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Complete List of Authors:	E, Sheeba Percis; Dr MGR Educational and Research Institute University, Electrical and electronics engineering A, Nalini; Dr MGR Educational and Research Institute University, Electrical and Electronics Engineering T, Jenish J, Jayarajan S, Bhuvaneswari S.T., Rama
Keywords:	Photovoltaic systems, Electric Vehicle, Alternative Energy, Sustainable Development, PSCAD/EMTDC, Microgrid, Power Quality

Design and Supervisory Control of a Self Sustained Hybrid Renewable Energy Microgrid for Rural Electrification of Dry lands in Southern India

Sheeba Percis E[1], Nalini A[2], Jenish T[3], J. Jayarajan[4], S. Bhuvaneswari[5], S. T. Rama[6]
[1,2]Associate Professor, Dr. M. G. R. Educational and Research Institute, Chennai - 95
[3,4,5,6] Assistant Professor, Dr. M. G. R. Educational and Research Institute, Chennai - 95
sheebapercis.eee@drmgrdu.ac.in

Abstract

Advancement of energy exploitation, increased the demand of various alternative generation methods and efficient production and utilization systems. Such kind of alternative energy systems would be of great use in certain terrains like dry lands wherein drought is prevalent and scope for solar PV installations is cost effective and a viable solution for power demand. Ramanathapuram is one such dry land in southern part of India which is a drought prone coastal district, which has surplus wind and solar energy to be harnessed effectively. However as Photovoltaic (PV) systems are affected by various conditions like position of the sun, change in temperature and irradiance due to passing clouds, improving the intermittency of solar power is mandatory which calls for an energy storage system, which is an electric vehicle in this article. The foremost idea behind this article is to develop a self sustained hybrid microgrid incorporating an electric vehicle in combination with the solar power system which enhances the performance of the system by absorbing the variations in power produced. In this work the real field data from NIWE (National Institute of Wind Energy) is used to show the variation in temperature and irradiance. The main objective of the article is sustainable development of the dry land through natural resources which helps in development of a permanent solution for the existing power crisis in the district. A coordinated control of a PV, Wind and EV based microgrid is designed by considering the State-of-Charge (SOC) of the battery to obtain desired outcome. The modeling is done in PSCAD/EMTDC and the results are verified through simulation.

Keywords — Alternative Energy, Sustainable Development, Photovoltaic systems, PSCAD/EMTDC, Electric Vehicle, Microgrid, Power Quality

Abbreviations:

PSCAD	Power System Computer Aided Design
SOC	State of Charge
NIWE	National Institute of Wind Energy
PV	Photovoltaic
RES	Renewable Energy Resources
TEDS	Tamilnadu Energy Development Agency
V2G	Vehicle to Grid
G2V	Grid to Vehicle
MNES	Ministry of Non-Conventional Energy Sources
Ni-MH	Nickel Metal Hydride
DFIG	- Doubly Fed Induction Generator
WECS	Wind Energy Conversion System
EV	Electric Vehicle
NITI	National Institution for Transforming India

1 INTRODUCTION

The dry land of Ramanathapuram is located between 9 ° 05 'and 9 ° 50' North of Latitude and 78 ° 10 'and 79 ° 27' East of Longitude. It is bordered by the Sivaganga District to the north, the Pudukkottai District to the northeast, the Palk Strait to the east, the Gulf of Mannar to the south, the Thoothukudi District to the west, and the Virudhunagar District to the northwest. It covers the 4175.00 Sq. Km. geographical area. The district has a Dry, hot weather condition throughout the year except the North East monsoon season in November and December. Since it drought prone, power supply is a major concern along with the woes of agriculture which lacks water. This calls for a self sustained alternative energy system which could produce power such that the barren land can be effectively used for sustainable livelihood.

One of the most versatile forms of energy is electricity which is widely used world over. Hence a much better system is needed in future from power generation and transport to final consumption. Also to mitigate the global changes in climate the electrical system needs to change quickly. To developing countries like India microgrid is a solution for reasonable power production and the same in combination with energy storage devices helps to light up remote locations like Ramanathapuram with necessary power. The population growth rate and vast industrialization in India has led to the large gap between the generated power and the energy supplied to various consumers. The current scenario has led to an growing need for alternative energy generation and microgrid technology has begun to become more popular. The microgrid has a small geographical scope and includes embedded generation or storage resources or both that can function in isolation or parallel to the grid [1-2]. A solar powered microgrid is sufficient to supply electrical energy to limited number of consumers connected together through a common distribution network. The solar power has the tendency to vary with respect to temperature changes due to which irradiance changes. When temperature and irradiance changes, the power output of the photovoltaic (PV) array also fluctuates. In order to compensate for these changes, a distributed energy storage system is essential. An intermittent source of input calls for an Energy storage system which in turn improves the system performance [3].

Recently many residential apartments have increased the usage of rooftop solar photovoltaic resources to reduce electricity bills. The impact of this high penetration has its own effects like excess supply during lean period and when there are passing clouds there PV array output decreases. Hence a storage system is required to mitigate this varying scenario [4-5]. The energy storage devices which are used normally adopt moving control. But the ramp rate cannot be controlled directly in this method and it depends on the previous value of PV output. But if the energy storage is controlled based on an inverse relation between the ramp rate and PV panel output, the fluctuations can be minimized. Also fast acting dc-link voltage-based energy management schemes are proposed for a hybrid energy storage system fed by solar photovoltaic energy. In this two modes are possible. For quick fluctuations of load super capacitors will supply and the average load demand is controlled by the batteries [6]. Therefore integrating a battery energy storage system helps in making the intermittent renewable resources easy to dispatch [7-8].

In some cases super capacitor is used to smooth out the fluctuations caused by PV resources [9]. But the main disadvantage is the cost of the super capacitor is very high. A microgrid is capable of operating in grid connected or islanded mode. Particularly in islanded mode of operation, energy storage system comes to the rescue. A cooperative control strategy enhances the power management of distributed energy resources and energy storage systems in islanded mode [10-12]. Another way of effective power management is to have interaction with the consumer and distribution network operator such that based on the solar irradiation data the energy storage can be utilized in an economical way [13]. To reduce stress on the feeder, a dc charger may be used in between the high voltage dc-bus of the inverter and battery combination which is capable of diverting the fast changing solar output to the battery system for stabilization [14]. By using energy storage system the power quality of the supply can be improved. Power quality is a major concern when renewable energy resources are used [15-17]. Another area where the application of electric vehicle is growing is the transportation sector where electricity is needed for storage and distribution. In bringing out a carbon free electric energy out solar PV's are sought after [18-20]. When the maximum power point tracking technique is used optimal usage of the varying solar energy can be captured and if it is integrated with energy storage system the microgrid becomes completely reliable [21].

In [22-23] the authors have proposed a novel approach of an autonomous hybrid system for a rural village in Egypt, highlighting the cost minimization factor. Also, environmental and economic aspects are studied for the choosen area such that the configuration of the system would be optimal. In [24-26] the optimal sizing of a hybrid microgrid is effectively presented using Hybrid Invasive Weed Optimization algorithm. The load demand of the local area under study is calculated and optimization is carried out covering aspects like initial cost and replacement cost. In the article, the authors have adressed on the standalone renewable electrification system for AlJouf in Saudi Arabia using wind, solar and biomass along with the techno economic feasibility of the proposed system. It is seen that such kinnd of alternative energy sytems are very effective in remote electrification [27-28]. The main contribution of this article is to develop a control for solar PV system in coordination with battery storage and wind energy conversion. The battery depending on the SOC helps in the vehicle-to-grid (V2G) or grid-to-vehicle (G2V) transaction of power. This self sustained microgrid configuration is very much suited for electrification of dry lands like Ramanathapuram in Southern India. The following sections describe the geographical location of the dry land, current power scenario of Ramanathapuram, the system modeling of grid connected hybrid system comprising of PV, Wind and energy storage system in PSCAD/EMTDC and the simulation results and conclusions drawn, follows in successive sections of this article. Advances in renewable energy, education , health and community growth are more general areas of focus. In terms of energy, Ramanathapuram provides unexploited potential for renewable energy (solar and wind), which could be harnessed by water pumping, agro-processing, mobile phone charging, etc. to minimize over-dependence on biomass and help income-generating activities. This would help to solve energy demand and the productive use of water supplies in a better way.

2 NEED FOR ALTERNATIVE ENERGY SYSTEM

The need and demand for power is a rapidly increasing scenario due to the increase in population and Urban life style. Major composition of the Energy is derived from the Fossil Fuel which lead to the emission of Carbon dioxide and various other gases which depletes the Ozone Layer and affects the global warming. In order to overcome these drawbacks, the substitute for the Conventional Energy Sources are the Non conventional sources of Energy which relies on Sun, Wind, biomass, Geothermal, Tidal etc which are inexhaustible.

India has vast opportunities for Non-conventional sources of Energy especially Solar and Wind. Many R& D and Educational Institutions and state electricity boards have proved the usage of Renewable Energy. Research is going in the entire field including Chulhas, Biogas Plants, Biomass Gasifiers, Solar Electric and Thermal systems, Wind Farms, Small and Micro Hydel system, Energy from Waste, Hydrogen Energy, Ocean Energy etc.

In Tamil Nadu, the Tamil Nadu Development Agengy (TEDA) is functioning as the Nodal Agency to the Ministry of Non Conventional Energy Sources (MNES). Since the inception TEDA, the growth in Renewable Energy has increased. The total Power capacity across Tamil Nadu is shown in Figure 1. From the graph it simply depicts the growth of Renewable since its installation.

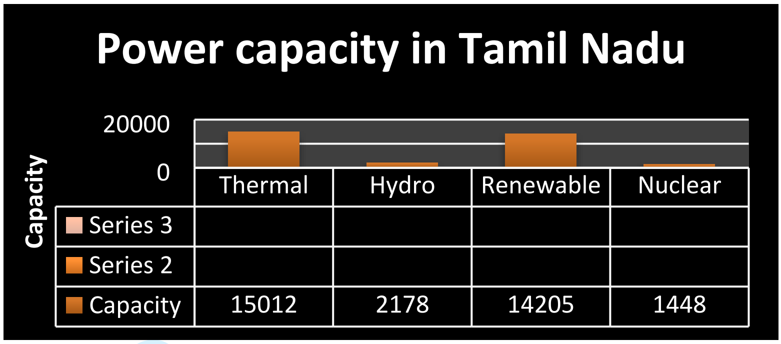

Figure 1 Power Scenario in Tamilnadu

The Renewable Energy Achievements as on 31-1-2020 by TEDA in Tamil Nadu is shown in Figure 2. It is understood that the largest Energy Source in Tamil Nadu is Wind and the second largest in Solar. The Proposed Area Ramanathapuram is a dry Area and there is a lot of scope for the Solar Energy which can be used for Charcoal Industries, Fishing and Storage etc. The Proposed area mainly relies on Agriculture and Fishing wherein the Renewable Energy like Solar and Wind can be used for Power Generation and utilized. At present in Kamuthi, Photovoltaic power Station, the world's largest solar power plant at a single location with a capacity of 648 MW of clean and green energy with an investment of Rs 4,550 Crore.

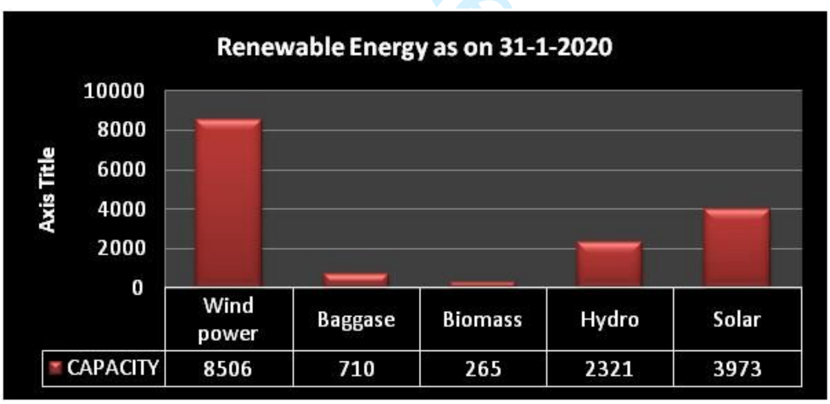

Figure 2: Statistics of RES as on 31-01-2020

The proposed area has high solar radiation with more than 300 sunny days per year and the availability of Wind is also more in the coastal regions of Ramanathapuram District, there by the solar and wind energy can be trapped for Power Generation and thereby many Microgrid can be installed.

3 SELF SUSTAINED MICROGRID

As wind and solar energy resources are surplus in the location under study, the article focuses on investigation of the future field of the self sustained standalone hybrid (solar, wind and electric vehicle) renewable energy source. The design and development of the microgrid is explained in the following section.

3.1 Modeling of Electric Vehicle

The main component of electric vehicles (EV) and of more electric systems in general is the battery. The battery is capable of storing a huge amount of energy according to the defined capacity and can release the same when necessary. Electric vehicles have become more popular in the transportation as fuel is not based on fossil resources and green energy is used. Not only that, the intermittent resources such as wind and solar energy need an energy storage system in the microgrid to achieve the best results with improved power quality. A battery management system ensures the EV's charging state (SOC) is tracked continuously and the battery charges or discharges accordingly depending on the input power from the PV array. Therefore a detailed description of the battery model is required. In this work a Nickel Metal Hydride (Ni-MH) battery is taken for study. The components of the Ni-MH battery are harmless to the environment and the batteries can be recycled which is the positive side of this technology. Figures 3 and 4 show the typical discharge characteristics of a Ni-MH battery and hysteresis phenomenon. If the battery reaches full charge the voltage will gradually decrease depending on the current amplitude. The battery management system needs to be effective to estimate the state of charge and allow power transactions by V2 G or G2V depending on the solar irradiation.

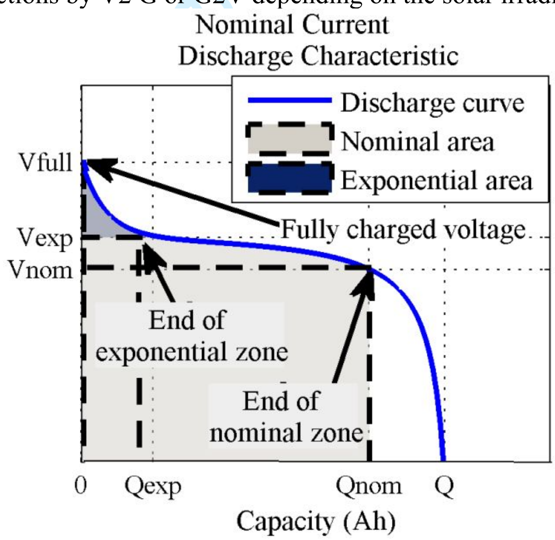

Figure 3: Typical discharge curve of battery

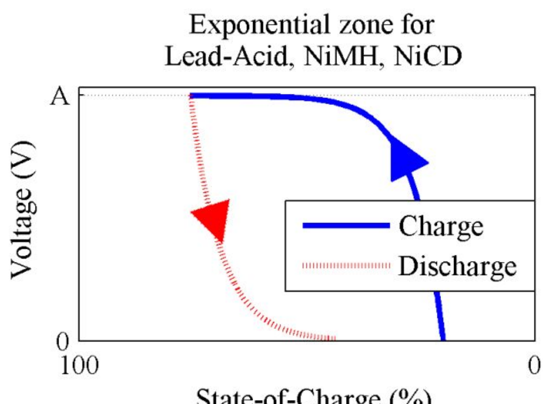

Figure 4: Typical discharge curve of battery

The discharge model is similar to the Shepherd model but can accurately represent the voltage dynamics when the current changes and takes the open circuit voltage (OCV) into account as a function of SOC[13]. The model of battery takes the advantage of a controlled voltage source in series with a stiff resistance. The discharge model of the battery is shown in figure 5 and figure 6 shows the battery model.

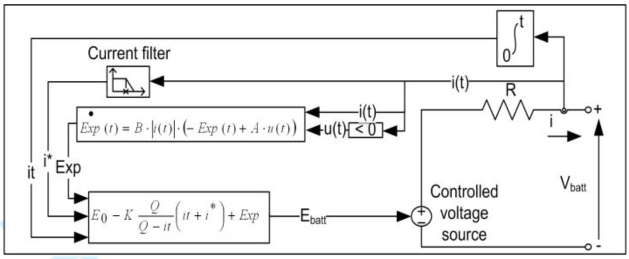

Figure 5: Model of the battery in discharge mode

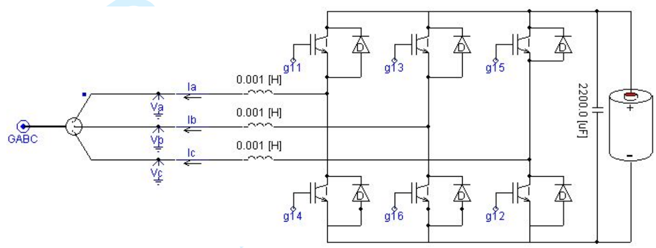

Figure 6: Model of the battery in PSCAD/EMTDC

For this case, a two-level, three-phase inverter and a Ni-mH battery are used to model the electric vehicle or DES. It is connected through the inverter to the grid, as can be seen in figure 6. The control of the electric vehicle inverter system is almost identical to that of the PV inverter except for one difference which is insignificant because the vehicle is connected to a constant DC voltage source.

3.2 Model of Solar Farm

In this research article, a 100 kW solar energy plant is modelled in PSCAD/EMTDC platform. There are 10 modules connected in sequence and eight parallel connected module in total numbers. Therefore, 216 solar PV cells are connected again in the same sequence (series) in each module, and eight cells in each string asynchronous (parallel) per module. Each connected cell incorporates a series resistance of 0.02 ohm and a shunt resistance of 1000 ohm [19]. The output voltage of the solar array is obtained across a capacitor C as shown in figure 7. The measure of L is 0.01H and C is 0.06µF.

Also, drawing out the utmost possible power from the PV panel using the Tracking algorithm is extremely necessary. The algorithm is embedded within the boost converter function. To monitor the suitable level, the MPPT block uses the Incremental Conductance function. The algorithm relies on the very fact that at the maximum power point (MPP), the slope of the PV array power curve is zero, positive on the left of the MPP and negative on the right side. Furthermore, the MPP may be tracked by comparing instant conductance against incremental conductance.

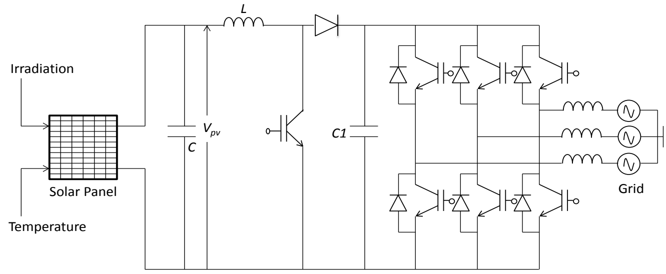

Figure 7: Layout of the grid connected PV system

3.3 Model of Wind Farm

In this paper, a 0.5 MW wind farm which uses a DFIG is simulated incorporating the vector control method in PSCAD/EMTDC as seen in figure 11. Since vector control is used, the power quality of the active power supplied to the system is improved. The control of DFIG is achieved in two stages, from rotor side and also from grid side converter. The main purpose of the rotor side converter is to regulate the DFIG rotor speed for maximum wind power acquisition, maintain constant frequency of the DFIG stator output voltage and control the DFIG reactive power. With just the incorporation of rotor current control in the stator flux-oriented frame of reference, the said objectives are achieved. Wind farm parameters are shown in Figure 8.

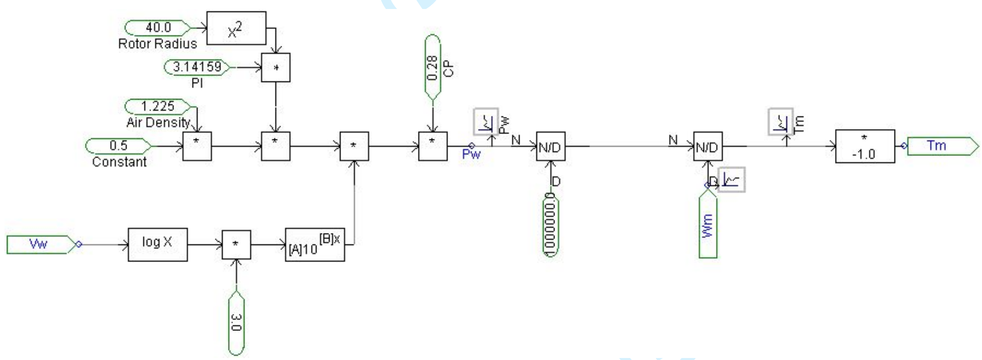

Figure 8: Wind Farm Parameters

The d-axis is aligned with the stator flux linkage vector in stator flux-oriented reference frame λ_s, which means $\lambda_{ds} = \lambda_s$ and $\lambda_{qs} = 0$. Therefore according to the two axis-equations of the DFIG, the following relationships can be obtained.

$$i_{qs} = -\frac{L_m \cdot i_{qr}}{L_s} \quad (1)$$

$$i_{ds} = L_m\left(i_{ms} - i_{dr}\right) / L_s \quad (2)$$

$$T_e = -\frac{3}{2}\frac{p}{2}\frac{L_m^2 i_{ms} i_{qr}}{L_s} \quad (3)$$

$$Q_s = \frac{3}{2}\frac{\omega_s L_m^2 i_{ms}\left(i_{ms} - i_{dr}\right)}{L_s} \quad (4)$$

$$v_{dr} = r_r i_{dr} + \sigma L_r \frac{d i_{dr}}{dt} - s\omega_s \sigma L_r i_{qr} \quad (5)$$

$$v_{qr} = r_r i_{qr} + \sigma L_r \frac{d_{idr}}{dt} + s\omega_s\left(\sigma L_r i_{dr} + L_m^2 i_{ms} / L_s\right) \quad (6)$$

where,

$$i_{ms} = \frac{v_{qs} - r_s i_{qs}}{\omega_s L_m} \quad (7)$$

$$\text{and } \sigma = 1 - \frac{L_m^2}{L_s L_r} \quad (8)$$

It is evident from the equations that the rotor speed of DFIG can be regulated by adjusting the current components of the q-axis rotor, i_{qr}. It can also be shown that i_{dr} the stator reactive power Qs can be effectively regulated by controlling the d-axis rotor current portion as seen in figure 9. As a consequence, i_{dr} and i_{qr} reference values can be calculated directly from the stator reactive power (Qs) and DFIG rotor speed (ω_r) commands. A PI controller produces the reference value i^*_{qr} for optimum extraction of wind power during this research work. Depending on the maximum wind power monitoring algorithm, the speed command ω*r is calculated. The grid side controller's other goal is to keep the dc-link condenser voltage constant, regardless of the magnitude and direction of the rotor power. The Grid side converter also takes control of the reactive power supply to the grid.

The equations indicate that it is possible to regulate the DFIG rotor speed anywhere by controlling the current components of the q-axis rotor, i_{qr}. It is also suggested that the stator reactive power Qs can be regulated by controlling the current portion of the d-axis rotor, i_{dr}. The reference values of i_{dr} and i_{qr} can therefore be calculated directly from the commands of the stator reactive power (Qs) and DFIG rotor speed (ω_r). A PI controller produces the reference value i^*_{qr} in this work for optimum harvesting of wind power. The speed order ω_r^* is calculated from the tracking algorithm for optimal wind power.

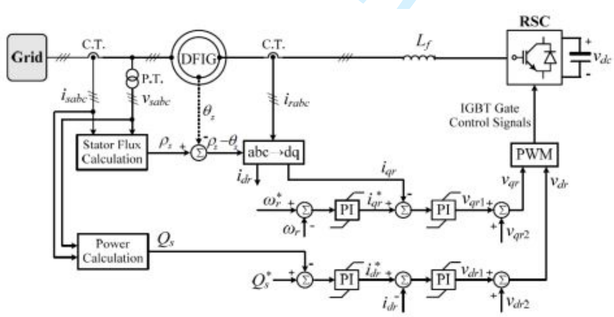

Figure 9: Rotor side Converter Control

The other control in the converter circuit linked back-to-back is the grid side controller whose goals are stated as defies: the first is to keep the dc-link voltage static irrespective of the intensity and direction of the rotor power depicted in figure 9. The grid side converter in figure 10, also provides the grid with reactive power, and regulates the voltage of the stator terminal.

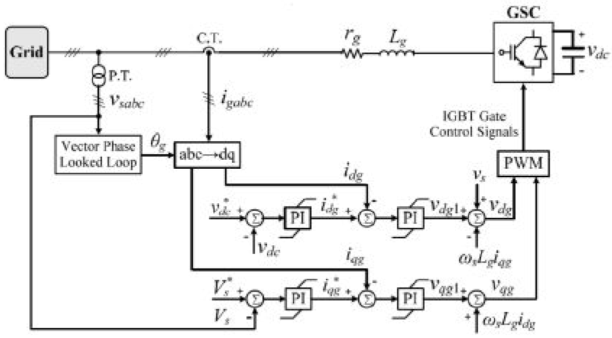

Figure 10: Grid side Converter Control

In this case a two-level three-phase inverter and a Ni-mH battery were used to construct the electric vehicle or Distributed Energy Storage. It is connected to the grid through the inverter as can be seen, the control strategy of the electric vehicle inverter structure is almost identical to that of the PV inverter besides one exception which is the DC voltage regulation, because the vehicle is connected to a stiff DC voltage source. Otherwise, the control system should regulate the ordered or controlled power directly (P^*_{EV}) from the plug in electric vehicle. Since the active power order in this work is derived from the coordinating controller, which on the other hand controls total power injection (PV+EV) into the power grid[19], the baseline current for the current controller is derived directly from the subsequent equation (9).

$$i_{d(ref)\_EV} = \frac{P^*_{EV}}{v_d} \tag{9}$$

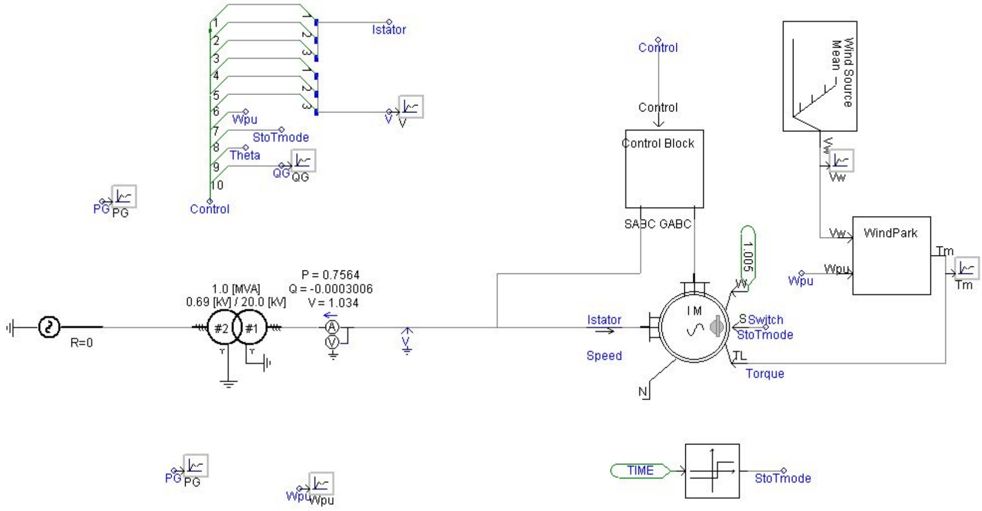

Figure 11: Design of wind farm

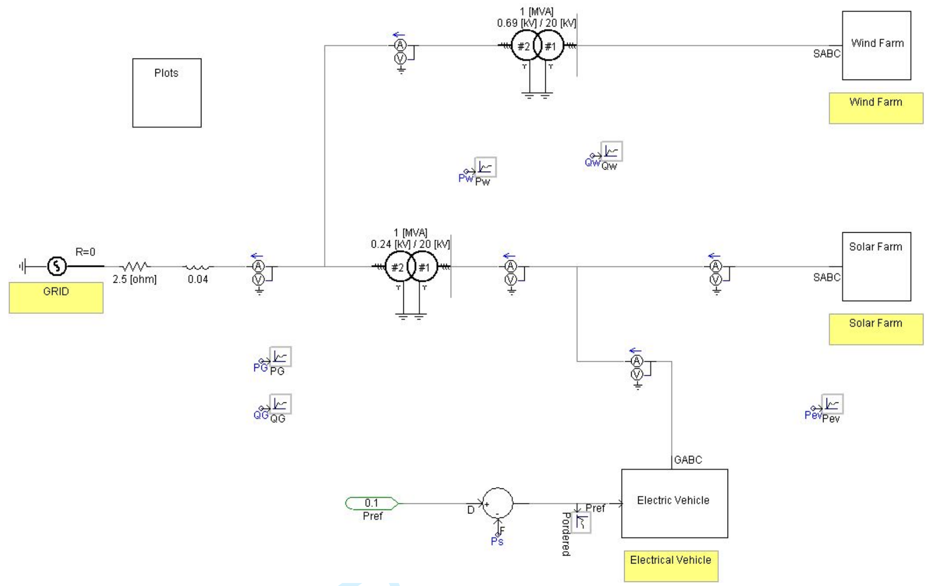

Figure 12: Design of PV-WECS-EV system connected to grid

A coordinating controller is required to level out the power fluctuations from the PV inverter and ensure the power injection to the utility grid is perfectly constant, shown in figure 11 and 12. The required Utility Grid power is provided to the coordinating controller as an input. It monitors the PV system output power too. And the contrast between those two powers, which is the coordinating controller output, can be used as the EV system's ordered power.

4 RESULTS AND DISCUSION

In Tamil Nadu, the Tamil Nadu Development Agengy (TEDA) is functioning as the Nodal Agency to the Ministry of Non Conventional Energy Sources (MNES). Since the inception TEDA, the growth in Renewable Energy has increased. The total Power capacity across Tamil Nadu is shown in Figure 13. From the graph it simply depicts the growth of Renewable since its installation.

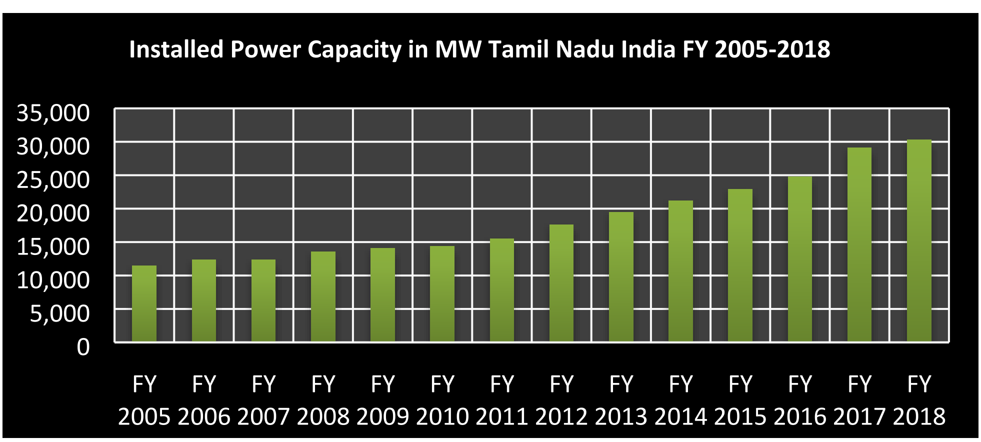

Figure 13: Growth of Renewable Energy installation in Tamilnadu

In Ramanathapuram, the potential areas of socio-economic concern and power thirty industrial areas are charcoal mnufacturing which is a predominant activity seen, country brick manufacturing and palmgar manufacturing units which are functioning in traditional methods due to lack of power in the blocks like Sayalkudi and Paramkudi. Most of the people living in this area are below poverty line and production stops during rainy season. Therefore using the proposed elf-sustained microgrid, modernization could be established which enhances productivity and also takes care of the power requirements which leads to improvement in the socio-economic status of the people living in the chosen area.

The self sustained microgrid designed consists of the Solar farm, Wind energy conversion system and Electric vehicle which is an effective combination leading to promising results for dry lands like Ramanathapuram. The E-vehicle inverter system control is analogous to the PV inverter control system. The coordinating controller controls the total power injected into the connected utility grid, which is calculated from the sum of PV+EV. In the control part as I_d follows I_{ord} successfully the control is implemented and the intermittency due to cloud cover is taken care of. Hence depending on the state of charge shown in figure 14, the EV charges or discharges such that the output power given to the grid is maintained constant. The SOC of the electric vehicle in figure 14 which varies approximately between a range of 80% to a minimum range of 74% accordingly the vehicle power due to varying solar input.

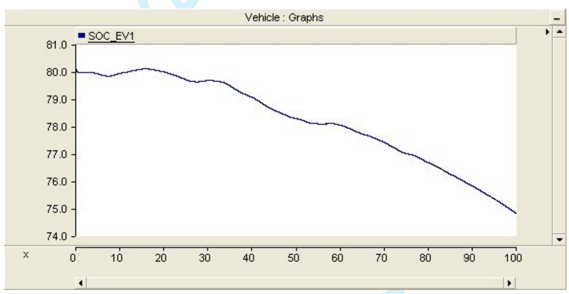

Figure 14: State of charge of battery

The current controller is one of the essential components of the Solar PV inverter. The controller for current in the d-axis should be a fast acting control system which will keep track of the reference current value generated by the DC voltage controller. At almost the same time, in the presence of transient occurrences, the current controller must be able to regulate the current, so that the converter valves do not encounter high excessive current above their value. In figure 15, the range and monitored values of the d-axis current controller is shown. From the obtained results, the satisfactory operation of the current controller is endorsed, which is more useful in industries like charcoal and cement manufacturing.

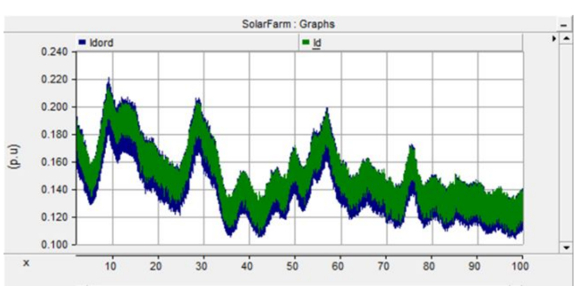

Figure 15: Values of range and monitored d-axis current of the solar inverter

The supervisory control of a PV, Wind and Electric Vehicle combined microgrid can be carried out by a dedicated master controller which is capable of scheduling the resources, calculating the SOC and accordingly share power allowing for V2G and G2V transactions, thus enabling a successful model for the dry land industry operations. By adjusting the value of real power, the voltage across the DC link capacitor is maintained at rated value by choosing proper I_{dref}. The actual voltage across the DC link capacitor E_{cap} is compared with the desired voltage E_{capref} and passed through a PI controller to generate the value of I_{dref}. The q-component is set to zero and therefore decoupled control is achieved. Once i_{dref} and i_{qref} are generated, it is converted to the stationary reference frame using inverse transformation and then the current references are used to generate the PWM pulses for the grid side converter, thereby fulfilling the purpose of the grid side converter circuit in maintaining a stiff DC voltage and also providing reactive power compensation. The simple PI controller helps to build the energy management system which balances the resources between the PV, wind and EV combined microgrid as seen in figure 16.

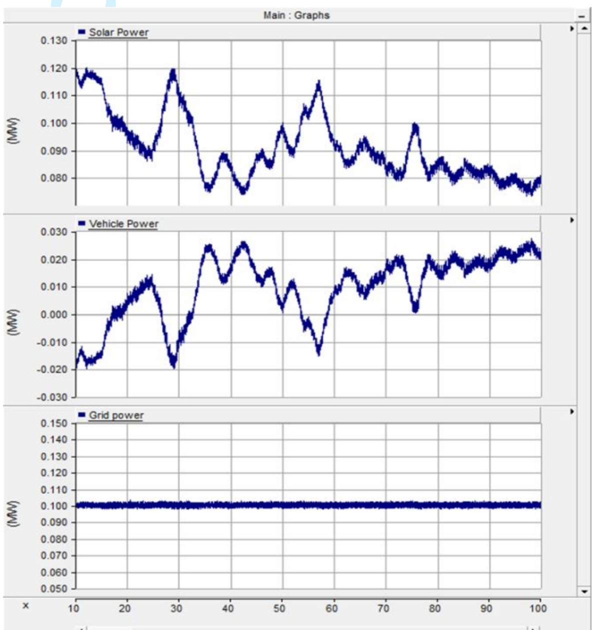

Figure 16: Constant Power Output of the Self Sustained Microgrid

5 CONCLUSION

India has agreed to reduce its global warming emissions as signed in the Paris Climate Agreement in the year 2016. Following this the NITI Aayog has proposed that, in 2030 India will sell only Electric Vehicles and vehicles with ICE will be abandoned. Also an e-highway is planned to be built with an overhead electric network for enabling the smart transportation. Therefore there is huge scope in the charging infrastructure of the EVs in future. Also Ramanathapuram is one of the aspirational districts according to NITI Aayog. The results shown in this paper are very convincing, in combination with a wind energy conversion, to develop the idea that Plug in electric vehicles can be utilized as external energy storage (EES) a solar PV based microgrid. As discussed the dry land of Ramanathapuram is a potential area where the implementation of the proposed self sustained microgrid will largely support the development of the socio-economic status of the people through modernization of industries using alternative energy and fuel resources.

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