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Contemporary Solution Towards Stabilization Of Grid Frequency Using Dynamic Demand Controller Integrated With Solar For Residential Loads - A Case Study In Chennai City

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ABSTRACT

Requirement of frequency regulation services increases due to increased penetration of unpredictable and intermittent renewable energy sources. In a normal interconnected vertically integrated power system, conventional Automatic Generation Control (AGC), a centralized control mechanism and Availability Based Tariff (ABT), a tariff based technique were used for stabilizing the grid frequency. These methods fail to adapt the deregulation changes happening in the power industry and in addition, the services provided by them are expensive and of bulk purchase. Dynamic Demand Controller (DDC) is a contemporary advancement in frequency regulation mechanisms of the grid from the load side. The proposed stochastic DDC with renewable energy aims to reduce the power system resilience by dynamically controlling the energy consumption of loads based on grid frequency and thereby enabling the demand side to contribute frequency regulation. In addition, flexibility of DDC effectively improves the system's ability to integrate variable renewable energy sources. As a case study, the proposed method is implemented in a household in Chennai City in India with assumption of 5% adaptation of this technology. Simulation result shows that the proposed DDC method not only reduces the rapid deployable ancillary services for peak load management but also reduces the CO_2 emission and energy consumption by 58.04% and 58.57% respectively.

Keywords: Frequency regulation, Dynamic Demand Controller, Solar energy, Residential loads, Reduced CO_2 emission.

1. INTRODUCTION

In an AC power network, the nominal frequency can be interpreted as the perfect balance between the real power generation and demand. The frequency value varies from its nominal value when the load in an interconnected power system changes [1]. Although, the National grid forecasts the demand, continuous random smaller fluctuations and sudden large fluctuations may occur at any time in the grid. The existing electric infrastructure in India does not support an efficient and viable means of controlling the frequency instability in the grid that exists due to mismatch of demand and supply.

The possible centralized schemes existing in the power system which regulate the grid frequency from the generation side are: conventional Automatic Generation Control (AGC) scheme and Availability Based Tariff (ABT) scheme. Conventional AGC scheme [2][3] which was originally developed to maintain the frequency of power system at its nominal value does not hold true for present deregulated scenario. In addition, the conventional AGC scheme faces challenge due to the increased penetration of intermittent and unpredictable renewable energy sources. Also, in some developing countries like India where the demand exceed the supply for most operating hours of a day [4], creates stress over the power system operation. Frequency regulation has been seen as the ancillary services in the present power market [3]. In 2002, ABT a new pricing scheme for bulk purchase with Unscheduled Interchange (UI), a frequency dependent price component has been introduced by Indian power engineers for regulating the system frequency [5]. Although the ABT scheme works better than the conventional AGC, some disadvantages exist in it [6].

Dynamic Demand Controller (DDC) is an intelligent controller technique which regulates the system frequency from the demand side and thereby reducing the power system resilience [7]. In [8] and [9], the possibility for the demand side to provide frequency regulation has been discussed, but it has been receiving increased attention due to its potential capability of incorporating intermittent renewable generation. The advantages and disadvantages of frequency control using the loads is discussed in [10] and [11]. In [7], [12], [13], [14] and [15] the system frequency has been regulated using different non - time critical electrical appliances which operates in duty cycles.

The additional flexibility for regulating the system frequency can be achieved by integrating large amount of renewable energy sources into the electricity system [16]. Furthermore, integration of variable renewable output into the system can be increased by using the benefits achieved by using DDC [7]. When the DDC concept is incorporated to the duty cycle operated loads, the loads tend to behave like an intelligent loads. Thus, an extremely simple and cost - effective way of regulating the grid frequency can be provided when these intelligent loads are aggregated.

In this paper, the proposed DDC method along with solar power has been implemented to the domestic loads and the economic and environmental benefits are listed. As a case study, the proposed method is implemented to the household in Chennai City in India with assumption of 5% adaptation of this technology. The thermal domestic loads to which the proposed DDC method is implemented are refrigerators, air - conditioners and water heaters.

The paper is organized as follows. Section 2 describes the potential of solar power in India. Section 3 describes the proposed DDC technique applied to refrigeration, air - conditioning and water heating devices. Section 4 provides the details of the area taken for a case study. Section 5 provides the results obtained by implementing the proposed method to the chosen area and finally conclusion is drawn in Section 6.

2. POTENTIAL OF SOLAR POWER IN INDIA

India has one of the world's fastest growing economies with a growth rate averaging 8% a year [17]. It has a rapidly increasing agricultural sector and a swelling middle class which are moving in droves to cities every year has led to an increase in energy consumption. India ranks fourth in consumption of energy in the world with total primary energy demand of 621 Million tonnes of oil equivalent (Mtoe) which is equal to the summation of primary energy demand of Brazil, Indonesia and Saudi Arabia. By 2035, India is expected to rank second in contribution to the increase in global energy demand which accounts a rise of 18 percent [18]. This has put onus on the government to ramp up electricity production and look into alternative sources of energy to meet demand, particularly solar, nuclear, wind, fuel cell and biomass.

According to Renewable Energy Country Attractive Index (RECAI) on June 2014, India ranks seventh and fifth for harnessing renewable energy and solar energy (solar photo voltaic) respectively. The outlook in the Indian market is highly positive when it comes to solar energy. India is a densely populated and high solar irradiation which is ideal for using solar power. [19]. In solar energy sector in India, some large projects have been proposed and Thar desert has been allocated for generating solar power between 700 to 2100 GW. The government of India promotes the usage of solar energy through various missions and strategies like reducing the customs duty on solar panels, reducing the cost of roof - top solar panel installation, giving subsidy on the installation cost of solar Photo Voltaic (solar PV) power plant, etc. The different schemes which promotes solar power projects in India are listed in [20]. Among different schemes in India, Jawaharlal Nehru National Solar Mission (JNNSM) alone has installed 421.9 MW of solar energy in India. The solar power reception in India with 300 sunny days in a year is about 6000000 GW. The solar energy incident over India varies from 4 to 7 kWh/m^2 averaging daily with about 1,500–2,000 sunshine hours per year, which greater than current total energy consumption.

The solar power generation in each state of India in MW as on March 2013 is listed in [20]. Tamil Nadu, one of the states of India has reasonably high solar irradiation with around 300 clear sunny days in a year. Southern Tamil Nadu is one of the most suitable regions for the development of solar power projects in India [21]. Tamil Nadu ranks fifth in the total installed solar power capacity in India next to

Gujarat, Rajasthan, Madhya Pradesh, Andhra Pradesh and Maharashtra. The policy announced by Government of Tamil Nadu proposes that 3000 MW of solar power generation will be achieved through utility scale projects, root tops and Renewable Energy Certificate (REC) mechanism by 2015 [22]. Chennai is the capital city of the Indian state of Tamil Nadu, located on the Coromandel Coast off the Bay of Bengal with geographical coordinates
Latitude: 13.08˚N
Longitude: 80.27˚E and
Altitude: 6 m above sea level.

The annual average solar irradiation in Chennai is 5.23 kWh/ m^2/ day with the monthly average of solar irradiation in Chennai is shown in Fig. 1 [23].

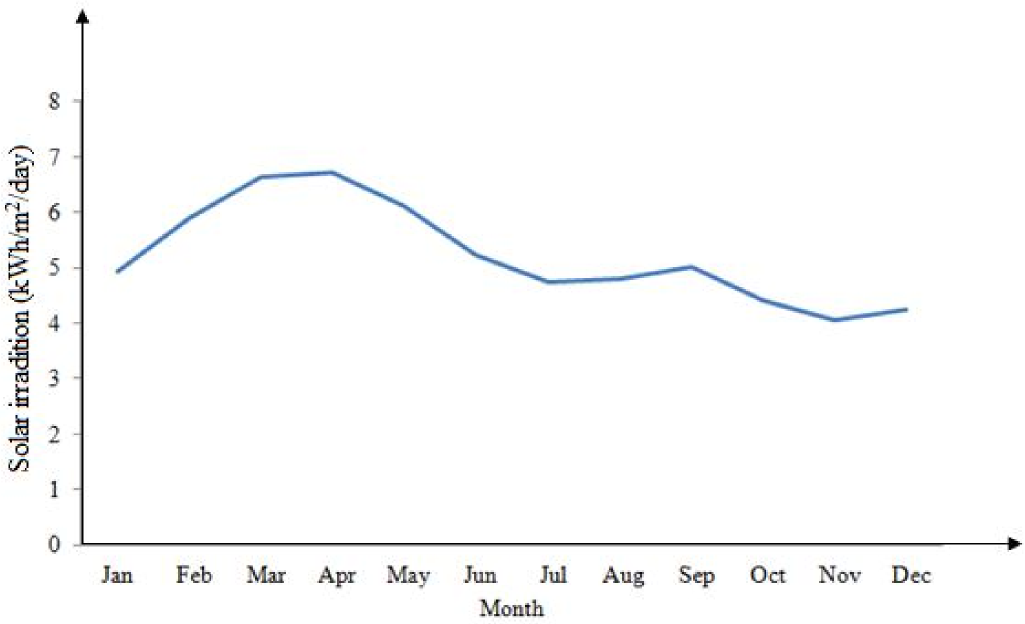

Fig. 1 Monthly solar irradiation in Chennai

Solar photo voltaic arrays are the most extensively prevalent form of distributed generation (DG), serving part of loads locally, at residential customer premises. The biggest and most important gain of rooftop solar installations is its quick deployment with no need of expansive transmission and distribution build out. Roof-top solar PV panels offer an excellent option for meeting the growing electricity demand.

3. DYNAMIC DEMAND CONTROLLER (DDC)

The nominal frequency in the grid represents the perfect match between generation and load. In the electrical grid, small load variations and more severe power imbalances might occur which result in smaller and larger frequency deviations. A frequency control mechanism is required and is to be implemented in the power system to avoid frequency drift and to increase the efficiency and stability of the grid [24]. A proper frequency control mechanism gains more importance in today's power systems as the frequency deviation significantly affects the controller design in the system [25]. The real time frequency deviation from nominal frequency in SRLDC in India for two hours is shown in Fig. 2 [26].

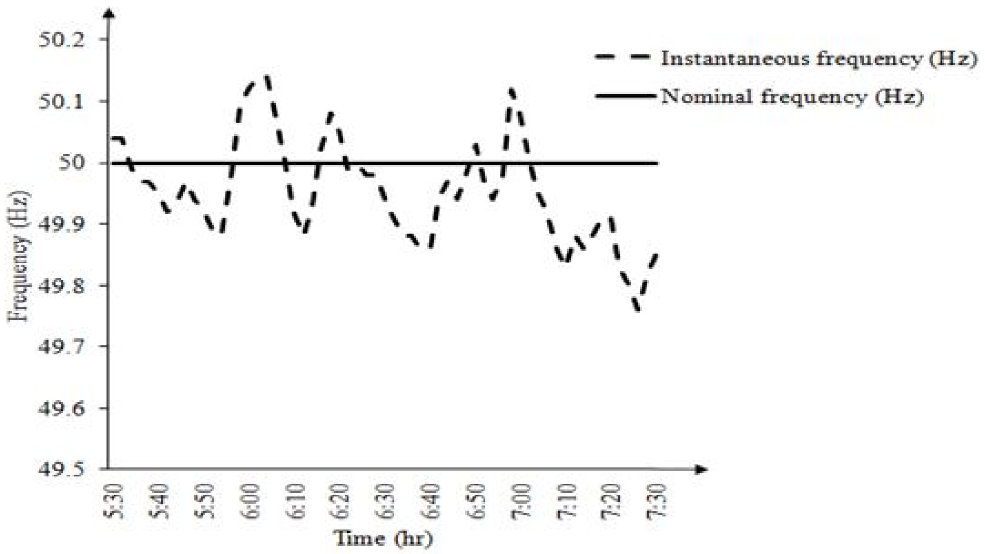

Fig. 2 Frequency deviation for 2 hours in Chennai

The centralized frequency regulation mechanism from the generation side has its own advantages and disadvantages. The proposed DDC concept regulates the system frequency from the load side without compromising the comfort of the consumer. It enables the non time - critical appliances to regulate grid frequency by altering their duty cycles in response to frequency deviations from its nominal value [7]. The proposed DDC concept will lead to significant carbon dioxide savings and helps in integrating renewable energy source, such as solar and wind power. In DDC any thermostatically controlled loads (TCLs) could be used to provide a regulation service by altering the duty cycles in response to system load and grid frequency as it is possible to design controllers for the electrical appliances for detecting the frequency imbalances in real time and change the duty cycles.

When the DDC is implemented to thousands (and eventually millions) of such TCLs acting in aggregation, it provides an extremely simple and cost-effective way of stabilizing the grid frequency [27]. The pictorial explanation of DDC when there is a sudden loss of generation in the system is shown in Fig. 3 [28].

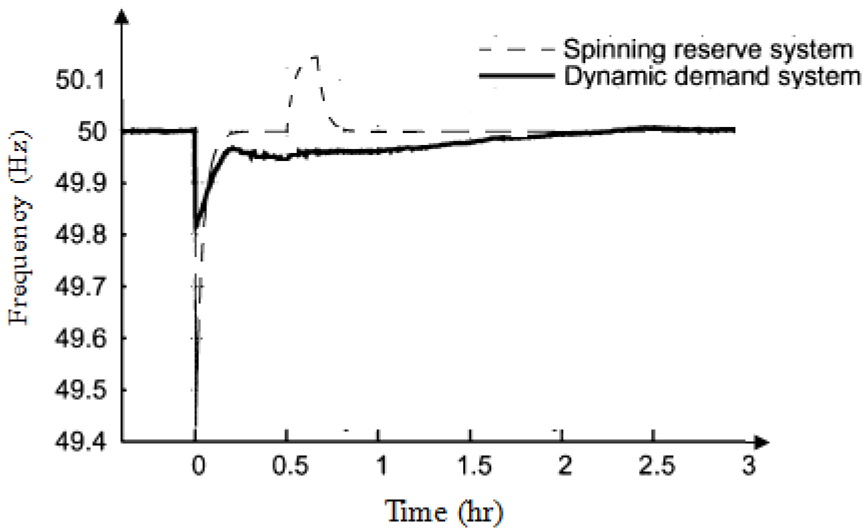

Fig. 3 DDC concept

For example, when a generation of 1320 MW is lost at time $T = 0$ as shown in Fig. 3, the frequency gets drop drastically from its nominal frequency and conventionally, a spinning reserve of 1320 MW generation will be used to restore the grid frequency. But when the proposed DDC concept is implemented in refrigerator, the drop in frequency will be stopped instantly by switching off the refrigerator and thereby the fall in frequency will be slower. Now, the temperature inside the refrigerator will be increasing and will demand more power even after the generation is restored. If the loss in generation is restored after 1 hour 30 minutes, the frequency will still be lower than the nominal frequency as the refrigerator whose temperature has been increased only by 1.1^0 C above normal temperature will demand more power and after 1 hour 57 minutes the system frequency will be restored without using the spinning reserve [27]. In this section the TCLs are modeled and energy saved by implementing the proposed DDC concept is presented. The TCLs to which the proposed DDC concept is implemented in this paper are refrigerator, air - conditioner and water heater.

3.1 Modelling of Thermostatically Controlled Loads (TCLs)

The electricity consumption of TCLs can be modulated by meeting the desired temperature by utilizing the thermal storage medium existing within the loads. The dynamic model of these TCLs is defined using the following equations [29].

$$\left.\frac{dQ}{dT}\right|_{\text{device}} = \left(T_{\text{device}} - T_{\text{room}}\right) c\ M_1 \tag{1}$$

$$\left.\frac{dQ}{dT}\right|_{\text{loss}} = \frac{T_{\text{room}} - T_{\text{out}}}{R} \tag{2}$$

$$\frac{dT_{\text{room}}}{dt} = \frac{1}{M\,c}\left(\left(\frac{dQ}{dt}\right)_{\text{device}} - \left(\frac{dQ}{dt}\right)_{\text{loss}}\right) \tag{3}$$

where

$\left.\frac{dQ}{dT}\right|_{\text{device}}$ is the thermal flow from device into the room

$\left.\frac{dQ}{dT}\right|_{\text{loss}}$ is the thermal loss from device into the environment

$\frac{dT_{\text{room}}}{dt}$ is the derivative of the room temperature

c is the heat capacity of air at constant pressure in J/kg-K

M is the mass of air inside the device in kg,

M_1 is the air mass flow rate through the device in kg/hr

R is the equivalent thermal resistance of the room in mK^2/W

T_{device} is the temperature of air from device in ^0C

T_{room} is the current room temperature in ^0C.

T_{out} is the average outdoor temperature in ^0C.

Using Eqn. (1) to Eqn. (3), the TCL is modelled in SIMULINK as shown in Fig. 4 and Fig. 5 to determine the duty cycle of the device for different temperature band $(T_{\text{low}}, T_{\text{high}})$ and also the power consumed by the device is determined using the duty cycle.

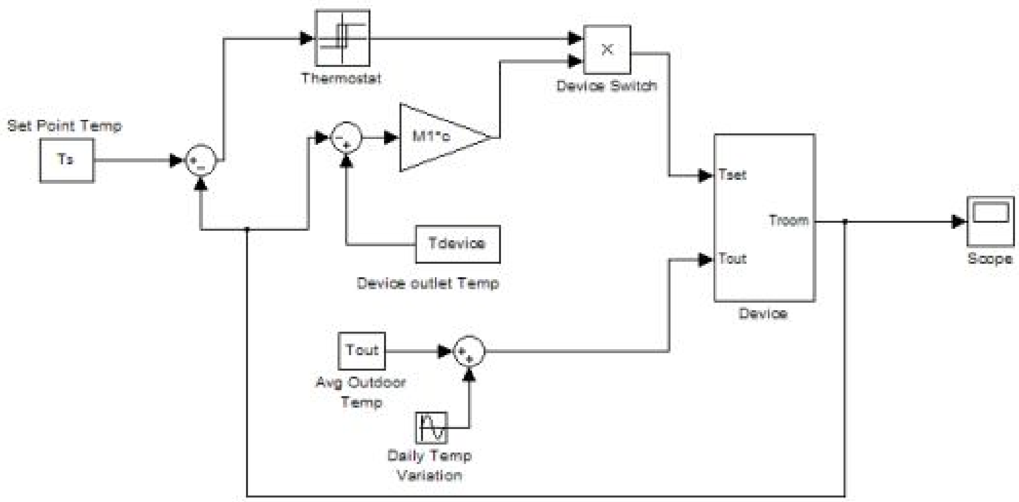

Fig. 4 SIMULINK model of a TCL

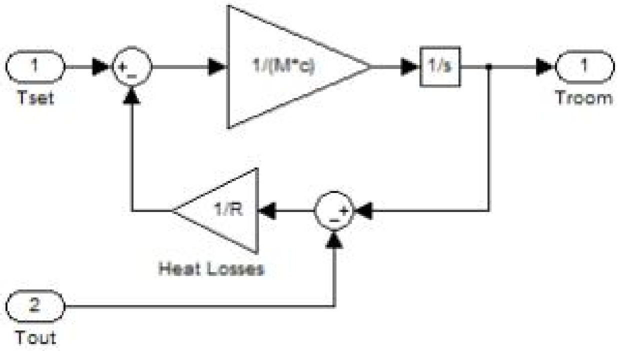

Fig. 5 SIMULINK model of subsystem device

The temperature of TCLs in SIMULINK model is maintained within a band by a controller denoted by thermostat using hysteresis ON / OFF control.

3.2 Duty cycle of TCLs for different temperature band

The duty cycle of refrigerator and air - conditioner for different temperature bands can be determined using the SIMULINK model shown in Fig. 4 and Fig. 5. But in this paper, the duty cycle of the TCLs have been determined practically using temperature sensors.

3.2.1 Refrigeration load

The duty cycle for a refrigerator for different temperature bands is calculated with room temperature maintained as 35°C and tracking the refrigerator for three hours. The practical implementation of determining the duty cycle of refrigerator of 200 W is shown in Fig. 6.

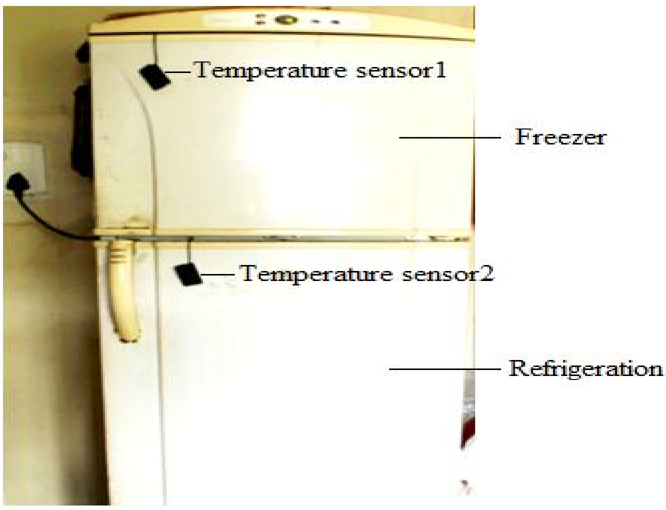

Fig. 6 Refrigerator with temperature sensor

The temperature band for set - point 1 and set - point 2 are $(10,18)$ and $(8,12)$ respectively. The working of refrigerator for the two set - points is shown in Fig. 7(a) and Fig. 7(b).

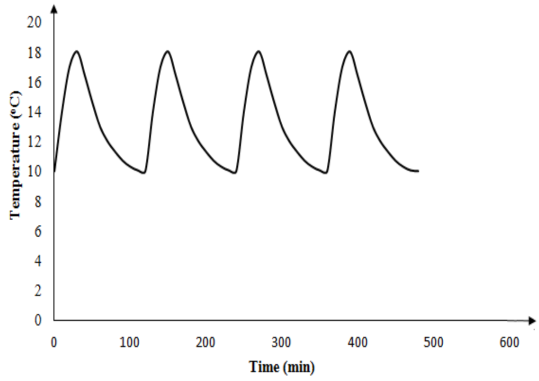

Fig. 7(a) Refrigerator working for set - point 1.

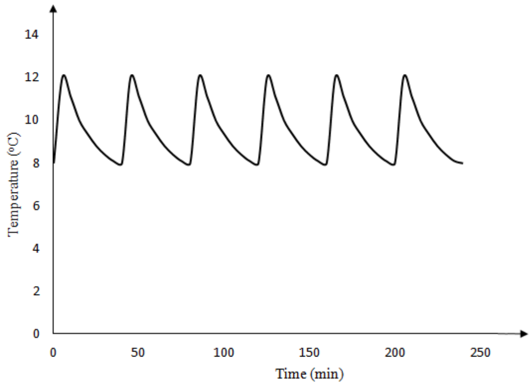

Fig. 7(b)Refrigerator working for set - point 2

3.2.2 Air - conditioning load

The duty cycle for an air - conditioner for different temperature bands is with room temperature maintained as 35°C and tracking the air - conditioner for one hour. Air - conditioner of 1200W is used determining the duty cycle practically.

The temperature bands for set - point 1 and set - point 2 are $(26, 28)$ and $(18, 21)$ respectively. The working of air - conditioner for the two set - points is shown in Fig. 8(a) and Fig. 8(b).

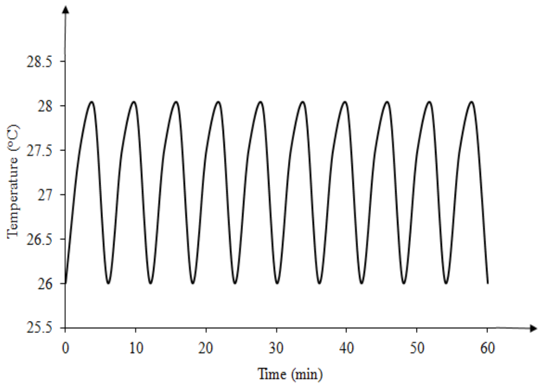

Fig. 8(a) Air - conditioner working for set - point 1.

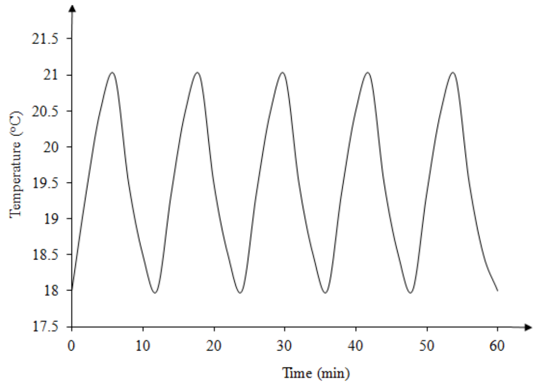

Fig. 8(b) Air - conditioner working for set - point 2.

The comparison between two set - points of the refrigerator and air - conditioner based on OFF time of the compressor, ON time of the compressor and duty cycle is given in Table 1.

Table 1 Comparison between set - points of refrigerator

	Refrigerator		Air – conditioner	
	Set - point 1	Set - point 2	Set - point 1	Set - point 2
Upper limit of the operating point (°C)	18	12	28	21
Lower limit of the operating point (°C)	10	8	26	18
ON time of the compressor (min)	90	35	2	6
OFF time of the compressor (min)	30	5	4	6
Duty cycle	0.75	0.875	0.33	0.5

The power consumption of the refrigerator and air - conditioner can be calculated as the product of duty cycle, rating of the device and number of hours the device being operated. Therefore, the power consumed by the device at lower set - points is greater than the power consumed at higher set - points.

3.3 Implementation of DDC to TCLs

When DDC is implemented to any one of the TCLs, the device will switch the temperature band to higher level without affecting the comfort of the consumers. The expected operation of refrigerator and air - conditioner when DDC is implemented to it is shown in Fig. 9(a) and Fig. 9(b) respectively.

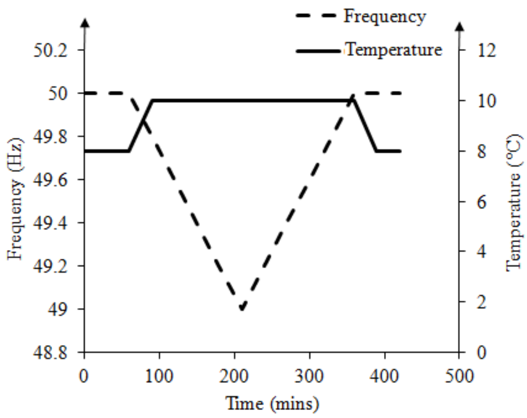

Fig. 9(a) Behaviour of refrigerator with DDC

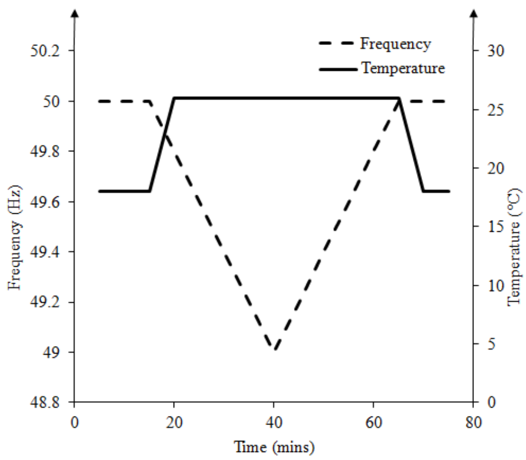

Fig. 9(b) Behaviour of air - conditioner with DDC

The main objective of this section is to implement the proposed DDC method to the chosen TCLs and to present the benefits achieved in implementing the controller. During peak hours, when the proposed DDC method is implemented, the operating point of the loads will be changed so that the frequency gets stabilized. Practically, experiments are carried out for single refrigeration and single air-conditioning loads and the results are extrapolated to derive the benefits of DDC on a large scale.

The refrigerator and air - conditioner are allowed to run at set - point 2 during off-peak hours and at set - point 1 during peak hours. The working of refrigerator and air - conditioner when the proposed DDC method is implemented is shown in Fig. 10(a) and Fig. 10(b) respectively.

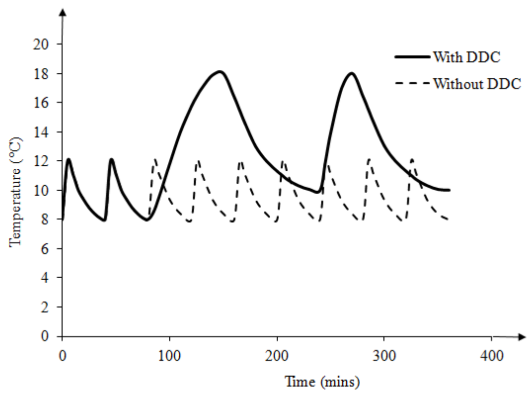

Fig. 10(a) Practical behaviour of refrigerator with DDC

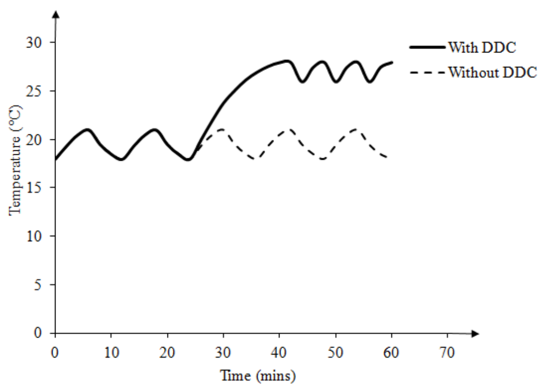

Fig. 10(b) Practical behaviour of air - conditioner with DDC

The benefits of proposed DDC method in refrigeration and air - conditioner is shown in Table 2.

Table 2 Benefits of DDC when implemented in TCL

	Refrigerator	Air - conditioner
Power consumed in set - point 2	1.05 units (for six hours)	1 unit (for 1 hour)
Power consumed with DDC	0.758 units (for six hours)	0.598 units (for 1 hour)
% Reduction in power consumed	27.77	40.2

Similar experiment is performed on water heater to calculate the power consumption of the device with DDC**.** In addition, the same method can be implemented on all other HVAC loads, motors and pumps, and battery charging operations to reduce the demand during peak hours which in turn lowers the stress on the grid and thereby stabilizing the grid. An interesting fact to be noted is that during peak hours the loads are not cut-off completely but only shifted to a different operating range within the comfort zone of the consumer. Estimations have shown a reduction of 2.3 units per day in one typical household by the application of this technology if the peak hours exist between 8.00 A.M to 1.00 P.M and between 5.00 P.M to 11.00 P.M as shown in the Table 3.

Table 3 Energy saved per day in a single household

	Quantity	Wattage	Energy saved
Refrigerator	1	200	0.6
Water - heater	1	1500	0.5
Air - conditioner	1	1200	1.2
		Total	2.3

4. Case Study

Chennai, the capital city of Tamil Nadu, the state of India is taken as a case study to implement the proposed DDC method. It is the biggest industrial and commercial centre of South India, making it the fourth most populous metropolitan area in the nation. Considering the last few years scenario in India, it has been observed that the migration from the rural area to the urban areas is on the rise. As this trend continues, the electricity demand is on the rise each year and there is an urgent need to ensure safe and uninterrupted power. The proposed technology is applied to one of the resident in Chennai and it is extended to the residents in Chennai with 5% technology.

4.1 3-D House Model

A medium sized, single storey domestic household with a floor area of 950 sq. feet in Chennai is taken as the model under study. Data's regarding building and the systems is sourced from building drawings/floor plans or operation, maintenance manuals [30]. There are four thermal zones in the house – balcony, dining hall with refrigeration load, bedroom with air- conditioner, living hall. The HVAC system of the house is a Packaged Terminal Air Conditioner (PTAC), which is used to supply cool air into the third thermal zone.

Using the above information, the Building Energy Simulation (BES) model of the single storey house is constructed using OpenStudio plug-in for Google Sketch, as shown in Fig. 11, while the modeling and performance is computed using EnergyPlus software, an energy consumption analysis tool. [31].

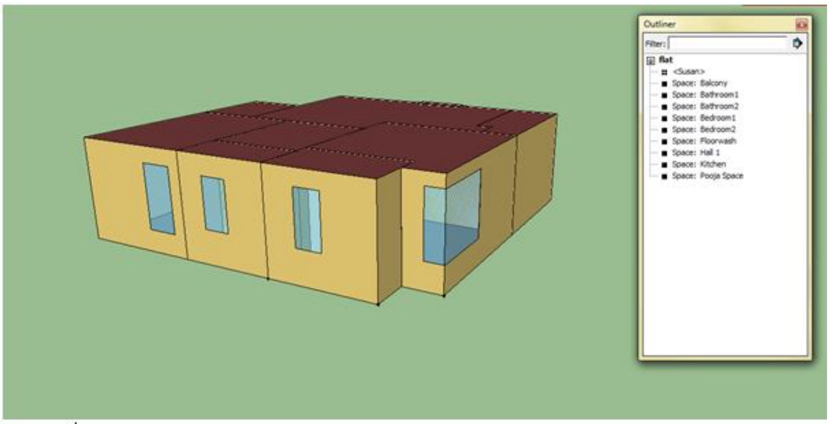

Fig. 11 3-D model of a two bedroom house

4.2. Electricity consumption

This residential single storey building is a Low Tension consumer, receiving three phase electricity supply from the Tamil Nadu Electricity Board (TNEB). The internal loads of a five residents including lighting and equipment loads such as television, computers, fans, etc. are specified in Table 4.

Table 4 Electrical loads in a single household

Load	Quantity	Wattage (W)
Fans	4	80
Tube - light	4	30
Compact Fluorescent Lamps (CFL)	6	10
Laptop	1	60
Desktop	1	150
Television (CRT)	1	120
Miscellaneous	-	100
Inverter / Battery - Charging*	1	300
Refrigerator*	1	200
Water - heater*	1	1500
Air-conditioner*	1	2000
Others*	-	1000

*refers to the loads connected to DDC, while the rest are connected to solar

A building audit (comprising of lighting audits and occupancy surveys) is accomplished to obtain more realistic data on electrical equipment such as lighting, power (AC units, refrigeration units, etc), general services (plug sockets) and sub-distribution. In EnergyPlus, simulated electrical data output is in Watt-hours, which is then converted to hourly average power consumption (kWh). The monthly consumption of single household using EnergyPlus software is shown in Fig. 12 and average energy consumed per month is calculated from the total energy consumed in a year.

Energy consumed in a year: 5100 kWh
Average Energy consumed per month: 425 kWh

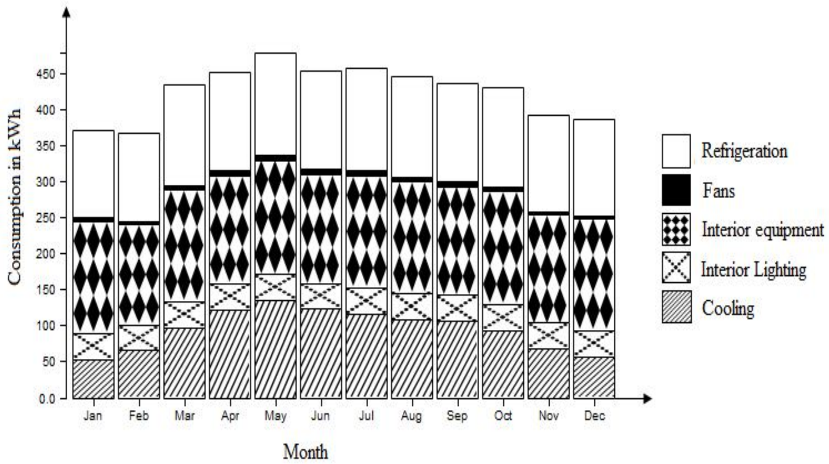

Fig. 12 Average monthly consumption of electricity

4.3. Electricity Tariff

LT Tariff 1A (Domestic) as approved by TNEB, is applicable to the house at the following rates and is given in Table 5 [32].

Table 5 LT Tariff 1A for Domestic loads

Bi - monthly energy consumption charges in units	Charge in rupees per unit	Additional fixed charges in rupees
Up to 100 units	1.00 for 0 - 100 units	20.00
Up to 200 units	1.50 for 0 - 200 units	20.00
Up to 500 units	2.00 for 0 - 200 units 3.00 for 201 - 500 units	30.00
Above 500 units	3.00 for 0 - 200 units 4.00 for 201 - 500 units	40.00

4.4. Solar Panel

The solar panel's output current and operating are ascertained by the load characteristics, for a given intensity of solar radiation. The thumb rule is that 12 sq. m of area (about 130 sq. feet) is required to install 1 kW of system [33]. The output power from the solar panel is directly proportional to the amount of solar radiation captured by the panel and in Chennai maximum amount of solar radiation can be captured, if the solar panel is oriented to 13.5^0 to the south [34].

An array of five 200W stationary solar panels in series clamped to the mounting racks on the roof top generate electricity from the incident of solar radiation. The electricity generated by the panels is supplied to the household, by means of an inverter-battery arrangement, as depicted in Fig. 13.

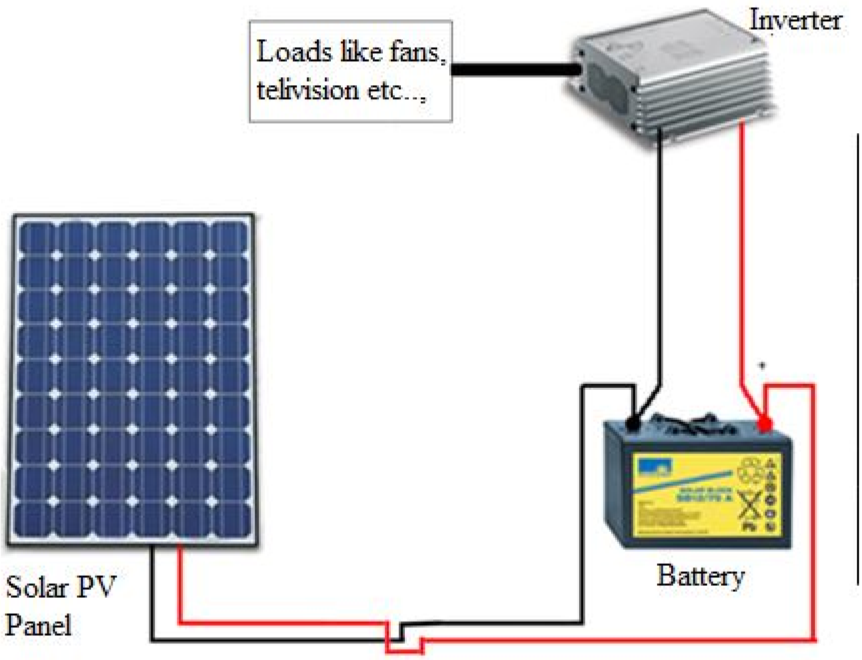

Fig. 13 Solar panel arrangement in a household

The DC power generated by the PV array is stored in battery, while the sun is shining and later converted into 230V AC power by the inverter to power the building. The specifications of the equipments employed for the roof-top installation are mentioned in Table 6. Assuming 6 hours of good sunlight per day, the average energy produced by solar panel per month is 180 kWh. This in turn reduces the average energy consumption to 245 kWh per month.

Table 6 Specifications of equipments

Equipment for Rooftop Installation	No of units	Specification
Battery	1	100 Ah, Lead Acid Battery
Line interactive UPS	1	600 VA, 230 V
Solar PV panels	5	200 W, Peak voltage – 14V, OC voltage – 18V

4.5. Implementation of proposed controller

The DDC is connected to UPS (Uninterrupted Power Supply) and to the HVAC loads (refrigerator, air-conditioner, water-heater). The functioning of all the appliances is slightly altered contingent to the grid frequency with the help of digital technology as shown in Fig. 14. The application of advanced digital technologies (i.e., microprocessor-based measurement and control, communications, computing, and information systems) are expected to greatly improve the reliability, security, and efficiency of the electrical grid, while reducing environmental impacts and promoting economic growth.

During peak hours the thermal loads are operated in a lower energy consumption mode, making delicate comprises in the comfort level with the help of DDC and the other loads will be operated with the help of Uninterrupted Power Supply (UPS) powered from solar PV. With a majority of the houses in Tamil Nadu being equipped with UPS to sustain the energy needs during power-cut, the digital technology can control the switching between mains and battery power, restricting battery charging to off-peak hours and utilizing the stored solar energy in the battery. The loads connected to the UPS run on the battery power during peak hours as long as its charge doesn’t drop below 50 percent. During off-peak hours the thermal loads and other loads are operated in a normal energy consumption mode by consuming energy from the grid. In this case, the power from solar PV is used to charge the UPS to its maximum value.

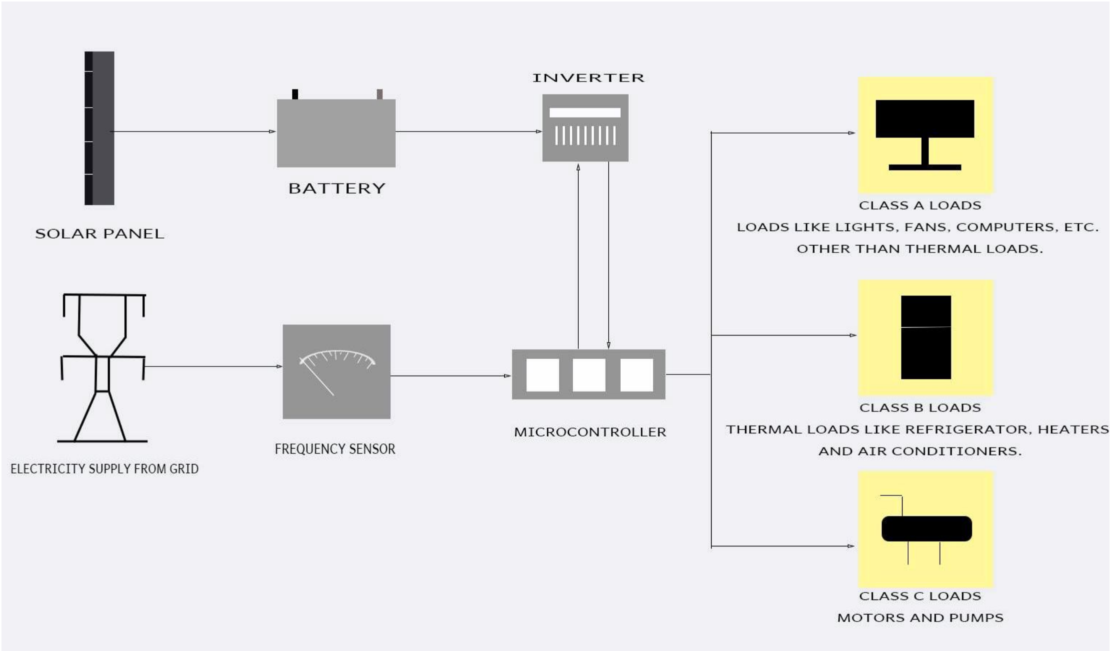

Fig. 14 Residential household with DDC and solar PV

5. RISK–BENEFIT ANALYSIS

5.1 Need of the hour

In worldwide most national energy policies aims at ensuring an energy portfolio that supports a cleaner environment and stronger economy simultaneously strengthening the national security by providing a stable, diverse, domestic energy supply. Clean energy is a global and urgent imperative. Renewable generation, especially from solar, and dynamic demand concepts are critical technologies needed to address these global warming and related issues. The key challenges are reducing the cost of renewable energies to affordable levels, lack of consumer awareness and lack of technical infrastructure for construction and verification.

5.2 Economic and Environmental Benefits

The proposed method is implemented in a single resident in Chennai and the results are studied. The economical and environmental assessments indicate that the proposed DDC method when incorporated with renewable energy has the potential to generate considerable cost savings and emission reductions for a wide range of future low-carbon generation systems. From the socio-economic viewpoint the benefits include, reduction of the national dependency on fuel imports, diversification and security of energy supply and significant cutback in the consumption of fossil fuels. The results derived from the case study are shown in Table 7.

Table 7 Analysis per household on a yearly basis

	Grid	Solar	DDC & Solar
Units consumed	5100	2940	2112
Reduction in units consumed	-	2160	2988
% Reduction in units consumed	-	42.34	58.57
Cost (rupees)	23118	7800	5280
Savings (rupees)	-	15318	17838
% Savings	-	66.26	77.16
Upfront cost (rupees)	-	75000	78000
Pay-off time (years)	-	4.9	4.37
CO_2 emission (metric tons)	1.12	0.65	0.47
Reduction in CO_2 emission (metric tons)	-	0.47	0.65
% Reduction in CO_2 emission	-	41.96	58.04
Amount of coal consumed (metric tons)	0.6264	0.3611	0.2594
Amount of coal saved (metric tons)	-	0.2653	0.37
% Reduction in amount of coal used	-	42.35	58.59

According to the 2011 CENSUS, there are totally 1.1 million households in Chennai. Assuming 5% of the households in the city adopt this technology, the benefits given in Table 8 seem to be skyrocketing [35].

Table 8 Estimated savings in Chennai city per year (5% adoption rate)

	Grid	Solar	DDC with Solar
Units consumed ($x10^6$)	280.5	161.7	116.16
Reduction in units consumed ($x10^6$)	-	118.8	164.34
CO_2 emission (metric tons)	61600	35750	25850
Reduction in CO_2 emission (metric tons)	-	25850	35750
Amount of coal consumed (metric tons)	34452	19860.5	14267
Reduction in amount of coal used (metric tons)	-	14591.5	20185

5.3 Savings

It is estimated that this model incorporating solar power along with DDC shows drastic a cut down in the electrical energy units consumed from the grid, thereby causing reductions in the cost of energy production, amount of green-house gas emission and amount of coal saved due to its generation. In addition, if 5% of the residents in Chennai city installs solar PV panels for powering the non - thermal loads, it has been estimated that it could save 445.5 MW which is equivalent to the capacity of spinning reserve used in grid.

6. CONCLUSION

A systematic method to design a continuous fast-acting load-side frequency control by formulating a DDC and renewable energy sources (RES) problem, where the objective is to stabilize grid frequency and to minimize the carbon dioxide emission subject to the increasing green-house effects has been discussed. This approach allows the loads to choose their consumption pattern based upon both their needs as well as power imbalance in the network utilizing a cost-effective strategy. Such frequency adaptive loads (loads with DDC) will allow the system to respond more readily to the fluctuating energy sources like solar. Also, “grid-friendly” devices like refrigerators, water heaters, and air conditioners, help manage energy discrepancy. Estimations and assessments have consistently shown an improvement in system performance, reduction in the need for spinning reserves and economic dispatch of power supply. In correspondence with DDC, utilization of solar power contributes to “clean energy” by considerably decreasing the green-house gas emission and amount of coal consumed and also reduces the energy dependence on the grid.

The goal is to stabilize the grid frequency from the demand side and contribute towards the pare down of spinning reserves using dynamic demand control (DDC). Advancing towards a more sustainable energy future and reducing the green-house effect are the motivations which lead to the penetration of RES in conjunction with DDC. In this article, we have reported on our efforts to residential loads and to extend to the residents in Chennai city with 5% adaptation of the technology . The benefits of implementing the technology to residential loads is also listed.

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