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Optimizing strategies of Transient Stability and Voltage Regulation in Multimachine Power Systems

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Abstract: The main contributions of this paper are threefold: 1) use of a STATCOM and battery energy storage procedure to enhance transient balance and furnish voltage regulation with SG and DFIG; 2) demonstrating the applying of nonlinear manipulate conception (particularly the IDA-methodology) for the design of a stabilizing suggestions controller in gigantic-scale power techniques to give a boost to transient approach efficiency; and three) establishing a methodology that can use the further levels of freedom in large-scale energy techniques with the intention to further reinforce procedure performance, in targeted the transient balance margin measured through critical clearing time (CCT)] and the dynamic transient performance of the process. In order to achieve power angle stability along with thesimultaneous regulation of frequency and voltage, the performanceof the proposed control scheme after the occurrence of large disturbances is evaluated and compared with a conventional powersystem stabilizer and a feedback linearizing controller.

Index Terms—Battery energy storage systems (BESS), interconnection and damping assignment passivity-based control(IDA-PBC), multimachine power systems.

I. INTRODUCTION

SYSTEM stability is the most important issue for power systems; if stability is lost, network collapse may occurwith devastating economical losses and power grid damages,see [1], [2]. Traditionally, transient (angle) instability has beenthe dominant stability problem. With the continuing growth ofpower system interconnections and the increased operation inhighly stressed conditions, different forms of system instabilityhave emerged. For example frequency stability, inter-areamodes of oscillations and voltage stability have become greatconcerns [3]. A clear understanding of different types ofinstability and how they are interrelated is most important forthe satisfactory control design and operation of power systems.The work presented in this paper is motivated by theoccurrence of system instability and blackouts which may bepreventable by use of advanced control techniques. Lack ofproperly automated and coordinated power system controllersto take immediate performance enhancing actions againstsystem events has been recognized as one of the contributingfactors for recent power system blackouts [1], [2], [4].

Power systems are modeled as complex, nonlinear andhighly structured systems. It is well known that the generator excitation control system can provide one of the mostcost effective ways to stabilize power systems. Conventionalpower system controls primarily deal with small disturbancesabout an operating point. This type of control can sufferperformance degeneracy and in fact linear controllers mayeven destabilize the system if the operating point of thepower system is changed away from the equilibrium pointat which the approximate linearization is realized [5]. Controlmethods for handling system-wide large disturbance problemsneed to be developed, particularly ones which concern powersystem nonlinearity and unforeseen circumstances leading to alarge sudden operating point deviations. To address this issue,this paper applies DFL as a flexible and structure preservingnonlinear control technique, see [6]–[8]. This technique simplyuses the Implicit Function Theorem to selectively eliminatesystem nonlinearities and the well known nonlinear controlapproach based on the geometric coordinate transformationis not needed. Considering the effect of plant parametricuncertainties and power system interconnections, the robustcontrol technique is further developed in this paper and appliedto ensure the stability of the DFL compensated system. Onlythe bounds of uncertain parameters need to be specified and theexact time varying network parameters need not to be known.Much effort has gone over the years into the mathematicalmodeling and market restructuring of large power systemsand, to a lesser extent, systematic stability control design.Development of stability control from both control theoryand practical point of view continues to be an interestingsubject. The major areas of concern are transient stability,oscillations and voltage stability/regulation. Particular featureswhich motivate the work in this paper are:

• power system nonlinearity, uncertainty and dimensionality in the design of stability controllers;
• the interplay between angle and voltage behavior;
• problems of control coordination;

The main concern is the operation of the generator in varcontrol mode while the power system stabilizer (PSS) is inoperation. In [6], [9] we have discussed detrimental stabilizingeffects through classical root locus analysis of the linearizedpower system model. A concern for coordination is a practicalproblem, which has become a theoretical problem in controltheory. How to achieve satisfactory stability performance isan important issue and this motivates the topic of globalcontrol [10]. Transient stability and voltage regulation areboth important properties of power system stability control,but they relate to different stages of system operation, i.e. thetransient period and the post fault period. Different behavior ofnonlinear power systems in different operating regions requiresdifferent control objectives and therefore different controllersneed to be activated or switched to under varying operatingconditions. One method to implement such control utilizesmembership functions pioneered in the well knownTakagiSugeno design which effectively provides smooth switching,see [11]. Global control is the weighted average of the localcontrollers, where the weights are provided by the operatingregion membership functions [12].

This paper continues this line of investigation and examinesthe application of an integrated STATCOM and battery systemusing an advanced nonlinear controller to enhance the transientstability of a power system that includes both conventional SGand DFIG as found in wind energy conversion systems. TheIDA-PBC control design methodology is used to achieve powerangle stability and to provide both frequency and voltage regulation. To evaluate the effectiveness of the proposed approachfor improving transient stability, simulation studies are carriedout on a classical four-machine benchmark system, and performance results of the proposed system are compared to conventional control system implementations.

II. SYSTEM MODEL

Consider the power network that includes – conventionalmachines (SG) and -wind power systems [doubly-fed induction generators (DFIGs)] with -STATCOM/battery units andload that is modeled as constant impedances. Dynamic models
of this multimachine power system can be divided into threemain groups: namely, synchronous generators (SGs), DFIGs,and STATCOM/battery systems as follows.

A. STATCOM/Battery Models

Here, the model of an integrated STATCOM and battery energy storage system is developed. This system relies on a power. electronic voltage-source converter and will be used as a regulating device in the ac transmission network by delivering andabsorbing both active and reactive power simultaneously.

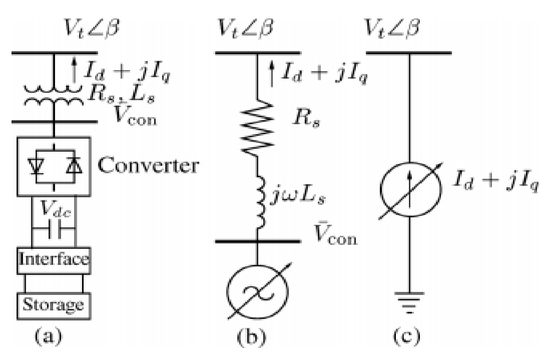

Fig. 1. STATCOM/battery model. (a) Schematic diagram. (b) Equivalent circuit (controllable voltage source) (c) Equivalent circuit (controllable current source)

Thesystem can support electricity networks by improving powerfactor and voltage regulation and helping to damp electromechanical oscillations and enhance transient stability of thefirst swing dynamics that result from severe fault conditions.

A basic schematic diagram of a STATCOM and energystorage system is shown in Fig. 1(a). The STATCOM/batteryincludes a voltage-source converter, a transformer or reactor,and a dc-link with the energy storage device, for example, withbattery energy storage systems that are considered in this paper.The STATCOM/battery can be modeled as either a controllable voltage source ( ) as shown in
Fig. 1(b) or a shunt-controllable current source , as shownin Fig. 1(c), where the STATCOM is used to regulate the terminal voltage by controlling the reactive power injectedor absorbed from the power system while energy stored in thebattery is used to maintain active power output, regulate systemfrequency, and damp power oscillations, hence increasing theoperational reliability and security of the power system. Forinstance, as a controllable current source, the converter is ableto inject or absorb a current into the powernetwork via the transformer. Both active and reactive powerare able to instantaneously be exchanged with the network
by controlling the amplitude and angle of the injected currentbased on the capacity of the battery energy storage device.

B. SG and DFIG Modeling

For the -machine conventional power system the nonlineardynamic model of the th synchronous generator.

Remark 1: Although this DFIG model is analogous to a oneaxis model of a synchronous machine, there are substantial differences, namely:
1) is analogous to a voltage behind atransient reactance in a synchronous generator despite the factthat it is not generated from an external excitation current;
2)the angle is similar to the angle of the rotor flux magnitudewith respect to the synchronously rotating reference frame nota stroboscopic angle of rotation of the shaft; and
3) the angledynamics contains two extra termsas compared with the angle equation of a synchronous machinebecause of the variable speed operation of the DFIG.

The representation ofthe DFIG model has a distinct advantage because the form ofthe model is similar to the SG and we can directly apply existingnonlinear control design techniques like feedback linearization,backstepping, etc.For both conventional (SG) and wind power systems (DFIG)including STATCOM/battery, the output electrical power of theth synchronous generator and the th DFIG can be computed,and, after some lengthy but straightforward calculations.

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III. IDA-PBC METHODOLOGYC

Interconnection and damping assignment-a formulation ofpassivity-based control (PBC), is a general design method for high-performance nonlinear control systems that can be described by a port-Hamiltonian model.This method not only assigns suitable dynamics to the closedloop system, but, as it is a Hamiltonian formulation, it is alsocapable of providing a control design that achieves stabilizationby rending the system passive with respect to a desired storagefunction and the injection of a suitable level of damping.Here, we present a brief recapitulation of the the IDA-PBCmethod applied to the control of a power system withSTATCOM/battery.

The key step in this design method is the solution of thePDE that guarantees the stability of the closed-loop system.This technique relies on the concept of exact model matchingof the closed-loop system with desired behavior determined bythe pre-specified interconnection structure and dissipation matrices.In order to solve the matching equation above, there are different approaches to solve the PDE (11) as follows.

• Nonparameterized IDA: and are selected toaccomplish the desired structure of the closed-loop system subsequently, all assignable energy functions compatiblewith that structure are characterized. This characterizationis provided in terms of a solution of the PDE. In addition, from the family of solutions, we choose the one withequilibrium .

• Algebraic IDA: when the desired energy function to be assigned is selected a priori, then PDE (9) becomes an algebraic equation in and . Eventually, the controller is designed.

In this multimachine power system application, the AlgebraicIDA approach is used to convert the PDE to an algebraic equation and this equation is used to find the controller that is capable of achieving the desired closed-loop system performancerequirements, namely:

1) the equilibrium point is asymptotically stable and

2) power angle stability along with voltage andfrequency regulation are simultaneously achieved.Implementation of the IDA-PBC design methodology toa practical power system requires modeling a multimachinesystem that consists of -SG and -DFIG and includes theSTATCOM/battery system.

Remark 1: In general, SGs, DFIGs, or both exhibit poor mechanical damping, and, when there is no coupling between theelectrical damping and the mechanical damping, this results insignificant power oscillations in the system under fault conditions. In order to avoid and mitigate any damage to the systems, these oscillations have to be damped effectively. Thus,additional damping should be included through a coupling between the mechanical subsystem (SGs and DFIGs) and the electrical subsystem (STATCOM/battery) which can be assignedby selecting suitable interconnection and damping structures.

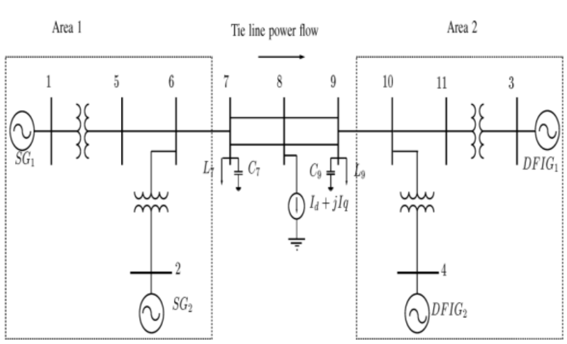

Fig. 2. Simple two-area system with STATCOM/battery.

In order to gain insight into the performance improvementsthat can be achieved in multi-machine power systems using theproposed control design approach, we study a classical fourmachine power system as shown in Fig. 2. We recognizethat even though these results are preliminary, they do suggest the improvements that can be achieved using the proposed approach. In particular, we evaluate the effectiveness of the proposed IDA-PBC control design methodology on transient stability enhancement when a STATCOM/battery is installed at themidpoint of the transmission line between area 1 and area 2.This system is modified by replacing two conventional generator and with two wind farms, in particularand in area 2 for the test system used in this paper. Forcontroller design, synchronous generators and of area1 are conventional plants or aggregates of plants along with aggregated wind generators (DFIGs) in area 2. The parameters and the normal operating condition along with the dataused for the synchronous generators, transformers, and linesof the four-machine system can be found.

IV. CONCLUSION

In this paper, the IDA-PBC nonlinear control design methodhas been proposed to enhance the transient stability and frequency and voltage regulation of multi-machine power systemsthat include both SG and DFIG and a STATCOM/batteryenergy storage device. Integrating the STATCOM/battery intothe power systems using the IDA-PBC control design methodology provides additional damping to the system and dynamicsimulations on a two-area multi-machine power system haveshown that the nonlinear IDA-PBC control design approachis capable of providing improved system damping and better transient stability performance.

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