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Feasibility of the concept of hybridization of existing co-generative plant with reverse osmosis and aquifer storage

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Abstract

This study considers the feasibility of hybridization of existing co-generation plant with reverse osmosis and aquifer storage. This hybrid system is characterized by the following technological, economic and strategic advantages: (1) increased range of variation of power to water ratio; (2) possibility to use seasonal surplus of unutilized power for production of additional quantity of water; (3) decreased specific CO_2 emissions; (4) improved economic indicators of co-generative technology; (5) creation of strategic water reserve, etc.

The proposed study focuses on comparison of conventional co-generative system representing the reference case with the hybrid innovative scheme. The conventional system consists of: (1) power-generating plant, (2) MSF-desalination system. The hybrid system includes (1) power-generating plant, (2) MSF-desalination, (3) RO desalination and (4) aquifer storage and recovery (ASR) technology. Unlike the reference case being based on the conventional systems, the hybrid scheme implies the concept where the seasonal surplus of available unutilized power-generating capacity is consumed by RO and seasonal excess of water accumulated within underground aquifer.

Proposed study is based on the following assumptions: (1) available power generating capacity ranges from 80% to 100% of the maximum output being equal to 180 MW; (2) total available capacity of existing thermal desalination plant is 38 MGD; (3) seasonal variation of both water and power demand (within the range 100–60%) is considered in the model; and (4) specific energy consumption of projected RO is 6 kW h/m^3.

For the scenario based on co-generation system (180 MW to 38 MGD) operating at 80–100% of the maximum generating capacity, the following data obtained: (A) unutilized capacity of power plant is sufficient for production of 40–80 MGD by RO; (B) unconsumed water supposes to be accumulated within underground aquifer. Calculated rate of seasonal variation of aquifer recharge ranges between 50 and 80 MGD.

Keywords: ASR; RO; Hybrid-desalination; Water resources management

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1. Introduction and formulation of the problem

Analysis of published statistics on water demand for Abu Dhabi emirate [1] reveals high rate of growth of seasonal variation of water demand over the last years and increase of cumulative gross annual water demand over the same period. According to this data seasonal difference between the highest and lowest water demand increases from 1452 MG/month (in 1998) to 2629 MG/month in 2003, this represents to 80% growth. Cumulative annual water demand over the same period ranges from 63,064 MG/year (in 1998) to 113,484 MG/year in 2003. Relying upon the statistics by ADWEC [1] the prevalent trends in development of demand pattern for Abu Dhabi region can be summarized as follows: (1) growth of range of seasonal variation of demand; (2) disproportional degree of growth of water and electricity demand and (3) increase of cumulative annual gross power and water demand.

Existing trend in variation of power to water demand cannot be provided by conventional co-generative systems currently used in Abu Dhabi emirate. These technologies are characterized by inflexible limits of variations of the power to water ratio. (The criteria referred to as the power to water ratio, is an essential indicator specifying the performance of dual purpose co-generative plant. This criterion is equal to ratio of produced power to water output.) Systems of this type are preferred for countries where demand pattern is characterized by high value of the power to water ratio. (Unlike the majority of countries, Abu Dhabi with high level of water demand is characterized by low value of this criterion.)

The growth of demand and seasonal fluctuation of demand pattern require reorganization of management, in particular it dictates implementation of the concept of integrated water-resource management through integration and hybridization of different technologies [2,3]. (It would make the system more flexible that in turn, allows optimization of water resource utilization.) Unfavorable disproportions between water and power demand can be reduced by implementation of additional desalination capacities and creation of water reserve. Within the context of the problem it is the hybridization of RO and the ASR technology with existing co-generative systems can be considered as a promising technological solution. The concept of ASR technology has been extensively scrutinized by many authors. Al-Katheeri [4,5] proposes restructuring the management through development of innovative co-generative systems including the ASR. According to the study done by Al-Katheeri [4,5], the hybridization of existing co-generative plants with the ASR technology is characterized by technological and economic advantages and expected to become a promising technological option. The ASR technology is an example of multipurpose technology; it can be used for (A) seasonal and water reuse water storage; (B) system for creation of strategic water reserve and it can be (C) integrated or hybridized with existing co-generative (or desalination) system.

Different functional, technical and economic aspects of the ASR technology are considered in [2–6]. Semi-analytical model for predicting the quality of water recovered by an ASR system is proposed by Ali Sedighi and Harald Klammler [7]. Some domains of potential applications of the ASR technology are outlined below:

(A) ASR as a technique for seasonal conservation and water reuse: The ASR is a well-known technology for accumulating large volumes of water where natural underground aquifer is used as storage. Along with seasonal storage the ASR technology can be applied as storage for reuse of reclaimed wastewater as well. Different aspects of the ASR technology were considered by Pyne [6]. The ASR-based technologies have been implemented in Australia, England, Canada, South Africa and India. The ASR technology has become attractive water conservative technology in Australia since 1980. The cases where the ASR technology was used as storage in water reuse were considered by Dillon [8]. In order to preserve native groundwater and restoration of groundwater, the ASR technology can be applied for reuse of reclaimed wastewater by artificial recharge of reclaimed wastewater into aquifer.

(B) ASR as a strategic water storage facility (for creation of strategic water reserve): According to published data [9] along with being a tool to reduce overall cost of water production the ASR can be considered as a strategic water storage facility. According to data [9], many Gulf Community Countries (GCC) have insufficient strategic water reserve facility. According to [9], average strategic reserve would be sufficient only for 2 days; in this regard the ASR technology can be considered as storage for strategic purpose. The total capacity of water reservoirs of Abu Dhabi Water and Electricity Authority (ADWEA) are equal to 400 MIG that can satisfy only two days of water demand [4].

(C) Hybridization of ASR with existing co-generative plant: Seasonal and long-term variation of pattern of power and water demand cannot be provided by conventional co-generative systems with inflexible limits of variations of the power to water ratio. Published statistics [1] reveals the growth of cumulative gross annual demand and increase of amplitude of seasonal difference between the highest and lowest water demand. In this regard hybridization of the ASR technology with existing cogeneration plants makes the system more flexible in order to meet seasonal demand that allows optimization of water and power resource utilization [10]. The ASR allows a treated water to be injected underground during the period with low water demand and recovered to the water distribution system during the periods with elevated water demand. Thus the scheme integrated with the ASR can provide season-dependent water demand. Relying upon the published data one of the prevalent tendencies consist in development and reorganization of existing co-generative systems aimed at extension of limits of variation of the power to water ratio. In this regard Integration and hybridization of thermal desalination with electrically driven processes such as RO allows utilizing idle power that makes broader the range of variation of the power to water ratio. Techno-economic analysis of hybrid systems is given in [11,12], those are essential for countries like the UAE.

Some published studies by Write, Maliva, Missimer, Almulla, Awerbuch [9,10,13–15] emphasize the fact that hybridization of the ASR with desalination system reduce overall cost of water production and the hybrid system can be considered as a cost-effective technological option. According to [9] the ASR is a tool to reduce overall cost of water production. Data on capital costs of the ASR system [13] ranges from 30 to 70 $\$/m^3$/day.

Within the context of the problem this study focuses on feasibility of hybridization of existing co-generative plant with reverse osmosis and aquifer storage where the RO suppose to utilize seasonally unused electricity and the ASR accumulates excess of desalted water. The proposed study focuses on comparison of the conventional co-generative scheme representing the reference case with the hybrid innovative scheme. The hybrid scheme includes (1) power-generating plant, (2) MSF-desalination, (3) RO desalination and (4) aquifer storage and recovery (ASR) technology. Unlike the reference case being based on the conventional systems, the hybrid scheme implies the concept where the seasonal surplus of available unutilized power-generating capacity is consumed by RO and seasonal excess of water accumulated within underground aquifer.

2. Hybridization of existing co-generative plant with reverse osmosis and aquifer storage (comparison of schemes and calculated projections)

Hybrid or integrated co-generative systems it is an example of new generation of co-generative technology. It is getting an attractive alternative to conventional technologies. Hybridization of thermally and electrically driven processes can provide essential economic, environmental and operational advantages over conventional, dual and mono-purpose stand alone plants. According to published data [13–15], the hybridization of thermally and electrically driven processes, can provide the following advantages: (1) ability to diversify range of the power- to water ratio, it is essential for regions where demand pattern is characterized by low level of its value, (e.g. Abu-Dhabi); (2) possibility to use seasonal surplus of idle power and unused water; (3) decrease of specific fuel consumption while RO is less energy consuming than thermal desalination; (4) decrease of specific CO_2 emissions.

Analysis of the triple hybrid including gas turbine (GT), heat recovery steam generator (HRSG), auxiliary boiler (AB), MSF and RO desalination was presented in [11–12]. The analysis was based on systemic approach where the system was presented as a set of models and submodels of different hierarchy levels. The following groups of models underlying the system were proposed: (A) models describing power-generating technology; (B) model describing RO-desalination, and (C) models describing MSF desalination. Any group of individual models, in turn, consist of a set of submodels

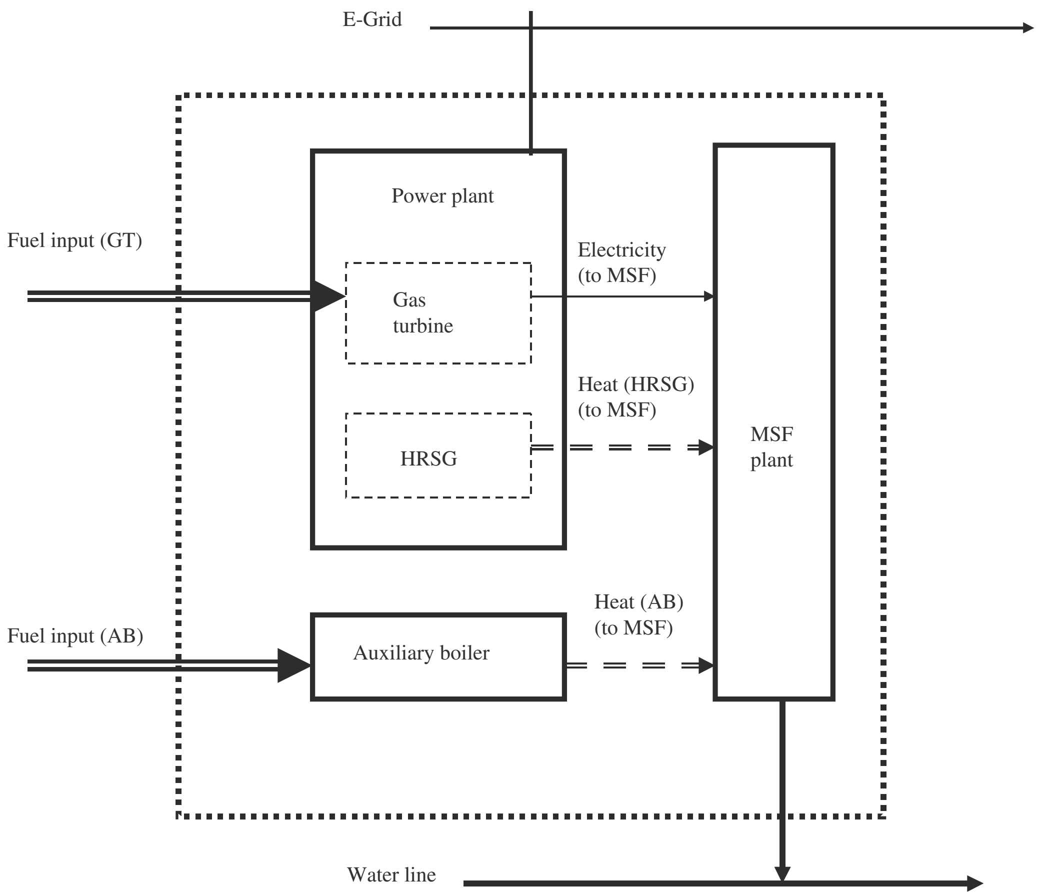

Fig. 1. Simplified flow-diagram of conventional cogeneration plant (the reference scheme).

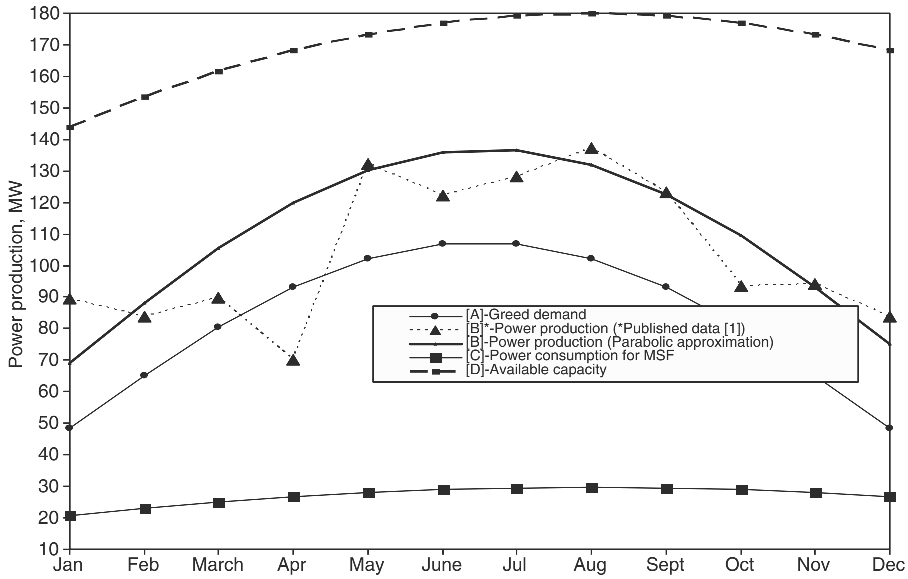

Fig. 2. Calculated projections of seasonal variation of power demand (reference case).

of different hierarchy level, they are (1) technological submodel, (2) fuel or energy submodel, (3) ecological submodel and (4) economic submodel.

The proposed study is an attempt of comparison of the conventional co-generative scheme representing the reference case with the hybrid innovative scheme.

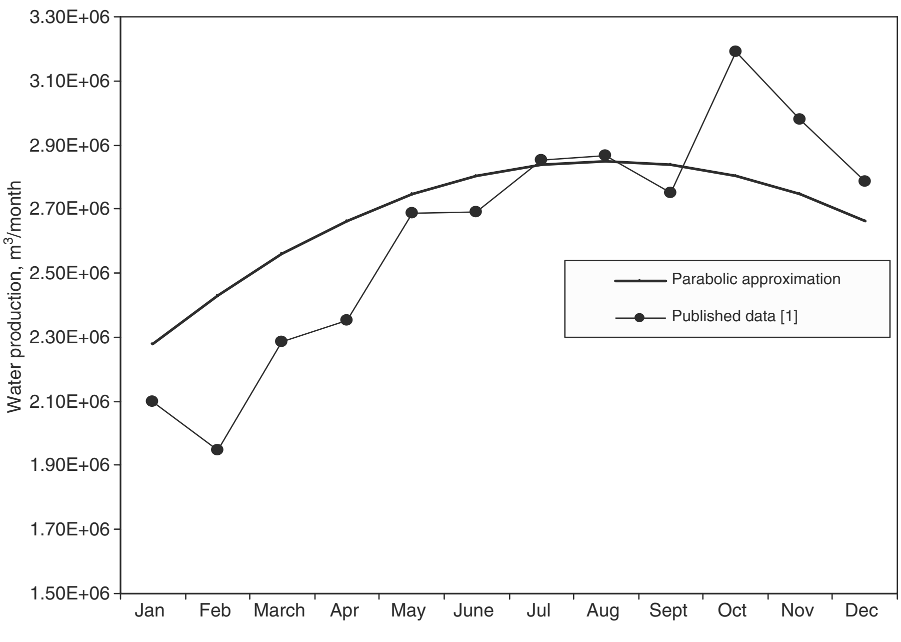

Fig. 3. Calculated projections of seasonal variation of water demand (reference case).

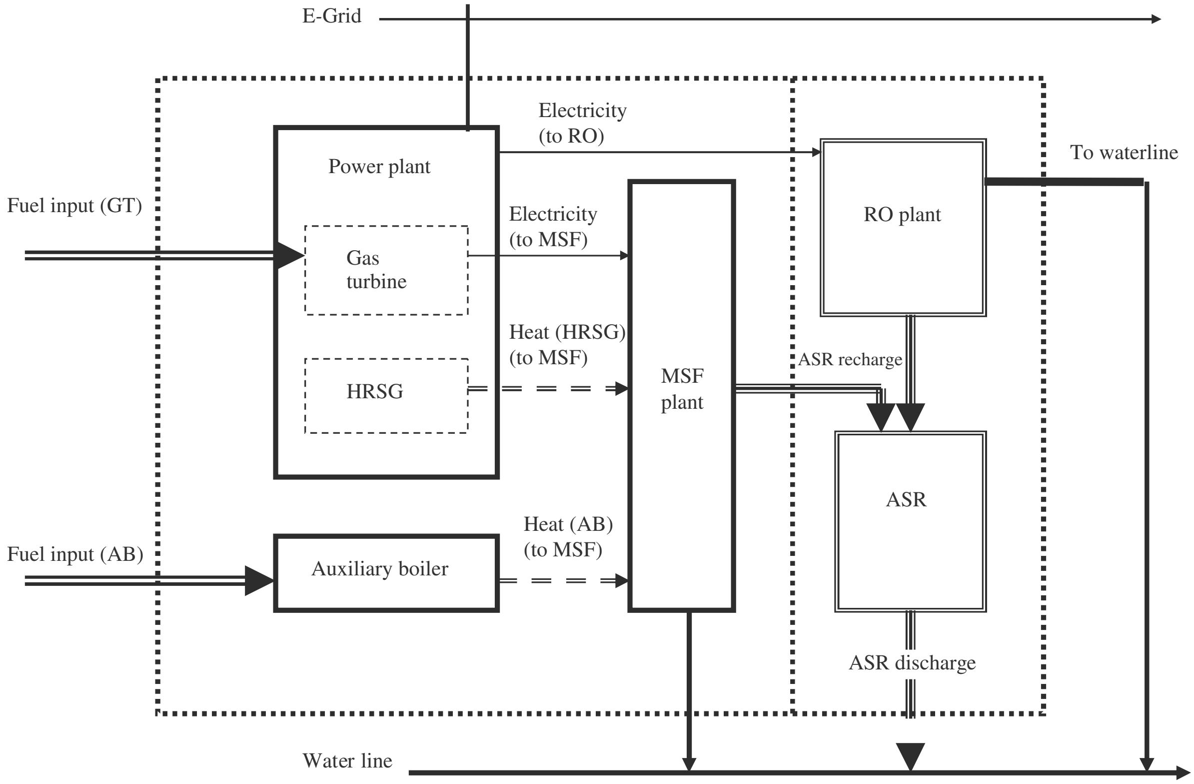

Fig. 4. Simplified flow-diagram of the hybrid scheme.

2.1. Reference case

Reference case represents conventional co-generation plant attached to grid (see Fig. 1). It includes power plant and system for thermal desalination. Power plant, in turn, includes gas turbine (GT), heat recovery steam generator (HRSG) and auxiliary boiler (AB). This scheme (reference case) represents one of the technological options widely used. Simplified flow-diagram of the scheme is shown in Fig. 1.

Reference case considered in this paper is based on the following assumptions: (1) maximum capacity of the power plant is 180 MW; (2) available power gen. capacity ranges from 80% to 100% of the maximum capacity; (3) seasonal production of the power plant ranges from 40% to 75% (that corresponds to the range 70–135 MW) of the maximum capacity; (4) maximum production capacity of existing MSF desalination plant is equal to 38 MGD; (5) available MSF desalination capacity is assumed to be 100% of its maximum capacity; (6) seasonal production of water by MSF ranges from 400 to 560 MG per month.

Calculated profiles of seasonal variation of power production, external grid demand, internal consumption for thermal desalination and available power gen. capacity are shown in Fig. 2. Current production of power plant is adjusted to current demand and it is equal to sum of external grid demand and internal demand required for thermal desalination. Current production of the power plant is less than the available capacity.

The required water production is assumed to be equal to water demand as well. There is no enormous seasonal variation of water demand in this region. Seasonal profile of total water production (being equal to demand) is shown in Fig. 3. For the mathematical treatment to be simplified, the available published statistics [1] were approximated by parabolic function.

2.2. Hybrid schemes

Along with technologies incorporated into the reference scheme the hybrid scheme includes electrically-driven (RO) desalination and aquifer storage and recovery (ASR) technology (within the hybrid scheme the RO suppose to utilize seasonally unused electricity while the ASR accumulates excess of desalted water). Conceptual flow-diagram of the hybrid scheme is shown in Fig. 4.

Modeling of the hybrid scenario is based on the following assumptions: (1) maximum capacity of the power plant is 180 MW; (2) available power gen. capacity ranges from 80% to 100% of the maximum output; (3) current load of the power plant within the hybrid scheme is assumed to be equal to available power generating capacity (80–100% of the maximum output); (4) total production capacity of existing thermal desalination plant is equal to 38 MGD; (5) seasonal variation of both water and power demand is considered in the model; (6) specific energy consumption of projected RO is 6 kW h/m^3.

Seasonal variation of production of power plant (being equal available power gen. capacity), external grid demand, internal consumption for thermal desalination and unused power capacity (or surplus) is shown in Fig. 5.

Current production of power plant being demand-independent is equal to the available capacity. This regime of operation being close to maximum generating capacity is characterized by elevated efficiency of fuel utilization, decreased specific CO_2 emissions and improved economic indicators. Within this regime the system produces extra power that can be stored or used for water desalination. Seasonal variation of (1) power production, (2) grid demand, (3) consumption for

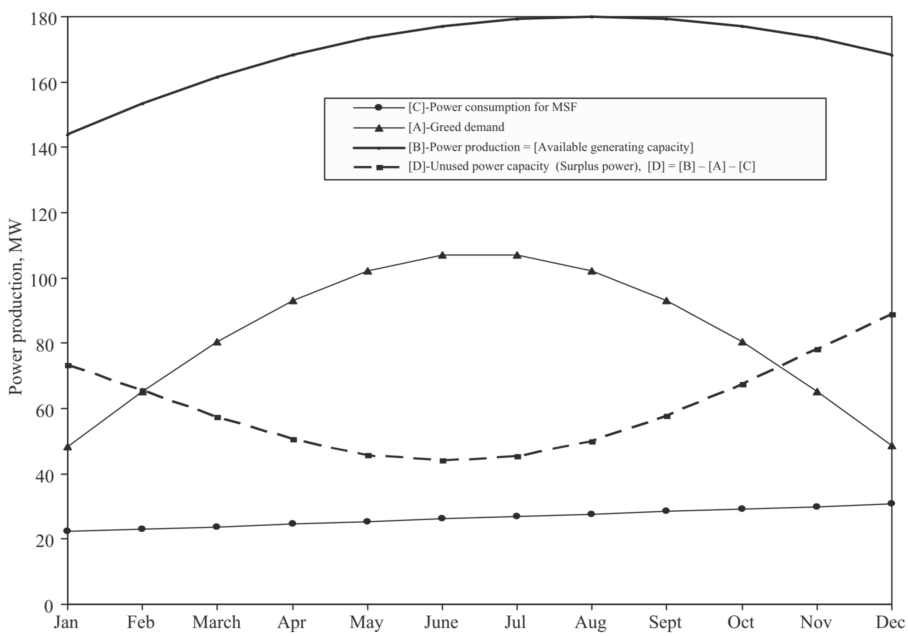

Fig. 5. Calculated projections of seasonal variation of power demand (hybrid scheme).

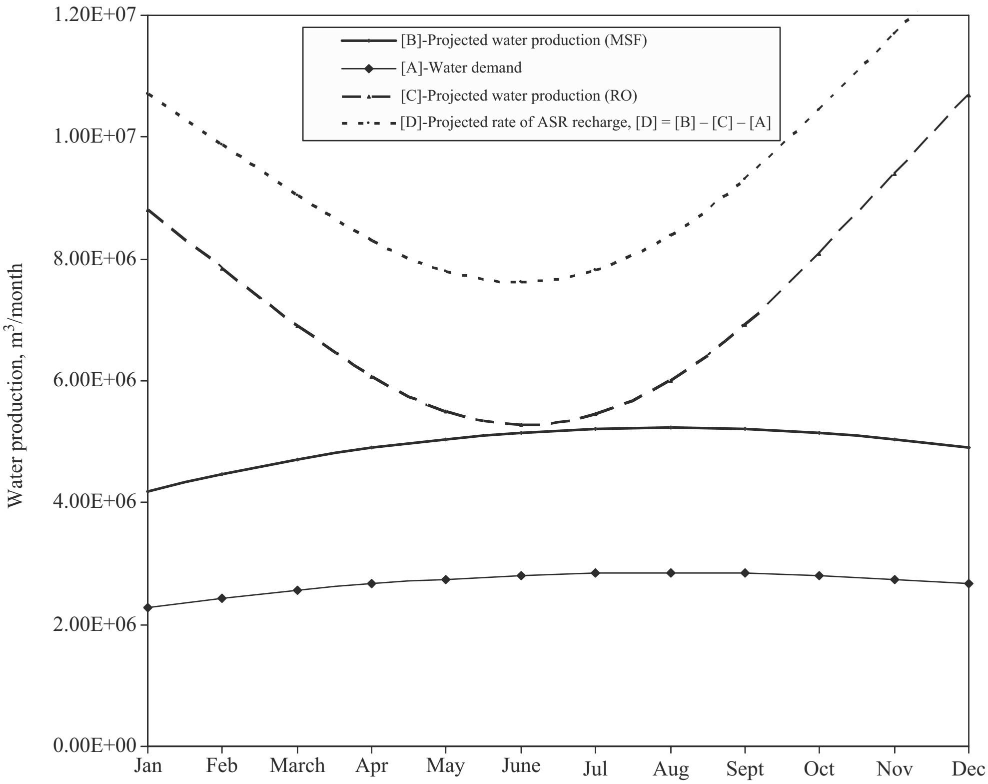

Fig. 6. Calculated projections of seasonal variation of water demand (hybrid scheme).

thermal desalination and (4) surplus of produced power is shown in Fig. 5.

For the scenario based on co-generative system (180 MW–38 MGD) operating at 80–100% of the maximum generating capacity, the unutilized capacity of power production ranges from 75 to 40 MW.

Seasonal variation of water production by MSF and RO, water demand and rate of ASR recharge is shown in Fig. 6. Water production in this scenario is assumed to be demand-independent and based on available power generated by the power plant. The surplus of produced power can be used for RO-desalination. It is sufficient for production of 40–80 MGD by RO. Unconsumed water can be accumulated within the underground aquifer. Calculated rate of seasonal variation of aquifer recharge ranges between 50 and 80 MGD.

3. Conclusions

Based upon the current study and published data it was concluded that the combination of existing co-generative systems with RO and ASR represents a new generation of co-generative technology. Within this hybrid system the RO suppose to utilize seasonally unused electricity while the ASR accumulates excess of desalted water. This system is characterized by the following technological, economic and strategic advantages: (1) increased range of variation of power to water ratio; (2) possibility to use seasonal surplus of unutilized power for production of additional quantity of water; (3) decreased specific CO_2 emissions; (4) improved economic indicators of co-generative technology; (5) creation of strategic water reserve for the region, etc.

For the scenario based on co-generative system (180 MW–38 MGD) operating at 80–100% of the maximum generating capacity, the following data obtained: (A) unutilized capacity of power plant is sufficient for production of 40–80 MGD by RO; (B) unconsumed water supposes to be accumulated within the underground aquifer. Calculated rate of seasonal variation of aquifer recharge ranges between 50 and 80 MGD.

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