Assignment #2 (**100 points**): Due 11:59 pm, Sunday, November 27, 2022

1. (**10 points**) Please rank the availability requirement for the following signals from high (1) to low (6) according to the NIST 7628r1 document:
   A. Protective relay commands
   B. Phasor measurement unit (PMU)
   C. SCADA telemetry data
   D. Meter reading from smart meters
   E. Planning of power transmission line upgrades

Signal	Ranking
A	4
B	3
C	1
D	2
E	5

2. (**30 points**) Please find the **Actors** and **Acronym** corresponding to the following Actor Number in NIST 7628r1 and use one sentence to describe in your own words what the actor is. Write **N/A** if the acronym is unavailable.

Actor #	Actor	Acronym	Description (in your words, one sentence only)
4	Customer Distributed Energy Resources: Generation ad Storage	DER	Power from the natural resources like solar and wind will be utilized to generate energy which will be stored and supplied to the customers.
6	Plug in Electric Vehicle	PEV	Rechargeable Batteries are used in electric vehicles. They store the energy which is used to power the electric motor of EV vehicle.
7	Home Area Network Gateway	HAN Gateway	It is the place where all the networks of the service providers, distribution works and all other devices within the network are intersected.
15	Distribution Remote Terminal unit or Intelligent Electronic Device	RTU or IED	These analyze the data from the sensors and other power equipment to generate the control command to prevent any abnormalities in voltage, current and frequency.
20	Independent System Operator or Regional Transmission Organization Wholesale Market	ISO / RTO	It is a control center that is present in the market but don't operate anything in the market which is open to anyone who wants to enter the market either to supply or buy the power.
21	Advanced Metering Infrastructure Headend	AMI	This system controls information exchanges between third-party or non-headend systems, like the AMI network and Meter Data Management System (MDMS).
24	Customer Service Representative	CSR	It is the customer service which can be provided by a person (sales and service professional) or by an automated system known as self-service (Interactive Voice Response [IVR]).
23	Customer Information System	CIS	Enterprise-wide software tools that enable businesses to manage various elements of their client relationships.

30	Energy Management System	EMS	It is a set of computer-aided tools that electric utility grid operators employ to monitor, regulate, and improve the operation of the generating and/or transmission systems.
33	Meter Data Management System	MDMS	A component of customer communication system also referred as billing meter which stores meter data and makes it available to the authorized systems.
38	Customer Portal	N/A	It is a service which makes webpages used by the customer to monitor their billing, prepayment, energy cost and to control customer equipment.
40	Work Management System	WMS	A system that gives project data and timelines to workers for power system infrastructure.
45	Phasor Measurement Unit	PMU	It measures the electrical properties of an electricity grid with respect to the universal time (UTC), such as phase angle, amplitude, and frequency.
46	Transmission Intelligent Electronic Device (IED)	N/A	They issue control commands to control any abnormalities in voltage, current and frequency to maintain the required level.
48	Security/ Network / System Management	N/A	It is a management device which is used to monitor and configure security, network, and system devices.

3. (**20 points**) From the NIST 7628r1 document, find answers to the following questions

    a) According to Section 10.3.6 in Volume 3, what are the four use case numbers assigned to *Plug-In Hybrid Electric Vehicles*? What are the main differences between the two categories initiated from the utility side and the other two initiated from the user side, in terms of 1) the Category/Scenario descriptions (in your own words); and 2) the *Smart Grid Characteristics*, the *Cybersecurity Objectives/Requirements*, and the *Potential Stakeholder Issues* (according to the tables)?

    b) According to Table H-2 in Volume 3, what is the difference between the Attributes applied to Logical Interface Categories 1 and 2? Why are these differences, according to your opinion?

    c) Find the table in Volume 2 and fill out the description of *Information Potentially Available Through the Smart Grid* for the following data elements:

Data Element	**Description**
Meter reading	
Financial information	
Lifestyle	
Distributed resources	
Meter Unique Identifiers	

a) As per the section 10.3.6 volume 3, the following are the four use cases assigned to Plug-In Hybrid Electric Vehicles

1) Customer connects PHEV to Energy Portal.
2) Customer connects PHEV to Energy Portal and participates in “Smart” (Optimized) Charging.
3) Customer receives and responds to Discrete Demand Response Events
4) Customer receives and responds to Utility Price Signals

In the above mentioned four use cases the first two use cases are initiated from the utility side and the other two are initiated from the user side.

1) Categories wise all the four use cases are same; their main intention is that the EV's are the future electric systems with a great impact on the society. Once they gain the importance the handling and the network of the EV infrastructure becomes complex like payment issues, load shifting and usage of EV as a shared resource.
   The main difference comes in the scenario where the ideas of the utility and user vary. As per initiatives from the utility, the EV's just simply plug-in to charge either on-premises or at a different location where the user travels and pay to the owner providing the power. Similarly, they also presented an idea to optimize the energy consumption at a particular time and eliminate the peaks on the electric equipment.
   From the user side, the customers should be engaged in the demand response situation where they can reverse charge the charging station with the excess of power they have during high times and receive a charging pricing data from utility to promote distributed resource program where their vehicles could provide power to the grid.
2) Utility side is more concerned about the keeping the vehicle safe with high standards, keeping the customers information private, optimize utilization, high power quality and active participation from consumers. The user side are also having the similar objectives as that of the Utility side along with improving systems availability and stability and keeping the DR messages and pricing signals more accurate and trustworthy.

b) The difference between the Attributes applied to Logical Interface Categories lies in the availability requirements (ATR 3) and the power source which is limited for primary power (ATR-17)
   1) If the availability is high, we can have continuous power distribution without any interventions, and information should be available within the time frames specified in logical interface 1, with an unrestricted power supply and no bandwidth limits.
   2) According to the second logical interface and ATR 3 and ATR-17, if there is low availability, there will be limited power sources and it cannot have the same bandwidth throughout the distribution, and some devices will go to sleep between activities, resulting in some bandwidth and power distribution constraints.

c)

Data Element	**Description**
Meter reading	Energy consumption (kWh) recorded between 15 to 60 minutes interval or even shorter during the current billing cycle.
Financial information	History of the late payments or failures to pay and past meter readings and bills.
Lifestyle	Depends upon the different appliances' usage, when home is occupied and unoccupied and when occupants are awake and asleep.
Distributed resources	Operational status, usage patterns, presence of storage devices or on-site generation, net supply from the grid and the consumption too.
Meter Unique Identifiers	There is internet protocol address for the meter.

4. (**25 points**) A one-line diagram of a 3-bus power system is shown below. Assume that we have one meter installed on each line to measure the power flows. For bus i and j connected by a line, the power flow P_{ij}, the reactance X_{ij}, and voltage angles θ_i, θ_j are considered to approximately follow the relation below when no noise is considered:

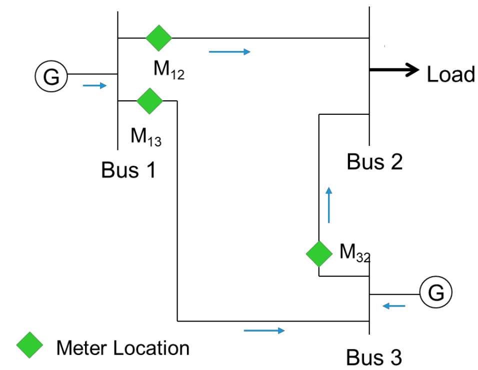
$$P_{ij} = (\theta_i - \theta_j)/X_{ij}$$

The line reactance has been measured in advance as:

$$X_{12} = 0.50\ p.u.$$
$$X_{13} = 0.10\ p.u.$$
$$X_{32} = 0.25\ p.u.$$

The meter readings have been reported as:

$$\mathrm{M}_{12} = 0.60\ p.u.$$
$$\mathrm{M}_{13} = 0.05\ p.u.$$
$$\mathrm{M}_{32} = 0.40\ p.u.$$



Solve the questions below.

a) Assume that $\theta_1 = 0$ is the reference angle. Using different pairs of meter readings specified below, solve the following questions:
   i. Find the values of θ_2, θ_3, and P_{32} using only the readings M_{12} and M_{13};
   ii. Find the values of θ_2, θ_3, and P_{13} using only the readings M_{12} and M_{32};
   iii. Find the values of θ_2, θ_3, and P_{12} using only the readings M_{13} and M_{32}.

b) Let $\mathbf{z} = [M_{12}, M_{13}, M_{32}]^T$ be the measurement vector and $\mathbf{x} = [\theta_1, \theta_2, \theta_3]^T$ be the state variables, where T indicates the vector/matrix transpose. Then from the ideal case $\mathbf{z} = \mathbf{Hx}$ when there is no noise, we have:

$$\begin{bmatrix} M_{12} \\ M_{13} \\ M_{32} \end{bmatrix} = \begin{bmatrix} P_{12} \\ P_{13} \\ P_{32} \end{bmatrix} = \mathbf{H} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}, \text{where } \mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$$

   Now, based on the relation $P_{ij} = (\theta_i - \theta_j)/X_{ij}$, find the entries h_{ij} in the 3-by-3 matrix $\mathbf{H}$.

c) As we assume $\theta_1 = 0$ as the reference angle, we do not need to estimate θ_1, so the state variables to be estimated are only $\mathbf{x}' = [\theta_2, \theta_3]^T$. For $\mathbf{z} = \mathbf{Hx}$, this means the column in $\mathbf{H}$ corresponding to the coefficients of θ_1 should be removed. According to the description above, find the 3-by-2 Jacobian matrix $\mathbf{H}'$, when the column in $\mathbf{H}$ corresponding to θ_1 is removed.

d) Let $\mathbf{R} = [\sigma_{ij}^2]$ be the 3-by-3 covariance matrix of the additive white Gaussian noise $\mathbf{n}$, where σ_{ii}^2 is the variance of noise of meter i and σ_{ij}^2 $(i \neq j)$ is the covariance between noises on meters i and j. Normally, we assume the noises on different meters are independent, so the covariance $\sigma_{ij}^2 = 0$ for $i \neq j$; we also know from factory tests that the variances of noise on the three meters are: $\sigma_{11}^2 = 0.05$ (for M_{12}), $\sigma_{22}^2 = 0.045$ (for M_{13}) and $\sigma_{33}^2 = 0.05$ (for M_{32}). According to the description above, find the covariance matrix $\mathbf{R}$ by specifying all its entries σ_{ij}^2 in the matrix form.

e) Now with $\mathbf{H}'$, $\mathbf{R}$, and $\mathbf{z}$ from **Questions 2-4**, the weighted least square solution will be given by the formula $\hat{\mathbf{x}} = (\mathbf{H}'^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{H}')^{-1}\mathbf{H}'^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{z}$. Use MATLAB, Excel, or any other computing program that can solve the matrix inverse to find $\mathbf{R}^{-1}$, $(\mathbf{H}'^{\mathrm{T}}\mathbf{R}^{-1}\mathbf{H}')^{-1}$, and finally, the state variable estimate $\hat{\mathbf{x}}$.

Solution:

a) Given the values,

i) Line reactance which is measured in advance

$X_{12} = 0.5$ p.u.

$X_{13} = 0.1$ p.u.

$X_{32} = 0.25$ p.u.

Meter readings are:

$M_{12} = 0.6$ p.u

$M_{13} = 0.05$ p.u.

$M_{32} = 0.40$ p.u.

$$P_{ij} = (\theta_i - \theta_j)/X_{ij}$$

$M_{12} = (\theta_1 - \theta_2)/X_{12}$

$0.60 = (0 - \theta_2)/0.50$

$\Rightarrow 0.3 = 0 - \theta_2$

$\Rightarrow \underline{\theta_2 = -0.3}$

$M_{13} = (\theta_1 - \theta_3)/X_{13}$

$0.05 = (0 - \theta_3)/0.1$

$\Rightarrow 0.005 = 0 - \theta_3$

$\Rightarrow \underline{\theta_3 = -0.005}$

Similarly $P_{32} = (\theta_3 - \theta_2)/X_{32}$

$\Rightarrow (-0.005 + 0.3)/0.25$

$\Rightarrow (0.295)/0.25$

$\underline{P_{32} \Rightarrow 1.18 \text{ p.u.}}$

ii) Given the values

$M_{12} = (\theta_1 - \theta_2)/X_{12}$

$0.60 = (0 - \theta_2)/0.50$

$\Rightarrow 0.3 = 0 - \theta_2$

$\underline{\theta_2 = -0.3}$

$$M_{32} = (\theta_3 - \theta_2)/X_{32}$$
$$0.40 = (\theta_3 - (-0.3))/0.25$$
$$\Rightarrow 0.1 = \theta_3 + 0.3$$
$$\Rightarrow \theta_3 = -0.2$$

Similarly, $P_{ij} = (\theta_i - \theta_j)/X_{ij}$

$$P_{13} = (\theta_1 - \theta_3)/X_{13}$$
$$P_{13} = (0 - (-0.2))/0.1$$
$$P_{13} = 2 \text{ p.u.}$$

iii) Given the values,

$$M_{13} = (\theta_1 - \theta_3)/X_{13}$$
$$0.05 = (0 - \theta_3)/0.10$$
$$\Rightarrow 0.005 = 0 - \theta_3$$
$$\Rightarrow \theta_3 = -0.005$$

$$M_{32} = (\theta_3 - \theta_2)/X_{32}$$
$$0.40 = (-0.005 - \theta_2)/0.25$$
$$\Rightarrow 0.10 = -0.005 - \theta_2$$
$$0.005 + \theta_2 = -0.10$$
$$\theta_2 = -0.10\cancel{0}5$$

Similarly,

$$P_{ij} = (\theta_i - \theta_j)/X_{ij}$$
$$P_{12} = (\theta_1 - \theta_2)/X_{12}$$
$$P_{12} = (0 + 0.105)/0.50$$
$$P_{12} = 0.21 \text{ P.U.}$$

b) Given the values,

Line reactance values has been calculated

$X_{12} = 0.5$ p.u.

$X_{13} = 0.1$ p.u

$X_{32} = 0.25$ p.u

$$\begin{bmatrix} P_{12} \\ P_{13} \\ P_{32} \end{bmatrix} = H \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}$$

we Know that $H = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix}$

$$\Rightarrow \begin{bmatrix} P_{12} \\ P_{13} \\ P_{32} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}$$

$$\begin{bmatrix} P_{12} \\ P_{13} \\ P_{32} \end{bmatrix} = \begin{bmatrix} h_{11}\theta_1 & h_{12}\theta_2 & h_{13}\theta_3 \\ h_{21}\theta_1 & h_{22}\theta_2 & h_{23}\theta_3 \\ h_{31}\theta_1 & h_{32}\theta_2 & h_{33}\theta_3 \end{bmatrix}$$

$$\Rightarrow P_{12} = h_{11}\theta_1 + h_{12}\theta_2 + h_{13}\theta_3$$
$$P_{13} = h_{21}\theta_1 + h_{22}\theta_2 + h_{23}\theta_3$$
$$P_{32} = h_{31}\theta_1 + h_{32}\theta_2 + h_{33}\theta_3$$

We Know that $P_{ij} = (\theta_i - \theta_j)/x_{ij}$

$$P_{12} = (\theta_1 - \theta_2)/x_{12}$$
$$= (\theta_1 - \theta_2)/0.50$$
$$= 2\theta_1 - 2\theta_2$$

$$P_{13} = (\theta_1 - \theta_3)/X_{13}$$
$$= (\theta_1 - \theta_3))\, 0.10$$
$$= 10\theta_1 - 10\theta_3$$

$$P_{32} = (\theta_3 - \theta_2)/X_{32}$$
$$= (\theta_3 - \theta_2)/0.25$$
$$= 4\theta_3 - 4\theta_2$$

$$\begin{bmatrix} P_{12} \\ P_{13} \\ P_{32} \end{bmatrix} = \begin{bmatrix} 2 & -2 & 0 \\ 10 & 0 & -10 \\ 0 & -4 & 4 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}$$

$$\Rightarrow \quad H = \begin{bmatrix} 2 & -2 & 0 \\ 10 & 0 & -10 \\ 0 & -4 & 4 \end{bmatrix}$$

c) Given that $Z = HX$

when we use,

$\theta_1 = 0$ as reference angle.

State variables to be estimated are only $X' = [\theta_2, \theta_3]^T$

If we remove the column H corresponding to the Coefficients of θ_1

$$Z' = H'X'$$

$$H = \begin{bmatrix} 2 & -2 & 0 \\ 10 & 0 & -10 \\ 0 & -4 & 4 \end{bmatrix}$$

$$Z' = \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} \quad \& \quad H' = \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix}$$

d.) Given the values,

$$\sigma_{11}^2 = 0.05$$
$$\sigma_{22}^2 = 0.045$$
$$\sigma_{33}^2 = 0.05$$

Covariance $\sigma^2 = 0$ for $i \neq j$,

$$\sigma_{12}^2 = \sigma_{13}^2 = \sigma_{21}^2 = \sigma_{23}^2 = \sigma_{31}^2 = \sigma_{32}^2 = 0$$

Covariance Matrix,

$$R = \begin{bmatrix} \sigma_{11}^2 & \sigma_{12}^2 & \sigma_{13}^2 \\ \sigma_{21}^2 & \sigma_{22}^2 & \sigma_{23}^2 \\ \sigma_{31}^2 & \sigma_{32}^2 & \sigma_{33}^2 \end{bmatrix}$$

$$\Rightarrow \quad R = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.045 & 0 \\ 0 & 0 & 0.05 \end{bmatrix}$$

e.) we know that value of

$$R = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.045 & 0 \\ 0 & 0 & 0.05 \end{bmatrix}$$

so $R^{-1} = \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.045 & 0 \\ 0 & 0 & 0.05 \end{bmatrix}^{-1} = \begin{bmatrix} 20 & 0 & 0 \\ 0 & 22.22 & 0 \\ 0 & 0 & 20 \end{bmatrix}$

Now remove the coefficients of θ_1,

$H = \begin{bmatrix} 2 & -2 & 0 \\ 10 & 0 & -10 \\ 0 & -4 & 4 \end{bmatrix}$ replaced by $H' = \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix}$

Now $(H^T R^{-1} H)^{-1} = \left(\begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix}^T \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.045 & 0 \\ 0 & 0 & 0.05 \end{bmatrix}^{-1} \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix} \right)^{-1}$

$$\Rightarrow \left(\begin{bmatrix} -2 & 0 & -4 \\ 0 & -10 & 4 \end{bmatrix} \begin{bmatrix} 20 & 0 & 0 \\ 0 & 22.22 & 0 \\ 0 & 0 & 20 \end{bmatrix} \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix} \right)^{-1}$$

$$\Rightarrow \left(\begin{bmatrix} -40 & 0 & -80 \\ 0 & -222.22 & 80 \end{bmatrix} \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix} \right)^{-1}$$

$$\Rightarrow \begin{bmatrix} 400 & -320 \\ -320 & 2542 \end{bmatrix}^{-1}$$

$$\Rightarrow \begin{bmatrix} 0.00278 & 0.00034 \\ 0.00034 & 0.00043 \end{bmatrix}$$

State variable $\hat{x} = (H^T R^{-1} H)^{-1} H^T R^{-1} z$

$$\Rightarrow \begin{bmatrix} 0.00278 & 0.00034 \\ 0.00034 & 0.00043 \end{bmatrix} \begin{bmatrix} -2 & 0 \\ 0 & -10 \\ -4 & 4 \end{bmatrix}^T \begin{bmatrix} 0.05 & 0 & 0 \\ 0 & 0.045 & 0 \\ 0 & 0 & 0.05 \end{bmatrix}^{-1} \begin{bmatrix} 0.21 \\ 2 \\ 1.18 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 0.00278 & 0.00034 \\ 0.00034 & 0.00043 \end{bmatrix} \begin{bmatrix} -2 & 0 & -4 \\ 0 & -10 & 4 \end{bmatrix} \begin{bmatrix} 20 & 0 & 0 \\ 0 & 22.22 & 0 \\ 0 & 0 & 20 \end{bmatrix} \begin{bmatrix} 0.21 \\ 2 \\ 1.18 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} -0.00556 & -0.0034 & -0.00976 \\ -0.00068 & -0.0043 & 0.00036 \end{bmatrix} \begin{bmatrix} 20 & 0 & 0 \\ 0 & 22.22 & 0 \\ 0 & 0 & 20 \end{bmatrix} \begin{bmatrix} 0.21 \\ 2 \\ 1.18 \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} -0.1112 & -0.075548 & -0.1952 \\ -0.0136 & -0.095546 & 0.0072 \end{bmatrix} \begin{bmatrix} 0.21 \\ 2 \\ 1.18 \end{bmatrix}$$

$$\hat{x} \Rightarrow \begin{bmatrix} -0.4047 \\ -0.1854 \end{bmatrix}$$

5. (**15 points**) An intrusion detector has been designed to monitor station bus traffic in an IEC 61850 substation and two tests (#1 and #2) have been conducted.

   In **Test #1**, the following numbers was reported. Answer questions (a)-(d) based on the reported numbers:
   - 30,000 samples were collected and analyzed, which had been manually labelled as *negative* for normal samples and *positive* for intrusion samples; these labels are unknown to the detector;
   - In the test, the detector predicted 14,580 samples to be negative and 15,420 samples to be positive;
   - After comparing the predicted and actual labels of samples, it was found that 35 of the samples predicted to be negative were in fact positive, and 70 of the samples flagged as positive were actually negative.

   Answer questions (a)-(d) based on the reported numbers in Test #1.

   a. Find the numbers of true positives (TP), false positives (FP), false negatives (FN), and true negatives (TN) in the table below:

Confusion Matrix of Test #1

Predicted \ Actual	**Positive**	**Negative**
Positive		
Negative		

   b. Find the accuracy, false positive rate, and false negative rate of the detector.

   c. Find the balanced accuracy, precision, recall, and F-1 score of the detector.

   In **Test #2**, the same intrusion detector was tested on a smaller dataset of 30,000 samples from another hardware-in-the-loop testbed; the performance is shown in the table below.

Confusion Matrix of Test #2

Predicted\Actual	**Positive**	**Negative**
Positive	2,775	55
Negative	50	27,120

   Answer the following question based on the reported numbers in Test #2:

   d. Calculate the values of the same metrics in (b)-(c).

Solution:

a) Given the values,

Number of collected and analyzed n = 30000
Number of samples predicted as negative = 14,580
Number of samples predicted as positive = 15,420

False Negatives (FN) = 35
False Positives (FP) = 70

Actual positives in positive sample => True positives (TP) = 15420 – 70 = 15350
Actual Negatives in negative sample => True Negatives (TN) = 14580 – 35 = 14545

Predicted \ Actual	**Positive**	**Negative**
Positive	15350	70
Negative	35	14545

b) Accuracy = (TP + TN) / Total samples
= (15350 + 14545) / 30000

= 0.9965

False positive rate of the detector = FP/ FP+TN

= 70 / (70 + 14545) = 0.0047

False negative rate of the detector = FN / FN+TP

= 35/ (35 + 15350) = 0.00227

c) Balanced accuracy = (TP/P + TN/N) / 2
= (15350 / 15420 + 14545 / 14580) / 2
= 0.995+0.997/2
= 1.992 / 2
= 0.996

Precision = TP / (TP + FP)
= 15350 / (15350 + 70)
= 0.9954

Recall = TP / (TP+FN)
= 15350 / (15350 + 35)
= 0.9977

F-1 score of the detector = 2 * precision * Recall / (precision + Recall)
= 2 * 0.9954 * 0.9977 / (0.9954 + 0.9977)
= 1.986 / 1.9931
= 0.9964

d) Given the values

Predicted\Actual	Positive	Negative
Positive	2,775	55
Negative	50	27,120

True Positive (TP) = 2775
True Negative (TN) = 27120
False positive (FP) = 55
False Negative (FN) = 50

Predicted as positive P = TP +FP = 2775 + 50 = 2825
Predicted as negative N = TN+ FN = 55 + 27120 = 27175

Accuracy = (TP + TN) / Total samples
= (2275 + 27120) / 30000

= 0.9965

False positive rate of the detector = FP/ FP+TN

= 55 / (55 +27120) = 0.0020

False negative rate of the detector = FN / FN+TP

= 50/ (50 +2775) = 0.0176

Balanced accuracy = (TP/P + TN/N) / 2

= (2775/ 2825 + 27120/ 27175) / 2
= 0.9823 +0.9998/2
= 1.9821 / 2
= 0.991

Precision = TP / (TP + FP)
= 2775/ (2775 + 55)
= 0.9805

Recall = TP / (TP+FN)
= 2775 / (2775 + 50)
= 0.9823

F-1 score of the detector = 2 * precision * Recall / (precision + Recall)
= 2 * 0.9805* 0.9823/ (0.9805 + 0.9823)
= 1.926 / 1.9628
= 0.9812