***Keywords*: Control Valves • Renewables • Solar**

Control valves for renewable energy

With the increasing demand of energy and the limited supply of carbon-based fuels, the development of renewable energy technologies has become essential. The variability of power generation with renewable sources like wind power or photovoltaic lead to instabilities of the electricity delivery system. Thermal solar power plants with heat storage capabilities are an excellent completion to other renewable technologies. Diversification of energy sources will result in significant energy security, environmental and economic benefits. Control valves have critical role in solar thermal power plants. Depending on the process conditions, modified designs with extended bonnets or bellows seal bonnets, and special sealing systems are required. Molten salt is a common heat transfer fluid for concentrated solar power generation. Specific attention shall be given to the heat tracing to avoid malfunction or damage on the control valve due to crystallization of the molten salt. Optimum thermal design is indispensable to meet the entire process requirement.

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Renewable energy technologies

The increasing demand of energy, the limited fossil fuels resources, and the greenhouse gas emissions from combustion of carbon-based fuel like wood, coal, oil, and natural gas are pushing the development of renewable energy technologies. Hydraulic fracturing which enables the production of fuel such as natural gas and petroleum from subterranean rock formations extra sources are found. But there is a high risk concerning the environmental impact like ground water contamination or migration of gases and fracking chemicals to the surface. The renewable energy technologies diverse the electricity generations and create flexibility in the electrical system, which result in significant energy security, environmental and economic benefits.

The main commercially used alternative energy technologies are biofuels, hydropower, wind turbines, geothermal energy, photovoltaic, and thermal solar power plants.

Electricity generated by hydropower, where the gravitational force of the flowing water is used, is a competitive source of renewable energy. It is very flexible since the amount of energy can be changed up or down very quickly to energy demands. When there is low electrical demand, excess generation capacity is used to pump water into a higher reservoir and when there is a higher demand, water is released back into the lower reservoir through a turbine. Hydroelectricity with pumped-storage is an effective and flexible way to produce electricity, but the resources are limited.

Wind power to produce energy is another effective and economic source for electrical energy, but a limiting factor is variable power generated by wind farms. In most locations the wind blows only part of time. Offshore wind parks have advantages concerning the efficiency upon the land based wind parks because water has less surface roughness than land so the average wind speed is usually considerable higher over open water. With offshore wind parks we have to take into consideration the costs and energy losses of the transmission lines to transport energy.

Renewable energy resources are significant opportunities for energy efficiency and they exist over wide geographical areas, but excessive use of one of these alternative technologies will have also a negative impact on the environment. Diversification and local generation will reduce the negative impact on the environment and help to establish a robust and resilient electricity delivery system.

Concentrated solar power generation

The two main approaches to generate power from the sun are photovoltaic technology which converts the sun radiation directly into electricity thus only effective during daylight; and solar thermal technology which could store heat during the day and convert into electricity during the night. Heat storage capability is what differentiates a solar thermal power plant from other renewable power plants. Unlike other renewables, it is a predictable and dispatchable. It is also competitively priced and taken from reliable source with high share of local content.

Concentrated solar power technology currently leads the way as the most cost-effective solar power technology on industrial scale. It uses reflectors, tracks the sun motion, and concentrate the solar radiation onto a receiver to create heat then into electricity by the turbine generator unit.

There are two methods for solar thermal collection which are the line-focus and the point-focus. The point-focus outperforms the line-focus especially when results are concerned. The maximum theoretical concentration of a line-focus is about 212:1, while point-focus is about 45000:1. The current line-focus techniques could reach 100x concentration and run a steam turbine to 25% efficiency. While current point-focus techniques could reach 1000x concentration and run a steam turbine to 35-50% efficiency.

The line-focus method is applied at solar plants using parabolic trough technology and those using linear Fresnel technology.

Figure 1: Solar thermal power plant, Plataforma Solar de Almeria (PSA).

The parabolic trough technology employs parabolic trough shaped mirrors which focus the sun rays using single axis tracking onto thermally efficient receiver tubes with fluid running down the focus line. The linear Fresnel technology uses array mirror approximates a very large parabolic surface, aligns the sun motion using single axis tracker, and reflects onto a central line absorber. The heat transfer fluid inside is heated then pumped through heat exchangers to produce superheated steam which later powers a turbine generator unit to produce electricity. The point-focus method is applied at solar plants that use central receiver technology also those that use parabolic dish technology. The central receiver technology uses a circular field array of heliostats with dual axis tracking mirrors to focus sunlight onto a central receiver mounted on top of a tower (Figure 1). These heliostats must be cleaned periodically to keep high efficiency of the entire system, as shown in Figure 2. The concentrated sun rays heats the flowing salt in the receiver tower then stored in a hot storage tank. The hot salt is pumped through a steam generator to produce electricity, and the cold salt return to cold storage tank to be reheated later in the receiver tower. The parabolic dish technology uses an array of parabolic dish-shaped mirrors using dual axis tracker to focus solar energy onto a receiver located at the focal point of the dish. The fluid in the receiver is heated and used to generate electricity in a small engine attached to the receiver.

Control valves for molten salt application

Due to reliability and harsh operating conditions, control valves have a critical role in solar thermal power plants. Applications with synthetic oil used as heat transfer fluid use control valves with a bellows seal bonnet and safety stuffing box because the fluid is extremely amenable to leaking. Control valves to be used for molten salt service (Figure 3) are specially designed because the media is corrosive and under certain condition abrasive. Salts could precipitate out during the process and will be

Figure 3: Flowserve control valves in molten salts service in a solar power plant at Andasol.

present in crystalline form. Molten salt is a strong oxidizing fluid therefore materials like carbon or graphite are of limited suitability. Gaskets and packing materials, where graphite is used at high temperatures have to be protected from direct contact with molten salt. Depending on the operating temperature suitable materials to be used for the body are steel grades for use at elevated temperatures like Cr-Mo steel or austenitic steel grades. Stabilized austenitic stainless steel usually is used as trim material.
The control valve types are usually pneumatic operated, globe control valves, butt welded with extended bonnet or bellows seal bonnet in shroudless design. Extended bonnets are needed in order

Figure 2: Cleaning of the heliostats at Gemasolar.

to keep the packing temperature within admissible values and to allow insulation of the valve body. To reduce dead room, a double stem guided design is preferred. Special tailored control valves will allow draining the pipe system. These are modified angle type valve flow over with contour in the seat. The contoured seat is optimized for flow to close and guarantee good control behaviour also at extreme low load. The seat leakage will remain low over a long period of operation because the sealing area is separated from the vena contracta and not exposed to a high flow velocity. A multi-step trim will avoid critical operating conditions at high differential pressure. Specific attention shall be given to the heat tracing to avoid malfunction or damage on the control valve due to crystallization of the molten salt.

Thermal simulations of the molten salt control valves

One of the main objectives for solar thermal power application using molten salt is to maintain the inner wall temperature considerably well above its melting point. A temperature of 271°C at the interface walls is usually set as the lower limit, which is 50°C above the melting point of molten salt with 60% Sodium Nitrate and 40% Potassium Nitrate. Heat tracers are installed around the valve wall to maintain at least such high temperature at the required locations.

To ensure optimum thermal design, Flowserve conducted a number of tests and simulations for various sizes, types, and configurations of the control valves. One example concerns with simulation of non-insulated and insulated configurations of 6" Mark One Control Valve with an extended bonnet and assumed molten salt temperature of 600°C. Figure 4 clearly shows that without insulation, the heat loss is considerably high and becomes comparably less and less as the insulation covers more critical areas.

Evaluation of the heat tracer power configurations before flowing with the molten salt is showed as the second example. In this simulation, the heating process is assumed from a room temperature of 20°C, and the gasket is limited to a temperature of 550°C. Therefore the bonnet heat tracer must be switched off when this temperature is reached, with the body heat tracer in this example remained to be switched on. Various power configurations of both heat tracer elements were simulated with temperatures monitored at various locations. **Figure 5** shows example of temperature contours of a 2" FlowTop Control Valve with a bellows seal bonnet using heat tracer of 600 W around the bonnet outer wall and 1000 W around the valve body outer wall. It shows the heating process after 30, 60 and 95 minutes as steady state is reached.

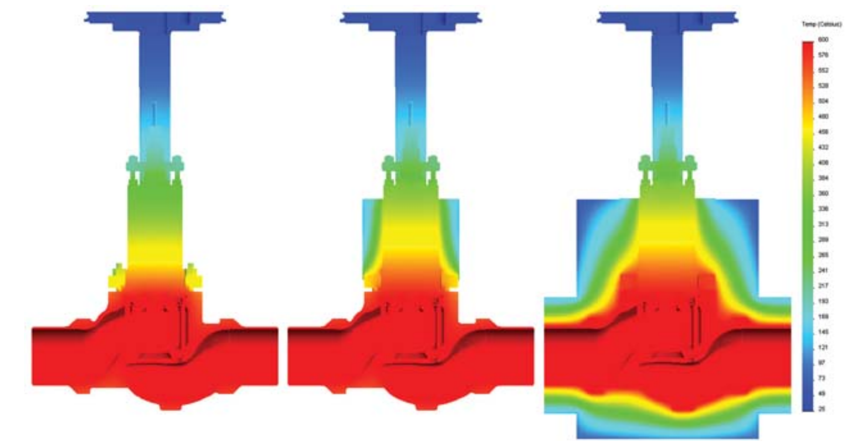

Figure 4: Temperature contours of non-insulated and insulated configuration of a 6" Mark One Control Valve with an extended bonnet.

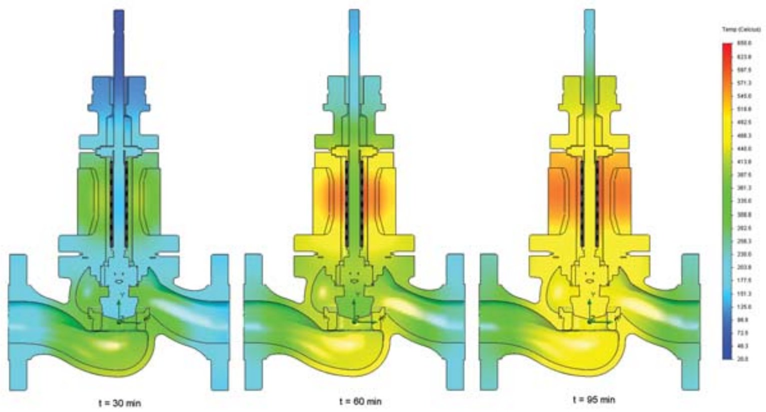

Figure 5: Temperature contours of a 2" FlowTop Control Valve with a bellows seal bonnet during heating process from a cold start with heat tracers of 600 W around the bonnet outer wall and 1000 W around the valve body outer wall.

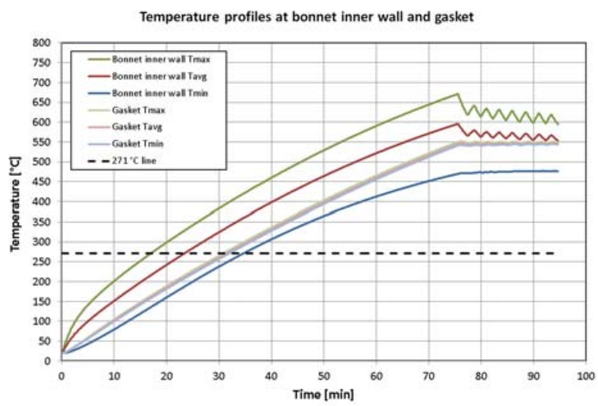

Figure 6: Temperature profiles of a 2" FlowTop Control Valve with a bellows seal bonnet at the bonnet inner wall and gasket during heating process from a cold start with heat tracers of 600 W around the bonnet outer wall and 1000 W around the valve body outer wall.

Figure 6 shows example of the temperature profiles at the bonnet inner wall and the gasket, which pass the 271°C line criteria at least after 35 minutes heating from a room temperature.

Different sizes and types of valves certainly require different heat power configurations. Therefore each molten salt valve shall be optimized to ensure proper heat transfer is given and maintained.

References of Flowserve Control Valves GmbH

Flowserve Villach Operation is developing and manufacturing top quality control valves (1/2" - 48", Class 150 - 2500 / DN 15 - 400, PN 10 - 400) for gases, vapors, steam and liquids. Since 2008 Flowserve Villach Operation delivers control valves for solar thermal power plants in Spain, Portugal, Italy, South Africa, and in the USA. For the control loop of the heat transfer and storage of molten salt, special valves to meet the high requirements on sealing components, operation and reliability have been developed. The excellent performances of Flowserve control valves guarantee an optimal process control. Reference List of Solar-Thermal Power Plants, Flowserve Control Valves (extraction):

Project		Country	Main User	Contractor
ANDASOL 1+2	50 MW x 2	Spain	ACS	SENER / COBRA
EXTRESOL 1+2+3	50 MW x 3	Spain	ACS	SENER / COBRA
MANCHASOL 1+2	50 MW x 2	Spain	ACS	COBRA / INITEC ENERGIA
SAMCASOL 1+2	50 MW x 2	Spain	SAMCA RENOVABLES	TKS / MAESSA
GEMASOLAR	17 MW	Spain	TORRESOL ENERGY	SENER / COBRA
PST La Risca	50 MW	Spain	ACCIONA	SERIDOM / IDOM
MAJADAS	50 MW	Spain	ACCIONA	SERIDOM / IDOM
NEVADA ONE	64 MW	USA	ACCIONA	
VALLE 1+2	50 MW x 2	Spain	ARCOSOL / TERMOSOL	SENER / COBRA
MORON	50 MW	Spain	IBEREOLICA SOLAR MORON S.L.	SERIDOM/ACCIONA
TERMOSOL 1+2	50 MW x 2	Spain	NEXTERA Florida Power & Light	SENER
ORELLANA	50 MW	Spain	ACCIONA	GHESA Ingenieria y
MONOTANQUE		Spain	SENER	SENER
ABENGOA		Spain	UTE ABENER TEYMA CRS II	UTE ABENER
EVORA	50 MW	Portugal	SIEMENS	BERTRAMS Heatec AG
ARCHIMEDE	5 MW	Italy	ENEL Power	
CASABLANCA	50 MW	Spain	Casablanca SL	UTE C.T. Casablanca
CRESCENT DUNES	110 MW	Spain	COBRA Themosolar Plants	COBRA
KAXU SOLAR ONE	100 MW	South Africa	Kaxu Solar One	UTE Abener Teyma Paulputs

About the authors

Arnold Muschet is Technical Director at Flowserve Control Valves GmbH for Villach Operation responsible for the development and design of control valves and pneumatic actuators. He has more than 20 years of experience in the control valve industry. He obtained his Dipl.-Ing. in Mechanical Engineering from the Technical University of Graz, Austria. He has cooperated in different standardization committees such as the Austrian ÖNORM, the German VDI and the European Committee for Standardisation (CEN).

Aryoso Nirmolo is R&D Supervisor at Flowserve Control Valves GmbH and has been working there for the last 6 years. He received his bachelor degree in Chemical Engineering from the Gadjah Mada University, Indonesia; and his master also doctorate degree in Fluid Dynamics and Thermodynamics from the University of Magdeburg, Germany. He has more than 15 years of experiences in process and thermal simulations, which include computational fluid dynamics simulations and finite element analysis.