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A Decentralized Dynamic Power Sharing Strategy for Hybrid Energy Storage System in Autonomous DC Micro Grid

S. Palaniyappa[1], P. Avirajamanjula[2]
[1]Department of Electrical and Electronics Engineering, PRIST University, Vallam, Thanjavur
[2]Department of Electrical and Electronics Engineering, PRIST University, Vallam, Thanjavur

***Abstract*–** As the requirement of Electricity is growing day by day and is already over the assembly of Electricity whereas reserves of fossil-fuel are depleting, there's a powerful have to be compelled to shift for different sources that are renewable energy sources. Concerning this, AC small grids and their energy management of those renewable energy sources have gained a lot of importance that is mentioned during this system. The most objective of the planned system is making uninterrupted power supply to the load systems that are settled at isolated sites of remote and rural areas. The planned system in the main deals with implementation of Energy Management System (EMS) to AC small grid exploitation most outlet chase (MPPT) algorithmic rule [3]. A coordinated and multivariable EMS is planned that employs a turbine and an electrical phenomenon array as governable generators by adjusting the pitch angle and therefore the shift duty cycles and a storage system consisting of batteries. So as to understand constant current, constant voltage (IU) charging regime and increase the lifetime of batteries, the planned EMS need being a lot of versatile with the ability curtailment feature. The planned strategy is developed as a web nonlinear model prognostic management (NMPC) algorithmic rule supported individual MPPTs of the system. The complete designed system is modeled and simulated exploitation MATLAB/Simulink design.

Index Terms – Battery Management, Maximum Power Point Tracking (MPPT), Nonlinear Model Predictive Control (NMPC), Power Sharing, and Voltage Regulation.

I. INTRODUCTION

Micro grids are new key components of recent power grids that improve the grids capability of hosting renewable energy and distributed storage systems consisting of AC and DC hundreds.[1] The close to future distribution networks can accommodate many interconnected small grids which can regionally generate, consume, and store energy. A small grid is also operated as associate degree extension of the most grid, i.e., grid-connected, or as a standalone network with no affiliation to the grid. Standalone DC small grids have some distinct applications in astronautics, automotive, or marine industries, furthermore as remote rural areas[2],[6].Substantial generation and demand fluctuations in standalone inexperienced micro-grids, energy management ways have become essential for the facility sharing purpose and regulation the small grids voltage. The classical EMSs track the utmost power points of wind and PV branches severally and place confidence in batteries, as slack terminals, to soak up any potential excess energy [2]. However, so as to shield batteries from being overcharged by realizing the constant current, constant voltage charging regime furthermore on contemplate the turbine operational constraints, a lot of versatile multivariable and non-linear ways, equipped with an influence curtailment feature are necessary to manage small grids. The steadiness of anAC small grid is measured in terms of the steadiness of its AC bus voltage level that is one in all the most management objectives.

The grid voltage supply converters (G-VSCs) area unit the first slack terminals to manage the voltage level of grid-connected small grids [8]. Battery banks, on the opposite hand, area unit effective slack terminals for standalone small grids. The curtailment ways of the battery bank that cannot absorb the surplus generation prohibit the batteries charging rate by the utmost engrossing power; but, the utmost charging current should even be restricted. What is more, they are doing not curtail the facility of every generator in proportion to its rating. So as to stop over-stressing conditions and current currents between generators, load demands have to be compelled to be shared between all slack DGs in proportion to their ratings. However, standalone AC small grids area unit sometimes placed in small-scale area unites wherever the facility sharing between DGs are often managed by centralized algorithms that are less suffering from 2 issues:

1) Batteries in charging mode area unit nonlinear masses inflicting distortions to the grid voltage; and
2) Absolutely the voltage level of a standalone small grid is shifted because the results of the load demand variation. Variety of phenomena has an effect on the batteries operation throughout the charging mode:

   a) Applying high charging currents, the batteries voltages quickly reach to the gassing threshold;
   b) The inner electrical device and thence power losses and thermal effects increase at high SOC levels; and [5]
   c) Batteries can't be absolutely charged with a relentless high charging current and conjointly restricts the utmost gettable SOC that results in unused capacities.

However, since batteries act as nonlinear masses throughout the charging mode, it doesn't essentially limit the charging currents. Betting on the proportion of the facility generation to the load demand magnitude relation at intervals standalone AC small grids, 3 cases area unit envisaged:

(i) Power generation and cargo demand area unit balanced;
(ii) load demand exceeds power generation causes AC bus voltage to come by absence of any load shedding; and 3) power generation is on top of load demand leads batteries to be overcharged and bus voltage to climb. This study focuses on case
(iii) Within which the generated power should be curtailed if it violates the batteries charging rates or if batteries area unit absolutely charged.

In distinction to the ways out there within which renewable energy systems forever operate in their MPPT mode, the projected multivariable strategy uses a turbine and a PV array as governable generators and curtails their generations if it's necessary. The projected EMS is developed as a web novel NMPC strategy that unendingly solves associate best management downside and finds the optimum values of the pitch angle and 3 switch duty cycles. It at the same time controls four variables of small grids:

a) Power constant of the wind turbine;
b) Angular speed of the wind generator;
c) Operational voltage of the PV array; and
d) Charging current of the battery bank. It’s shown that using new on the market nonlinear improvement technique and tools, the procedure time to unravel the ensuing NMPC strategy is in permissible vary [9]. Not like dump load-based ways that solely shield the battery from over charging, the planned strategy implements the IU charging regime that helps to extend the batteries era.

II. EXISTING CONSTRUCTIONS

The stability of a DC small grid is measured in terms of the soundness of its DC bus voltage level that is one amongst the most management objectives. The grid voltage supply converters are the first slack terminals to control the voltage level of grid-connected small grids. Battery banks, on the opposite hand, are effective slack terminals for standalone small grids their energy fascinating capacities are restricted relating to variety of operational constraints [8].

III. PROPOSED CONSTRUCTION

The planned strategy is developed as an internet nonlinear model prophetical management algorithmic rule. Applying to a sample standalone AC small grid, the developed controller realizes the IU regime for charging the battery bank. The variable load demands also are shared accurately between generators in proportion to their ratings. The AC bus voltage is regulated at intervals a predefined vary, as a style parameter

System Description and Modelling

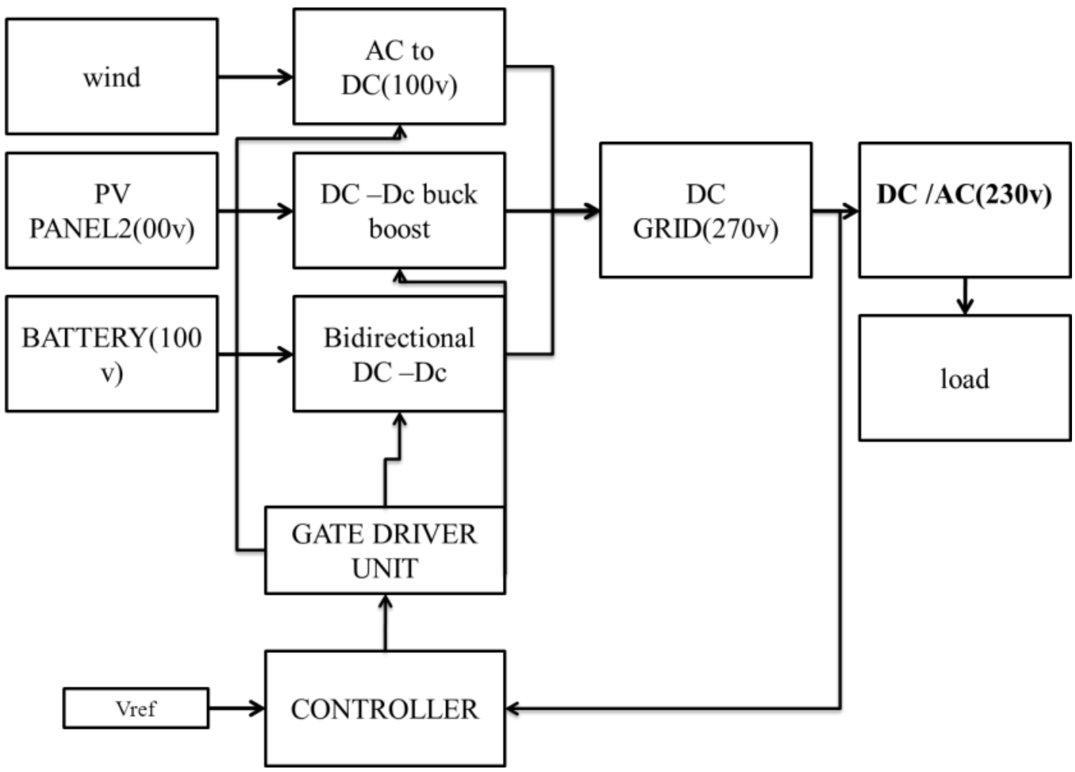

Fig 1. Topology of a small-scale and standalone AC Micro grid with connected loads

Fig.1. shows the Topology of a small-scale and standalone AC small grid with connected masses. The mathematical model of stand- alone inexperienced AC small grids is delineated as hybrid differential algebraically equations (hybrid DAEs). The below figure Fig.2 summarizes a changed version of the projected model. Since this method focuses on the case during which there's AN excess power larger than or adequate to the most attainable gripping rate of the

battery bank the subsequent notations square measure accustomed model the standalone AC [10].

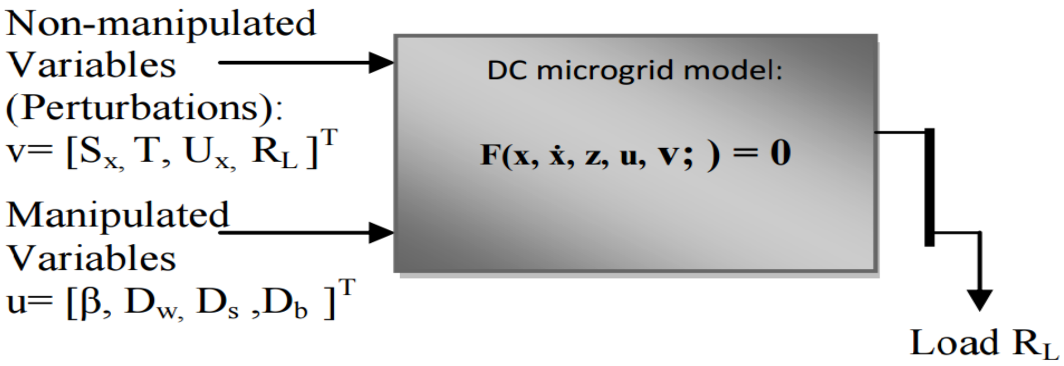

Fig 2. Modified version of the system model

$$\mathbf{X= [If, Qact, \omega r]\ T} \quad (1)$$

$$z = Ipv ,Vpv , Ipvdc ,Ibat ,Ibatdc ,Vbatdc, Iwt , Vwt , Iwtdc , Te , Tm , \lambda , Cp , SOC, Iload, VdcT \quad (2)$$

$$Fx, u, v = [f1\ x, x, z, u, v; f2\ x, x, z, u, v; \ldots\ldots; f24\ x, x, z, u, v;] = \text{zero} \quad (3)$$

Where F could be a set of implicit differential and algebraically useful fi for i € [1, 2, 3 …24].the primary 2 constraints f1 and f2 square measure thanks to the actual fact that in standalone AC small grids the total of the generated, stored, and consumed powers is often zero:

$$f1 = \mathbf{VdcIpvdc + Iwtdc + Ibatdc} \quad (4)$$

$$f2 = \mathbf{Vdc - IloadRL} \quad (5)$$

a) Wind

Wind turbines (WTs) convert the mechanical energy of wind to mechanical power. So as to come up with the utmost power by a WT at variable wind speed, it's necessary to use a most electrical outlet trailing (MPPT) management strategy. A turbine will be connected to associate in nursing electrical generator directly or through a gear-box. So as to convert the three-phase output of a PMSG to AC voltage, it's essential to deploy a three-phase rectifier. A general structure that consists of a full-bridge diode rectifier connected asynchronous to a DC-AC convertor is common thanks to lower value. Performance of the wind turbines is measured because the power constant curve with relevance the tip speed magnitude relation and pitch angle. Equation shows the facility constant curve of three-blade wind turbines [7].

f3 = $\boldsymbol{Cp}, -\mathbf{1Cp}, \times \mathbf{C1}\boldsymbol{C2\lambda i} - \boldsymbol{C3\beta} - \boldsymbol{C4}\mathbf{exp} - \boldsymbol{C5\lambda i} + \boldsymbol{C6}\lambda$ **(6)**

f4=$\boldsymbol{\lambda} - \boldsymbol{Rad} \times \boldsymbol{\omega rUx}$ **(7)**

f5= $\boldsymbol{\lambda i} - \mathbf{1}\boldsymbol{\lambda}+\mathbf{0.08}\boldsymbol{\beta} - \mathbf{0.035}\boldsymbol{\beta}\mathbf{3}+\mathbf{1}\ -\mathbf{1}$ **(8)**

Where λ and β, severally, square measure the tip speed magnitude relation and pitch angle. Rad is that the radius of the blades and **Cp**, is that the most realizable power constant at the optimum tip speed magnitude relation of **λout** .The below equation presents the connected PMSG generator.

f6= $\mathbf{d\omega rdtt1JeTmF\omega r}$ **(9)**

f7= $\mathbf{Te} \times \mathbf{\omega rIwtdc} \times \mathbf{Vdc}$ **(10)**

f8= $-\boldsymbol{Tm} \times \boldsymbol{\omega r} - \boldsymbol{Cp}, \boldsymbol{ase3Pnom}$ **(11)**

Energy management methods of small grids should estimate the AC bus voltage level deviation from its point in regarding each 5–10 sec. It implies that except the angular speed of the generator (9) all different quick voltage and current dynamics will be unnoticed. It's additionally assumed that there aren't any mechanical and electrical losses through the facility train and so the magnetic force power given by (10) is up to the output electric power of the wind branch. Equation (11) shows that the PMSG is connected on to rotary engine that rotates at low speed, and so has to have multiple pole pairs P. Hence, the electrical frequency is P times quicker than the mechanical angular speed. The shaft inertia J (Kg.m2) and therefore the combined viscous friction constant F (N.m.s) of PMSG square measure given by the makers. For energy management methods, the typical model of the buck converter is restored with the steady-state equations for the continuous conduction mode (CCM) [11].

f9= $\boldsymbol{Vdc} - \boldsymbol{DwVwt}$ **(12)**

f10= $\boldsymbol{Iut} - \boldsymbol{DuIwtdc}$ **(13)**

Where $\boldsymbol{Dw}$ is that the change duty cycle of the device. The typical AC output voltage of the rectifier Vwt in presence of the non-instantaneous current communication is calculated as below.

$\boldsymbol{Vwt} = \mathbf{1.\ 35}\boldsymbol{VLL} - \mathbf{3}\boldsymbol{\pi\omega eLsIwt}$ **(14)**

Then considering the R.M.S price of line to line voltage the AC output current of turbine is given byis given by

f11 = $\boldsymbol{Iwtdc - \pi 3 P\omega r L s D w 1.353 P \Psi \omega r 2 - VdcDu}$ **(15)**

b) Battery

There are differing types of batteries applicable to the backup/storage functions across small grids. Among all the lead-acid batteries have some blessings for hybrid renewable energy system (HRES) applications. Lead-acid batteries are wide obtainable in several sizes and are applicable for little to massive applications.Moreover, the normalized value of this kind of batteries is affordable and it's mature in ideas, mathematical model and technology. In fact, the performance characteristics of lead-acid batteries are well understood and modeled. The charging operation of a lead acid battery bank, consisting of Nbatp × Nbats batteries is modeled as below [10].

f12 = $\boldsymbol{VbstackNbats - V0 + RbatIbstackNbatp + P1CmaxCmax - QactQact + P1CmaxQact + 0.1CmaxIf}$ **(16)**

f13 = $\boldsymbol{dQactdtt - 13600IbstacktNbatp}$ **(17)**

f14 = $\boldsymbol{dIfdtt + 1TsIf - IbstackNbatp}$ **(18)**

f15 = $\boldsymbol{Vbstack - Vdc1 - Db}$ **(19)**

f16 = $\boldsymbol{Vbstack - 1 - DbIbatdc}$ **(20)**

f17 = $\boldsymbol{SOC - 1 - QactCmax}$ **(21)**

Where Vbstack, Ibstack, and SOC are, severally the voltage, current, and state of charge of the battery bank. If is that the filtered price of the battery current with the time constant of Ts and Qact is that the actual battery capability. The experimental parameter p1 needs being known for every style of battery whereas the utmost quantity of the battery capability, Cmax, internal resistance of battery, Rbat, and also the battery constant voltage, V0, are given by makers. By ignoring the discharging mode of the battery bank operation, the bi-directional device acts as a boost-type device. [12].

c) Solar

PVs ar among the popular renewable energy parts to reap alternative energy. A PV cell, because the basic PV component may be a tangency that converts star irradiance to the electricity. Normally, makers give PV modules, additionally referred to as PV panels that

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incorporate many PV cells connected along nonparallel. A PV cell may be a non-linear element that its operation is defined by a group of current-voltage curves at completely different insulation levels and junction temperatures. The equivalent electrical device of the PV module is employed to mathematically model the star branch, consisting of a PV array and a lift device [9].

The below equations shows the characteristic equations of a PV array, consisting of Npvp × Npvs PV modules:

f18 = $\boldsymbol{Ipv - Iph + I0expVpv + NpvsNpvpRsIpvndNsq \times NpvsKTc - 1 + Vpv + NpvsNpvpRsIpvNpvsNpvpRsh}$ **(22)**

f19 = $\boldsymbol{Iph - Npvp \times Rs + RshRshIsc, + KITc - Tc, tc}$ **(23)**

f20 = $\boldsymbol{I0 - Npvp \times Isc, + KITc - Tc, stcexpVoc, stc + KVTc - Tc, stcndNsqKTc - 1}$

(24)

Where Iph denotes the photocurrent and I0 is that the diode reverses saturation current. Rs and Rsh, severally, are the series and parallel equivalent resistors of every PV module. Almost like the wind branch, the typical model of the boost device is replaced with the steady-state equation.

f21= $\boldsymbol{Vpv - 1 - DsVdc}$ (25) f22 = $\boldsymbol{Ipvdc - 1 - DsIpv}$ **(26)**

d) MPPT

MPPT may be a technique used ordinarily with wind turbines and electrical phenomenon (PV) star systems to maximize power extraction beneath all conditions. The MPPT technique is additionally helpful for the operation of battery. Relying upon the MPPT technique charging and discharging modes of operations of batteries are controlled. It's helpful in protective the battery from over charging, and to implement the IU charging regime of the battery that helps to extend the generation of batteries. The output power evoked by the PV modules and turbine are influenced by variety of things that are radiation, temperature, wind speed etc. to maximize the ability output from the system it's necessary to trace the utmost power points of the individual energy sources. There are many strategies to trace the mpp's of the system among them P&O is that the ordinarily used technique [2].

e) A nonlinear Model prognosticative management (NMPC)

Non-linear model prognosticative management (NMPC) ways are inherently multivariable and handle constraints and delays. During this thesis, the EMS is developed as a NMPC strategy to extract the optimum management signals thatare duty cycles of 3 AC-AC converters and pitch angle of a turbine. 1) Optimum management issues (OCPS): OCPs, create express use of the system model, given by the below functions so as to seek out AN optimum management law u*(.), that meets variety of equality and difference constraints. The term optimum here is outlined with relation to a precise criterion that suggests the management objectives. This criterion is given with a price purposeful, consisting of the Lagrangian term and also the terminal value term. Whereas the Lagrangian term indicates the value perform throughout the amount of your time, the terminal value penalizes final values.

IV. CONTROL SYSTEM

The planned EMS in turn gets the calculable system states, as inputs and calculates the optimum resolution, as outputs. The external state reckoned and also the predictor of the non-manipulated variables is out of the scope of this technique. N step ahead predictions of the star irradiance, wind speeds, and cargo demands are extracted either from a earth science centre or AN external predictor victimization autoregressive-moving-average (ARMA) technique. The bus voltage level of the small grid, VAC, is about outwardly and therefore the developed controller will act because the secondary and first levels of the hierarchic design.

V. INVERTER CONTROL

a) SPWM (sinusoidal pulse width modulation) signal generation

In this type of the modulation the control voltage (Vc) has a sinusoidal waveform. This control voltage is compared with a triangular waveform to obtain the gates signals of the inverter switches. The triangular waveform is maintained at constant amplitude (Vt) and its frequency called switching or carrier frequency. While the control voltage magnitude (Vc) could be varied to obtain different values of the modulation index, where the modulation index (M) is the ratio of Vc to Vt.

i.e. M= Vc/Vt

The fundamental frequency of the inverter equals the control voltage frequency. The frequency modulation index (mf) is defined as the ratio of the switching frequency (fs) to fundamental frequency (f1).

i.e. mf = fc/f1

In this paper, a bi-polar SPWM was used. In this type of modulation a single sinusoidal waveform is compared with a triangular. Figure (2.13) shows a bi-polar SPWM with modulation index of 0.7 and frequency modulation index of 10. Note that when VC >Vt then there is a positive voltage and when VC <Vt there is no voltage. So, this signal could be used as a gate signal for the inverter switch.

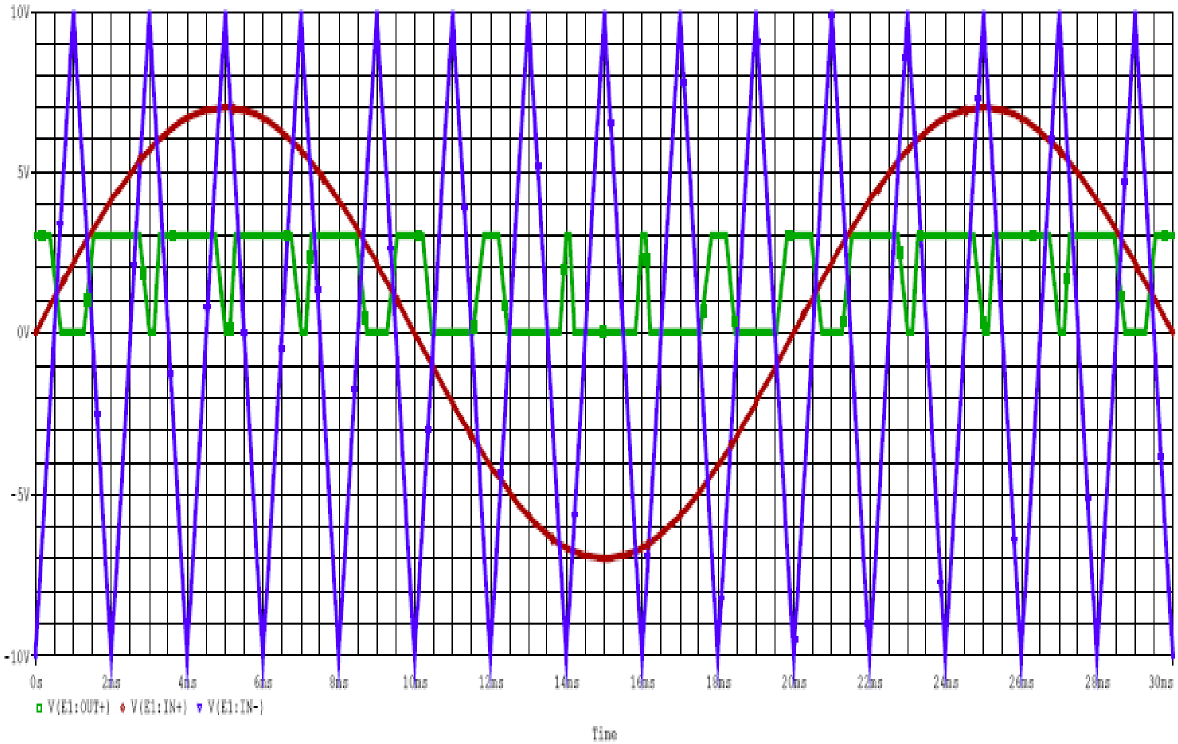

Fig 3. Comparison of Sine vs Triangular Waveform

The designed inverter has a required output voltage is of 220Vrms and a frequency of 50Hz. The output voltage of the inverter is specified in the equation (2.9). Vo(t) = M*VAC*sin(wt) + harmonics Since VAC is equal to 220Vrms, then choosing M to be 1 and using equation (2.9) results in an AC output with a magnitude of 220Vrms.

Hence, the required inverter is an inverter with a modulation index of 1, output voltage of 220Vrms, and a fundamental frequency of 50Hz. Also to eliminate the harmonics that above 50Hz we deigned RLC filter and it was connected after H Bridge.

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VI. SIMULATION AND RESULTS

Overall Simulation Diagram

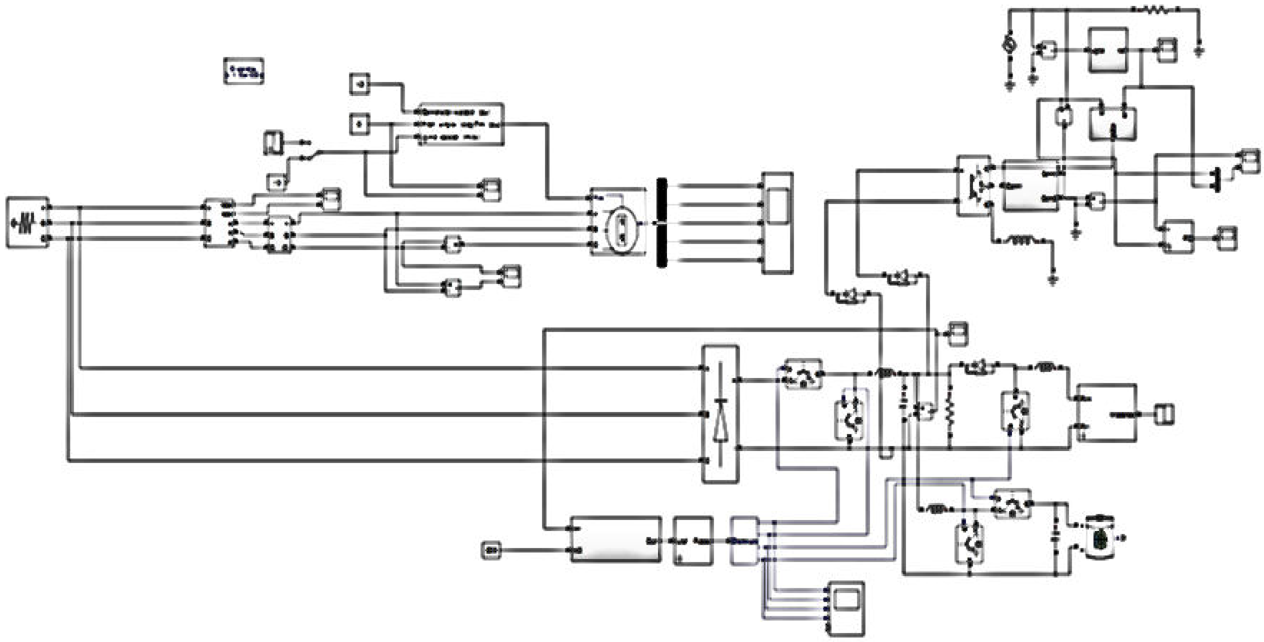

Fig 4. Overall simulation diagram

To evaluate the performance of the developed optimum EMS, 2 check eventualities are dole out. They are 1.) State of affairs I: Constant current charging mode. 2.) State of affairs II: Constant voltage charging mode. 1) State of affairs I: Constant Current Charging Mode: This state of affairs covers the subsequent 3 completely different cases that are run successively:

Case I. Turbine and PV array generate enough power at their MPPs to sup-ply consignment demands and charge battery bank by means of its nominal charging current.

Case II. The generated power is simply enough to produce the load demands and thus battery bank isn't charged or is charged with the present but its nominal charging current.

Case III. The generated power is over the specified power to produce the load demands and charge battery bank with its nominal charging current. Every case lasts for five minutes and thus the overall amount of the simulation time is15 minutes. So as to calculate the optimum management variables each five seconds, the developed NMPC controller runs specifically sixty times as per every case. 2) State of affairs II: Constant voltage charging mode: Terminal voltage of battery bank rises by state of affairs II as a result of constant charging currents. Once the battery terminal voltage level reaches its gassing voltage, charging current ought to be bit by bit reduced so as to stop extraordinary gassing voltage threshold [10]. This constant voltage charging strategy helps battery bank to be totally charged while not the danger of permanent harm

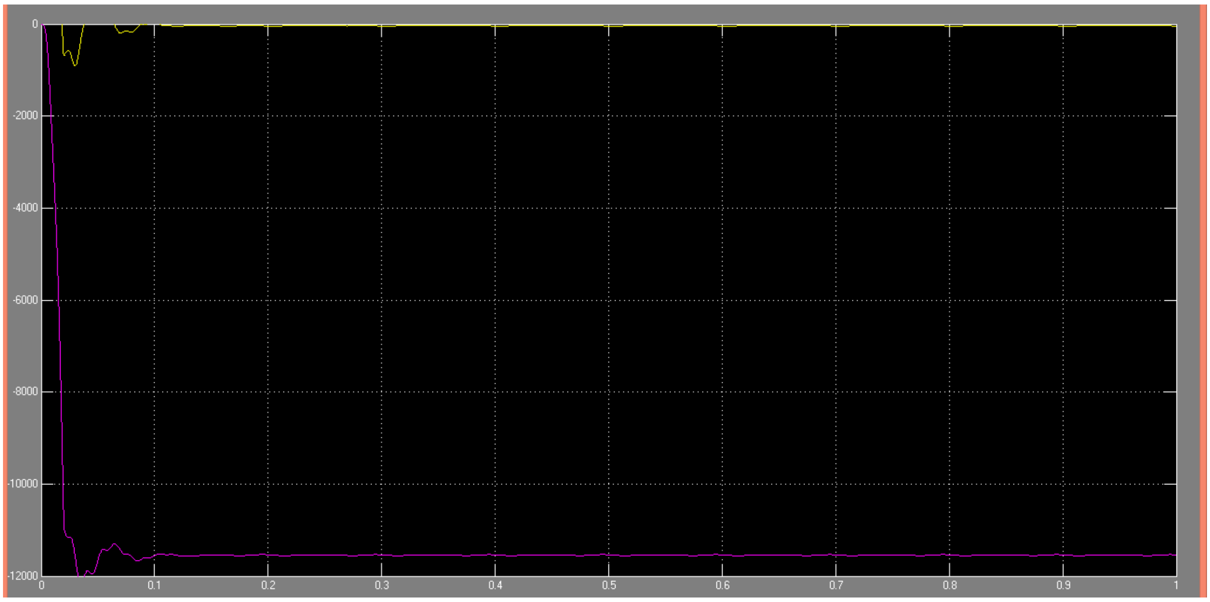

Fig 5. Simulation Output (1)

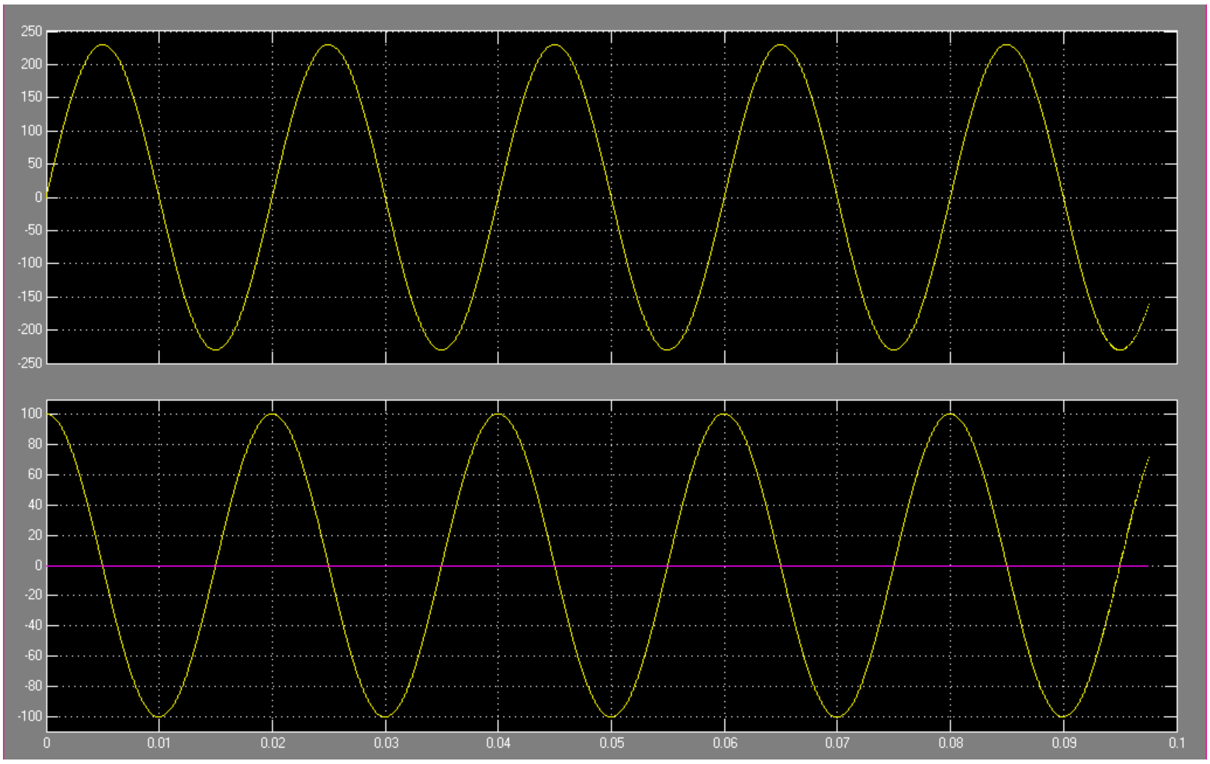

Fig 5. Simulation Output (2)

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VII. CONCLUSION

A coordinated and multivariable on-line NMPC strategy has been developed to handle the optimum EMS that deals with 3 main management objectives of standalone AC micro grids. These objectives are the voltage level regulation, proportional power sharing, and battery management. So as to handle these objectives, the developed EMS at the same time controls the pitch angle of the turbine and also the change duty cycles of 3 DC/AC converters. It's been shown that the developed controller tracks the MPPs of the wind and star branches inside the conventional conditions and curtails their generations throughout the beneath load conditions. The provided versatile generation curtailment strategy realizes the constant current, constant voltage charging regime that doubtless will increase the generation of the battery bank. The simulation results are shown its ability to attain all management objectives.

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