load. Fig 8 shows the switching instant of the load and corresponding change in current.



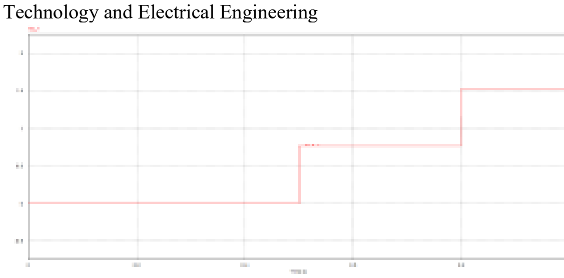


Fig 7 DC current for the stepped load

c) Battery Charging /Discharging curve:

The battery charging and discharging depends upon the connected load. In no load condition the battery is charging with full swing, but as the load increases the charging current decreases to zero. Now if, the load still increases battery will supply power to load. This phenomenon can be seen in figure 8.

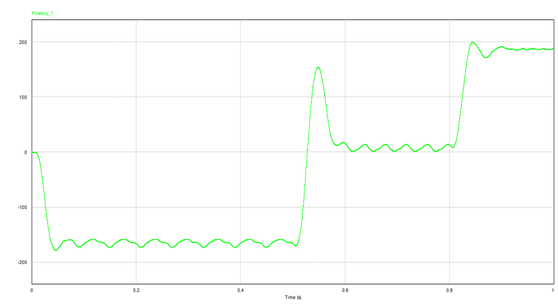


Fig 8 DC Battery Charging /Discharging curve

From above discussion it is conclude that the simulation made shows proper response to the increasing and decreasing load. Figure 6 to 9 shows the system response to power to DC load, battery and solar generated power, DC voltage, DC current and battery charging/ discharging. The responses are compared with the actual load duration curves and finds that they are matching.

6 CONCLUSION

This paper presents a simplified and efficient operation of the small scale DG system with optimal planning model incorporating load demand. This can utilize renewable sources to fulfill the customer demand with Nanogrid option. Nanogrid optimizes the load curve to match the profile of renewable sources. Simulation results are for solar power generation, DC Supply, and DC distribution shows minimum fluctuation and hence low regulation and high power quality. System stability to change in load is high.

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AUTHOR PROFILES

Mr. Sachin P. Jolhe received the degree in Electrical Engineering from Amravati University, Amravati, India in 2001. He is a research student of Gondwana University, Gadchiroli, India. Currently, he is an Assistant Professor at Government College of Engineering, Nagpur, India.

Dr. Gunwant A. Dhomane currently he is Professor at Government College of Engineering, Amravati, India. His research area is Power Electronics, Renewable Energy Sources and Power System.

Ms Minal D. Karalkar received the degree in Electrical Engineering from Dr. Babasaheb Ambedkar Technological University, Lonere, India in 2001. Currently, she is an Assistant Professor at Priyadarshini J. L. College of Engineering, Nagpur, India.