Super-Twisting Algorithm based Load Frequency Control of a Two Area Interconnected Power System

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OUTLINE

INTRODUCTION

The load frequency control (LFC) can be done by Automatic Generation Control (AGC) which deals with **frequency** and **active power**.

The objective of LFC is to bring the value of area control error (ACE) to zero.

The two area interconnected power system consist of turbine, generator, primary and secondary controllers.

The sliding mode controllers (SMC) can also be used as secondary controller.

Higher Order SMC exhibit better prospects for

- Fast and finite time convergence.
- High precision control.
- Removal of **chattering phenomenon** on the control input.

MOTIVATION

- Normally used PID controllers will not address the **matched disturbances** and it cannot be used for non-linear type of loads.
- Optimal control of Area Control Error (ACE) of two equal area interconnected power system need to be solved using appropriate controller.

PROPOSED CONTROLLER FOR LFC

- Sliding Mode Controller (SMC)

  1) **Dynamic behaviour** of the system can be controlled by the particular choice of the sliding function.
  2) The **closed loop response** becomes totally insensitive to some particular uncertainties which are bounded.

From practical point of view, SMC allows control of nonlinear processes subject to **external disturbances** and **heavy model uncertainties.**

- SMC consist of two phases

Phase 1 :Sliding surface design **(**σ**)**
Phase 2 :Control input design **(u)**

- The sliding surface depends on the tracking error together with a certain number of its derivatives
  ie, $\sigma = \sigma\left(e, \dot{e}, \ddot{e}, ..., e^{(k)}\right)$
- The function σ should be selected in such a way that it is vanishing.
- $\sigma = 0$, gives rise to a **stable** differential equation.
- Any solution $e_y\left(t\right)$ of which will tend to zero

Typical choice for the sliding manifold is

$$\sigma = \dot{e} + c_0 e$$

$$\sigma = \ddot{e} + c_1 \dot{e} + c_0 e$$

$$\sigma = e^{(k)} + \sum_{i=0}^{k-i} c_1 e^{(i)}$$

Finding a control action that directs the system trajectories onto the sliding manifold,or able to steer the σ variable to zero in finite time.

There are two parts in control input

- Bring the system tragectory to the sliding surface $\Rightarrow$ **Equivalent control**
- Maintain the system tragectory on the surface $\Rightarrow$ **Switching control**

Common feature of all sliding mode based techniques is

- No precise information about the original system dynamics is requested, the controlled system being treated as a completely uncertain.

- Conventional SMC provide **robust and high-accuracy solutions** for a wide range of control problems under uncertainty conditions. However, **restrictions remain**.

Restriction-1

The constraint to be held at zero in conventional sliding modes of degree one, which means that the control needs to explicitly appear in the first time derivative of the constraint. Thus, one has to **search for an appropriate constraint**.

Restriction-2

High-frequency control switching may easily cause unacceptable practical complications (**chattering effect**).

- The chattering effect can degrade the system performance or may even lead to instability and may even damage the plant

SUPER-TWISTING SMC

- Super-twisting controller is free from chattering due to continuous control action.

- It can accurately track and regulate the system even though the disturbance is continuously acting on it.

- It requires only the output information and does not requires the time derivatives of the output. Consequently, the control law is relatively simple, reduces the computational burden and achieves wide applications.

General Algorithm

$$u = -k_1|\sigma|^{1/2} sign(\sigma) - k_2 \int sign(\sigma)\, dt$$

where $k_2 \succ k_1$

Block Diagram Realization

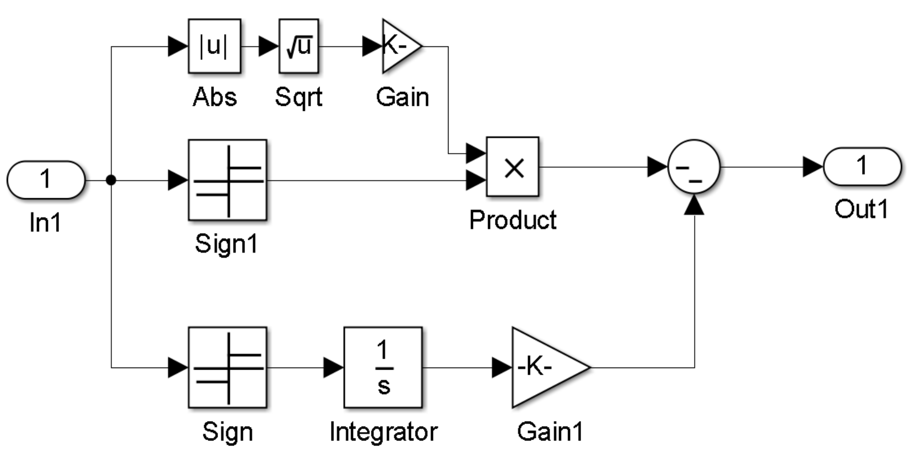

Figure: 1

BLOCK DIAGRAM

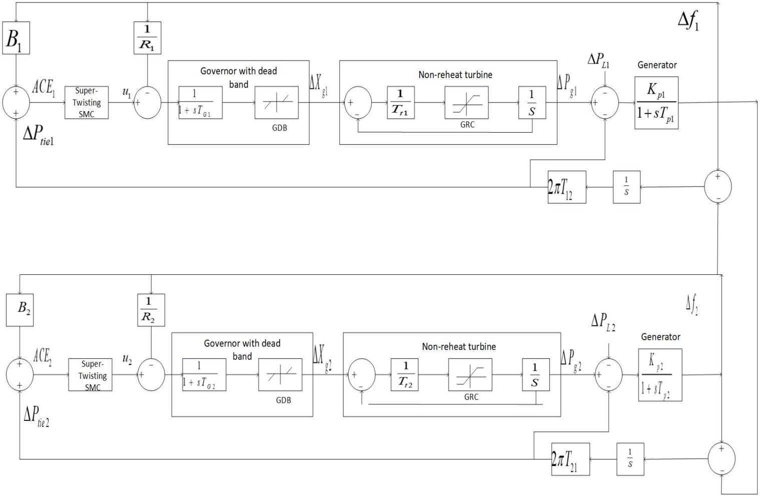

Figure: 2

SYSTEM STATE EQUATIONS

For area 1

$$
\begin{aligned}
\Delta \dot{f}_1 &= \left(\frac{K_{p1}}{T_{p1}}\right)\left(\Delta P_{g1} - \Delta P_{tie1} - \Delta P_{L1}\right) - \left(\frac{1}{T_{p1}}\right)\Delta f_1 \\
\Delta \dot{P}_{g1} &= \left(\frac{1}{T_{t1}}\right)\Delta X_{g1} - \left(\frac{1}{T_{t1}}\right)\Delta P_{g1} \\
\Delta \dot{X}_{g1} &= \left(\frac{1}{T_{G1}}\right)u_1 - \left(\frac{1}{T_{G1}R_1}\right)\Delta f_1 - \left(\frac{1}{T_{G1}}\right)\Delta X_{g1} \\
\Delta \dot{P}_{tie1} &= 2\pi T_{12}\left(\Delta f_1 - \Delta f_2\right)
\end{aligned}
\tag{1}
$$

For area 2

$$
\begin{aligned}
\Delta \dot{f}_2 &= \left(\frac{K_{p2}}{T_{p2}}\right)\left(\Delta P_{g2} - \Delta P_{tie2} - \Delta P_{L2}\right) - \left(\frac{1}{T_{p2}}\right)\Delta f_2 \\
\Delta \dot{P}_{g2} &= \left(\frac{1}{T_{t2}}\right)\Delta X_{g2} - \left(\frac{1}{T_{t2}}\right)\Delta P_{g2} \\
\Delta \dot{X}_{g2} &= \left(\frac{1}{T_{G2}}\right)u_2 - \left(\frac{1}{T_{G2}R_2}\right)\Delta f_2 - \left(\frac{1}{T_{G2}}\right)\Delta X_{g2} \\
\Delta \dot{P}_{tie2} &= 2\pi T_{21}\left(\Delta f_2 - \Delta f_1\right)
\end{aligned}
\tag{2}
$$

Here output information and all the states of the system is known and measurable. So it **does not require an observer**.

The controller can be directly designed based on the information of states. Therefore, it is necessary to consider a **sliding surface of relative degree one** for the application of super-twisting controller.

The **sliding surface is designed using the given states and the output information of the system** along with the controller designed can be used for both areas because of its similarity.

Sliding surface is

$$\sigma = c_1 \Delta \dot{f}_1 + c_2 \Delta \dot{P}_{g1} + c_3 \Delta \dot{X}_{g1} + c_4 \Delta \dot{P}_{tie1} \tag{3}$$

The state trajectories of the closed-loop system can be driven onto the sliding surface in finite time and further asymptotic stability of the states are established with the **control law:**

$$u = -\sum_{i=1}^{n-1} c_i x_{i+1} - \lambda_1 |\sigma|^{1/2} sign(\sigma) - \lambda_2 \int_0^t sign(\sigma)\, dt + K \tag{4}$$

with the condition that $\lambda_2 > \lambda_1$
where $K = k_n sign(e)$, n is the relative degree, x is the state variables, e is the error that is ACE for this system and c_i,k_n,λ_1,λ_2 are constants. By properly tuning these constants the control input will nullify the effect of fault on system.

The discontinued high-frequency switching term sign(σ) is hidden under square root and other one on under integral term hence the **overall equation becomes continuous.** This controller brings the states to equilibrium in finite time by a continuous control action.

INTEGRAL CONROLLER

The Integral controller is used for the comparison of Super-twisting SMC because its a commonly used control method and it is popular among industries for LFC.

mathematical expression

$$y(t) = -K_I \int_0^t \left(B\Delta x_i\left(t\right) + \Delta P_{tiei}\right) dt \tag{5}$$

The integral gain K_I is obtained through online tuning during the simulation. It is adjusted to achieve the fastest settling time and smallest overshoots in the time response of Integral controlled systems.

In order to compare Super-twisting SMC and Integral controller, **the Matlab/Simulink tool is used**. The simulations are done on two area interconnected system with nonlinearities GDB and GRC along with the corresponding two cases are given below

SIMULATION

Case A: Disturbance applied to one area

The comparison of controllers are done by applying a load disturbance of 0.02 pu magnitude of power on area-1 at 2 sec for a simulation time of 20 sec. There is no load disturbance added to area-2. The frequency error, tie-line power error, and area control error under the control of a super-twisting SMC and Integral controller for area 1 are compared and the corresponding caparisons are tabulated in tables.

Case B: Disturbance applied to both areas

Here the controllers are compared by applying a load disturbance of 0.02 pu magnitude of power on area-1 at 2 sec and on area-2 at 4 sec for a simulation time of 20 sec. The frequency error, tie-line power error, and area control error under the control of a super-twisting SMC and Integral controller for area 1 are compared and the corresponding caparisons are tabulated in tables.

SIMULATION PARAMETERS

The nominal system parameter values are listed as follows.

$T_{g1} = 0.08s$, $T_{g2} = 0.09s$
$T_{t1} = 0.3s$, $T_{t2} = 0.4s$
$T_{p1} = 20s$, $T_{p2} = 25s$

$K_{p1} = 120 Hz/pu.MW, K_{p2} = 130 Hz/pu.MW$

$R_1 = 2.4 Hz/pu.MW, R_2 = 2.6 Hz/pu.MW$

$B_1 = 0.425 puMW/Hz, B_2 = 0.44 pu.MW/Hz$

$2\pi T_{12} = 0.545 pu.MW/rad$
$2\pi T_{21} = 0.6 pu.MW/rad$

SIMULATION RESULTS

Frequency error in area 1 under case A

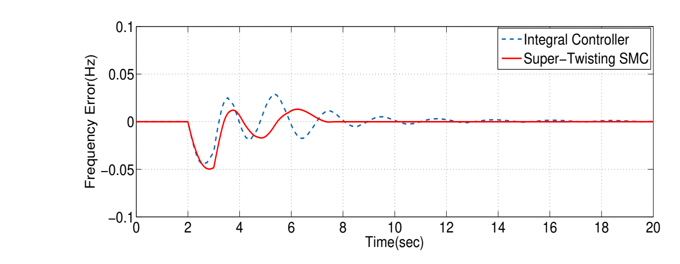

Figure: 3

Tie-line power error in area 1 under case A

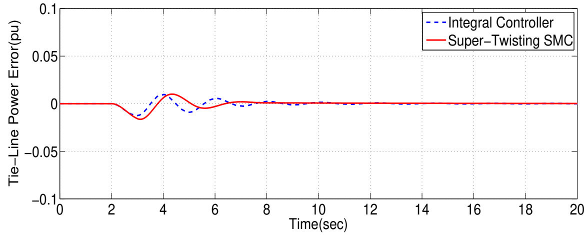

Figure: 4

SIMULATION RESULTS-Continue

Area control error in area 1 under case A

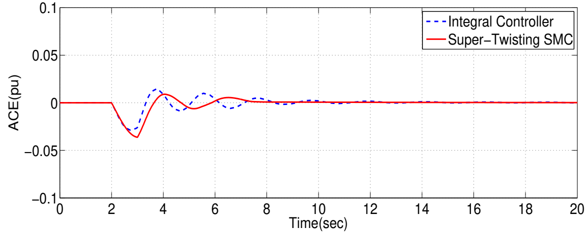

Figure: 5

SIMULATION RESULTS-Continue

From Frequency v/s Time graph Under Case A

Table: 1

Controller	Settling time	Upper Bound	Lower Bound
Integral	12	0.03	-0.045
Super-Twising SMC	7	0.02	-0.05

SIMULATION RESULTS-Continue

From Tie-line power v/s Time graph Under Case A

Table: 2

Controller	Settling time	Upper Bound	Lower Bound
Integral	8	0.02	-0.01
Super-Twising SMC	6.5	0.02	-0.025

SIMULATION RESULTS-Continue

From ACE v/s Time graph Under Case A

Table: 3

Controller	Settling time	Upper Bound	Lower Bound
Integral	8	0.02	-0.03
Super-Twising SMC	7.5	0.02	-0.04

SIMULATION RESULTS

Frequency error in area 1 under case B

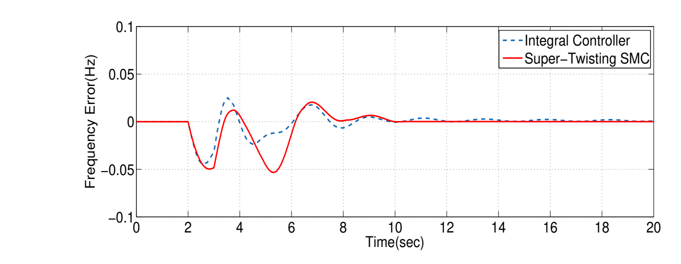

Figure: 6

SIMULATION RESULTS-Continue

Tie-line power error in area 1 under case B

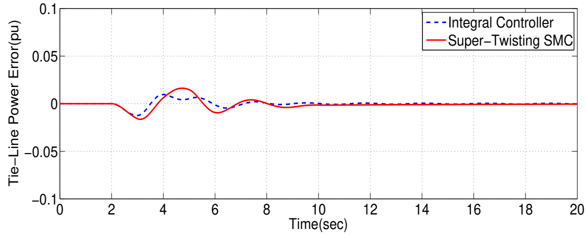

Figure: 7

SIMULATION RESULTS-Continue

ACE in area 1 under case B

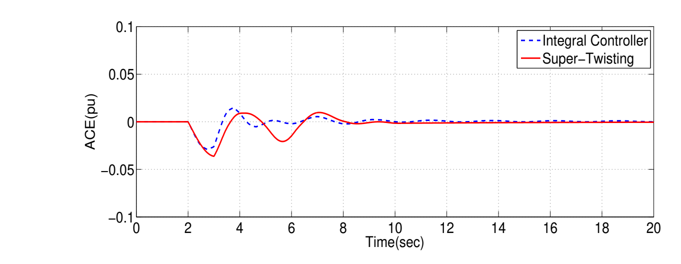

Figure: 8

SIMULATION RESULTS-Continue

From Frequency v/s Time graph Under Case B

Table: 4

Controller	Settling time	Upper Bound	Lower Bound
Integral	14	0.025	-0.045
Super-Twising SMC	10	0.02	-0.052

SIMULATION RESULTS-Continue

From Tie-line power v/s Time graph Under Case B

Table: 5

Controller	Settling time	Upper Bound	Lower Bound
Integral	10	0.02	-0.025
Super-Twising SMC	9.5	0.025	-0.02

SIMULATION RESULTS-Continue

From ACE v/s Time graph Under Case B

Table: 6

Controller	Settling time	Upper Bound	Lower Bound
Integral	12	0.02	-0.03
Super-Twising SMC	9	0.025	-0.05

CONCLUSION

In this paper, performance of Super-twisting and Integral controllers which are applied for the LFC of two area interconnected power system with non-reheat thermal turbine **has been compared**.

The simulation results illustrates the frequency error, tie-line power error and **ACE are converges to zero**. Also the superiority of the Super-twisting SMC over Integral controller in terms of settling time, upper bounds and lower bounds are validated.

FUTURE WORK

Possible applications of other higher order sliding mode control algorithms for load frequency control problem.


Thank You!

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