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New Dynamic Model for Gas Power Plants for Increasing Wind and Solar Energy in the Egyptian Power System

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Abstract: The Strategy of the Egyptian Electricity Holding Company (EEHC) aims to increase the proportion of power totally generated from renewable energy wind power (WP) and photovoltaic (PV) to 20% by 2022. With increasing such amount of renewable energy in the Egyptian electricity system some of the on line conventional power plants will be shut down and replaced by WP and PV, putting the Egyptian system in big challenge. So, the dynamic behavior of on line conventional power plant must be illustrated to fulfill the requirement of integrating renewable energy in the Egyptian system, especially for system contingencies. This research aims to identify a new dynamic model for gas power plants in the Egyptian power system so that they can be reliable basis for further use. A site visit to three different real gas power plants in the Egyptian network enables the paper to apply the study. The first study is applied on SGT5-4000F (V94.3A) Siemens Gas power plant in Nobaria Station in West-Delta Zone, while the second is AE94.2 Ansaldo Gas power plant in Mahmodia Station in Delta Zone and the third is MS9001FA Hitachi Gas power plant in El-Atf station in Middle-Delta Zone. The comparison between actual and simulated MW response of each turbine is investigated due to load variation. The simulation is made by DIgSILENT Power Factory Software.

Index Terms: Gas Turbine, Turbine-Governor Model.

I. INTRODUCTION

The Strategy of the EEHC aims to increase the proportion of renewable energy (WP and PV) to 20% by 2022 [1]. The integration of the renewable energy in this way while maintaining the security level of supply puts the Egyptian power system with a big challenge. Replacing the conventional power plants with inertia by renewable energy while the total power of the system still constant makes more oscillation and large deviation of system frequency after system disturbance, which causes system stability reduction [2]. Since conventional plants contribute in the primary control, shutting down these power plant will reduce the primary control reserve. Therefore the behavior of the on line Gas power plants need to be illustrated so that they can be reliable basis for further use, especially at system disturbance[3].

To conduct the appropriate dynamic model, a proper mathematical representation of power units and their controls are required. Finding these models is the subject of ongoing research and educational activities [4], [5]. Standard models were created which were used in different dynamic programs during the past years [6]. A major problem in this regard is the parameter identification for these models.

The aim of this paper is to select the standard dynamic model GGOV1 for modeling gas power plants in the Egyptian power system [7]. The study is applied on three different gas power plants in the Egyptian power system. The first study is applied on SGT5-4000F (V94.3A) Siemens Gas power plant in Nobaria Station in West-Delta Zone, while the second is AE94.2 Ansaldo Gas power plant in Mahmodia Station in Delta Zone and the third is MS9001FA Hitachi Gas power plant in El-Atf station in Middle-Delta Zone.

II. OVER VIEW OF THE EGYPTIAN POWER SYSTEM

In The Egyptian network, Thermal power plants (Steam, Gas and Combined) are considered the main power in terms of about 90% of the total power generated , this in addition to 8% Hydro power plants and 2% renewable energy (Wind and Solar). Gas stations produce 14% of the total generation power in the Egyptian network as shown in Fig. 1[1], [8]. The power generation From gas station has been increased from 1376 MW in 2010 to about 4874 MW in 2015. The Egyptian network is divided into several zones according to the geographical location as follows (Upper and Middle Egypt Zone, Cairo Zone, Canal Zone, Delta, Middle Zone, West Delta Zone and Alex. Zone) all of which are interconnected. Each of these zones have its own generating plants, transmission system and distribution networks [8]. The peak load has been increased from 17300 MW in 2006 to 28015 MW in 2015. This has been countered with an increase of the generated

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power from 108368 GWh to about 154054 GWh in the same period [8]- [12]. The total loss in the Egyptian network on the transmission and distribution level reached to 11.77% at 2014 and arrived to 12.88% in 2015. The Egyptian network includes over 45 power stations which incorporate hydraulic, steam, gas, combined, solar as well as wind farm plants [1]. Different projects of power stations, substations, and transmission lines besides upgrading the existing projects have been carried out.

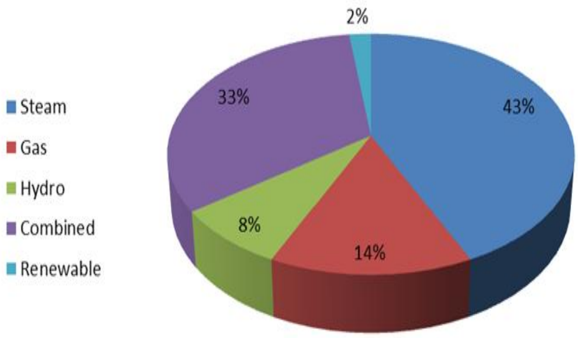

Fig. 1. Egyptian networks generation types

Moreover, other projects like the exchange of energy with neighboring countries through electrical interconnection have been performed. A complete model for such a power system which includes about 250 synchronous machines in addition to hundreds of power transformers, buses, and thousands kilometers of transmission lines is not available until now [13]. So it has to be to find a suitable model for gas turbines and this is the subject of the paper.

III. GAS TURBINE POWER PLANT

Gas turbine consists of three main parts: a compressor, a combustor, and a turbine as shown in Fig. 2. the compressor is used to compress both air and the working fluid in adiabatic compression (no loss or heat gain), then in the combustion chamber under constant pressure condition the combustor is used to burn the mixed with fuel
The work is performed by The resulting hot gas, which expands through the turbine (adiabatic expansion) [14], [15]. Whenever the turbo speed increased whenever caused to increase the speed of the compressor forcing more air through the combustion chamber which increases the burn rate of the fuel making more hot gases with high pressure into the gas turbine increasing its speed more. The fuel supply line is controlled to prevent uncontrolled runaway, the control is based on limiting the amount of turbine fuel which limiting its speed.The compressor is running using most of the power produced in the turbine and the rest are used to run the auxiliary component and do useful work. The air is not reused, therefore the system is an open system and the cycle fourth step (cooling the working fluid) is neglected [15].

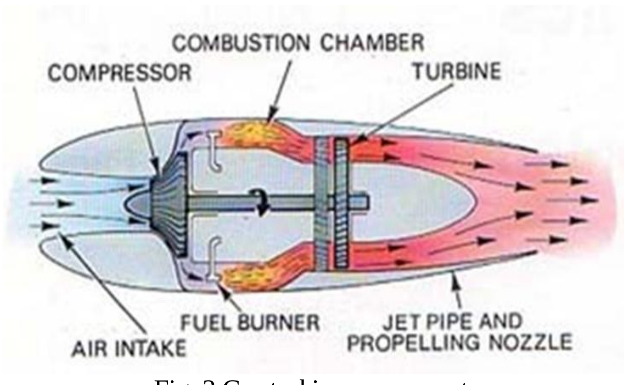

Fig. 2 Gas turbine component

In generation application there are two basic configuration used for the gas turbine power generators. The first is a simple system which consists of the gas turbine driving the electrical generator with low efficiencies (range between 30% and 40%) while the second type is designed for maximum efficiency (up to 60%) called Combined Cycle Systems, in that system the hot exhaust gas coming out from gas turbine are used for boiling water in steam turbine with both turbine are connected to electrical power generators. Another advantage of gas turbines is the flexibility of fuel. They can be adjusted to use almost any flammable gas or light distillate petroleum products [14].

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IV. TURBINE-GOVERNOR MODEL GGOV1

The GGOV1 model was created as a general turbine-governor model to be used for studies the dynamic simulation as shown in Fig. 3 [7]. The GGOV1 model was created as a general turbine-governor model to be used for studies of dynamic simulation model for any prime mover with a PID governor. In this model much of the same simplifying assumptions are made, In terms of the gas turbine [16]. The GGOV1 model represents the principal elements of gas turbine controllers. Such as the acceleration control, speed/power governor and a temperature limit controller. In grid studies, temperature limit controller is the one most frequently of importance [17], [18].

For PID governor control fsrn is The output signal of the governor blocks, which goes through a Low Value select block. The temperature limit controller (fsrt) and the acceleration controller (fsra) are the other two signals. If the signal fsrn is selected, it becomes the input for the other blocks that represent the dynamics of the fuel stroke. The model of valve stroke includes rate limiters and a time constant T_{ACT} .V_{MAX} and V_{MIN} are the fuel stroke demand limits. Generally V_{MAX} is set to 1.0 pu (on the turbine MW base). For a gas turbine V_{MIN} is set to a value for the minimum fuel flow. The turbine model is represented with the remaining blocks. K_{TURB} is the turbine gain and for gas turbines the time constant T_{ENG} is set to zero. If the turbine has a liquid fuel source the constant flag is set to 1.0 to represent the dependence of fuel flow on shaft speed. The lags for the gas turbine are representing using the block containing the lead-lag function with time constants T_C and T_B.

For acceleration control in GGOV1 model, fsra is the output signal. A block consisting of a derivative with a lag filter is processing the speed signal. The steady rate of change in the speed is providing by the output of this block and it is compared to the value assigned to A_{SET}. fsrt is the signal which provides limiter and L_{DREF} is the load in per unit as specified by the parameter and the maximum output of gas turbine MW for different ambient conditions. The lead-lag and lag blocks for the limiter in GGOV1 are selected as those in the Rowen model [19]. For temperatures control, GGOV1 provides The parameters T_{SA} and T_{SB} to augment the exhaust gas temperature measurement subsystem in gas turbines. The developed steady-state mechanical power from the model is given by:$P_{mech} = K_{turb} \times (W_f - W_{fnl})$ where W_{fnl} is the fuel flow for full speed and no load conditions. This allows a representation of fuel consumption at no-load for running the axial compressor [16].

However, a detailed complete gas turbine control system model is not appropriate for grid studies, because of the difficulties of managing the data required and because the main controllers in the internal turbine variables have only small influence on the behavior of the grid. Therefore the GGOV1 model provides a description of the expected behavior of a adjusted gas turbine engine, but not a detailed description of any particular turbine. For studies where the plant is connected to a large grid GGOV1 model is preferable [7].

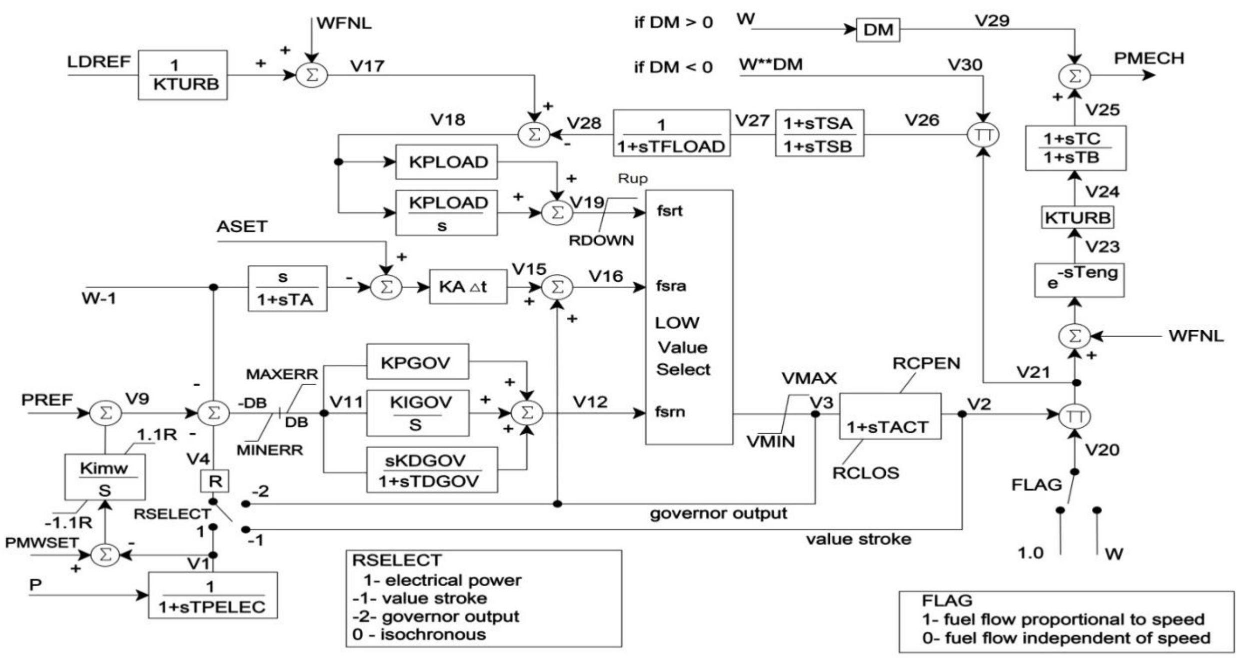

Fig. 3. Turbine –governor model GGOV1

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TABLE I TYPICAL PARAMETER VALUES OF GGOV1 MODEL

Parameter/ Unit	Definition	Typical Value	Parameter / Unit	Definition	Typical Value
R(p.u)	Permanent Droop	0.04	R_{SELECT}	Governor Droop Feedback Signal Selector	1
T_{PELEC} (s)	Electrical Power Transducer time cons.	1	T_{DGOV}(s)	Governor Derivative Controller Time Constant	1
Maxerr (pu)	Maximum Speed Error Signal	0.05	V_{MAX} (pu)	Maximum Valve Position Limit	1
Minerr (pu)	Minimum Speed Error signal	-0.05	V_{MIN} (pu)	Minimum Valve Position Limit	0.15
K_{PGOV}(pu)	Governor Proportional gain	10	T_{ACT} (s)	Actuator Time Constant	0.5
K_{IGOV}(pu)	Governor Integral Gain	2	K_{TURB}(pu)	Turbine Gain	1.5
K_{DGOV}(pu)	Governor Derivative Gain	0	W_{FNL}(pu)	No Load Fuel Flow	0.2
T_B(s)	Turbine Lag Time Constant	0.1	K_{PLOAD}(pu)	Load Limiter Proportional Gain	2
T_C(s)	Turbine Lead Time Constant	0	K_{ILOAD}(pu)	Load Limiter Integral Gain	0.67
flag	Switch for Fuel Source Characteristic	1	L_{DREF}(pu)	Load Limiter Reference Value	1
T_{ENG}(s)	Diesel Engine Transport Time Constant	0	D_M (pu)	Mechanical Damping Coefficient	0
T_{FLOAD}(s)	Load Limiter Time Constant	3	R_{OPEN} (pu/s)	Maximum Valve Opening Rate	0.1
K_A(pu/s)	Acceleration Limiter Gain	10	R_{CLOSE} (pu/s)	Maximum Valve Closing Rate	-0.1
T_A(s)	Acceleration Limiter Time Constant	0.1	K_{IMW}(pu)	Power Controller Reset Gain	0
DB(pu)	Speed Governor Deadband	0	R_{DOWN} (pu/s)	Maximum Rate of Load Limit Decrease	-99
T_{SA}(s)	Temperature Detection Lead Time Cons.	4	A_{SET}(pu/s)	Acceleration Limiter Set point	0.01
T_{SB}(s)	Temperature Detection Lag Time Cons.	5	R_{UP}(pu/s)	Maximum Rate of Load Limit Increase	99
T_{RATE}(MW)	Turbine Rated Power	user	P_{MWSET}(pu)	Power Controller Set Point	N/A

V. MODELING GAS TURBINE USING GGOV1 MODEL

In this section several different types of gas stations in the Egyptian network are simulated using GGOV1 model with typical parameter values. The MW response of each stations are investigated. The simulation is made by DIgSILENT power factory software [20], [21].

SGT5-4000F (V94.3A) Siemens Gas Turbine

The SGT5-4000F (V94.3A) turbine is characterized by low costs at power generating, high performance, and long intervals between major inspections as well as an easy maintenance. More than 200 units have been installed worldwide since 1996. The (SGT5-4000F) V94.3A) is based on proven standard design concepts with optimized flow combustion, and cooling systems as well as new materials, the efficiency of that gas turbine type nearly 40 % [22].

The requirements have been trending toward fast startup times, higher load gradients, and peak load capacity. Research predicts the development in the direction of even higher flexibility required of gas turbine operation modes. The Advanced Stability Margin Controller (ASMC), Turn Down, Turn Up, Advanced Compressor Mass Flow Increase (CMF) and Wet Compression and Operational Flexibility Upgrade (OFU) are the most powerful upgrade and modernization that enhance the flexibility of the F-class gas turbine [22]. Turbine specifications are shown in Table II.

This type is used in Nobaria station in West-Delta Zone in the Egyptian network with capacity of 292 MW. It was installed in 2010 using the natural gas or oil as fuel source [1]. The actual control unit over view is shown in Fig. 4, Which explains pressure and temperatures of different turbine stages.

The test was as follows; Modeling SGT5-4000F (V94.3A) Siemens Gas Turbine using GGOV1 with its typical parameters values as shown in Table I . Turbine MW was selected as 250 MW [1]. GGOV1 Model subjected to the same

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load variation conditions, as in fact. The MW response of the model are compared to the actual unit MW response as shown in Fig. 5. The overall response of the model is good, but Some deviations from actual Unit performance are exist since the GGOV1 model provides a description of the behavior to be expected of a properly built and adjusted gas turbine engine, but not a detailed description of any particular turbine.

TABLE II SGT5-4000F (V94.3A) SIEMENS GAS TURBINE SPECIFICATION

Grid frequency (Hz)	50
Gross power output (MW)	292
Gross efficiency (%)	39.8
Gross heat rate (kJ/kWh)	9,038
Gross heat rate (Btu/kWh)	8,567
Exhaust temperature (°C/°F)	577/1,071
Exhaust mass flow (kg/s)	692
Exhaust mass flow (lb/s)	1,526
Pressure ratio	18.2
Length x width x height (m)	13x6x8
Weight (t)	308

AE94.2 Ansaldo Gas Turbine

The AE94.2 gas turbine is a benchmark for both fuel flexibility and operational. The ability to adapt rapidly to provide the requested grid power is becoming a vital important [23]. The VeLoNOx™ burner, designed by Ansaldo Energia to reduce NOx emissions in fuel gas mode, achieves NOx emissions levels lower than 30 mg/. Unit is characterized by the following;

- Start up and loading time: full speed no load reached in less than 5 minutes and base load conditions about 15 minutes later. This time can be reduced to about 6 minutes using fast loading gradient procedures
- In few seconds, dynamic performance during grid support is 40 MW.
- Optimum operation with a broad variety of fuel compositions and characteristics
- Gas/oil fuel change-over, Mixed operation (concurrent combustion of gas and oil).
- Compressor cold-end driver with variable inlet guide vanes, Disk-type rotor with two bearings.
- Improved compressor exhaust diffuser.
- 2 vertical silo type combustion chambers.
- 16 hybrid burners (diffusion or premix operation) for natural gas and light oil, Axial exhaust.
- Gross power output 170MW, Gross efficiency 34.7 %.
- Exhaust temperature 552 C °, Exhaust mass flow 535 kg/s

This type is used in Mahmodia station in Delta Zone in the Egyptian network with capacity of 170 MW. It was installed in 2015 using the natural gas or oil as fuel source [1]. The actual unit over view is shown in Fig. 6.

By the same way using GGOVI with its typical parameters values as shown in (Table I) for modeling AE94.2 Ansaldo Gas Turbine. Turbine MW was selected as 170 MW [1]. The MW response of the unit are compared to the actual unit response as shown in Fig. 7.

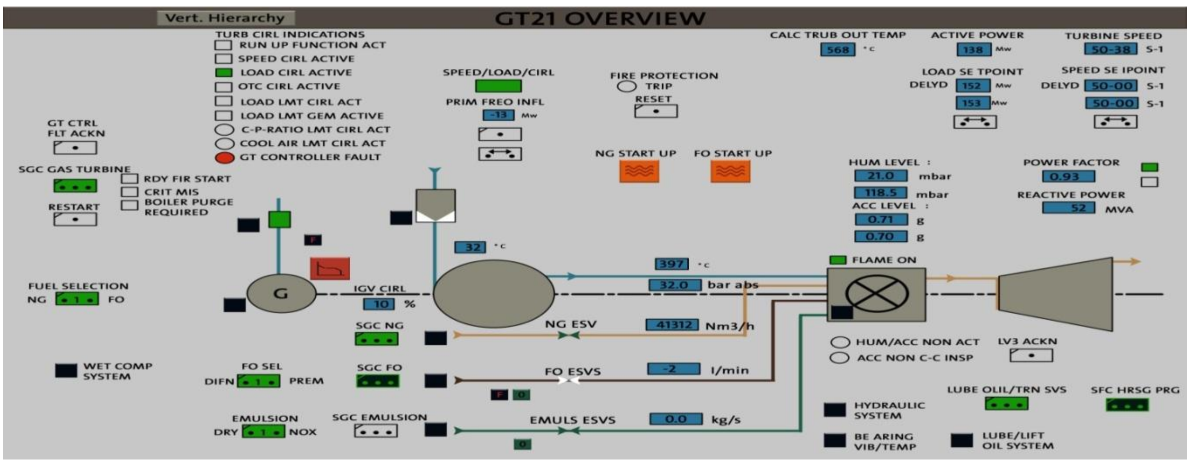

Fig. 4. Actual turbine control unit over view

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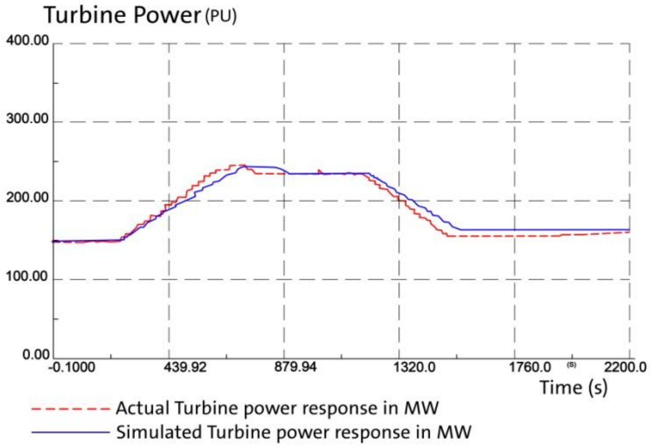

Fig. 5. Comparison of actual and simulated unit MW response using GGOV1 model

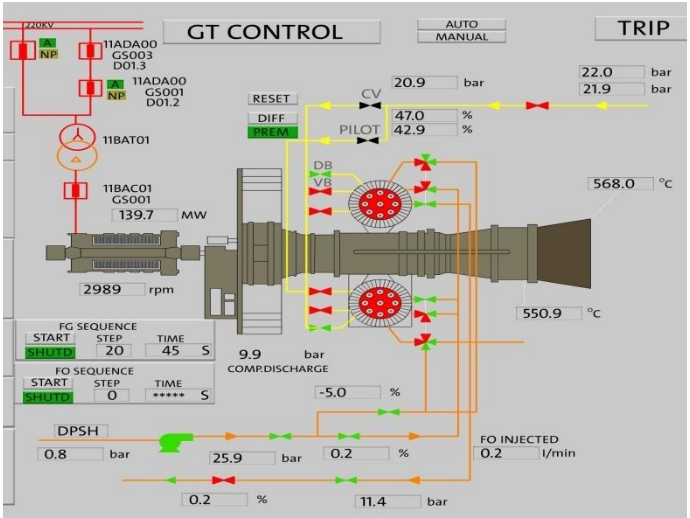

Fig. 6. AE94.2 Actual gas turbine control unit over view

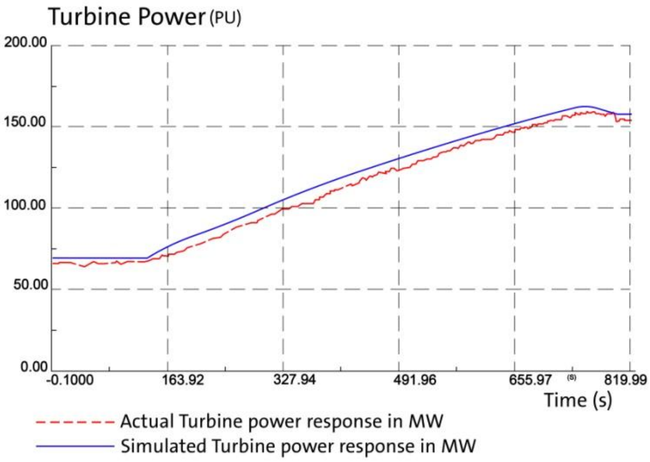

Fig. 7. Comparison of actual and simulated unit MW response using GGOV1 model

MS9001FA Hitachi Gas Turbine

Hitachi's involvement with gas turbines dates back to 1938. The 1960s and 1970s were the formative years for Hitachi's gas turbine business during which it expanded sales outside Japan. Large capacity, high-performance gas turbines in response to growing demand for large capacity, high performance gas turbines, the 60-Hz MS7001 was developed based

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on the MS5001M, followed by the 50-Hz MS9001. El-Atf station uses MS7001FA gas turbines for single shaft combined cycle power generation with high efficiency and excellent operating characteristics these are subsequent LNG-fired units used dry low nitrogen oxide (NOx) combustors developed in-house by Hitachi. The 1,300C°-class MS6001FA was developed with GE, with the first Hitachimade unit being the Hitachi Rinkai Power Station in 2000 [24].
This type is used in El-Atf station in Middle-Delta Zone in the Egyptian network with capacity of 250MW. It was installed in 2009 using the natural gas or oil as fuel source [1]. As stated previously, MS7001FA gas turbine is modeled using GGOV1 with its typical value. The MW response of the unit are compared to the actual unit response as shown in Fig. 8. The actual unit over view is shown in Fig 9.

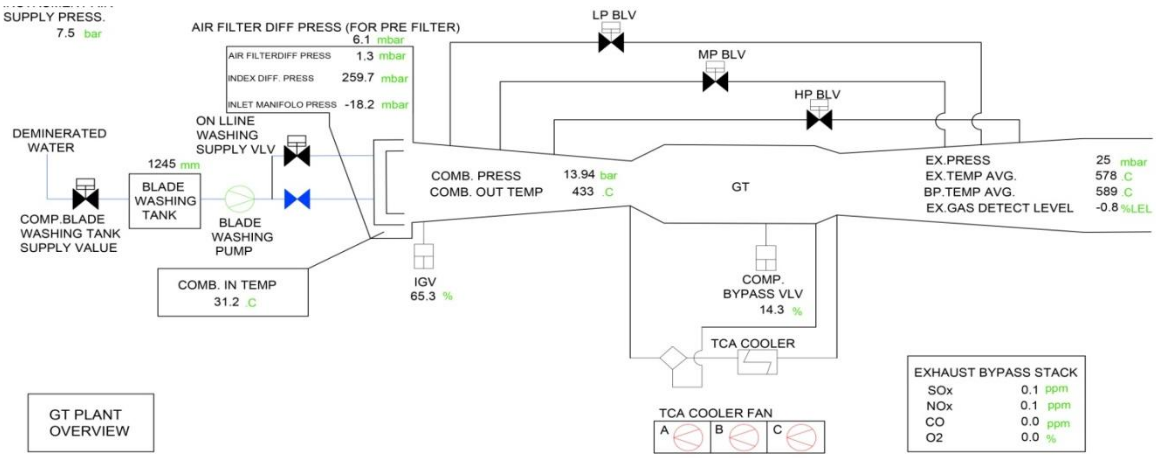

Fig. 8. Actual turbine control unit over view

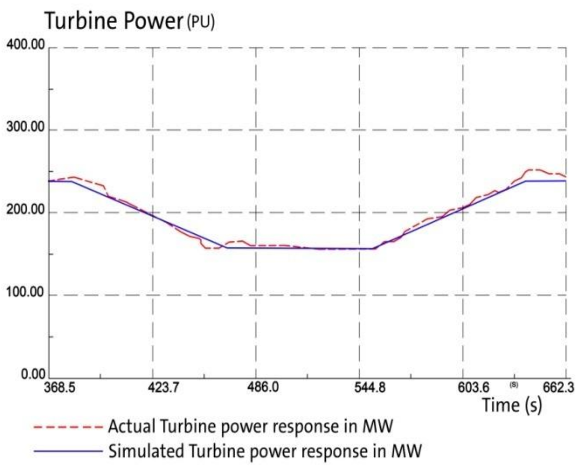

Fig. 8. Comparison of actual and simulated unit MW response using GGOV1 model

VI. CONCLUSION

This paper presented a new dynamic model for gas power plant in the Egyptian power system. The selected model was the Turbine-Governor model (GGOV1) for modeling gas power plants for large interconnected systems such as the Egyptian network. The study was applied on three different gas power plants in the Egyptian network, SGT5 4000F (V94.3A) Siemens Gas Turbine in Nobaria station, AE94.2 Ansaldo Gas Turbine in Mahmodia station and MS9001FA Hitachi Gas Turbine in El-Atf gas station. Each turbine was simulated using GGOV1 model. Paper has used GGOV1 typical parameter values according to IEEE report. GGOV1 Model subjected to the same load variation conditions, as in fact. The MW response of each unit was compared to the actual unit MW response. The simulations were made by DIgSILENT power factory software. The overall response of the model was good, but Some deviations from actual unit performance are exist since the GGOV1 model provides a description of the behavior to be expected of a properly built and adjusted gas turbine engine, but not a detailed description of any particular engine. Finally GGOVI model is recommended for modeling gas turbine in large interconnected system such as Egyptian network. With the growing of

WP and PV in the Egyptian electricity system, this paper helps the EEHC to study different method required to simulate the scheduling of on line conventional power plant which contribute in the primary control, the system stability and upgrading Egyptian grid code during system disturbance.

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BIOGRAPHIES

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