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RESEARCH ARTICLE

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AN OPTIMAL ENERGY MANAGEMENT STRATEGY FOR STANDALONE DC MICROGRIDS

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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, DC 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 |to make 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 DC small grid exploitation most outlet chase (MPPT) algorithmic rule. A coordinated and multivariable EMS is planned that employs a turbine and a 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.

Key words: Battery Management, Maximum Power Point Tracking (MPPT), Nonlinear Model Predictive Control (NMPC), Power Sharing, and Voltage Regulation.

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. 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. thanks to 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. 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 a dc small grid is measured in terms of the steadiness of its dc 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. 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 dc small grids area unit sometimes placed in small-scale area unitas 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 have an effect on the batteries operation throughout the charging mode:

1) Applying high charging currents, the batteries voltages quickly reach to the gassing threshold;

2) the inner electrical device and thence power losses and thermal effects increase at high SOC levels; and

3) Batteries can't be absolutely charged with a relentless high charging current and conjointly restricts the utmost getable 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 DC small grids, 3 cases area unit envisaged:

1) Power generation and cargo demand area unit balanced;

2) load demand exceeds power generation causes dc 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

3) 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:

1) Power constant of the wind turbine;

2) Angular speed of the wind generator;

3) operational voltage of the PV array; and

4) 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. 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.

EXITING CONSTRUCT

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 ar 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.

PROPOSED CONSTRUCT

The planned strategy is developed as an internet nonlinear model prophetical management algorithmic rule. Applying to a sample standalone dc 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 DC bus voltage is regulated at intervals a predefined vary, as a style parameter

SYSTEM DESCRIPTION AND MODELLING

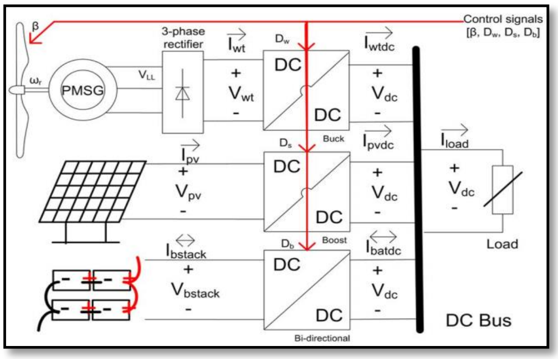

Fig.1.Topology of a small-scale and standalone dc micro grid with connected loads.

Fig.1. shows the Topology of a small-scale and standalone dc small grid with connected masses. The mathematical model of stand- alone inexperienced dc 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 dc.

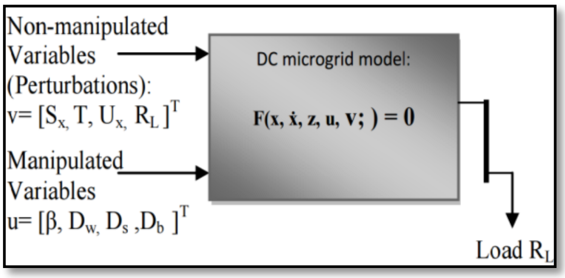

Fig 2 Modified version of the system model

X= [If , Qact , **ω**r] T(1)

z = Ipv ,Vpv , $Ipvdc$,$Ibat$,$Ibatdc$,$Vbatdc$,Iwt , Vwt , $Iwtdc$, Te , Tm , λ , Cp , SOC ,$Iload$,Vdc T (2)

$F\ x,\ ,z,u,v$ = [$f1\ x,x\ ,z,u,v$; $f2\ x,x\ ,z,u,v$; …… ;$f24\ x,x\ ,z,u,v$;] = zero (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 dc small grids the total of the generated, stored, and consumed powers is often zero:

f1 = **Vdc Ipvdc** + **Iwtdc** + **Ibatdc** + **Ilo**(4)

f2 = **Vdc** − **Iload RL** (5)

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 dc 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-dc 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

$\boldsymbol{f3}$ = $\boldsymbol{Cp,rm}$ − **1 Cp,max** × **C1** $\boldsymbol{C2\ \lambda i}$ − $\boldsymbol{C3\ \beta}$ − $\boldsymbol{C4}$ **exp** − $\boldsymbol{C5\ \lambda i}$ +$\boldsymbol{C6\lambda}$ (6)

f4=$\boldsymbol{\lambda}$ − $\boldsymbol{Rad}$ × $\boldsymbol{\omega r\ Ux}$ (7)

f5= $\boldsymbol{\lambda i}$ − **1** $\boldsymbol{\lambda}$+**0.08**$\boldsymbol{\beta}$ − **0.035** $\boldsymbol{\beta}$**3**+**1** −**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 $C_{p,x}$ 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= $d\omega r\ dt\ t\ 1\ Je\ Tm\ F\omega r$ (9)

f7= $Te \times \omega r\ Iwtdc \times Vdc$ (10)

f8= $-Tm \times \omega r - Cp,rm\ UZ\ UZ,base\ 3\ Pnom$ (11)

Energy management methods of small grids should estimate the dc 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).

f9= $Vdc - Dw\ Vwt$ (12)

f10= $Iut - Du\ Iwtdc$ (13)

Where Dw is that the change duty cycle of the device. the typical dc output voltage of the rectifier Vwt in presence of the non-instantaneous current communication is calculated as below.

$Vwt = 1.35\ VL\ L - 3\ \pi\ \omega e\ LsIwt$ (14)

Then considering the r.m.s price of line to line voltage the dc output current of turbine is given byis given by

f11 = $Iwtdc - \pi\ 3P\omega rLsDw\ 1.35\ 3\ P\ \Psi\ \omega r\ 2 - Vdc\ Du$ (15)

Battery

There ar 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 ar wide obtainable in several sizes and ar 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 ar well understood and modelled. The charging operation of a lead acid battery bank, consisting of Nbatp × Nbats batteries is modelled as below.

$f12 = Vbstack\ Nbats - V0 + Rbat\ Ibstack\ Nbatp + P1\ Cmax\ Cmax - Qact\ Qact + P1\ Cmax\ Qact + 0.1\ Cmax\ If$ (16)

f13 = $dQact\ dt\ t - 1\ 3600\ Ibstack\ t\ Nbatp$ (17)

f14 = $dIf\ dt\ t + 1\ Ts\ If - Ibstack\ Nbatp$ (18)

f15 = $Vbstack - Vdc\ 1 - Db$ (19)

f16 = $Vbstack - 1 - Db\ Ibatdc$ (20)

f17 = $SOC - 1 - Qact\ Cmax$ (21)

Where Vbstack, Ibstack, and SOC ar, 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, ar given by makers. By ignoring the discharging mode of the battery bank operation, the bi-directional device acts as a boost-type device [(19), (20)].

Solar

PVs are 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 incorporates 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 insolation 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.

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

$f18$ = $Ipv - Iph$ +$I0$ exp Vpv + $Npvs$ $Npvp$ Rs Ipv nd Ns q × $Npvs$ K Tc − 1 + Vpv + $Npvs$ $Npvp$ Rs Ipv $Npvs$ $Npvp$ Rsh (22)
$f19$ = $Iph - Npvp$ × Rs + Rsh Rsh Isc,c + KI Tc − Tc,stc S $Sstc$ (23)
$f20$ = $I0 - Npvp$ × Isc,stc + KI $Tc - Tc,stc$ exp Voc,stc + KV $Tc - Tc,stc$ nd Ns q K Tc −1 (24)

Where Iph denotes the photocurrent and I0 is that the diode reverse saturation current. Rs and Rsh, severally, ar 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= Vpv − 1 − Ds Vdc (25) f22 = $Ipvdc$ − 1 − Ds Ipv (26)

Maximum electrical outlet pursuit

Maximum electrical outlet pursuit (MPPT) may be a technique used ordinarily with wind turbines and electrical phenomenon (PV) star systems to maximise 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 ar influenced by variety of things that ar radiation, temperature, wind speed etc. to maximise the ability output from the system it's necessary to trace the utmost power points of the individual energy sources. There ar many strategies to trace the mpp's of the system among them P&O is that the ordinarily used technique.

A nonlinear Model prognosticative management (NMPC)

Non-linear model prognosticative management (NMPC) ways ar inherently multivariable and handle constraints and delays. during this thesis, the EMS is developed as a NMPC strategy to extract the optimum management signals, that ar duty cycles of 3 DC-DC 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.

$\mathbf{u}*$. = arg minimize J ($\mathbf{t}$), ($\mathbf{t}$), $\mathbf{u}$($\mathbf{t}$),$\mathbf{N}$ = U(.) ∈ $\mathbf{R}$ $\mathbf{n}$ $\mathbf{x}$ τ , $\mathbf{z}$ τ , $\mathbf{u}$ τ $\mathbf{t}$+$\mathbf{T}$ t $\mathbf{d}$τ + $\mathbf{x}$ τ , $\mathbf{z}$ τ (27)
s.t : Φ $\mathbf{x}$ $\mathbf{t}$, $\dot{\mathbf{x}}$ $\mathbf{t}$, $\mathbf{z}$ τ , $\mathbf{u}$ τ , $\mathbf{v}$ τ = $\mathbf{0}$ (28)
H $\mathbf{x}$ τ , $\mathbf{z}$ τ , $\mathbf{u}$ τ < zero (11c) R $\mathbf{x}$ $\mathbf{T}$, $\mathbf{z}$ $\mathbf{T}$ = $\mathbf{0}$ (29)
$\mathbf{x}$ τ = $\mathbf{x0}$, $\mathbf{z}$ τ = $\mathbf{z0}$ (30)
∀ τ ∈ $\mathbf{t}$,t+ $\mathbf{T}$ (31)
$\mathbf{x}$ τ ∈ Ξ, $\mathbf{z}$ τ ∈ Z, $\mathbf{u}$ τ ∈ Y (32)

CONTROL SYSTEM

The planned EMS in turn gets the calculable system states, ẋ, as inputs and calculates the optimum resolution, U*(.), as outputs. The external state reckoner and also the predictor of the non-manipulated variables ar 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 victimisation autoregressive-moving-average (ARMA) technique. The bus voltage level of the small grid, Vdc, is about outwardly and therefore the developed controller will act because the secondary and first levels of the hierarchic design.

SIMULATION AND RESULTS

To evaluate the performance of the developed optimum EMS, 2 check eventualities ar 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 ar 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. This constant voltage charging strategy helps battery bank to be totally charged while not the danger of permanent harm

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 dc 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 dcdc 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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