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Modelling and Simulation of a Hybrid Controller for Solar Thermal Generation

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ABSTRACT

In this paper, Parabolic Solar Thermal Generation (PSTG), is studied and analyzed. The optimum control of oil cycle of PSTG is essential in its operation. Improved control techniques of solar thermal generation results to solar energy optimization, so modeling of this system is vital from the control point of view. To control such a complete oil cycle, two controllers are required: 1- a continuous controller to maintain output oil temperature of the collectors' field at a desired level and 2- a switching (discrete) controller to determine active working loop. a combination of continuous and switching controllers are used in this work for control system that is: PID switching + Conditional switching. Here after modelling of PSTG, a hybrid control system is suggested and employed in PSTG with real data so the results for different working days are obtained through this method.
KEYWORDS: Solar Thermal Generation (STG), Parabolic Technology, Hybrid control, Optimization.

I. INTRODUCTION

Many other forms of renewable energies are indirectly powered by the sun. For example, the sun's heat is captured by wind turbines that drives the winds which produce energy Winds, so, cause ocean waves, producing energy that can be converted to electricity. Today a great variety of solar technologies for electricity generation is at disposition that the major technologies are: Photovoltaic, Solar Dish, Solar Ponds, Solar Chimney, Central Receiver and Parabolic Troughs. The profitable aspects of solar thermal electric technology promoted huge in the mid 1980's and early 1990's with the development of the 'Solar Electric Generating System' (SEGS) plants in California by LUZ International Ltd. Solar electricity has a large potential due to the uniformity and sheer magnitude of its primary source in most regions. Consider that utilizing only 1% of the earth deserts and applying a conversion efficiency of 15% to produce electric energy would develop more electricity than is currently produced entire the world by fossil fuels [1].

II. SOLAR HEATING SYSTEMS FOR PRODUCE ELECTRICITY

We use heating collectors in produce electricity energy in indirect method and by a thermo dynamic cycle, heating energy changes to electricity energy.

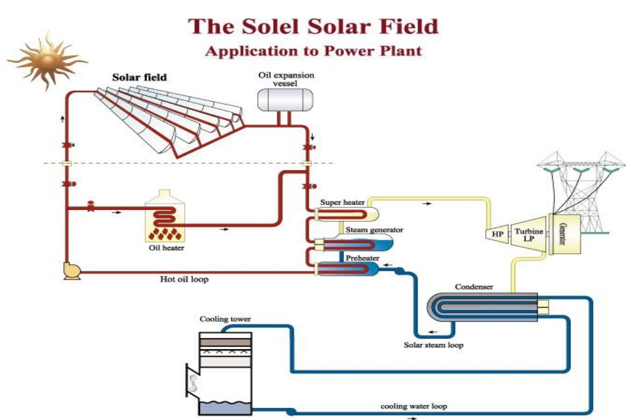

Fig. 1 Structure of Solar Thermal Generation

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Except solar chimney, efficiency of five other kinds is according to reflex light in a point or line and heating the heat transfer fluid (HTF) and all of these systems should tracking sun during the day to receive maximum energy from the sun.

III. SOLAR THERMAL GENERATION (PARABOLIC TECHNOLOGY)

Shiraz STG (see figure 2) is the first solar thermal generation in Iran. Oil cycling involves collectors field, which combine of 48 collectors which place in 8 rows combine of 6 items. An other parts are connection pipeline, oil reservation tanks and heating converters.

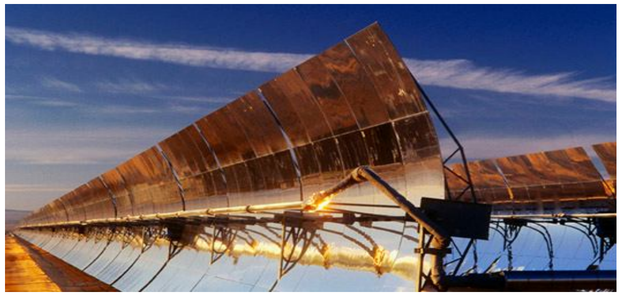

Fig. 2 Shiraz thermal generation

This thermal generation design for electricity producing. Its collector field is from distributing kind. Shiraz STG, is kind of thermal generation which in it absorbed solar shining energy, and use in a thermodynamic process because of producing steam gas which can install a steam turbine or steam engine. Kind of usage collectors in this thermal generation are parabolic trough. Today's parabolic technology is the most economic and the best heating-electricity solar technology in the world and use for building STGs in large size and commercial aspects [2].

This STG combines of two principle cycles: oil cycle and steam cycle. In oil cycle, heat transfer fluid (HTF) makes heat by heated receiving pipe and comeback to a collection of heating transformer in which use of fluid in order to produce superheated steam with high pressure. In steam cycle, for producing electricity, superheated steam enters in an ordinary steam turbine-generator or in a steam engine-generator. External steam from turbine or engine to be heaped up in a standard condenser and comeback to heating transformer by water pump in order to change to steam again. After pass of HTF from heating transformer, cool HTF will cycle again in collector field.

A. Collectors Field

Collector has a parabolic surface in order to can concentrate sun direct ray on a receiver tube which place in parabola focal point. Heat transfer fluid pumps to inside of receiver tube and absorb transferred heat from receiver tube. These tube uses from concentrated sun shine in order to heat oil which extract from down parts of heat reservation tank. This oil cycle in collector field and comeback to the top of tank by a pomp which place in input of filed. Because of suitable heating adjectives of tank and the effect of thermoclin, oil will stay on top of tank and held in high temperature for a few days.

B. Oil cycle modelling

Available model which explains dynamic of oil cycle, create situation for designer to simulate uncountable different work situations. This cause to a pro-designing which in real process has acceptable results. With use of contemporary energy equation for tube wall and oil and glasses coverage during the time of dt. We have below equation [2]:

$$\rho_f C_f A_f \left(\frac{\partial T_f}{\partial t} + V_f \frac{\partial T_f}{\partial x} \right) = U_C \pi d_{ri} \left(T_m - T_f \right) \qquad (1)$$

$$\rho_m C_m A_m \left(\frac{\partial T_m}{\partial t} \right) = \eta_o G I_b - U_L \pi d_{ro} \left(T_m - T_a \right) - U_C \pi d_{ri} \left(T_m - T_f \right) \qquad (2)$$

Write below equation for modelling solar direct shining for Iran's cities.

$$I_b = I_0 \times (1 - C_{fa}) \left\{ 1 - \exp\left[-0.075 \left(\frac{\pi}{2} - \theta_Z \right) \right] \right\} \qquad (3)$$

For shiraz $I_0 = 960(W/m^2)$ and clouds average factor (C_{fa}) for each month counted by Mr.Daneshyar.[5]

C. Frequency response analysis

In order to receive more information about process dynamic done, PRBS test in order to reach input-output data for counting process frequency response based on different work situations. Figure 5 shows the theory (with counting heat casualty) and reality in one point of work. As seen in special frequencies will reduce amplitude: but don't reach to zero: because the field heat casualty cause to damping this reduction.

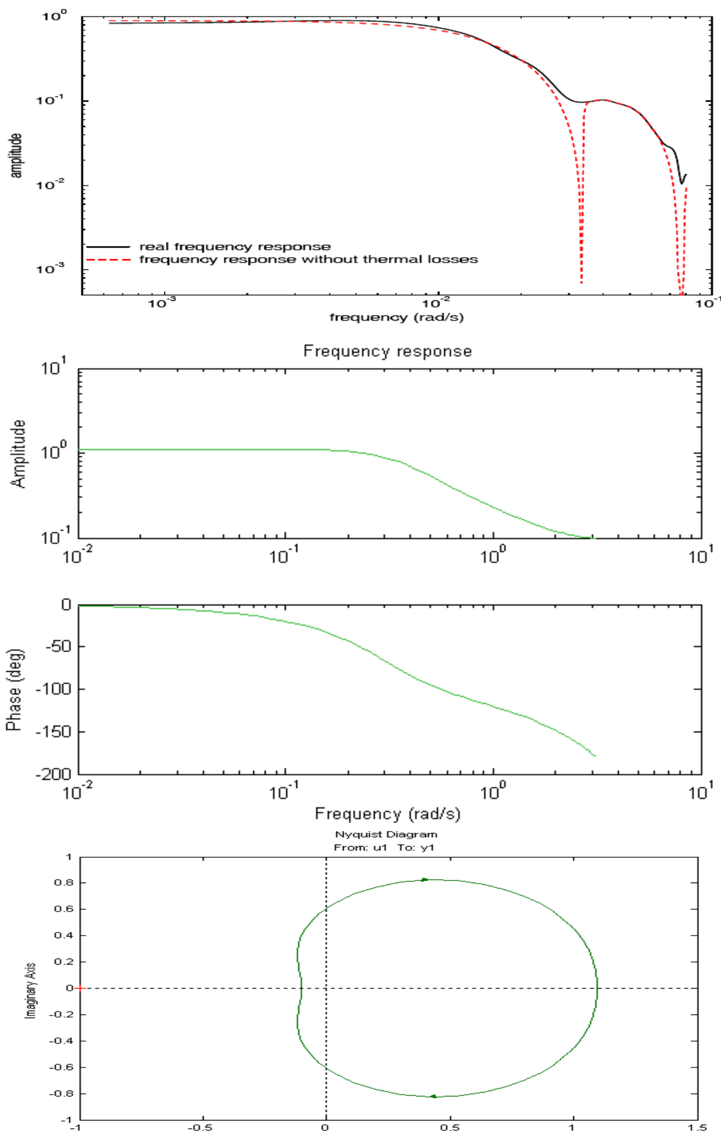

Fig. 3 Frequency response

D. Control of Solar Thermal Generations

From a theoretical point of view, in most of researches which have been implemented in the field of control of solar thermal generations, only collectors' filed is considered. The objective of control system in a distributed collectors' field is usually to maintain the output oil temperature of the loop at a desired level in spite of disturbances such as changes in the solar irradiance level (for example, caused by clouds), mirror reflectivity, etc. This problem has attracted the attention of control engineers and researchers since behaviour of collectors' field is nonlinear and the governing equations are a set of nonlinear partial differential equations. In addition, the system is affected by disturbances such as unknown variation of solar radiation, wind velocity, variation of ambient temperature, etc. From a control point of view, in contrast to fossil fuel thermal generations which the amount of fuel is the main control parameter, in solar thermal generations solar radiation acts as a disturbance. In collectors' field, mass flow rate of oil is usually the control parameter. In the literature, the main purpose of analysis of solar thermal generations has been to develop a modern control strategy being able to cope with changing dynamics of collectors' field (nonlinear terms and uncertainties) and disturbances (like variable solar irradiation).

IV. HYBRID CONTROL OF THE COMPLETE OIL CYCLE

Most of the works in the control field of solar thermal generations have been concentrated on control of oil temperature of only collectors' field by means of oil mass flow rate. In those works, the reasons mentioned for using advanced control strategies are uncertain parameters, nonlinear equations and various disturbances. Because of switching nature of the oil cycle which causes changes of system field's equations and non-uniform disturbances such as solar irradiation during a day, a conventional continuous controller can't satisfy all design specifications for these different situations all together. In this thesis, the main objectives are study, modeling and design of a controller for the complete oil cycle as a hybrid system. In addition to the oil cycle hybrid modelling, two hybrid controllers structure will be introduced.

A. *Controller Design for the Complete Oil Cycle*

The main objective of control of STG is generation of maximum uniform electricity in possible largest time during a day. It should be considered that it is not an optimization problem. This objective should be reached by the control system strategy. Based on this objective and design constraints in some components of the oil cycle (i.e. heat exchangers), following objectives are defined for design strategies of control system for the oil cycle:

The output oil temperature of collectors' field should be maintained at a desired level in spite of disturbances such as changes in the solar irradiation level (caused by clouds …), and system non-linearity.

To start generation of superheated vapor in the heat exchanger, a minimum level of hot oil mass flow rate should be reached.

B. *Structure of the Oil Cycle Controller*

In design of controller structure for the oil cycle as a complex system following items should be considered:

Conventional mathematical models of real processes cannot take all aspects of reality into account. Simplifying assumptions have to be made and models are only approximations of reality. For linear approaches, a linear mathematical model of the plant is needed and finding one is not a trivial problem in many cases. Most of processes are nonlinear and time variant. Also, they may have an interaction with discrete dynamics caused by their nature or by control actions. Because of changing environmental conditions, such as ambient temperature, solar irradiation, humidity, etc., most processes are not time invariant. While in other thermal generating processes, the main source of energy (the fuel) can be manipulated as it is used as the main control variable, in solar energy systems, the main source of power which is solar radiation cannot be manipulated and furthermore it changes in a seasonal and in a daily basis, acting as a disturbance when considering it from a control point of view. Therefore, the only continuous control variable in the oil cycle is the amount of oil mass flow rate. But, according to the mentioned objectives, it is not possible to cover all situations by applying only one continuous controller on the oil mass flow rate of the cycle. Also, because of changes in environmental conditions during a day and considering design constraints, it is necessary to change working loops or add another working loop to the active loop. For example, when steam generation loop (loop 3) is active and by increasing oil mass flow rate, maximum design level of oil mass flow rate for the heat exchangers will be exceeded and it is not possible to control this situation by keeping oil mass flow rate constant or reducing it, because output oil temperature of the collectors' filed will overpass the desired level. So, tank's charging loop (loop 4) should be activated besides steam generation loop to store additional amount of oil mass flow rate (loop 6). Making decision on which loop should be activated in order to fulfill all the above objectives, is a control task and definition of a function to perform switching actions is a part of controller design.

Based on the switching nature of the oil cycle and defined objectives in the previous section, structure of control system consists of two parts:

- a continuous controller for continuous subsystems
- a controller to make decision on switching actions

The objective of continuous controller is to hold output oil temperature of the collectors' field at its desired level in each continuous subsystem (working loop). The duty of the controller of switching actions which is a supervisory controller, is to determine suitable loop to be activated based on various situations and design constraints and determine proper gains for the continuous controller. For continuous controller, two methods are studied. The only control variable which can be determined by continuous controllers is the oil mass flow rate. Therefore, the output parameter of continuous controllers is the amount of working oil mass.

C. *Combinations of Controllers for the Controller System*

In this combination, switched dynamical system was employed. Figure 4 shows a block diagram of the controller structure of the combination and the continuous subsystem.

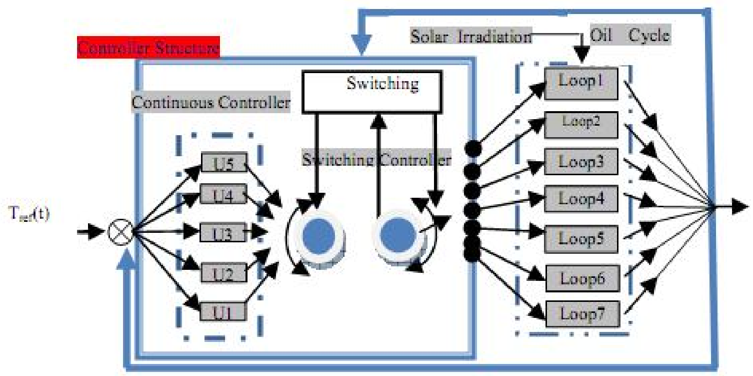

Fig. 4 Block diagram of the controller structure

D. *Simulation Results for a Hot and a Cold Day*

Simulation is performed for two different days: for a hot day (Jun. 15th) and for a cold day (Nov. 15th). For each day various conditions are studied. White noise is added to all solar irradiation models. Wind velocity is assumed to be constant during the day. In the following figures, these points should be considered:

- Total number of the collectors' field lines is 8 and is scaled to 1 for the simulation purpose; it means that by taking one line out of tracking, the number of active collectors' field lines is 7/8.
- P-C stands for PID switching controller-Conditional switching controller.
- Parameters and gains of continuous controllers are fixed for all cases.
- Gains of PID switching controller are:

$$K_P = \begin{cases} -0.005 & abs(e) > 10 \\ -0.0025 & 4 < abs(e) \le 10 \\ -0.001 & 0 \le abs(e) \le 4 \end{cases} \qquad K_d = \begin{cases} -0.08 & abs(\dot{e}) > 0.12 \\ -0.035 & 0.05 < abs(\dot{e}) \le 0.12 \\ -0.01 & 0 \le abs(\dot{e}) \le 0.05 \end{cases}$$

K_i= -0.00000001 for all e

The simulation results are presented for following cases:

1- Jun. 15th, without moving clouds
2- Nov. 15th, with moving clouds

Set points for charge and discharge oil mass flow rate of the storage tank are presented in Table 1. 'chg' is the set point for charge of the tank and 'dchg' is the set point for discharge of the tank. During charge time, excessive amount of oil mass flow rate of collectors' field relative to 'chg' is stored in the tank. While the storage tank is discharged, amount of oil mass flow rate through heat exchanger is kept constant equal to 'dchg', and any deficiency of hot oil mass flow rate of collectors' field is compensated by using stored hot oil in the tank.

In Fig. 1, the model of solar irradiation without moving clouds is shown. Jun. 15th is one of hottest days of the year in which the storage tank may be fully charged.

Table1. Set points of oil mass flow rate for charge and discharge

case	1	2	3	4	5	6	7	8
chg	14.98	15	14.8	14.7	14.98	11.6	14.7	11.4
dchg	13.41	13.5	13.4	13.5	13.41	11.23	13.5	11.01

V. Result and Conclusion

Solar thermal Generation (STG) is a nonlinear energy transformer system, and the input power is solar radiations that change over the time. A combination of actual and simulation data have been employed for this task. Moreover different models for the system have been presented and studied. In the proposed model the input and output have been assumed to be the entering oil flow and outgoing oil temperature. Improved control techniques of solar thermal generation results to solar energy optimization, so modeling of this system is necessary from the control view.

This combination for control system of complete oil cycle is hybrid systems, too. Simulation results of the complete oil cycle and the control systems show that applied control systems can manage the oil cycle in different situations especially in presence of large step disturbances (moving clouds) and white noise. By applying such control systems, it is found that the behavior of the controlled system is stable.

In general we need a model of the system in order to control it as much as better and easier. The numerical models for simulation of a thermal generation have an important role in design of different control methods. They avoid time-consuming and costly adjustment experiments in STGs. We can use more effective control methods and better modeling leading to better responses, in order to have collector field with more work time. Nonlinear model describe thermal generation manner in each operational point.

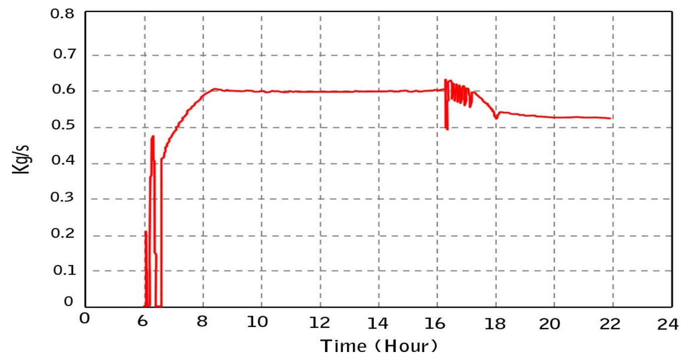

Fig. 5 Oil Flow

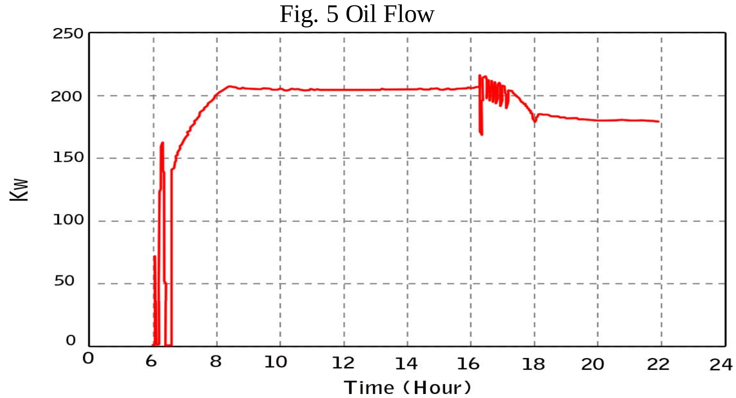

Fig. 6 Generated electrical power

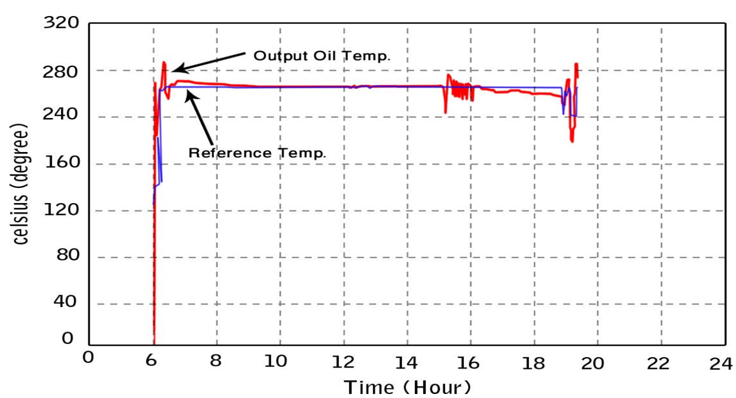

Fig. 7 Collectors' field output oil temperature

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