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An Intelligent Multi-multivariable Dynamic Matrix Control Scheme for a 160 MW Drum-type Boiler-Turbine System

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Abstract – A 160 MW drum-type boiler-turbine system is developed in the present research through a multi-multivariable dynamic matrix control (DMC) scheme and a multi-multivariable model approach. A novel intelligence-based decision mechanism (IBDM) is realized to support both model approach and control scheme. In such case, the responsibility of the proposed IBDM is to identify the best multivariable model of the system and the corresponding multivariable DMC scheme to cope with the system at each instant of time in an appropriate manner.

Keywords: Drum-type boiler-turbine system, Multi-multivariable DMC scheme, Multi-multivariable model approach, Intelligence-based decision mechanism

1. Introduction

To date, the control of a nonlinear drum-type boiler-turbine system has been investigated by several researchers, such as Chen et al., Moon et al., Peng et al., Dieck-Assad et al., and others, suggesting a number of appropriate solutions in the area of the present system control [1-4]. The dynamic matrix control (DMC) scheme, as an efficient algorithm in the field of process control, is realized based on the multiple model approach. In such case, the present system should first be represented at some chosen operating points, as a number of multivariable DMC schemes are correspondingly realized to handle all the chosen operating points. Hereinafter, a new intelligence-based decision mechanism (IBDM) is investigated to identify the best multivariable linear model of the system at each instant of time and subsequently to handle the corresponding multivariable DMC scheme appropriately.

The remainder of the present paper is organized as follows. The proposed control strategy is given in Section 2. The simulation results and concluding remarks are presented in Sections 3 and 4, respectively.

2. The Proposed Control Strategy

The proposed control strategy, as shown in Fig. 1, is organized in accordance with a multi-multivariable DMC scheme, a multi-multivariable model approach, and a novel IBDM to deal with a three-input, three-output drum-type boiler-turbine system, the mathematical relations of which are completely given in [5].

Regarding the proposed IBDM, the best multivariable linear model of the system and the corresponding multivariable DMC scheme are identified through this intelligence-based decision maker at each instant of time, as outlined by the following [6-16].

- Define the following performance indices:

$$
\begin{aligned}
{}^{r}J_k^i &= \alpha\, {}^{r}e_k^{i\,2} + \beta \int_0^t e^{-\nu(t-\tau)}\; {}^{r}e_\tau^{i\,2}\, d\tau \\
e_k^i &= {}^{s}y_k^i - {}^{r}y_k^i
\end{aligned}
\tag{1}
$$

where $k = 1, 2, ..., \infty$ is the discrete time index, $r = 1, 2, ..., \lambda$ is the operating point number, ${}^{s}y_k^i$ is the i^{th} system output at k^{th} instant of time, and ${}^{r}y_k^i$ is the i^{th} multivariable linear model output at r^{th} operating point of the system. Here, $\alpha \ge 0$, $\beta > 0$, and $\nu > 0$ are the weighting factors, long-term accuracy, and forgetting factor, respectively.

- Define the following Gaussian probability density function:

$$
{}^{r}p_k^i = \frac{\exp\left(-\frac{1}{2}\sum_{m=1}^{k}\sum_{n=1}^{k} {}^{r}\alpha_{k\times k}^{m,n}\,({}^{r}J_m^i - \overline{{}^{r}J_m^i})({}^{r}J_n^i - \overline{{}^{r}J_n^i})\right)}{\sqrt{(2\Pi)^k \det({}^{r}C^i)}}
\tag{2}
$$

where $\overline{{}^{r}J_m^i} = E({}^{r}J_m^i)$ and $\overline{{}^{r}J_n^i} = E({}^{r}J_n^i)$ are the expectation values of the present performance indices, and ${}^{r}\alpha_{k\times k}^{m,n}$ is taken as $inv({}^{r}C^i)$ once ${}^{r}C_{k\times k}^i$ denotes the steady-state covariance matrices of ${}^{r}J_k^i$.

- Calculate the Gaussian probability distribution function as ${}^{r}P_k^i = \int_0^{{}^{r}J^{i*}} {}^{r}p_k^i\, d({}^{r}J_k^i)$, where ${}^{r}J^{i*}$ denotes the minimum of the performance indices values.

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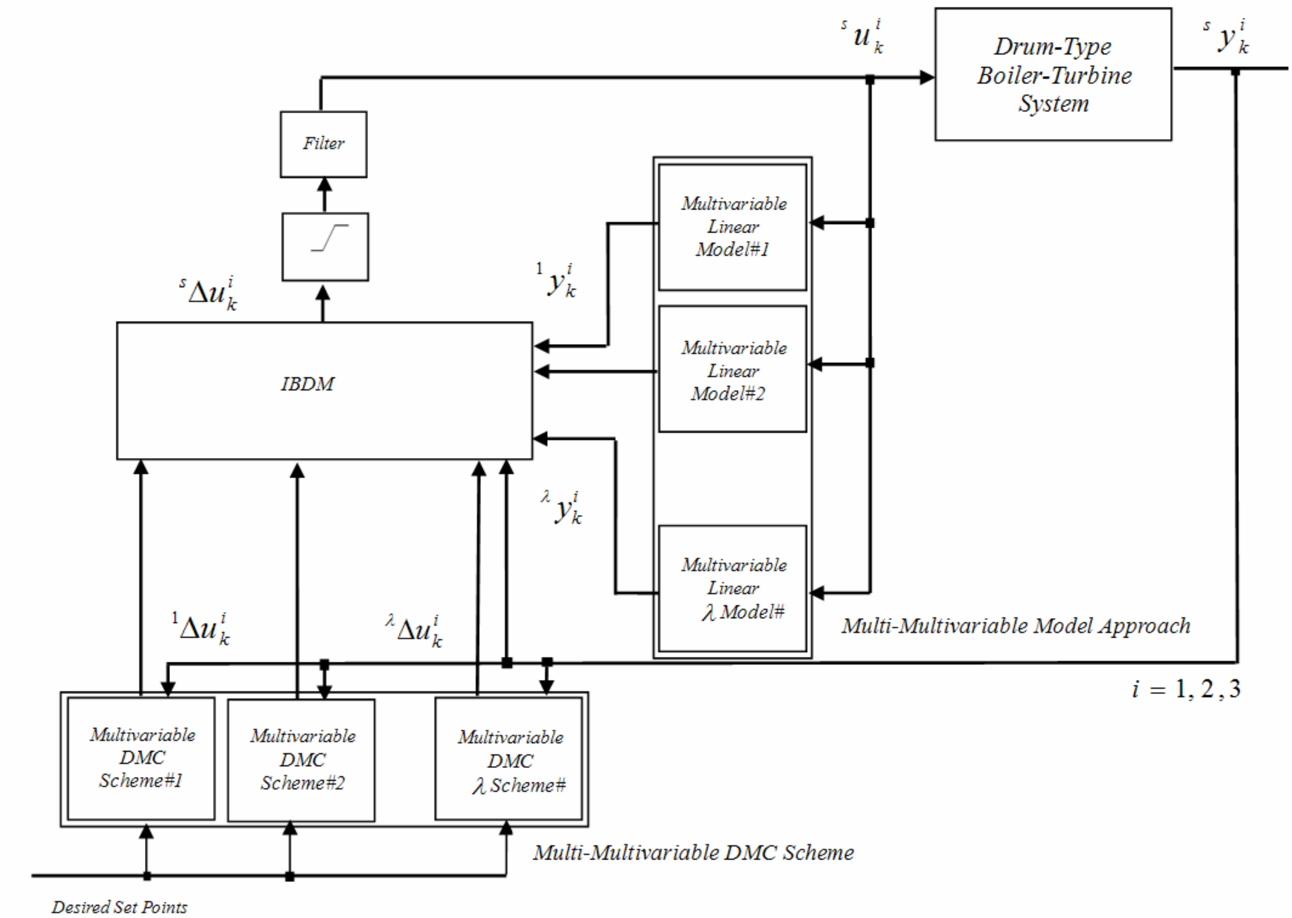


Fig. 1. The proposed control strategy

- Define the fuzzy sets for ${}^{r}P_{k}^{i}$, as shown in Fig. 2(a), corresponding to the acceptable, conditionally

Acceptable, and unacceptable fuzzy sets, i.e., ${}^{r}AFS^{i}$, ${}^{r}CAFS^{i}$ and ${}^{r}UAFS^{i}$, respectively, where the average of ${}^{r}P_{k}^{i}$ is ${}^{r}\overline{P_{k}^{i}}$, and ${}^{r}P^{i*}$ is the marginal value.

- Define the decision-maker parameters ${}^{r}\zeta_{k'}^{i} = {}^{r}\overline{P_{k}^{i}} - {}^{r}P^{i*}$, where k' is related to the specified span of time.

- Define the fuzzy sets for ${}^{r}\zeta_{k'}^{i}$ corresponding to the acceptable and unacceptable decision fuzzy sets ${}^{r}ADFS^{i}$ and ${}^{r}UDFS^{i}$, respectively, as shown in Fig. 2(b).

To identify the best multivariable DMC scheme (TBMD), the proposed IBDM is presented by the following:

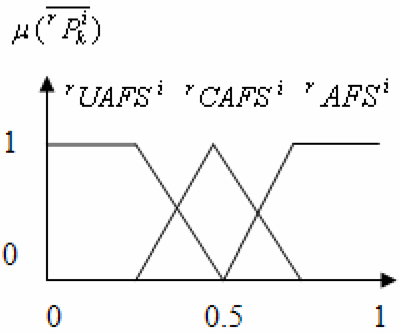
IF ${}^{r}\overline{P_{k}^{i}}$ *is* ${}^{r}AFS^{i}$
THEN $TBMD \triangleq DMC\#r$, *i.e.,* ${}^{s}\Delta u_{k}^{i} \equiv {}^{r}\Delta u_{k}^{i}$
IF ${}^{r}\overline{P_{k}^{i}}$ *is* ${}^{r}CAFS^{i}$ *AND* ${}^{r}\zeta_{k'}^{i}$ *is* ${}^{r}ADFS^{i}$
THEN $TBMD \triangleq DMC\ \#r$

IF ${}^{r}\overline{P_{k}^{i}}$ *is* ${}^{r}CAFS^{i}$ *AND* ${}^{r}\zeta_{k'}^{i}$ *is* ${}^{r}UDFS^{i}$
THEN $TBMD \triangleq DFDMC\ \#r$; *(Deviation from the DMC)*
IF ${}^{r}\overline{P_{k}^{i}}$ *is* ${}^{r}UAFS^{i}$
THEN $TBMD \triangleq DFDMC\#r$

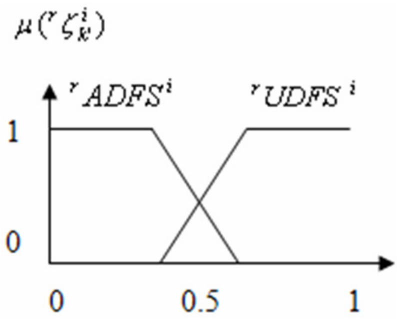
3. Simulation Results

To deal with the present drum-type boiler–turbine system through the proposed control strategy, a number of typical operating points of the system should be chosen first, as tabulated in Table 1.

In the control strategy presented, all three multivariable DMC schemes ($\lambda = 3$ in Fig. 1) are designed using MATLAB/SIMULINK. The control coefficients, including the control horizon, prediction horizon, and sampling time, are given as 3, 3, and 10 ms, respectively. With these coefficient assumptions, the proposed multi-multivariable DMC scheme (MMDMC) is carried out using a personal computer. A single multivariable DMC scheme (SMDMC) is also used as a benchmark approach. In the case of the MMDMC realization, Figs. 3-5 present the first, second, and third outputs of the system, respectively. In these



(a)



(b)

Fig. 2. Fuzzy sets used in the IBDM

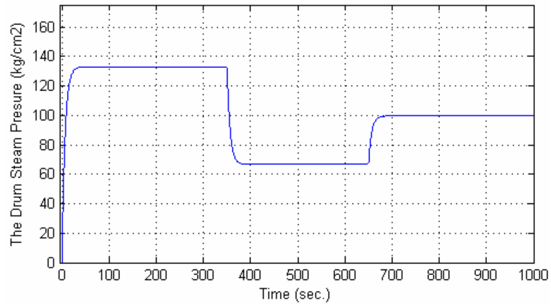


Fig. 3. First output of the system using the MMDMC scheme

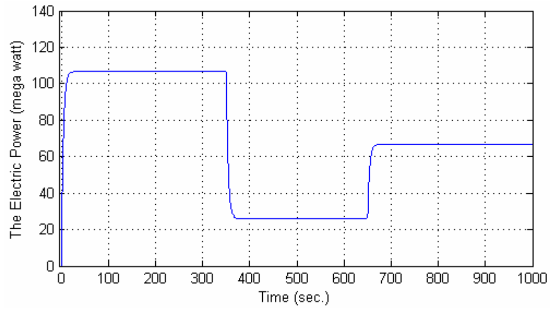


Fig. 4. Second output of the system using the MMDMC scheme

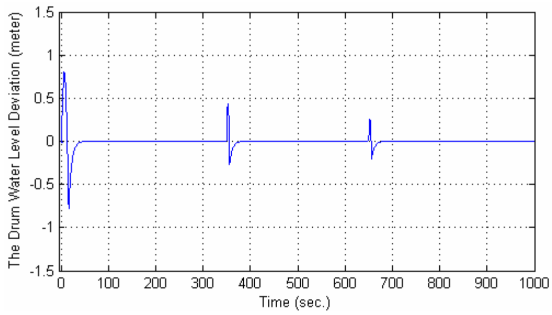


Fig. 5. Third output of the system using the MMDMC scheme

Table 1. Typical operating points of the system

op^r	$r=1$	$r=2$	$r=3$
x_{10}^r	86.40	108.0	129.6
x_{20}^r	36.65	66.65	105.8
x_{30}^r	342.4	428.0	513.6
u_{10}^r	0.209	0.340	0.505
u_{20}^r	0.552	0.690	0.828
u_{30}^r	0.256	0.433	0.663
y_{30}^r	-0.650	0	0.640

Table 2. Desired set point information

Time (sec.)	1st desired set poing	2nd desired set poing	3th desired set poing
0-350	133	107	0
351-650	67	26	0
651-1000	100	67	0

figures, the desired set point information is tabulated in Table 2. Regarding the IBDM outcomes, as presented in Table 3, ${}^{s}\Delta u_{k}^{i}$ should be updated through ${}^{r}\Delta u_{k}^{i}; r=1,2,3$, as given in the last column of the table, while the maximum of ${}^{r}P_{k}^{i}$ in its span of time is acquired. In fact, ${}^{s}\Delta u_{k}^{i}$ should be updated to realize the appropriate amounts once ${}^{r}P_{k}^{i}$ is truly optimized. In this table, to present the results appropriately, only the maximum of ${}^{r}P_{k}^{i}$ is presented as the IBDM outcome.

In this case, using (1), the performance index coefficients are given as $\alpha=1, \beta=0.15, \nu=2$. The marginal values are taken as ${}^{r}P^{i*}=0.1\,{}^{r}P_{k}^{i}$. Figs. 6-8 present the system outputs using the SMDMC scheme. In this case, the SMDMC scheme, as a benchmark control approach, is solely realized at the second operating point of the system, whereas the coefficients of the multivariable DMC scheme in the strategy of the MMDMC scheme are directly used. In accordance with these outcomes, all the chosen operating points of the system are handled well through the proposed MMDMC scheme, in which the SMDMC scheme does not perform appropriately in comparison with the previous one.

Table 3. IBDM outcomes

Time (sec.)	$^{1}\overline{P_k^i}$	$^{2}\overline{P_k^i}$	$^{3}\overline{P_k^i}$	$^{s}\Delta u_k^i$
	$i=1$			
0-6	0.931			$^{1}\Delta u_k^i$
7-16		0.513		$^{2}\Delta u_k^i$
17-352			0.712	$^{3}\Delta u_k^i$
353-354		0.534		$^{2}\Delta u_k^i$
355-656	0.838			$^{1}\Delta u_k^i$
657-1000		0.983		$^{2}\Delta u_k^i$
	$i=2$			
0-3	0.807			$^{1}\Delta u_k^i$
4-8		0.623		$^{2}\Delta u_k^i$
9-352			0.830	$^{3}\Delta u_k^i$
353-354		0.930		$^{2}\Delta u_k^i$
355-655	0.949			$^{1}\Delta u_k^i$
656-1000		0.843		$^{2}\Delta u_k^i$
	$i=3$			
0-3		0.804		$^{2}\Delta u_k^i$
4-13			0.787	$^{3}\Delta u_k^i$
14-15		0.863		$^{2}\Delta u_k^i$
16-20	0.511			$^{1}\Delta u_k^i$
21-353		0.812		$^{2}\Delta u_k^i$
354-363			0.743	$^{3}\Delta u_k^i$
364-365		0.624		$^{2}\Delta u_k^i$
366-370	0.837			$^{1}\Delta u_k^i$
371-653		0.681		$^{2}\Delta u_k^i$
654-663			0.544	$^{3}\Delta u_k^i$
664-665		0.849		$^{2}\Delta u_k^i$
666-670	0.563			$^{1}\Delta u_k^i$
671-1000		0.613		$^{2}\Delta u_k^i$

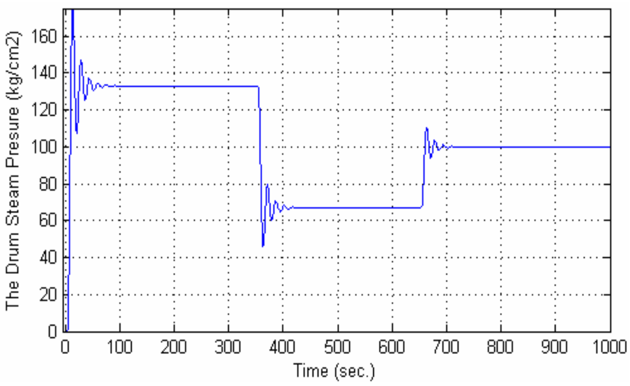


Fig. 6. First output of the system using the SMDMC scheme

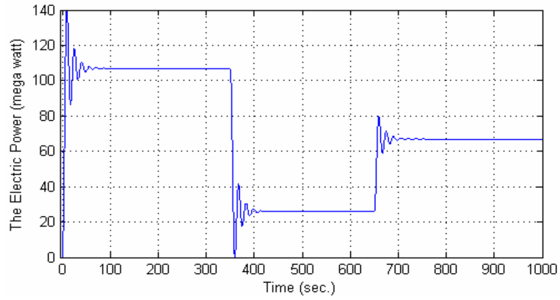


Fig. 7. Second output of the system using the SMDMC scheme

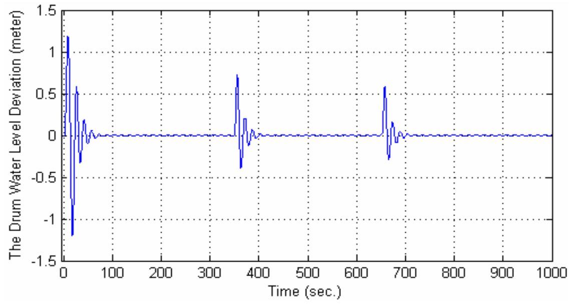


Fig. 8. Third output of the system using the SMDMC scheme

5. Conclusion

A multivariable drum-type boiler–turbine system is developed in the current research using a new control solution. In the control scheme presented, the system is first represented at a number of chosen operating points through a multi-multivariable model approach, while a multi-multivariable DMC scheme is correspondingly realized to handle the system appropriately. A new IBDM is investigated to support the best representation of the system and its corresponding multivariable DMC scheme at each instant of time.

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References

[1] P. Chen, J. S. Shamma, "Gain-scheduled ℓ^1-optimal control for boiler-turbine dynamics with actuator saturation", *Journal of Process Control*, pp. 263-277, 2004.

[2] U. Moon, K. Y. Lee, "A boiler-turbine system control

using a fuzzy auto-regressive moving average (FARMA) model", *IEEE Transactions on Energy Conversion,* pp. 142-148, 2003.

[3] D. Peng, H. Zhang, P. Yang, "The boiler-turbine coordinated control system based on immune feedback mechanism", *International Conference on Machine Learning and Cybernetics,* pp. 449-453, 2007.

[4] G. Dieck-Assad, G. Y. Masada, R. H. Flake, "Optimal set-point scheduling in a boiler-turbine system", *IEEE Transactions on Energy Conversion,* pp. 388-395, 1987.

[5] R. D. Bell, K. J. Astrom, "Dynamic models for boiler-turbine-alternator units: Data logs and parameter estimation for a 160 MW unit", *Lund Inst. Technol*., Lund, Sweden, Rep. TFRT- 3192, 1987.

[6] A. H. Mazinan and M. F. Kazemi, "Analysis and Control of a High-Purity Distillation Column System", *Transactions of the Institute of Measurement & Control*, SAGE Publisher, 2011.

[7] A. H. Mazinan and M. Sheikhan, "On the Practice of Artificial Intelligence Based Predictive Control Scheme: A Case Study", *Applied Intelligence*, Springer Publisher, In press, DOI: 10.1007/s10489-010-0253-0, 2011.

[8] A. H. Mazinan and M. F. Kazemi, "An Efficient Approach to Industrial Multivariable System Modeling and Control", *World Applied Sciences Journal*, In press, 2011.

[9] A. H. Mazinan and M. F. Kazemi, "Artificial Intelligent Predictive Control Scheme with its Application to a 160 MW Drum-Type Boiler-Turbine System", *Engineering Intelligent Systems for Electrical Engineering and Communications*, 2010.

[10] A. H. Mazinan and N. Sadati, "On the Application of Fuzzy Predictive Control Based on Multiple Models Strategy to a Tubular Heat Exchanger System", *Transactions of the Institute of Measurement & Control*, SAGE Publisher, DOI: 10.1177/0142331209345153, 2010, pp. 1-24.

[11] A. H. Mazinan and A. H. Hosseini, "Application of Intelligence-Based Predictive Scheme to Load-Frequency Control in a Two-Area Interconnected Power System", *Applied Intelligence*, Springer Publisher, In press, DOI: 10.1007/s10489-010-0236-1, 2010.

[12] A. H. Mazinan and M. F. Kazemi, "A New Approach to Intelligent Model Based Predictive Control Scheme", *Intelligent Information Management*, Scientific Research Publisher, DOI: 10.4236/iim.2010.21002, In press, January 2010, pp. 14-20.

[13] A. H. Mazinan and N. Sadati, **"**An Intelligent Multiple Models Based Predictive Control Scheme with its Application to Industrial Tubular Heat Exchanger System", *Applied Intelligence*, Springer Publisher, DOI: 10.1007/s10489-009-0185-8, In press, June 2009.

[14] A. H. Mazinan and N. Sadati, "Fuzzy Predictive Control Based Multiple Models Strategy to a Tubular Heat Exchanger System", *Applied Intelligence*, Springer Publisher, DOI: 10.1007/s10489-009-0163-1, In press, February 2009.

[15] A. H. Mazinan and N. Sadati, "Multiple Modeling and Fuzzy Predictive Control of a Tubular Heat Exchanger System", *Transactions on Systems and Control*, vol. 3, January 2008, pp. 249-258.

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