DESIGN OF AUTOMATION CONTROL THERMAL SYSTEM INTEGRATED WITH PARABOLIC TROUGH COLLECTOR BASED SOLAR PLANT

by

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This paper presents enhanced design for automation control of processes involved in a solar system which utilizes programmable logic controller to automate tracking system for obtaining maximum solar radiation. Three areas are involved in this proposed multi area system where 1st and 2nd area considers solar power plant with thermal system based parabolic trough collector with fixed solar isolation and random isolation of solar energy whereas third area comprises of solar thermal system with dish Stirling realistic unit. Energy efficiency can be increased by using solar concentrator along with Stirling engine. Optimization of gain of the controller is by utilizing crow search novel algorithm. Crow search algorithm is an optimization technique, which provides better performance at complex time varying noisy condition and time in-varying noisy condition. The proposed controller is evaluated by obtaining the optimized parameters of the system whose comparison is done by operating proposed controller with and without renewable sources of energy thereby revealing better performance for both conditions. Testing is done in different areas with fixed solar isolation and random stisolation of solar energy involved in solar thermal power plant based on parabolic trough collector. Gain and parameters of the controller of the solar power plant are optimized by utilizing automation for operation of solar concentrator with parabolic trough collector. Data acquisition and monitoring is done by human machine interface in order to report safe operation. The simulation results of integrated solar thermal system involving dish Stirling with parabolic trough collector, shows that dynamic response of the proposed controller operating with renewable solar energy is better than that of non-renewable energy source.

Key words*: automation control, power system, thermal power, human machine interface, solar energy*

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Introduction

In real time power systems (PS), perturbations occurs suddenly towards load side which causes disagreement between amount of power generated and load in demand leading to divergence in power and frequency of tie line [1]. This variation between generated power and load can be mitigated by manipulating automatically the position of gate or valve of the turbine using an automatic generation control. In the past, automatic generation control was used in thermal system consisting of single area with simple design [2]. This is extended still for thermal system operating in multi-area which is realistic with physical constraint consideration namely generation rate constraints and governor dead band with their non-linearity in a system of multi area [3]. Automatic generation control applied for system with multi area which includes thermal power unit, hydro power unit and gas power unit is presented [4]. But continuous usage of fossil fuels leads to its depletion which can be mitigated partially by the usage of renewable sources of energy. Implementation of automatic generation control (AGC) applicable for RES namely solar photovoltaic system is possible. Efficiency of energy conversion can be increased by usage of modern techniques which have reduced impact on the atmosphere. Availability of abundance amount of solar energy has dominated other sources of renewable energy.

Solar power can be stored in the form of thermal energy obtained from concentrated solar receivers or plate collectors. The solar receiver allows heat transfer fluid to pass through it, which is then used for steam generation. Mechanical energy from the turbine is converted into electrical energy using this generated steam [5]. The solar based ocean thermal system which is not applicable for interconnected problems of automatic generation control [6]. Controlling of frequency is studied in for a system with hybrid isolation using solar concentrator for the operation of solar thermal plant efficiently [7, 8]. The proposed method has the main aim to automate the sequence of operations in a solar power generation such as starting phase, operating phase and shut down phase with at most safety along with monitoring of parameters. Performance is considered to be stable if heat exchanger's temperature is same as engine's working temperature. The proposed method develops human machine interface for data acquisition and data monitoring such that safe operation is reported. Tracking system for solar radiation is automated for obtaining maximum solar radiation. Promising solution is provided by Stirling engine combined with solar concentrator such as parabolic trough collector.

Related work

Dish Stirling based solar thermal system (DSTS) considers solar isolation at both fixed value and random value in thermal system of multi area. The AGC applied for combined gas system along with thermal system together known as gas thermal system [9]. Squirrel cage induction generator operated by enhanced techniques combining DSTS system along with conventional PTSTP. Frequency regulation is not provided by these generators and operates only at narrow speed even with the presence of speed adjustments for the generator [10-12]. In order to mitigate this, generators with energy storage operating at variable speed is utilized to provide spinning reserve. But in the above research works, solar collector is focused for operation of solar thermal plant which is not considered in combination with conventional thermal system along with DSTS applicable for various control areas together with fixed solar isolation and random solar isolation considered at the same time. Also dish Stirling system at fixed speed for DSTS system and compensation for transient droop represented as realistic DSTD (RDSTS) is not considered for analyzing AGC.

Raise in population leads to increases load demand of PS hence capability of power transfer must be enhanced to meet the increased load demand in PS with inter area. This can be achieved by enhancing AC used presently with parallel added high voltage DC. Combination of AC along with DC possess certain merits [13]. Transfer function for approximate model for DSTS applicable for AGC is presented [14]. Capabilities of power control for DSTS including storage of energy is proposed [15]. Level of inertia reduces in PS due to presence of RES as they have less inertia or zero inertia. The scheme of DSTS with multi terminal where the power is transferred for long distances [16]. The DSTS with virtual inertia considers storage of energy with AGC for two-area using the method of derivative control [17-19]. By considering the previous discussed research work following objectives is included in the proposed method which is mainly concerned with automatic control of solar thermal power plant with optimal parameters:

- Incorporation of RES namely solar concentrator based solar power plant with fixed solar isolation and random solar isolation for realistic DSTS system with compensation of transient droop and fixed speed dish Stirling system in automatic control for thermal systems with three unequal areas which includes generation rate constraints in all areas.
- Parameters of the controller can be optimized by applying crow search algorithm (CRSA) for various controllers correlating the dynamic response such that realistic DSTS and parabolic trough collector based solar power plant together obtains best results for thermal system with three area.
- Evaluation of characteristics of convergence of algorithm such as CRSA.
- The DSTS s are modeled accurately by mathematic formulation using strategy of Inertia Emulation Control Strategy (INEC) for system of three areas.
- Incorporation of model of DSTS along with objective in first optimal parameters evaluating performance of DSTS with and without AC tie line in order to find location that is optimal for DSTS.

Proposed automation system of solar power plant

Dish Stirling solar thermal system

Power generation by solar thermal power plant can be optimized by the installation of Stirling unit involved in solar conversion process which significantly consists of two circuits namely main circuit and secondary circuit. Main circuit of Stirling unit utilizes helium as the working fluid, while secondary circuit utilizes water as the working fluid for cooling purpose, hence secondary circuit of Stirling unit is also represented as cooling circuit. Three areas involved in Stirling unit are working fluid, engine functionality and destination of the unit. Sunflower 35 type solar-collector with its main components is as shown in fig. 1.

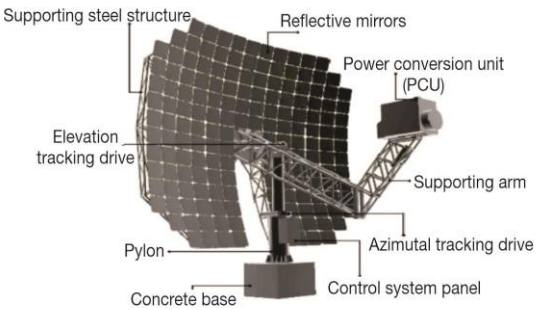

Figure 1. Solar-Collector of 35 Type Sunflower

Dish Stirling's main circuit with helium as working fluid

The main circuit is very complex for a Stirling engine as shown in fig. 2 with the following significant blocks involved in the circuit. Position of temperature sensor is on the hot bulb acting as the main exchanger. There are physically twenty sensors, out of which monitoring of temperature is done by ten sensors namely BT1 to BT10 positioned on the hot bulb situated inside a local connector box via connector. Interconnection is provided from the cabinet of automation to these input and output connectors. Remaining ten sensors are maintained as backup for replacing any failure. Presence of pressure switches, one on BP1 – the oil circuit and other on BP2 – the water circuit along with speed sensor for the generator BR1. Presence of pressure transmitters, one on BP3 – heat exchanger consisting of water and other on BP4 – heat exchanger consisting of oil. The BR1 – rotation sensor for reading the flywheel rotations of Stirling engine along with motors and solenoid actuators.

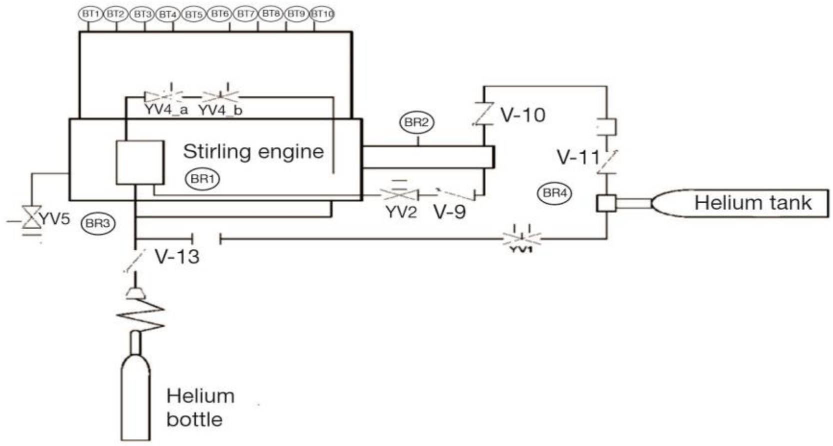

Figure 2. Stirling Engine with its main circuit

Dish Stirling's secondary circuit

Stirling engine consists of secondary circuit which is utilized not only for performing cooling process but also for supplying thermal agent as shown in fig. 3. Main blocks included in the secondary circuit for 25 kW power generation are temperature sensors BT11 and BT12 for monitoring temperature of the cooling water in the circuit, BP2 – pressure switch, pulse compensator, valves, actuators, and motors.

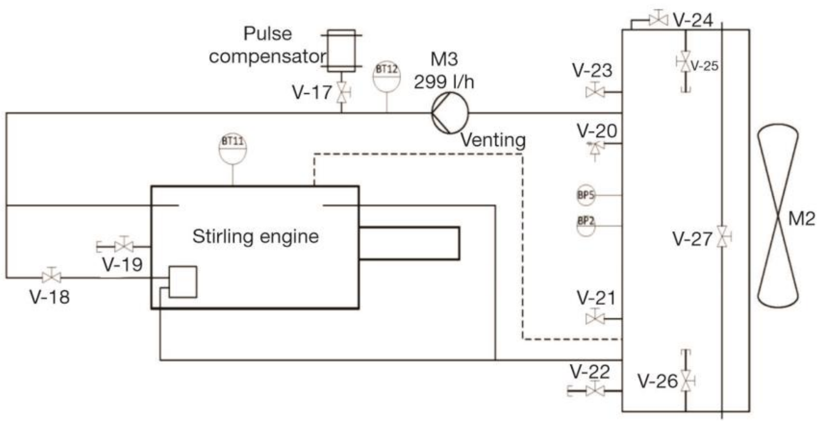

Figure 3. Stirling Engine with secondary circuit

Scheme of automation

In Stirling engine, automation is achieved by controlling of components in its main circuit and secondary circuit. Automation loop is designed for temperature sensors (BT1 to BT2) in module 2 rack. Automation loop for the pressure sensors (BP3 and BP4), rotational sensor (BR1) along with motor crank case housing fixed with temperature sensor (BT11) is designed for module 3 rack. Pressure sensors (BP1 and BP2) along with actuator (M2) are designed in automated loops in module 4 and 5 rack. Solenoid valves (YV1-YV6) are involved in the automation loops of module 6 rack.

Crow search algorithm

Optimal performance is obtained from solar controller by implementation of crow search algorithm. Crow is a clever bird which is habitat of living in flocks which are greedy in nature and has the ability of face recognition, able to communicate with recalling power so that it finds hidden food even after months. It also observes places where other living beings hide their food, steals it in the absence of the owner and again hides it in a new location. This scheme is considered in crow search algorithm. Let the dimensional space be d, with size of flock be n, with the current position of crow at a particular time in the iteration be p, then the vector for search space is represented:

$$\left[X_{p,\,\mathrm{iter}}\right] = \left[X_1^{p,\,\mathrm{iter}},\, X_2^{p,\,\mathrm{iter}},\, X_3^{p,\,\mathrm{iter}}, \ldots\ldots\, X_d^{p,\,\mathrm{iter}}\right] \tag{1}$$

where p ranges from 1 to n and iter value ranges from 1 to maximum iterations.

In the iteration each crow has its memory which remains about the hidden place, also memorizes its best experience in each of the iteration. Crow p has best hiding place for food at iteration p is obtained from $m^{p,\mathrm{iter}}$. For instance, crow p involved in reaching the hiding place of its food and crow q follows it then two possible approaches can be followed. In first approach crow p is not aware that crow q is next to it hence crow q reaches a new position which is the hiding place of crow p. In second approach, crow p is aware that crow q is behind it hence changes its position therefore crow p reaches a random position. In the proposed work, gain of the controller are optimized utilizing CRSA as the best position of the crow indicates the optimized gain which can even compensate the transient droop.

Data acquisition, controlling and monitoring of parameters

Controlling system is of distributed type consisting of programmable logic controller (PLC), its controlling application and SCADA monitoring interface acting as HMI. Inputs to the PLC are given by the transducer signals or sensor signals that are connected to the PLC. Controlling is done by the program stored in its internal memory leading to automation. Open platform communication server transmits the data from PLC to SCADA application through Ethernet. Dish Stirling engine is controlled and monitored through HMI which acts as an interface between human and the system. Data obtained from the system is converted by the graphical interface into representations that are human intuitive. Operator is able to visualize, control the equipments such as on/off or speed control which depends on temperature of cooling water in the engine. Dynamic equipments such as shutter motor of solar radiation, recirculation pump of cooling water are also controlled. Two modes of operation can be realized namely manual mode and automatic mode. Manual mode is operated for testing while automode is for operation of the solar power plant in which the protection program controls the operation such as maintaining optimum pressure, temperature, control over cooling fans, pressure switches for controlling pressure of helium and cooling water. The PLC is programmed for operating in auto-mode such that each process parameter can be visualized based on graphical symbols and can also be controlled. Equipment condition can be studied at any time by the colors of the graphical symbols which represents start or stop, operating normally or any other discrepancy. All the data collected from the equipments are saved in excel sheet which is then analyzed by the process analyst.

Results and discussion

Testing of the automated solar power plant based on dish Stirling engine and parabolic trough collector is done for analyzing the results of proposed work. Firstly the automation system is powered which leads to operation of the turbine valve such that the circuit of dish Stirling engine is charged. Thermal energy supply is started using a propane type thermal burner which needs to set the temperature as 450 to 500 °C. In the Stirling engine, *K*-type thermocouple has to be positioned for the primary exchanger. 26 L tap of the cylinder has to be opened for providing propane supply. Burner is ignited and the air-flow is adjusted that passes through the chamber of mixing. Once the operating temperature exceeds 450 °C, Stirling engine started initially using electric generator in order to start the process of rotation by which Stirling engine proceeds with the operating mode. Monitoring of data is done by the automation system confirming the system stability. Speed of the engine reduces and stops when the temperature reduces to 350 °C. Temperature values obtained by the sensors of the automation system positioned on the Stirling engine's primary exchanger is presented by a graph as shown in fig. 4 which clearly proves that the engine stabilizes fastly while reaching the working temperature which is based on the thermal power obtained from the solar energy, iterated at a rate of 330 ms.

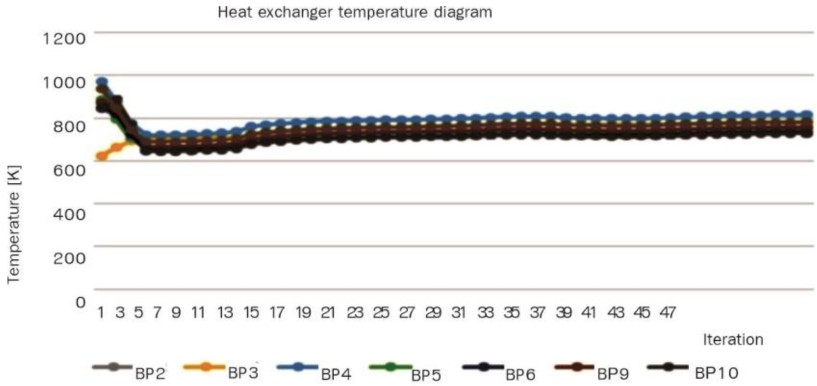

Figure 4. Analysis of temperature of Stirling engine

Engine speed is obtained by plotting graph between number of rotations *vs*. number of iterations represented as generator rotation graph as shown in fig. 5, where rapidly engine attains its synchronized speed which is maintained as constant as 1475 rpm. Monitoring of pressure of the Stirling engine BP3 and pressure in helium cylinder BP4 is represented by the graph as represented by fig. 6. By observing these parameters it is obvious that solar thermal plant operated based on Stirling engine is automated by the proposed system. Based on control of these parameters, positioning of solar concentrator is controlled leading to implementation of automation system. Data acquisition system collects data for controlling the position of solar concentrator towards the sunlight using two motors which controls elevation angle of rotation and azimuth angle of rotation for maximum exposure of radiation.

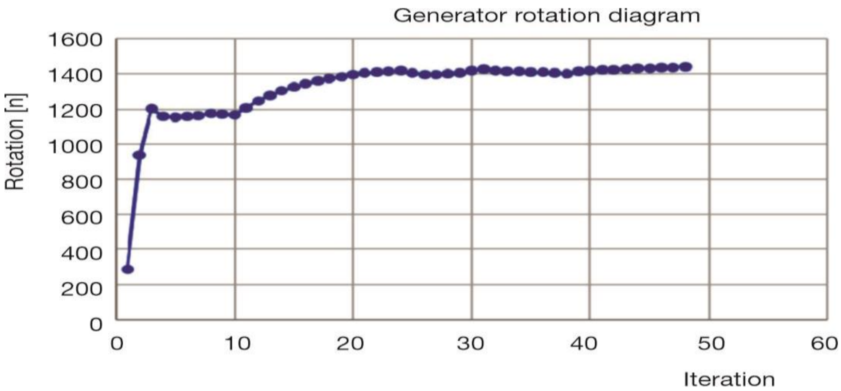

Figure 5. Analysis of speed of Stirling engine

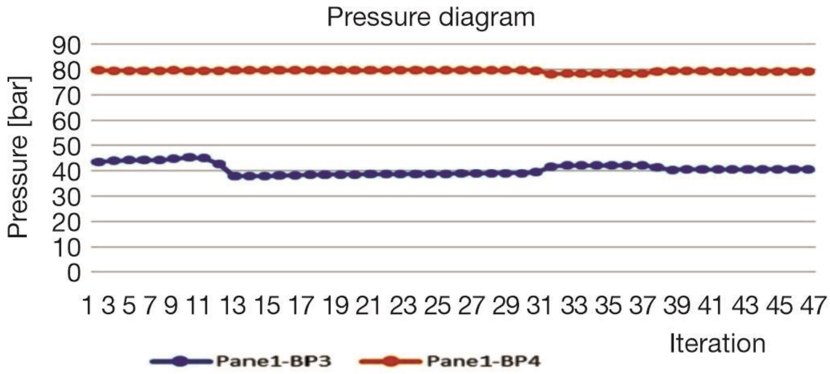

Figure 6. Analysis of pressure of Stirling engine

Conclusion

The proposed system realizes automation of solar thermal power generation plant which involves solar concentrator (parabolic trough collector) for concentrating sun light which is then transformed into electrical energy using the conversion unit which involves dish Stirling engine with heat exchanger. This system aims to process sequence of operations in a solar thermal power plant in a safe mode such that it also monitors various parameters during start up, operation, protection and stopping of the system. Gain of the solar collector is optimized using the crow search algorithm which obtains the best hiding position of food representing the optimal values of the parameters. Analysis of various parameters is done such as temperature, speed of the engine, and pressure of helium cylinder in Stirling engine. Based on these parameters, the solar concentrator is positioned such that it is exposed to maximum solar energy by automatic controlling of elevation rotational angle and azimuth rotational angle. Hence the response obtained from renewable solar energy is better than non-renewable sources. This work can be extended by improving security protocol for this system.

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