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Application of modular multilevel converter for AGC in an interconnected power system

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A B S T R A C T

This article demonstrates the maiden application of a new Modular Multi level Converter based Series Compensation (MMCS) technique for multi area Automatic Generation Control (AGC) interconnected system. Primarily MMCS has been modeled in state space form and proposes an appropriate location in AGC to obtain the better dynamic responses in frequency, tie-line power and individual generating power; further to quench the oscillation for sudden changes in load. The system has been studied the operation of MMCS and investigated with Generation Rate Constraints (GRC) of reheat turbines used in system. Further, selection of suitable integral and proportional–integral controller gain has been investigated with Integral Square Error (ISE) technique and Particle Swarm Optimization (PSO) technique for step load perturbation (SLP) in area-1 with performance index as its objective function by making control parameters as variables. System with MMCS is compared with out MMCS and observed performance has been increased and results are explored.

Introduction

Many investigations in the field of automatic generation control of interconnected power system have been reported over the past few decades [1]. These investigations deal with selection of a frequency bias, controller parameters and speed regulator parameters of speed governor [2]. Investigation regarding to the AGC of interconnected thermal system is limited to the selection of controller parameter and effect of generation rate constraints (GRC). Intelligent control scheme for interconnected reheat thermal generating system is investigated and examined [3]. In [4], considered the problem of AGC in interconnected thermal system in continuous-discrete mode using conventional integral and proportional–integral controllers. It has studied the effect of generator rate constraints and governor dead band. The effect of governor dead band and stability analysis of AGC is explained in the contest of recent developments in industry [6], additionally includes the effect of GRC and governor dead band. In [2], it provides a detailed design of automatic generation and voltage control for steady the performance of power systems. Literature shows that, very little attention has been given to the study of AGC of multi-area systems with compensation of tie line. It [4,5] describes the design, implementation and operational performance of a fuzzy controller as part of the Automatic Generation Control (AGC) system. The fuzzy controller was implemented in the control ACE calculation, which determines the shortfall or surplus generation that has to be corrected. In AGC, the basic problem is highlighted while designing the controller parameters. In literature it has been used ISE [7] Bacterial Foraging optimization technique [8] has been applied and results shows application of artificial intelligence technique provides better results than conventional technique[9]. However, the results obtained in [10,11] has much peak deviation and taking significant time to settle down to steady state.

In order to decrease the peak deviation and to arrive steady state in less time, series compensation in the tie line is introduced. There are several compensation techniques available in literature [12,13] by using thyristors. But thyristors require forced commutation, while doing so it experiences many problems and handling of high voltages became difficult to the string of thysristors and introduces harmonics in to the system which affects the system performance. Hence, in order to do smooth compensation and to handle high voltages without harmonics it introduces a Modular Multi Level Converter based Series compensation (MMCS) in AGC. In order to overcome the above drawbacks, a new iterative controller has with MMCS been proposed in this article. This not only mitigates the lower and higher order harmonics but also reduces the peak deviation and decreases the settling time of the

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Nomenclature

f	nominal system frequency
i	subscript referred to area i
$*$	superscript denotes optimum value
P_{ri}	area rated power in area i
H_i	inertia constant for two areas
ΔP_{Di}	incremental load change in area i
ΔP_{gi}	incremental generation change in area i
D_i	$\Delta P_{Di}/\Delta f_i$
T_{12}	synchronizing coefficient
R_i	governor speed regulation parameter
T_g	steam governor time constant
T_G	governor response time
T_R	governor reset time
Δ	governor temporary droop in per unit
K_r	steam turbine reheat constant
T_r	steam turbine reheat time constant
T_t	steam turbine time constant
B_i	frequency bias constant
T_{pi}	$2H_i/f^* D_i$
K_{pi}	$1/D_i$
K_i	integral gain
K_P	proportional gain
K_d, K_p, K_i	electric governor derivative, proportional and integral gains respectively
β_i	$(D_i + 1/R_i)$
ACE_i	area control error of area i
a_{12}	$-P_{r1}/P_{r2}$
J	objective function
T	sampling time period

system. The important advantage of MMCS is, it does not require any coupling transformer while connected to the system. Resulting as a cost effective solution.

The field of modular multi-level converters has witnessed many rigorous investigations leading to successful operation in high voltage DC (HVDC) systems. In the recent times, better known to be the power transmission era, very long distance HVDC transmission lines based current source converters (CSC) and voltage source converters (VSC) were used which offered more economic and cost-effective power transmission. But, it is only in the recent times that the HVDC transmission systems based on VSCs have been bestowed with warm-welcome owing to the manifold opportunities like the grid access of weak AC networks, independent control of active and reactive power, supply of passive networks and black start capability, high dynamic performance and small space requirements. In particular, the novel power converter topology for Modular Multi level Converter (MMC) has been intensively researched and developed, and then was evaluated by many features like high modularity, simple scalability, low expense of filters, robust control, simple in design and redundancy. This converter is composed by identical power cells connected in series, each one build up with standard components, enabling the connection to high voltage poles. Furthermore, Medium Voltage Converters are an interesting area for the application of MMCs [14,15]. The ever increasing demand of industry for stability, adjustability and accuracy of control of power electronic equipment at very high voltages led to the development of relatively less total harmonic distortion (THD) based modern power electronic static converters. Although solid state power electronic switches, such as the IGBTs have brought well-marked variance in control techniques, nonetheless the main disadvantage is that they produce multiple frequency components called as harmonics. Harmonic voltages can cause an unacceptable disturbance on the supply network and adversely affect the operation of even the other connected electrical equipment [13]. Hence there is requirement to reduce the harmonic content to an acceptable level. The THD should be kept within limits by designing converters equipped with proper tuned controllers. Harmonic currents can never be totally eliminated from an electrical system. They can, however, be effectively reduced by using harmonic controllers. All power electronic converters produce complex waveforms, which can be resolved into a series of sinusoidal waves of various frequencies. Hence any complex waveform is the sum of a number of odd or even harmonics, which can be eliminated by designing a proper controller by tuning to the distorted frequencies [13–15]. The proposed MMCS introduces required reactive power while require and absorbs when not requires by which system is reaching to steady state with in less time.

In view of the above discussion, the following are the main objective of the present work.

(1) To develop a model with the new power electronic based technique (MMCS) to power system, especially in AGC.
(2) To explore the new technique in terms of design, operation and control.
(3) To introduce the optimum controlling of AGC with MMCS by PSO.
(4) To compare the performances of an optimum integral (I) and proportional–integral (PI) controllers for AGC of a reheat thermal generating system in continuous-discrete mode considering GRC in both areas by using ISE and PSO.
(5) To study the performance of MMCS after application to MMCS.

All investigations have been carried out for two area thermal reheat turbine system under consideration of GRC.

Modeling and operation OF MMCS

The basic circuit topology is shown in Fig. 1a. It is a three phase 'N' level MMCS having '$N-1$' sub modules in upper limb and '$N-1$' sub modules in lower limb. Each sub module basic circuit is shown in box of Fig. 1a and expanded circuit of each leg shown in Fig. 1b. This circuit mainly consists of an inductor having self-inductance L_1 and L_2, also called as arm inductors. Each module consists of main switch S_1 and auxiliary switch S_2 with their anti-parallel diodes D_1 and D_2 respectively as shown in Fig. 1b. Main switch and auxiliary switch consist of a capacitor, connected in parallel as C_{s1}. The instantaneous voltages across the capacitors are denoted as V_{c1}, V_{c2}, V_{c3}, $V_{c4}\ldots V_{cN}$. Also, the voltage distribution across the capacitors is considered as equal. The current flowing through the R phase top limb, bottom limb, circulating current and R phase currents are represented by 'it_r', 'i_{lr}', 'i_{cir}' and 'i_r' respectively. In order to find out voltage for the 'R' phase, KVL is applied to Fig. 1b.

Then the voltage across the R phase top limb 'Vt_r' and resistance R_{top}, is found out, keeping the following parameters in picture – Voltage for bottom limb is 'V_{lr}', resistance is R_{low}, circulating current is 'i_{cir}' with supply voltage, 'V_{dc}', 'Vnt_r' represents the voltage