Automatic Frequency Response for Autonomous Distributed V2G (Vehicle-to-Grid) Using IoT Technology

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Abstract

Nowadays, the use of electric vehicle has been increased, due to the increase in fossil fuel and decreasing in its resources. On the other hand environmental pollution is the major concern. On the power systems the charging of Electric Vehicles (EVs) has been imposed. The deregulation of power system with new and major loads introduces the uncertainties of grid which is new challenges of frequency control and stability of power system. In order to overcome this problem EVs as moving batteries are imposed. In this method based on the Grid frequency the charging and discharging of EVs takes place. This technology is so called Vehicle to Grid (V2G). The Arduino microcontroller development board is used to make decisions over the controlling operations. The Internet of Things (IoT) is used for the communication purposes such as collecting data from all sensors and giving information to the authorizers. The simulation is done through the MATLAB / SIMULINK and thus the results illustrate good performance of the proposed method.

Key words: Electric Vehicles, Vehicle to Grid (V2G), Arduino, Internet of Things (IoT).

I. INTRODUCTION

Renewable energy has the significant increase in the energy system because of global changes in climate change, energy security and the environmental pollution. For the promotion of renewable energies the ambitious target are set in many countries. The electricity generation from the renewable source in 2020 is set for 35% of its goal in European Union[1]. The world's energy supply provides 14% of renewable energy [2-3]. The spinning reserve is required for the compensation of generation and the demand unbalance. For the compensation of unbalance, the batteries can be used as charge storing devices. But, the increase in size of batteries is the restriction of this solution.

By converting conventional power systems into deregulated power systems, the new uncertainties have been introduced in the power systems. In traditional power systems (VIU) Vertically Integrated Utility which are owned by single entity. A distribution company is contracted individually in independent of power producers for the different areas [4]. Therefore, in deregulated power systems the frequency control is more complex.

The electric vehicles have gained interest in global research and industrial sector in recent years. The promotion

of EV is because of pollution free and emission free transportation which could be sustainable in future [1]. From [2], in United States the EV is from the period of 2020, 2030, and 2050 that will reach 35%, 51% and 62% respectively. For the frequency control of power systems, the control of EVs are as the load controllable and their use of batteries with the spinning reserve is the one of the solution. In this method, the EVs are connected to the grid through the bidirectional converter. Charging and discharging of EV batteries takes place based on the load in the grid. The concept of V2G was used in [5] for the first time. EV availability is shown in Fig.1 the EV are charged at day through proper manner. Hence in ancillary services the V2G concept is used. The V2G concept is employed in frequency ancillary services because of its high charging rate [6]. V2G concept is used in many papers in the frequency control of the grid [7-12]. In [7], for grid frequency control the V2G concept was used with scheduled charge method.

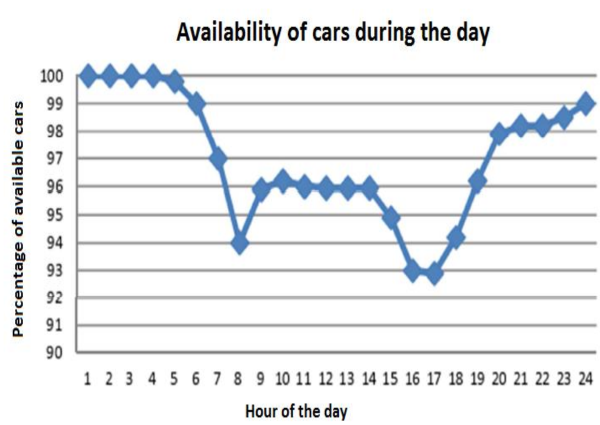


Fig. 1 EV availability

Thus the proposed paper describes about the control of frequency through the load scheduling method. The load scheduling is done based on the priority of the load. Thus for the process of controlling frequency a controller adopted is called Arduino Mega 2560(AT Mega2560). It is an open source electronic platform which can perform the easiest way for hardware and software. The concept of Arduino is used because of it has the advantage of easy and fast prototyping, display message in a minute, power and convenient tool and can optimizes the code. In order to control from anywhere at any place and also at anytime the IoT concept is used. The basic characteristics, the key technologies, the network architecture and security problems of the Internet of things is explained in [8]. IoT is the Internet of Things which is the internetworking of physical devices, vehicles, buildings and other items. The IoT has the advantages of tracking behavior for real time marketing, enhanced situational awareness, process optimization, optimized resource consumption, instantaneous control and response in control. Because of such advantages the AT Mega2560 and IoT are used to control the frequency by load scheduling. The remainder of this paper is organized as follows. Section II introduces EV system. Section III introduces Synchronous SOC control. Then Frequency control is explained in Section IV. Communication system is explained in Section V. Result is expressed in Section VI. In section VII conclusion is explained.

II. EV SYSTEM

The motor vehicles that are recharged from the external source of electricity is called Plug-in Electric Vehicles (PEVs). The external source of electricity can be of wall sockets. The wheels are driven by the rechargeable battery packs with the stored electricity. The PEV serves many advantages that it has low operating maintenance cost and no local air pollution. The PEVs are utilized to the utility power by recharging the batteries. The power to the motor is controlled by motor controller which is the simplest configuration of PEV as shown in Fig. 2**.** The electric battery or traction battery can be used as the battery for the propulsion of power of the electric vehicle.

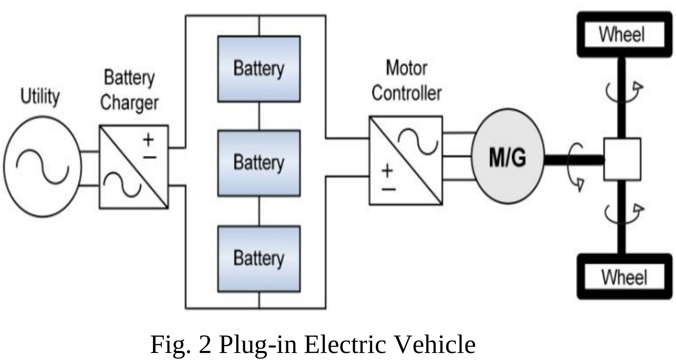


Fig. 2 Plug-in Electric Vehicle

III. SYNCHRONOUS SOC CONTROL

In general, to the contrast to the total number of cars, few cars are driving on the load. Generally all the cars are being parked. The some situation is expected in future with large discretion of EVs. When gasoline vehicle are used, the travel to the longer distance are limited. On the other hand, the charging can be done everywhere through the support of EVs. On expectation, it is indented the EV users charges frequently. According to the parking, the EVs are plugged nearly to full State of Charge (SOC).

As shown in Fig. 3, there are totally 3 main states of EV i.e driving state, charging and controllable states respectively.

a) Driving state

When it is plugged out for the trip an EV enters the driving state. The EV changes from the controllable state to driving state. Each EV is equipped with the battery voltage rating of 360V.

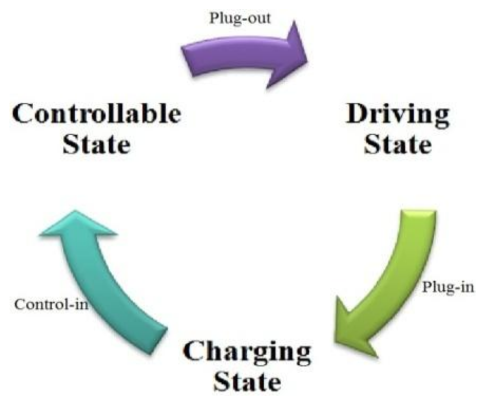


Fig. 3 EV state

b) Charging state

The charging state is entered by EV when it is plugged in to charge the battery. The EV cannot respond to LFC signal when the charging period is one hour i.e. not controllable.

c) Controllable state

When EVs entering the controllable rate per second is called control-in rate as shown in Fig.4.

It is assumed that to the EV the central load dispatching centre sends and receives control signal from the EV through the local centers. There are of total 500 local control centers. The control of 100 EVs is assumed for each local control centers. The EVs are of 50, 000 controllable in which is 10% of the EVs equipped with V2G. SOC synchronous control is explained in [13].

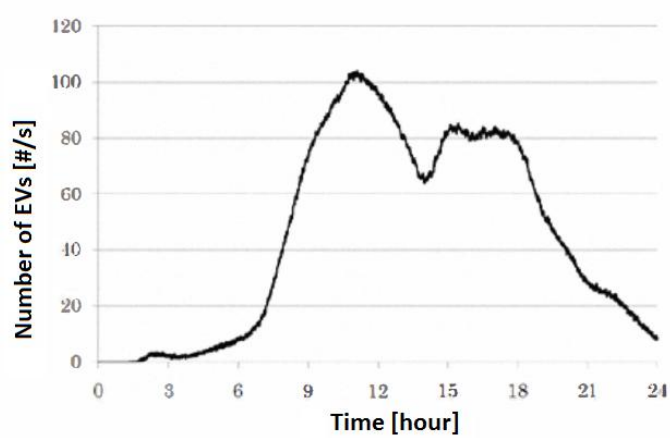
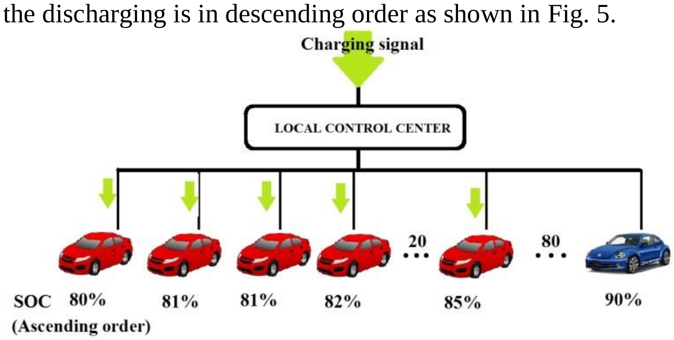
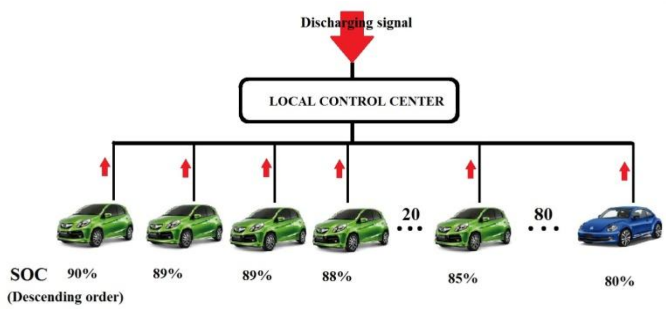


Fig. 4 Control-in rate

LFC signal to EVs is sent from control centre that is arranged in area of every 1second. The restriction of charging and discharging is in MW limit and MWh limit(80% - 90%) of SOC. Whether the local control centre is controllable or not is explained by the EV. The information about the local control centre is controlled in or plugged out is sent through the EV for every 30sec, the EVs sends the information on SOC for 30sec each. The SOC of EVs are assigned in the area which receives the information from local control centre. The control signal of local control centre dispatch is as follows. The priorities of charging and discharging of EVs are determined according to SOC of every 30sec. The charging signal is dispatched in ascending order whereas the discharging is in descending order as shown in Fig. 5.



(a)



(b)

Fig. 5 Examples of dispatching signal method (a) Charging signal (b) discharging signal

IV. FREQUENCY CONTROL

Let us consider the different types of loads. The loads are based on the certain priority. The Load1 is set as first priority which is a critical load and an essential load. The Load 2 is the second priority which is the lighting loads and finally the PEV charge station. The total capacity of the utility is 1000kVA. The rating of the critical load is 800kVA. The rating of the lighting load is 100kVA. The need of power by the charging station is 100kVA. The batteries used in PEVs are laminated Lithium-ion battery with the voltage rating of 360V. The schematic diagram of the proposed system is shown in Fig. 6.

The power system delivery frequency is an electrical system will affect inductive and capacitive reactance and will have very little effect on purely resistive loads. It will affect the power factor of the delivered voltage. There are some types of equipment that can handle the change in frequency but some types of equipment that is running on the exact frequency that it was designed to most efficiently and some equipment should not be run outside the manufacturers target frequency. So maintaining the frequency as constant is important for the better performance of the utility as well as load. But the frequency is inversely proportional to the demand of the system. In the proposed system the base power is 1000KVA. When the power demand increases more than 1000KVA the frequency will be reduced less than 50Hz. When the power demand is less than base power then the frequency will increase more than 50Hz. The load scheduling technique is used to maintain this frequency as constant even variation in demand. In proposed system six switches (S1, S2, S3, S4, S5, S6) are used to schedule the load which are controlled by AT Mega2560 as per the requirement of the load.

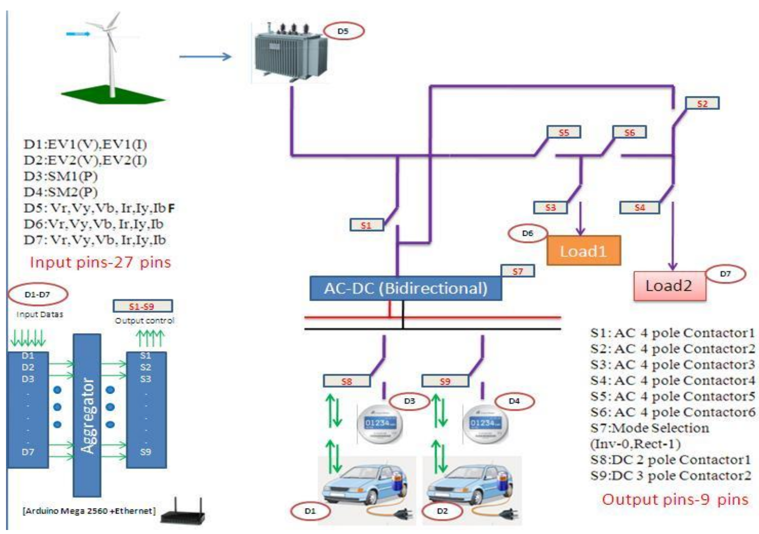


Fig. 6 Schematic diagram of the proposed frequency control system

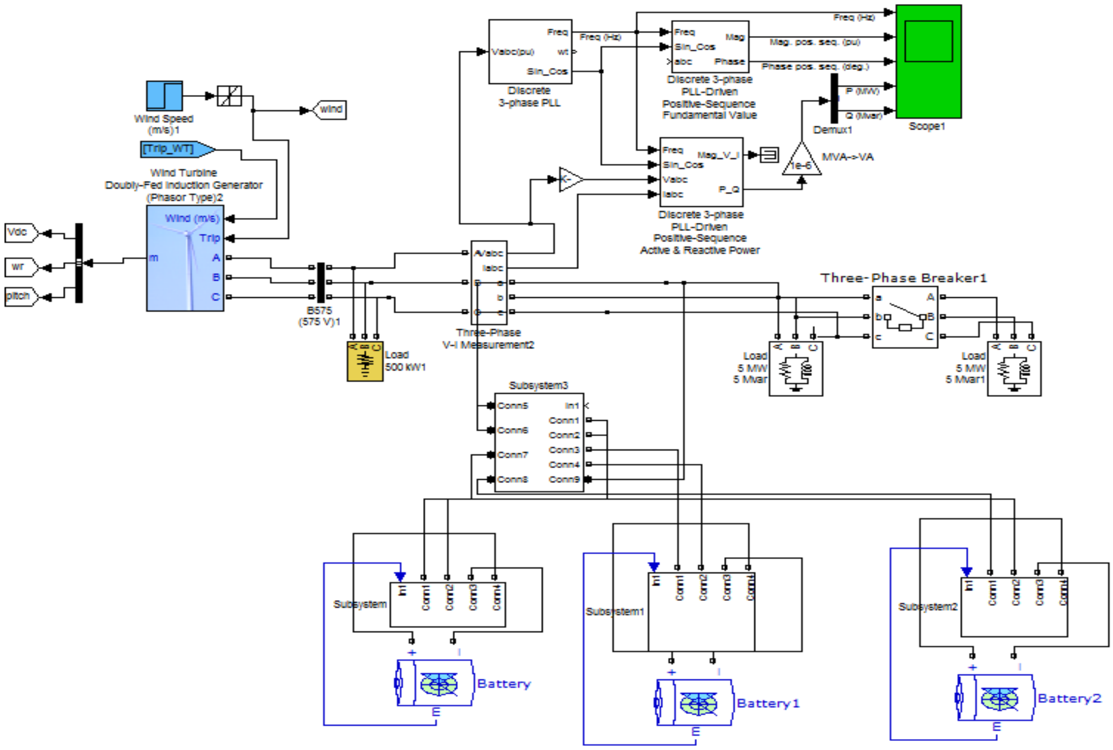


Fig. 7 Proposed frequency control system

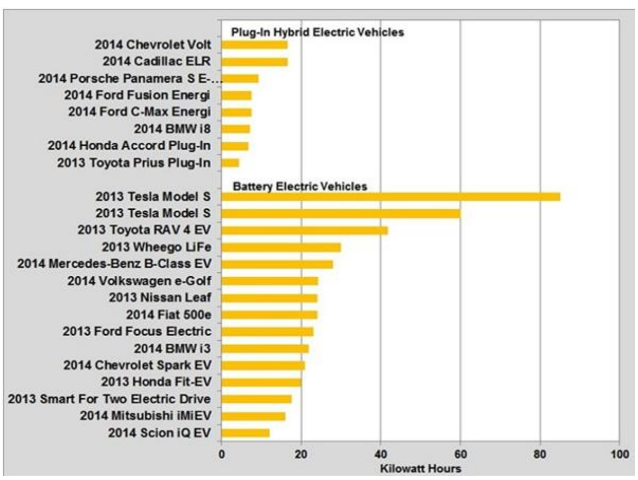


Fig. 8 Battery capacity of different PEVs

Case (1) Demand is more than 1000kVA

The Switch 1(S1) will be opened and the frequency is checked by AT Mega2560. Still the frequency is low then Load2 is isolated by closing Switch 6 (S6) and opening Switch 2 (S2). Then PEVs are used as service provider for Load2. For that the SOC level of the PEV battery and PEV owners willing are checked. The vehicles which have the SOC of above 80% with owner acceptance the vehicles are used as service provider for Load2. It is called inverter mode of operation, because of the DC supply of battery is converted into AC supply for lighting loads. The battery of a car can deliver power from 12kWh to 85kWh as per the manufacturing. It differs from one manufacturer to another as shown in Fig.8. As average 30kWh capacity battery is considered in proposed system. By converting kWh to kW using the equation 1 a battery can supply 25.5kW when the system power factor is considered as 0.85. In average four vehicles are enough to meet the demand of the Load2. The smart meter reads and records the kWh consumed by and from the PEVs.

$$P_{(kW)} = S_{(KVA)} \text{ X } pf \quad (1)$$

Where

$P_{(kW)}$=Real Power in Kilo Watts

$S_{(KVA)}$=Apparent power in Kilo Volt Ampere

Pf=Power factor

Case (2) Demand is less than 1000kVA

The Switches S1, S5, S6, S3 and S4 are closed and Switch S2 is opened. This mode is called rectifier mode. In this mode the AC supply from the service provider is used to charge the batteries of the PEVs.

To achieve the inverter and rectifier mode of operation there is a need of special device which is called back-to-back (bidirectional) converter. This comprises the both rectifier and inverter. It can convert AC to DC in rectifier mode and DC to AC in inverter mode. The bidirectional converter is shown in Fig.9.

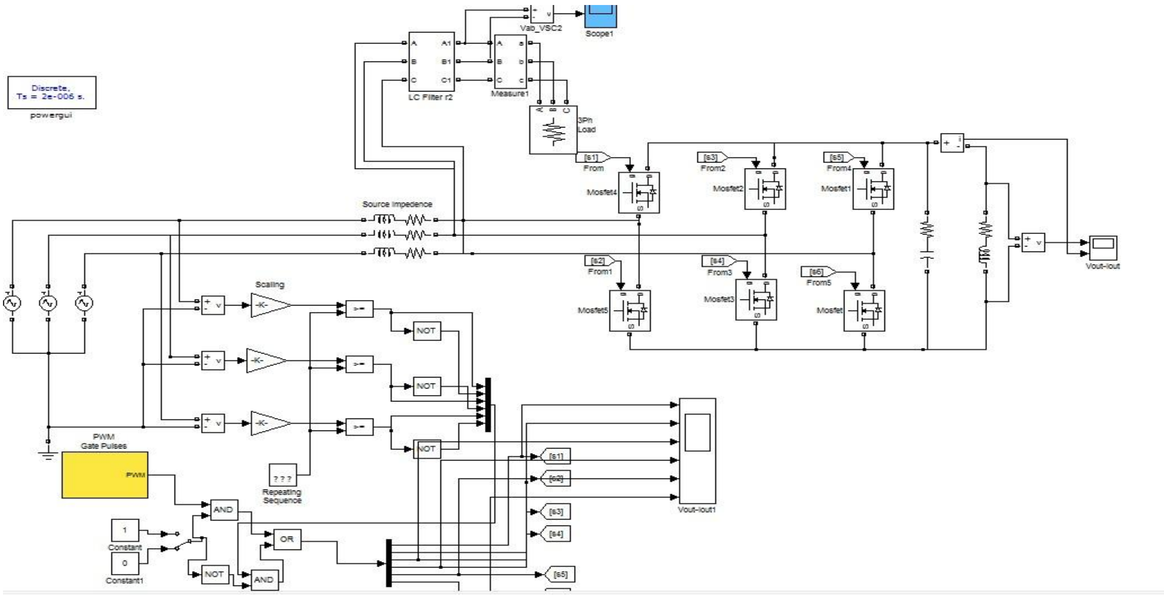


Fig. 9 Back-to-back converter

The switching operations are controlled and the system status are observed and controlled by the AT Mega2560 and the monitoring and sending control signals are send through IoT by the authority. By using IoT technique the authority can monitor and control the system from anywhere and anytime. The overall simulation of the proposed frequency control system is shown in Fig 7.

V COMMUNICATION SYSTEM

The three layers of the communication system architecture are

- Home environment
- Home Gateway
- Remote environment

Remote environment are an authorized user who can access the system on their phone and computer app using the internet via data connection to 4G/ 3G network and Wi-Fi. Home environment are router and the home gateway is a micro web server which is embedded with microcontroller based Arduino Ethernet as shown in Fig.10 and 11. Managing, controlling, monitoring are the main task of the server. This system enables hardware interface module to execute their task which is assigned. This can be done by sensors such as the sensors from the input D1 to D7 and actuators through cables. This system has the control over the load scheduling switches, charging station and SOC of the electric vehicle. For monitoring and controlling the system it supports sensors such as voltage sensor, current sensor, SOC of batteries, and the demand of loads.

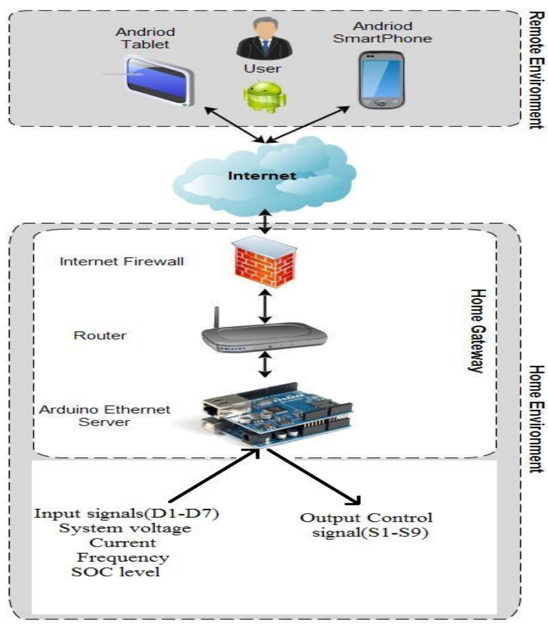


Fig. 10 Conceptual Architecture

If the end user enters the correct real IP address and password then the micro web server is connected successfully. The response code will be received when the android web server grants permission if the response time indicates the password is correct. The application will be synchronized to reflect the real time status of the proposed system. The space is used for the separation of response code and the system status the colon (:) is uses for the separation of system and its status.

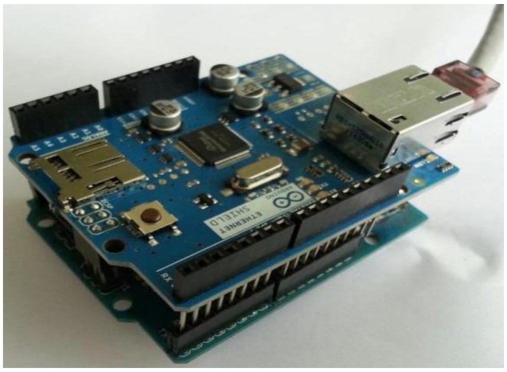


Fig. 11 Picture depicting the Arduino with Ethernet

(b) Software development for Gateway

The two parts of software web server are server application software and microcontroller firmware. For successful communication between the proposed system and gateway, the sensor control stage and config stage are implemented on the AT Mega2560. The data is received in <ethernet.h> libraries and Java Script Object Notation(JSON) format the output are displayed. Fig. 12 shows the flowchart of the established connection between Arduino and the Internet.

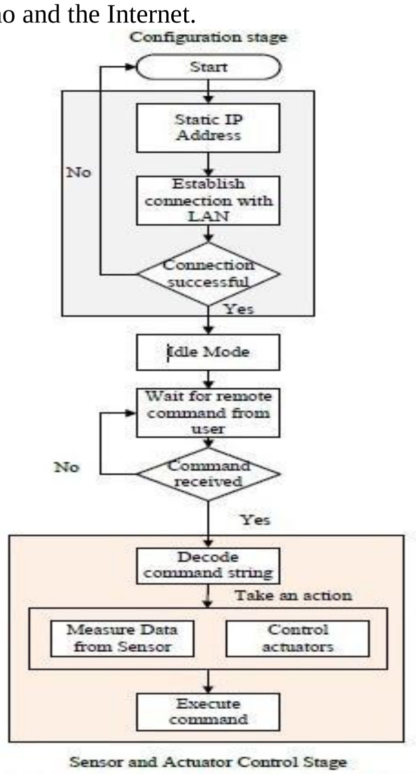


Fig. 12 Gateway flowchart

To the Internet TCP/ IP protocol the gateway is connected. Arduino Ethernet supports TCP/ IP stack. Now the design is focused on software connection to the remote user. At initial phase, once gateway is started it enters to the conFiguration stage. In next phase, the conFiguration stage establish the connection with the LAN (Local Area Network) by the use of static IP address. The use of static IP instead of Dynamic Host ConFiguration Protocol (DHCP) optimizes the process. When the gateway is initialized, it enters into an idle state till the command receives from the remote system. The control action is taken as required when the control command is given from the system.

VI RESULTS

The simulation of proposed system is carried out using MATLAB/SIMULINK which verifies the feasibility of the proposed system. The performance of the system is investigated for the both inverter and rectifier mode of operation. The inverter mode is carried out up to 1.5sec and from that instant to 3 sec it works in rectifier mode as shown in Fig. 13.

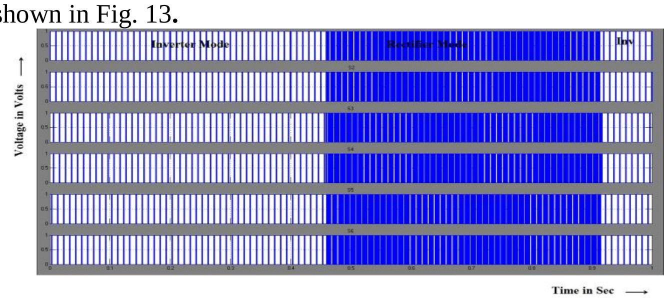


Fig. 13 Pulse pattern of rectifier and inverter mode

When the demand is equal or less than the base power then the service provider supplies to all the loads as well as it will charge the PEVs. This is called rectifier mode where the AC supply of service provider is converted into DC. Fig. 14 shows the inverter mode of operation where the DC voltage is converted into AC voltage.

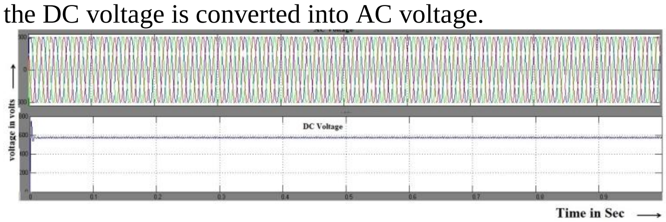


Fig. 14 Waveform of Rectifier mode of operation

When the demand is more than the base power then the Load2 is isolated and the DC supply from the PEVs is converted into AC supply to support the Load2 which is called inverter mode of operation. It is shown in Fig. 15 where the AC voltage is converted into DC voltage.

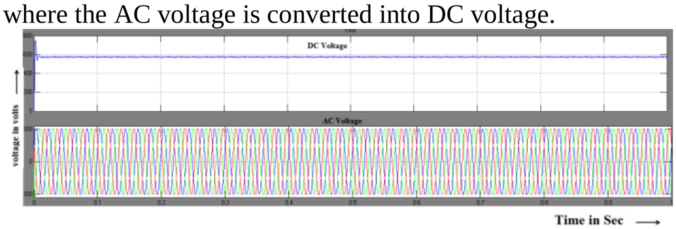


Fig. 15 Waveform of Inverter mode of operation

The load is added to the system at 0.5sec to 3sec. At that instant the system voltage drops from 500V to 480V. As voltage and current are inversely proportional, the current increases at the time period of 0.5sec to 3sec. Due to the addition of load the power demand increase from. This is shown in Fig. 16.

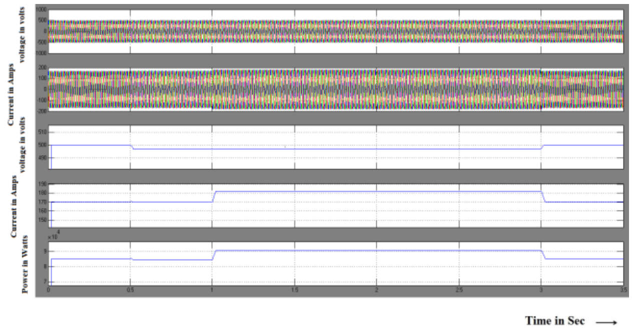


Fig. 16 System voltage, current and power waveform

Since the frequency and power are inversely proportional, the increase in the power demand reduces the frequency from 50Hz to 47Hz at that particular instant say 0.5sec -3sec . It is shown in Fig. 17.

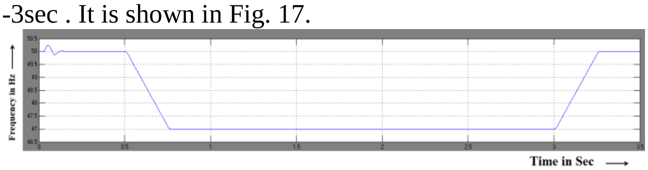


Fig. 17 Frequency drop at increase in power

As it is said earlier when there is increase in power decreases frequency. At that state, the PEV checks the SOC. The PEV which has the SOC as 80% and above supports the system by discharging it the batteries from 1.5sec to 3sec. From 0.5 sec to 1.5sec there is no PEV has the SOC of 80% and above so that there is no PEV to support the system as shown in Fig. 18. Even though the PEV in control-in state without owner's willingness the PEV cannot support the system.

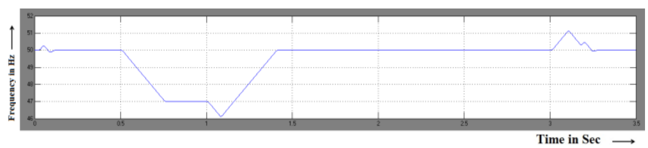


Fig. 18 Frequency compensation by PEV

The SOC level of the battery cannot be measure directly so that the voltage of the battery is used to indicate the SOC level. Because of the Voltage and SOC are directly proportional. Fig. 19 shows the voltage and SOC level of PEV's battery when it starts to support the system by discharging the power.

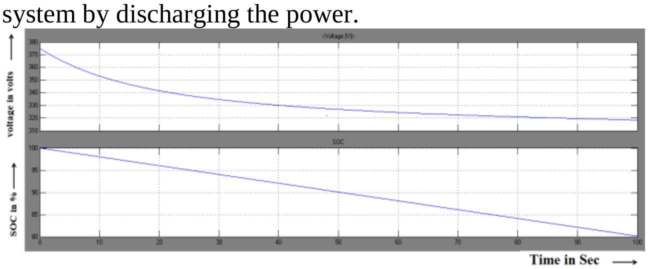


Fig. 19 Voltage and SOC level of PEV's battery at discharging state

When many PEVs are considered according to its SOC level that supports the system to meet its demand by maintaining the system frequency and voltage as constant. As shown in Fig. 20 at the instants 1sec to 1.5sec and 2sec to 3sec the PEVs supports the system so that the system voltage is constant at that instant. From 0.5sec to 1sec and 1sec to 1.5sec the PEVs may be in driving state or charging
state.

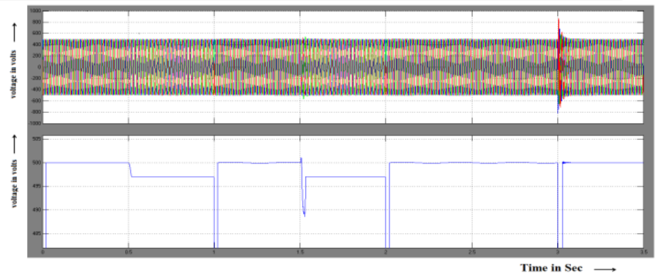


Fig. 20 Multiple PEVs supports the system to maintain constant frequency

VII CONCLUSION

Thus the advancement in power system has increased in its demand based. The change in demand changes the system frequency. This change in frequency will affect the power system performance thus the frequency control based on load scheduling is adapted and controlled. This done by the controller called AT Mega2560 and the monitoring action was done through IoT.

FUTURE SCOPE

In the future, on the one hand we need to study the Modern Technology for the electric vehicle joining in the frequency adjustment; On the other hand, in order to better data communication to Control centre we can use ESP8266.Because ESP8266 module does not require any wired communication.

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