UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2016/2017 Academic Session

June 2017

EKC 462 – Advanced Control System for Industrial Processes
[Sistem Kawalan Lanjutan untuk Proses Industri]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains ELEVEN printed pages and FIVE printed page of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEBELAS muka surat yang bercetak dan LIMA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai].

Answer ALL questions.

1. [a] Explain the following :

[i] Nonlinear Control

[3 marks]

[ii] Adaptive Control

[3 marks]

[iii] Model Based Control

[3 marks]

[b] A polymerisation reactor has the following input-output model, for control of output temperature (°C) by manipulating the jacket temperature (°C). The time is in minute.

$$\tilde{g}_p(s) = \frac{-2.5}{(-10s+1)(2s+1)}$$

Design an IMC-based PID controller for this system.

[16 marks]

2. [a] A waste stream (dilute nitric acid) is neutralized by adding a base stream (sodium hydroxide) of known concentration to a stirred neutralization tank, as shown in Figure Q.2.[a]. The concentration and the flow rate of the waste acid stream vary unpredictably. The flow rates of the waste stream and base stream can be measured. The effluent stream pH can be measured, but a significant time delay occurs due to the downstream location of the pH probe. Experience has indicated that it is not possible to tune a standard PID controller so that satisfactory control occurs over the full range of operating conditions. As a process control specialist, recommend advanced control strategies that have the potential of greatly improved control. Justify your proposed method, being as specific as possible. Also, cite any additional information that are needed.

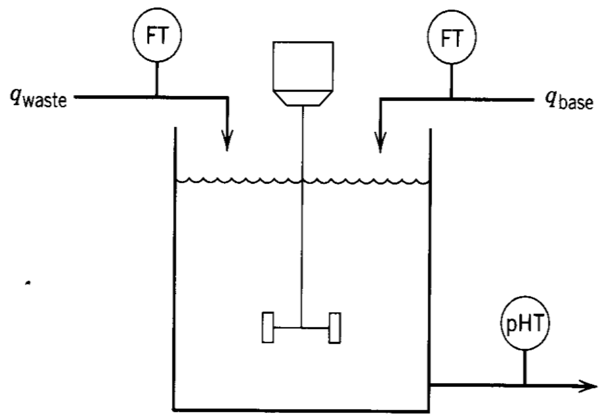


Figure Q.2.[a]: Stirred Neutralization Tank

[7 marks]

Jawab <u>SEMUA</u> soalan.

1. [a] *Terangkan perkara-perkara yang berikut :*

[i] *Kawalan Tak Lelurus*

[3 markah]

[ii] *Kawalan Suai*

[3 markah]

[iii] *Kawalan Berasaskan Model*

[3 markah]

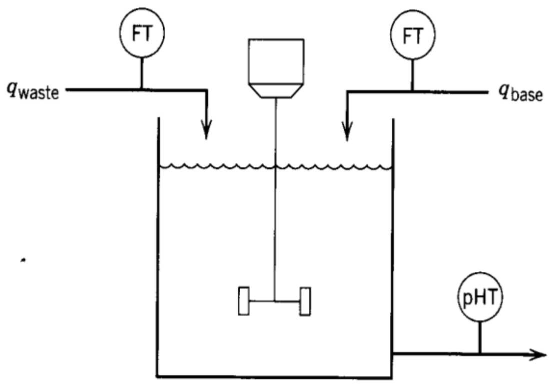
[b] *Satu reaktor pempolimeran mempunyai model masukan-keluaran seperti berikut, bagi kawalan suhu keluaran (℃) dengan mengubah suhu jaket (℃). Masa adalah dalam minit.*

$$\tilde{g}_p(s) = \frac{-2.5}{(-10s+1)(2s+1)}$$

Rekabentukkan pengawal PID berasaskan IMC bagi sistem ini.

[16 markah]

2. [a] *Satu alur sisa (asid nitrik cair) dineutralkan dengan menambahkan satu alur bes (kalium hidroksida) yang diketahui kepekatannya ke tangki peneutralan seperti yang ditunjukkan dalam Rajah S.2.[a]. Kepekatan dan kadar aliran bagi alur sisa berubah secara tak teramal. Kedua-dua kadar aliran alur sisa dan alur bes boleh diukur. pH bagi alur keluar boleh diukur tetapi menyebabkan berlakunya masa lengah yang bererti disebabkan kedudukan di hilir kuar pH. Pengalaman menunjukkan, tidak mungkin untuk menala pengawal PID untuk mendapat kawalan yang memuaskan sepanjang keadaan operasi. Sebagai seorang pakar kawalan proses, cadangkan strategi kawalan termaju yang berpotensi untuk menambahbaik kawalan tersebut. Berikan justifikasi terhadap kaedah yang dicadangkan dengan secara khusus. Juga, nyatakan sebarang maklumat tambahan yang diperlukan.*



Rajah S.2.[a]: Tangki Peneutralan Teraduk

[7 markah]

[b] Figure Q.2.[b] shows a step response behaviour for a packed-bed reactor. A step decrease in steam valve position was made at t = 5 minutes.

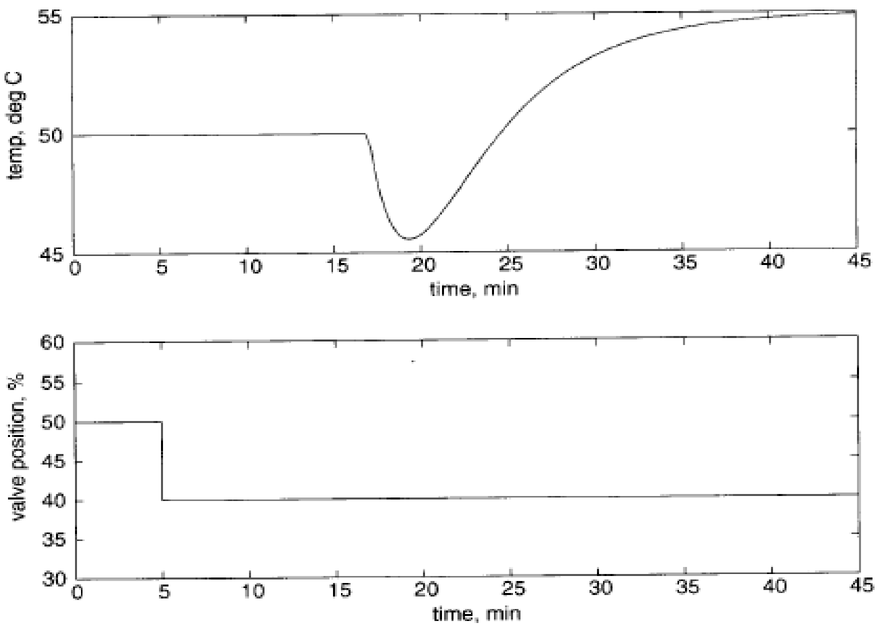


Figure Q.2.[b]: Step Response Behaviour for a Packed-Bed Reactor

The process model (the time unit is minute) that representing the process is given as:

$$\tilde{g}_p(s) = \frac{K(-10s+1)\,e^{-\theta s}}{(5s+1)(3s+1)}$$

[i] Calculate the value of K and θ.

[4 marks]

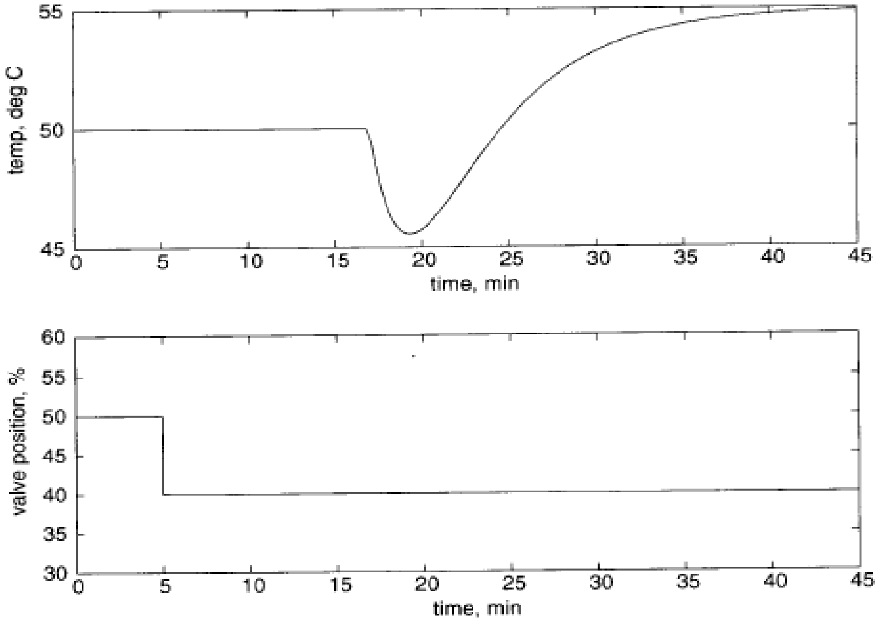
[ii] Design an Internal Model Control *(IMC)* for this process. Use the all-pass factorization and assume that *q(s)* is semiproper.

[5 marks]

[iii] Assuming a perfect model, plot qualitatively how the temperature will respond to a step setpoint change of 1 °C.

[9 marks]

[b] *Rajah S.2.[b] menunjukkan kelakuan satu sambutan langkah bagi reaktor lapisan terpadat. Satu pengurangan langkah bagi kedudukan injap stim telah dibuat pada masa* t *= 5 minit.*



Rajah S.2.[b]: Kelakuan Sambutan Langkah bagi Satu Reaktor Lapisan Terpadat

Proses model (unit masa ialah minit) yang mewakili proses tersebut diberikan seperti berikut :

$$\tilde{g}_p(s) = \frac{K(-10s+1)e^{-\theta s}}{(5s+1)(3s+1)}$$

[i] *Kirakan nilai* K *dan θ.*

[4 markah]

[ii] *Rekabentukkan Kawalan Model Dalam* (IMC) *bagi proses ini. Gunakan pemfaktoran lulus-semua dan andaikan bahawa* q(s) *adalah separa wajar.*

[5 markah]

[iii] *Dengan mengandaikan model adalah sempurna, plot secara kualitatif bagaimana sambutan suhu terhadap perubahan langkah titik set 1 °C.*

[9 markah]

3. Figure Q.3.1 to Figure Q.3.4 shows the profiles of control variables for Multi Input Multi Output *(MIMO)* for the two-point composition control in a binary distillation column after step test method was applied. The manipulated variables are vapor boil-up rate, *V(MV2)*, and reflux flow, *L (MV1)*, to control top and bottom compositions, *xD (CV1)* and *xB (CV2)* respectively.

[a] Determine the transfer function for the MIMO system based on the CV profiles in Figure Q.3.1 to Figure Q.3.4. **Show the calculated values provided in Appendix and attached with your answer booklet.**

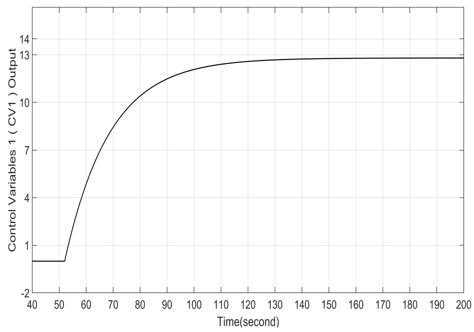


Figure Q.3.1

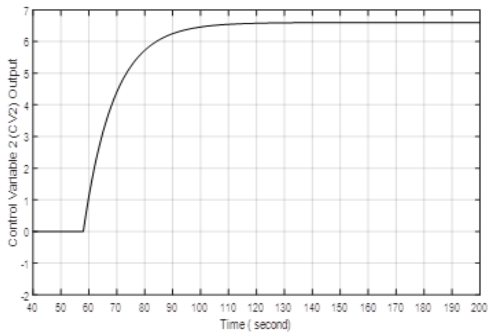


Figure Q.3.2

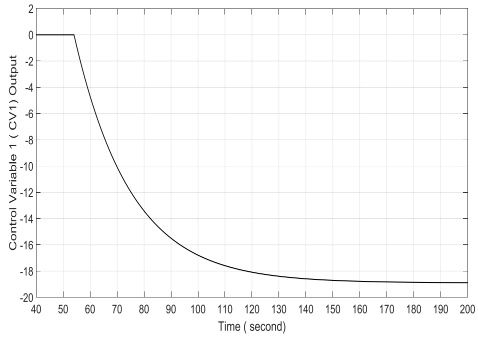


Figure Q.3.3

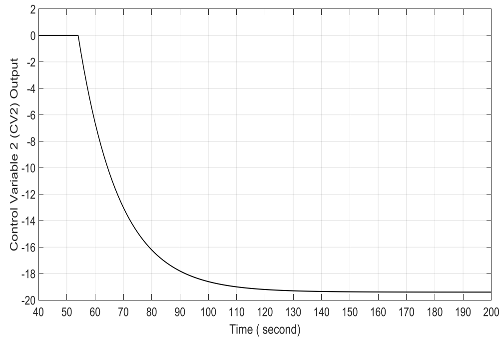


Figure Q.3.3

Figure Q.3.1: The profile of Control Variable 1 *(CV1)* when the manipulated variables 1 *(MV1)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 2 *(MV2)* remain constant.

Figure Q.3.2: The profile of Control Variable 2 *(CV2)* when the manipulated variables 1 *(MV1)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 2 *(MV2)* remain constant.

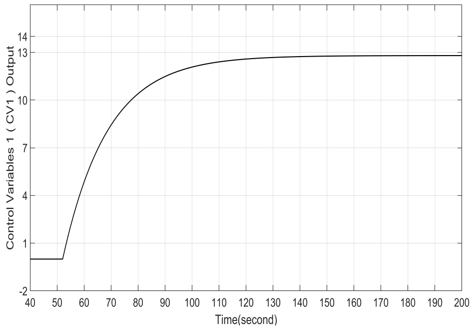
Figure Q.3.3: The profile of Control Variable 1 *(CV1)* when the manipulated variables 2 *(MV2)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 1 *(MV1)* remain constant.

Figure Q.3.4: The profile of Control Variable 2 *(CV2)* when the manipulated variables 2 *(MV2)* change in the magnitude of 1 in the step time of 50 second while manipulated variable 1 *(MV1)* remain constant.

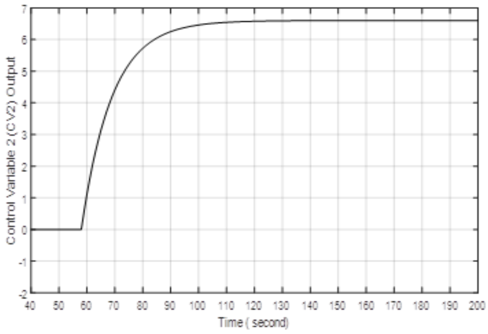
[12 marks]

3. *Rajah S.3.1 hingga Rajah S.3.4 menunjukkan profil pembolehubah kawalan untuk berbilang masukan berbilang keluaran bagi kawalan dua titik komposisi dalam turus penyulingan perduaan selepas kaedah ujian langkah dilaksanakan. Pembolehubah pengolah ialah kadar wap didih,* V(MV2), *dan aliran refluk,* L(MV1), *bagi mengawal komposisi di atas dan komposisi bawah,* xD (CV1) *dan* xB (CV2).

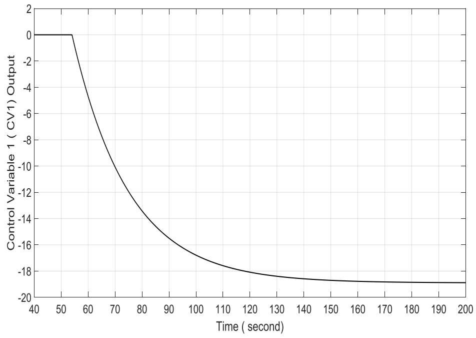
[a] *Tentukan rangkap pindah bagi sistem berbilang masukan berbilang keluaran berdasarkan profil pembolehubah kawalan di Rajah S.3.1 hingga Rajah S.3.4.* ***Tunjukkan kiraan nilai di lampiran dan sertakan bersama buku jawapan anda.***



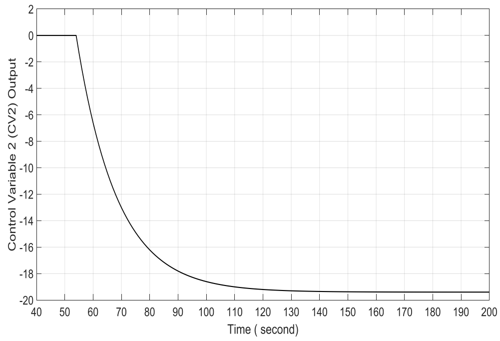
Rajah S.3.1



Rajah S.3.2



Rajah S.3.3



Rajah S.3.4

Rajah S.3.1: Profil bagi pembolehubah kawalan 1 (CV1) *bila pembolehubah pengolah 1* (MV1) *berubah dengan magnitud 1 pada masa langkah 50 saat manakala pembolehubah pengolah 2* (MV2*) kekal tidak berubah.*

Rajah S.3.2: Profil bagi pembolehubah kawalan 2 (CV2) *bila pembolehubah pengolah 1* (MV1) *berubah dengan magnitud 1 pada masa langkah 50 saat manakala pembolehubah pengolah 2* (MV2) *kekal tidak berubah.*

Rajah S.3.3: Profil bagi pembolehubah kawalan 1 (CV1) *bila pembolehubah pengolah 2* (MV1) *berubah dengan magnitud 1 pada masa langkah 50 saat manakala pembolehubah pengolah 1* (MV2) *kekal tidak berubah.*

Rajah S.3.4: Profil bagi pembolehubah kawalan 2 (CV1) *bila pembolehubah pengolah 2* (MV1) *berubah dengan magnitud 1 pada masa langkah 50 saat manakala pembolehubah pengolah 1* (MV2) *kekal tidak berubah.*

[12 markah]

[b] The pairing chosen for the system are *MV1-CV1* and *MV2-CV2*. Justify whether the selection of control loop pairing for two single loop controllers in this system is appropriate.

[6 marks]

[c] To assess the system sensitivity, you have to consider:

[i] a change in *MV1* of magnitude 1 with *MV2* held constant
[ii] a change in *MV2* of magnitude 1 with *MV1* held constant

Calculate what are the effective gains that correspond to this input direction?

[6 marks]

[d] If the ratio of the two effective gains is the condition number of the plant, explain the significance of the two effective gains?

[2 marks]

[e] By using the value obtained for the condition number in Q.3.[d] make comments about the sensitivity of the plant and the feasibility of applying a decoupling control law.

[2 marks]

[f] Draw the block diagram for the decoupling control strategy.

[6 marks]

4. Consider the following diagram representation of conventional and nonlinear model predictive control strategy.

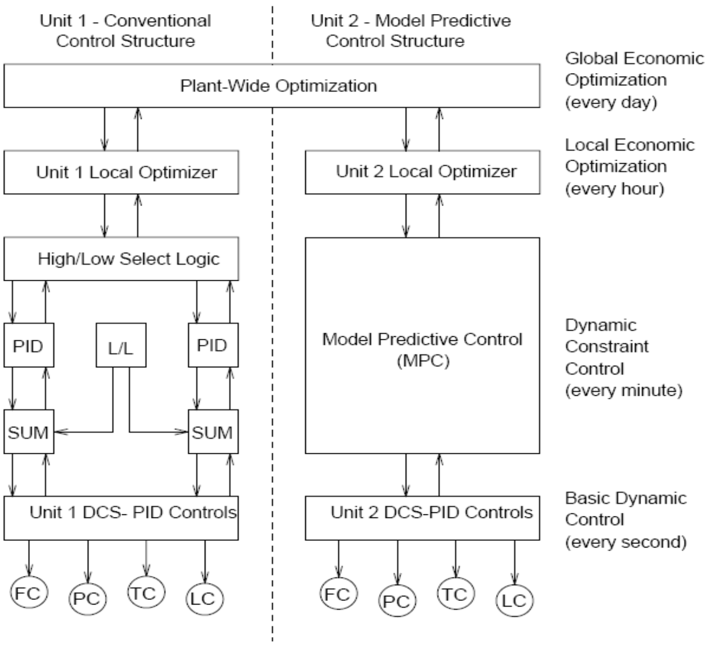


Figure Q.4: Hierarchy of control system functions in a typical processing plant.

[b] *Pemilihan pasangan pada sistem tersebut ialah* MV1-CV1 *dan* MV2-CV2. *Beri justifikasi sama ada pemilihan pasangan gelung kawalan untuk dua pengawal gelung tunggal dalam sistem ini adalah sesuai.*

[6 markah]

[c] *Untuk menilai kepekaan sistem, anda harus mempertimbangkan :*

[i] *perubahan magnitud 1 pada* MV1 *dengan* MV2 *ditetapkan malar*
[ii] *perubahan magnitud 1 pada* MV2 *dengan* MV1 *ditetapkan malar*

Kirakan apakah gandaan berkesan yang sepadan bagi arah masukan tersebut.

[6 markah]

[d] *Jika nisbah bagi dua gandaan berkesan adalah syarat bagi nombor keadaan sesebuah loji, terangkan apakah kepentingan dua gandaan berkesan tersebut?*

[2 markah]

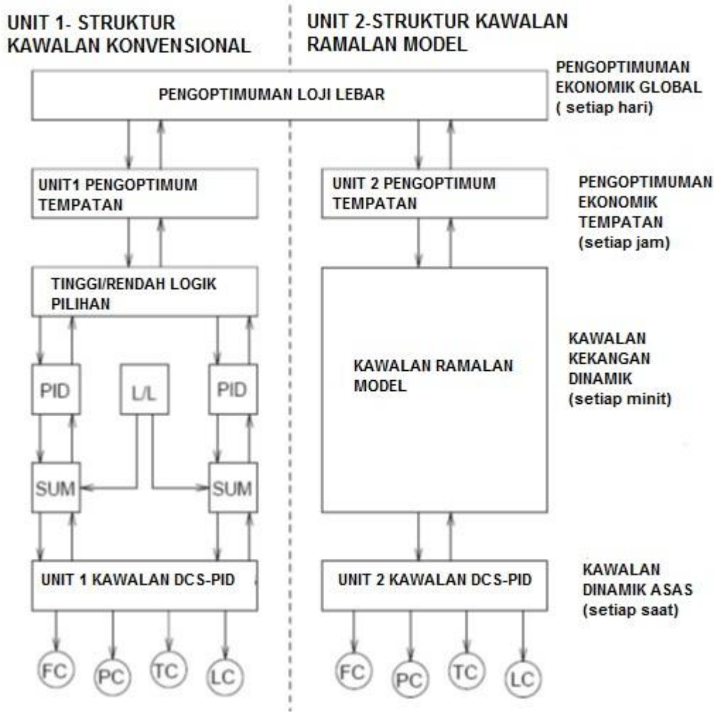
[e] *Dengan menggunakan nilai yang diperolehi untuk nombor keadaan pada S.3.[d] berikan komen mengenai kepekaan loji dan kebolehlaksanaan penggunaan hukum kawalan tak berpasangan.*

[2 markah]

[f] *Lukiskan gambarajah blok bagi strategi kawalan tak berpasangan.*

[6 markah]

4. *Pertimbangkan rajah berikut yang mewakili strategi kawalan konvensional dan kawalan ramalan model tak lelurus.*



Rajah S.4: Susunatur fungsi sistem kawalan bagi loji pemprosesan yang biasa.

[a] Outline the circumstances under which use of Model Predictive Control *(MPC)* could be considered and comment upon the potential benefits.

[4 marks]

[b] Briefly discuss the key features of *MPC* compare to conventional control strategy based on the Figure Q.4.

[4 marks]

[c] Write down a typical controller objective function used in model predictive control laws and defining all terms.

[5 marks]

[d] One of the general objectives of an *MPC* controller is to prevent violation of input and output constraints. Briefly explain how to support this statement.

[3 marks]

[a] *Rangkakan keadaan di mana penggunaan model kawalan ramalan* (MPC) *boleh dicadangkan dan komen kepada potensi faedah yang boleh diperolehi dari perlaksanaan cadangan tersebut.*

[4 markah]

[b] *Bincangkan secara ringkas ciri-ciri utama* MPC *jika dibandingkan dengan strategi kawalan konvensional berdasarkan Rajah S.4.*

[4 markah]

[c] *Tuliskan objektif pengawal fungsi yang biasa digunakan dalam hukum kawalan ramalan model dan definasikan semua terma yang dinyatakan.*

[5 markah]

[d] *Salah satu objektif umum pengawal* MPC *adalah untuk mengelakkan kekangan masukan dan kekangan keluaran dilanggar. Terangkan secara ringkas untuk menyokong kenyataan tersebut.*

[3 markah]

- oooOooo -

Appendix

Table Laplace Transforms for Various Time-Domain Functions[a]

$f(t)$	$F(s)$
1. $\delta(t)$ (unit impulse)	1
2. $S(t)$ (unit step)	$\frac{1}{s}$
3. t (ramp)	$\frac{1}{s^2}$
4. t^{n-1}	$\frac{(n-1)!}{s^n}$
5. e^{-bt}	$\frac{1}{s+b}$
6. $\frac{1}{\tau}e^{-t/\tau}$	$\frac{1}{\tau s+1}$
7. $\frac{t^{n-1}e^{-bt}}{(n-1)!}$ $(n>0)$	$\frac{1}{(s+b)^n}$
8. $\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$	$\frac{1}{(\tau s+1)^n}$
9. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$	$\frac{1}{(s+b_1)(s+b_2)}$
10. $\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
11. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2t}$	$\frac{s+b_3}{(s+b_1)(s+b_2)}$
12. $\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$	$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$
13. $1-e^{-t/\tau}$	$\frac{1}{s(\tau s+1)}$
14. $\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$
15. $\cos \omega t$	$\frac{s}{s^2+\omega^2}$
16. $\sin(\omega t+\phi)$	$\frac{\omega\cos\phi+s\sin\phi}{s^2+\omega^2}$
17. $e^{-bt}\sin\omega t$ (b, ω real)	$\frac{\omega}{(s+b)^2+\omega^2}$
18. $e^{-bt}\cos\omega t$ (b, ω real)	$\frac{s+b}{(s+b)^2+\omega^2}$
19. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\neq\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0\le\lvert\zeta\rvert<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
23. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1\neq\tau_2)$	$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$	$sF(s)-f(0)$
25. $\frac{d^nf}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$	$e^{-t_0s}F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t\geq 0$ only.

Note: Please attached with your answer book.
Nota: Sila kepilkan bersama buku jawapan.

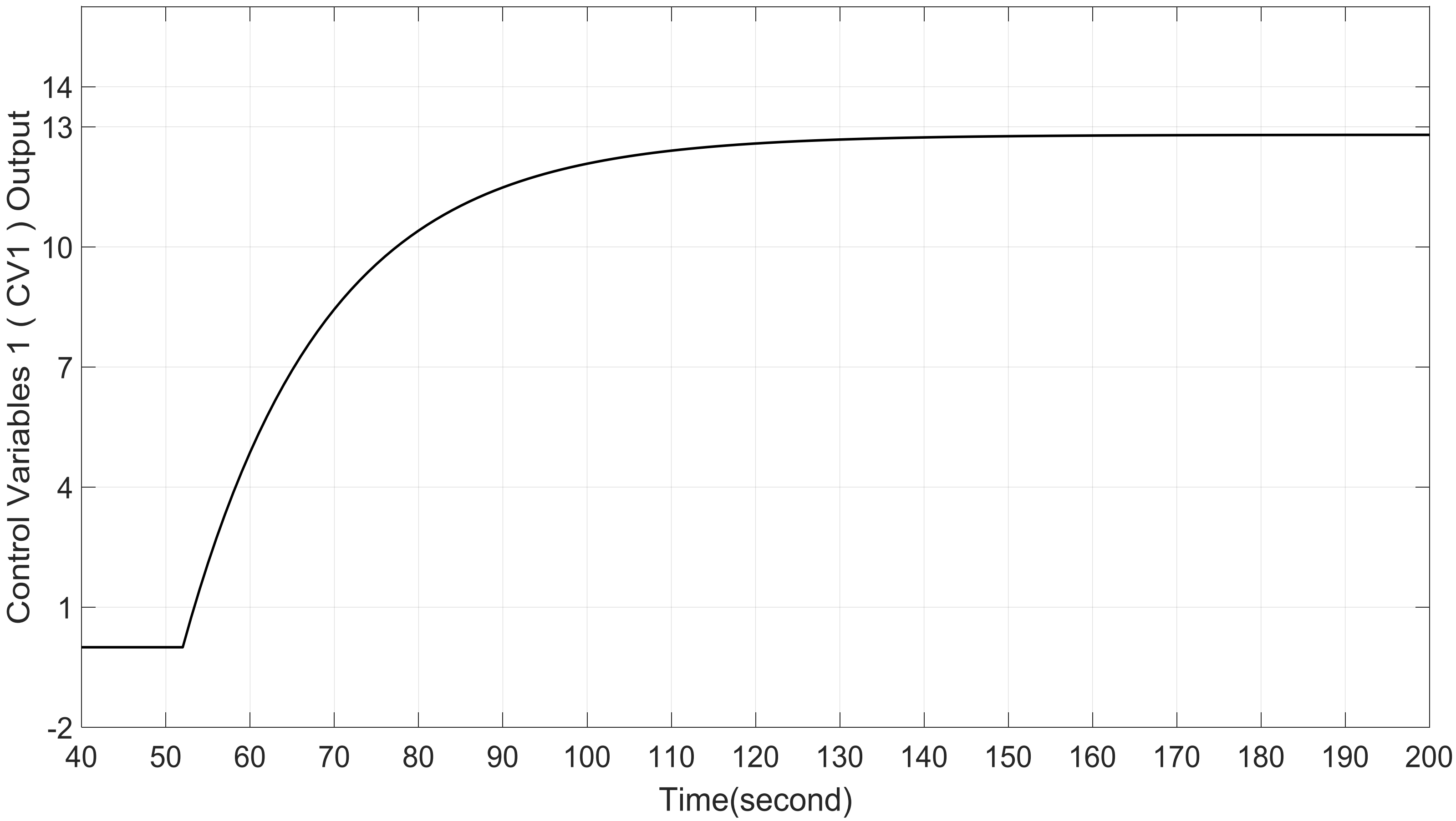


Figure Q.3.1: The profile of control variable 1 *(CV1)* when the manipulated variables 1 *(MV1)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 2 *(MV2)* remain constant.

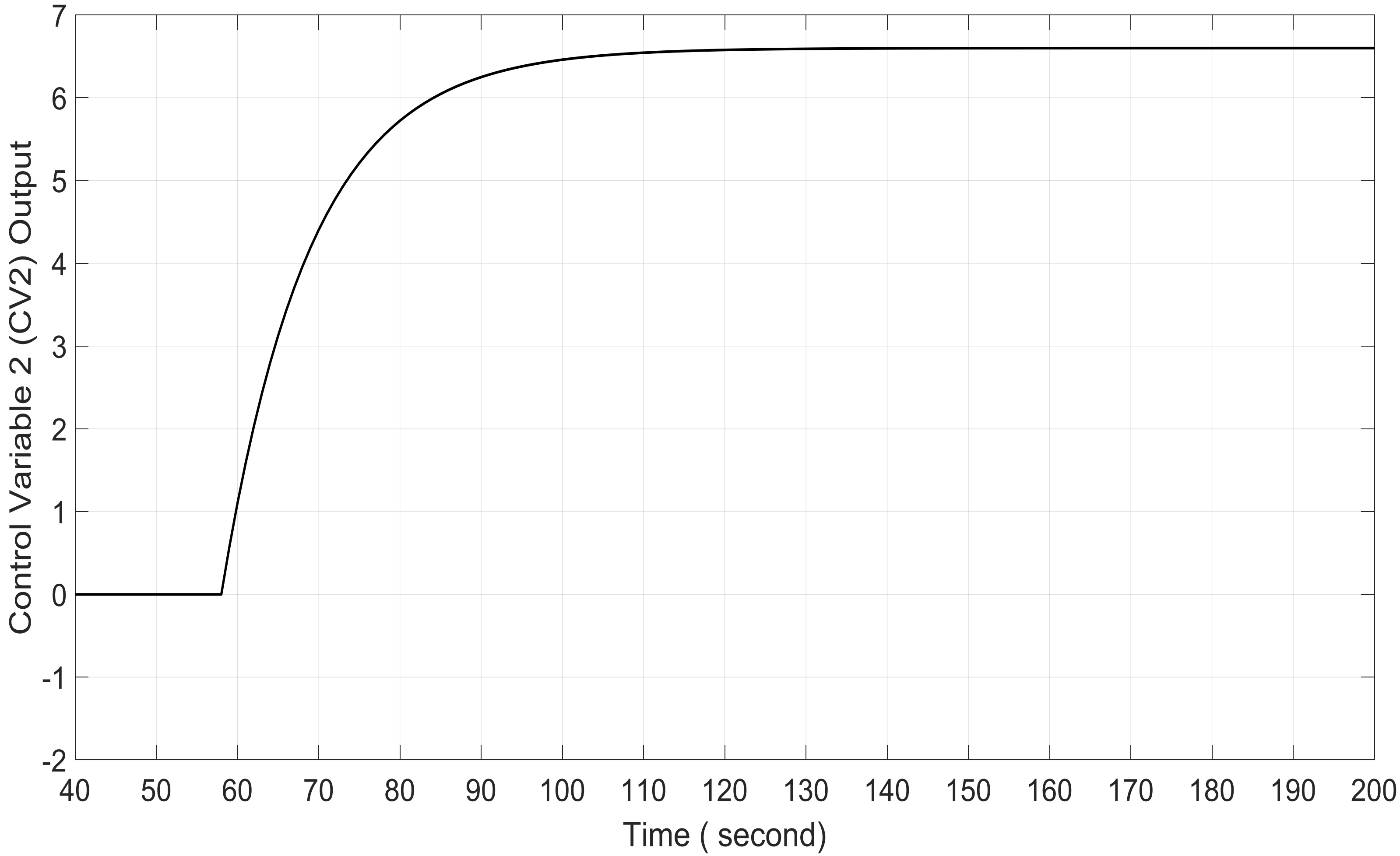


Figure Q.3.2: The profile of control variable 2 *(CV2)* when the manipulated variables 1 *(MV1)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 2 *(MV2)* remain constant.

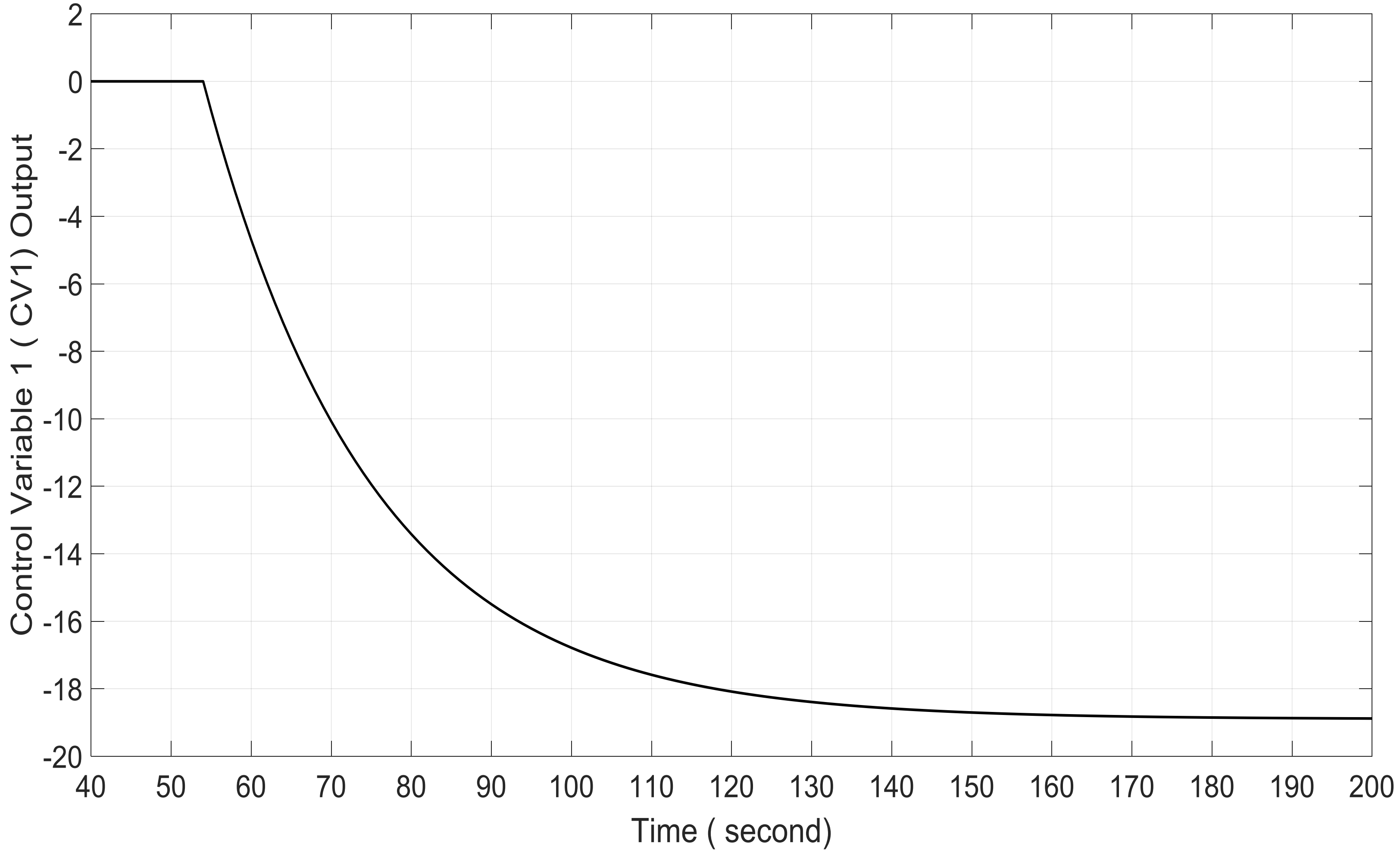


Figure Q.3.3: The profile of control variable 1 *(CV1)* when the manipulated variables 2 *(MV2)* change in the magnitude of 1 at the step time of 50 second while manipulated variable 1 *(MV1)* remain constant.

…5/-

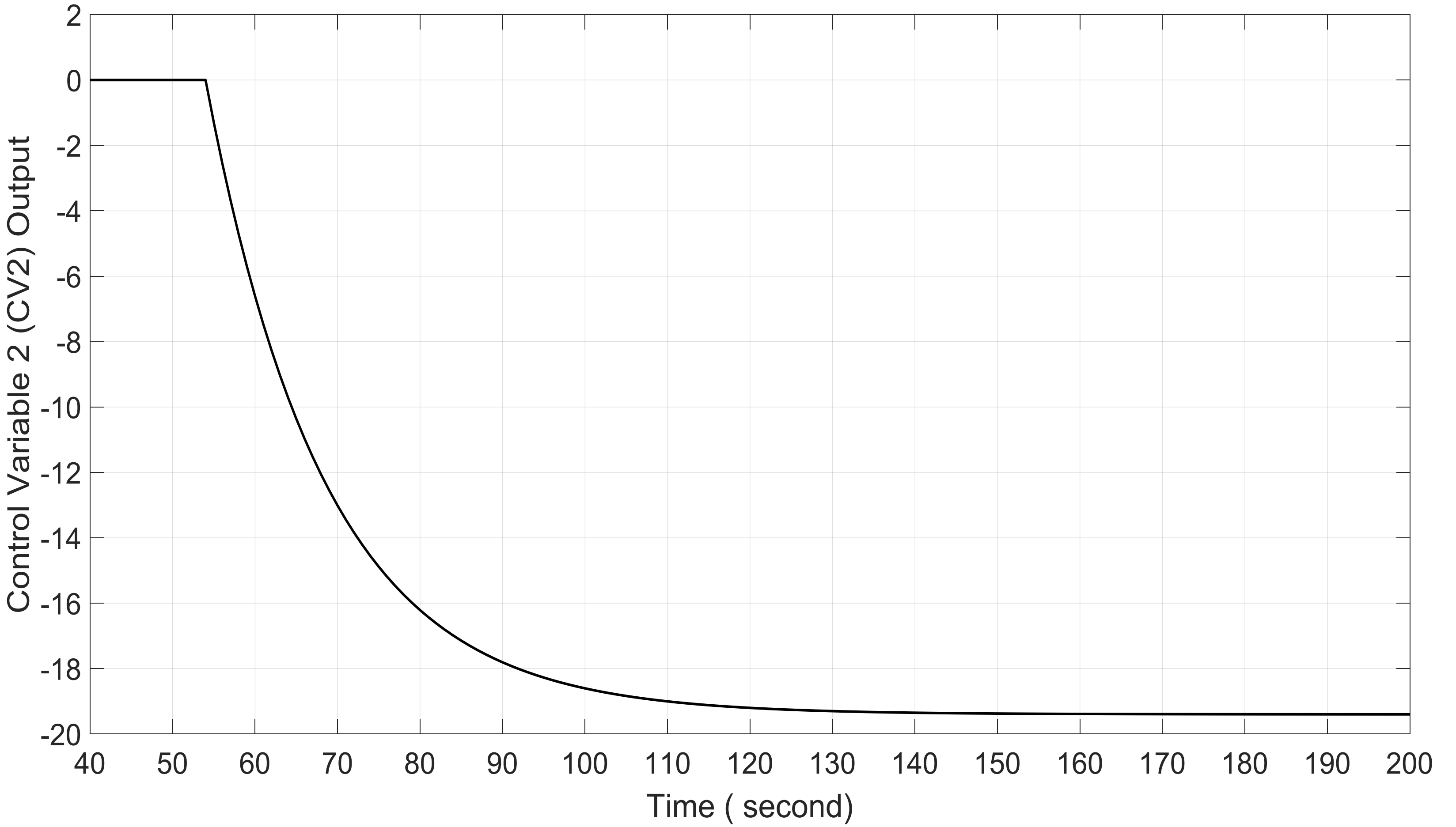


Figure Q.3.4: The profile of control variable 2 *(CV2)* when the manipulated variables 2 *(MV2)* change in the magnitude of 1 in the step time of 50 second while manipulated variable 1 *(MV1)* remain constant.