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# Respimatic 100




*Sunil Nanda (PARC)*

# US and INDIA IP Protection

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(54) **VENTILATOR**

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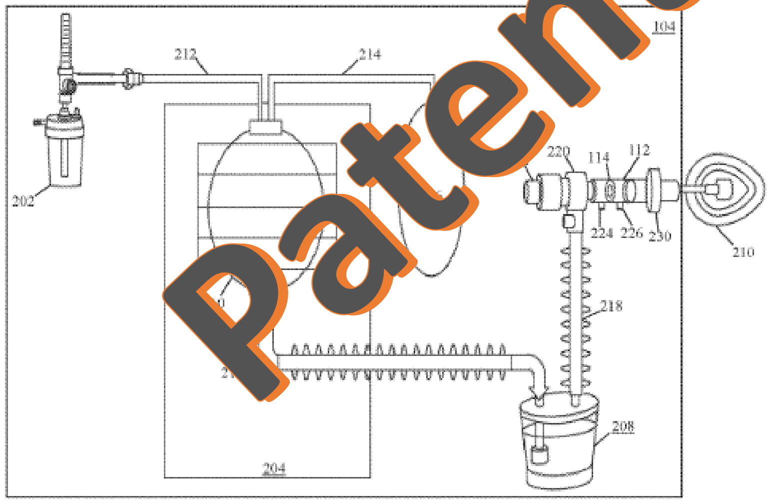
(57) **ABSTRACT**


Provided is a ventilator that includes a breathing system, a mechanical system coupled to breathing system, and a control system coupled to breathing system and mechanical system. The control system includes pressure sensors, processing circuitry, and memory configured to store a look-up table. The processing circuitry receives a set of values for plurality of parameters, identifies a compression value from a plurality of compression values in the look-up table based on the received set of values. The processing circuitry causes the mechanical system to compress a bag valve of the breathing system in accordance with the identifi... sion value. The compression of the bag ... gaseous inhalant to flow through the breathi... m wit... a time-interval. The processing circuitry ... actual volume of the gaseous inhalant and itera... fies the compression value of the bag valve to ... desired volume of the gaseous inhalant.


Patent Pending

$$Q \propto \sqrt{\frac{(P_{G1}-P_{G2})}{(P_{G1}+P_{G2})+2*Patmosphere}}$$

An important and necess... simplifi...n is t... and $P_{G2}$ encountered in our system are of the order of tens of cmH$_2$O wh... mosp... is of ... rder of a thousand cmH$_2$O of pressure. At sea level, Patmosphere is a... 1000... O. Even at an altitude of 15,000 feet, Patmosphere is appr...ely 60... . On the other hand, the $P_{G1}$ and $P_{G2}$ in the system range from 1 ... 60...

...$P_{G1}$ ...) term is negligible compared to (2* Patmosphere ) , even more so since it ...ed by a square root. The flow equation can be simplified to the one below.

$$Q \propto \sqrt{\frac{(P_{G1}-P_{G2})}{Patmosphere}}$$

Recalling *Equation 2* from the theory section above, this equation can be recast as below given that the orifice characteristics and pressure tap locations are the same for every system.

$$Q = C*\frac{\sqrt{(P_{G1}-P_{G2})}}{\sqrt{(Patmosphere)}} \quad where \;\; C = f(Re) \text{ Reynold's number}$$

At a given geographical location, Patmosphere is also a constant. So, the above equation further reduces to the one below.

$$Q = \left(\frac{C}{\sqrt{Patmoshpere}}\right) * \sqrt{(P_{G1}-P_{G2})}$$

The equation needs further simplification to ease the computation burden of the square root computation for and inexpensive micro-controller. The constraints are as below.

CONFIDENTIAL

# *Setting the Context*

The Motivation

The Problem Statement

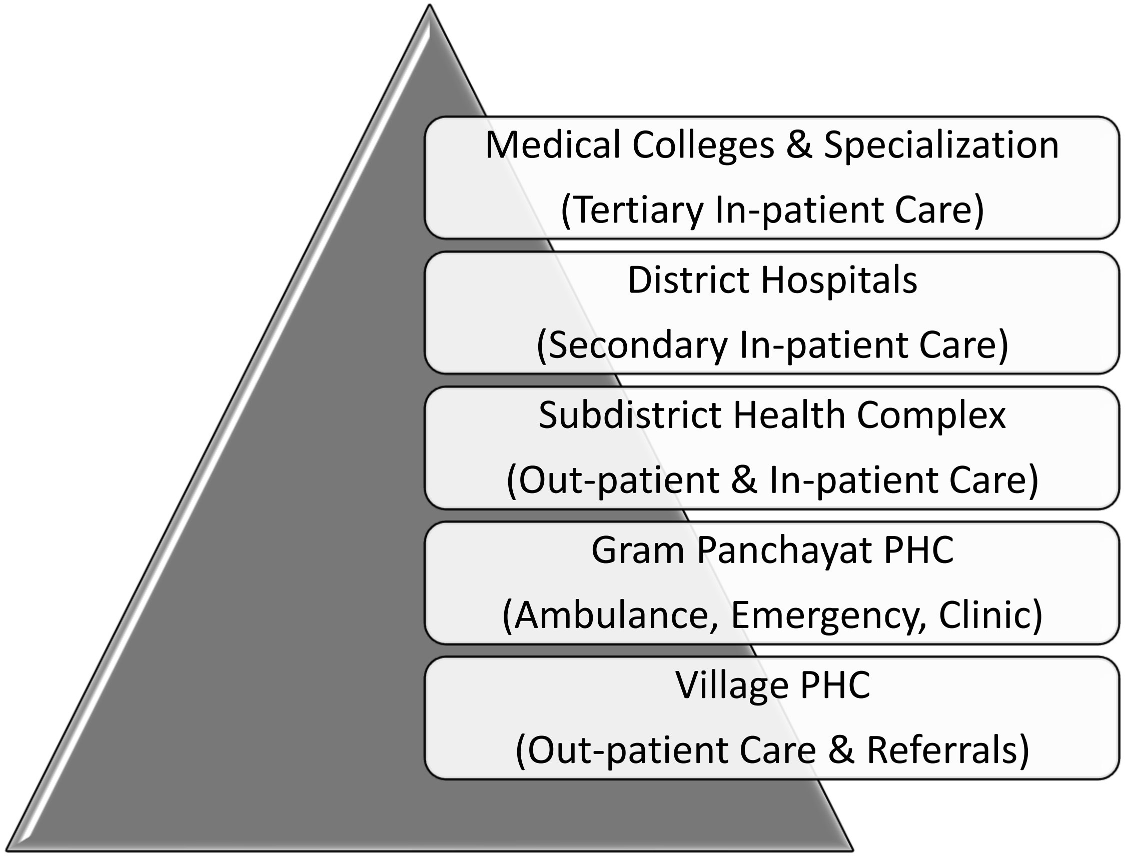
# RESPIMATIC 100
*(Patent Pending)*

*Is it right for you?*

- *Need adult, non-invasive respiratory support?*
- *Support from Initiation to Weaning?*
- *No compressed air or piped Oxygen?*
- *Connect to $O_2$ Cylinder or Concentrator?*
- *Full range of Respiration parameters?*
- *Breath Synchronization for Patient Comfort?*
- *Remote monitoring capability?*
- *Handle harsh-uncontrolled Environment?*
- *Easy-to-use System?*
- *Budget Friendly?*

NO PROBLEM!

# The Motivation
## *Serve the Bottom of the Pyramid*




A robust, portable respiration support system for remote Primary Health Centers in India and other developing countries.

A system that works in a harsh uncontrolled environment and as a travel ventilator without piped compressed air or piped oxygen.

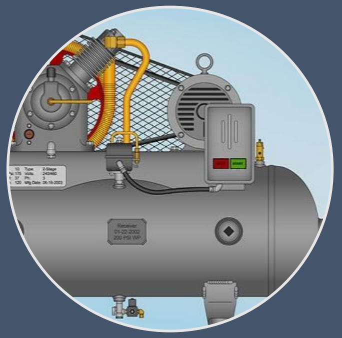
A system that requires minimum training.

Fits budget of the bottom of the pyramid.

# 2 BIG Challenges

- Lack of Affordability leading to Scarcity
- Lack of Skilled Practitioners

# Observations on Ventilator Evolution



Iron Lung Age

Pneumatic Age

µController Age

Smart "E"-Age

## Most-used Ventilation Modes have not changed

- Volume and Pressure Control
- Control BPM, I/E, VT and PS
- Monitor pressures and flow
- Safety Alarm systems

## Diminishing Returns from what has evolved …

- Exotic Ventilation modes
- Multitude of Sensors
- Fancy Touch-screen LCD Displays

# Respimatic – Respiratory Technology Revisited

## Remote Diagnosis and Monitoring (Telemedicine)

*Rural, remote areas* do not have skilled specialists

BUT *Communication Technologies* have come of age

## Leverage Time-proven Technologies

*Simplify* design and feature list

*Simplify* Human-Machine Interface

Use *Off-the-shelf* proven components

## Maintenance Breaths in case of unexpected errors

System *must never* stop delivering breaths.

Implement *Fallback* mechanism for each error scenario.

# *Respimatic 100 Details*

System Components

Technical Details

Respimatic 100 - Preliminary and Confidential

# *Our Solution RESPIMATIC 100*

4 Commonly Used Ventilation Modes

CMV, ACV, SIMV, PSV

Respiration Rate, Tidal Volume, PEEP, Pressure Support & FiO2 Controls

Volume Controlled and Pressure Supported Breaths

Mandatory & Spontaneous Breaths with Full Breath Synchronization

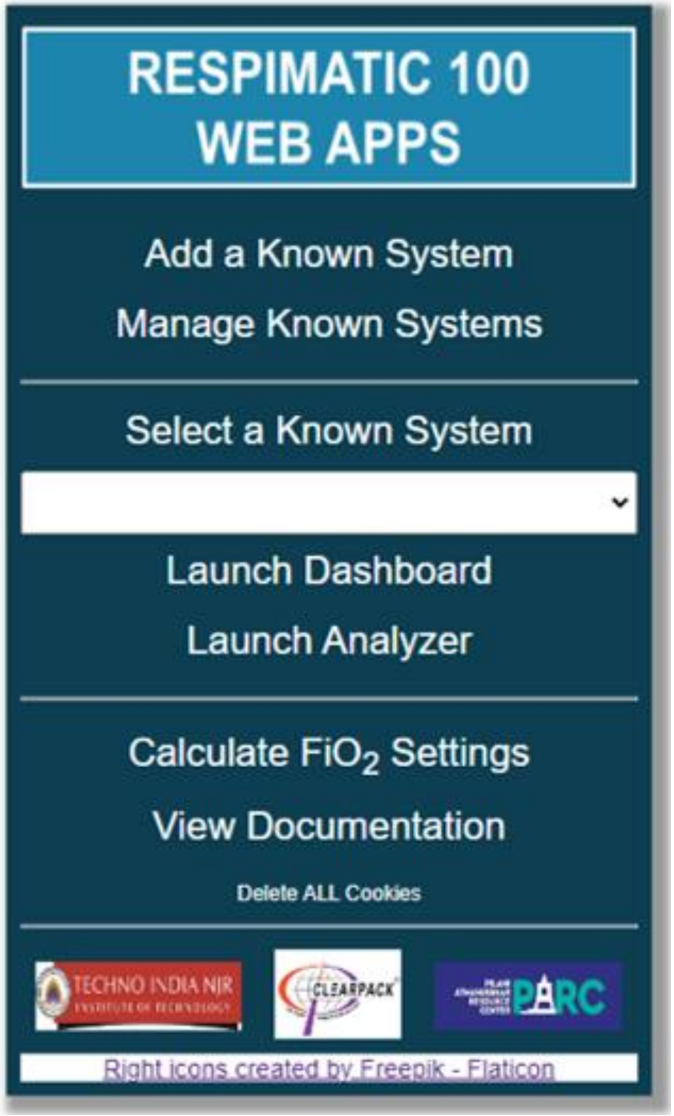
Complete set of WEB Apps

- Remote Dashboard
- Remote Recorder
- Remote Analyzer
- $FiO_2$ Calculator

Low-speed Wi-Fi sufficient

Phone Hot-spot sufficient

Uses secure HTTPS protocol




https://www.respimatic.com

# *Dashboard Snapshot View*

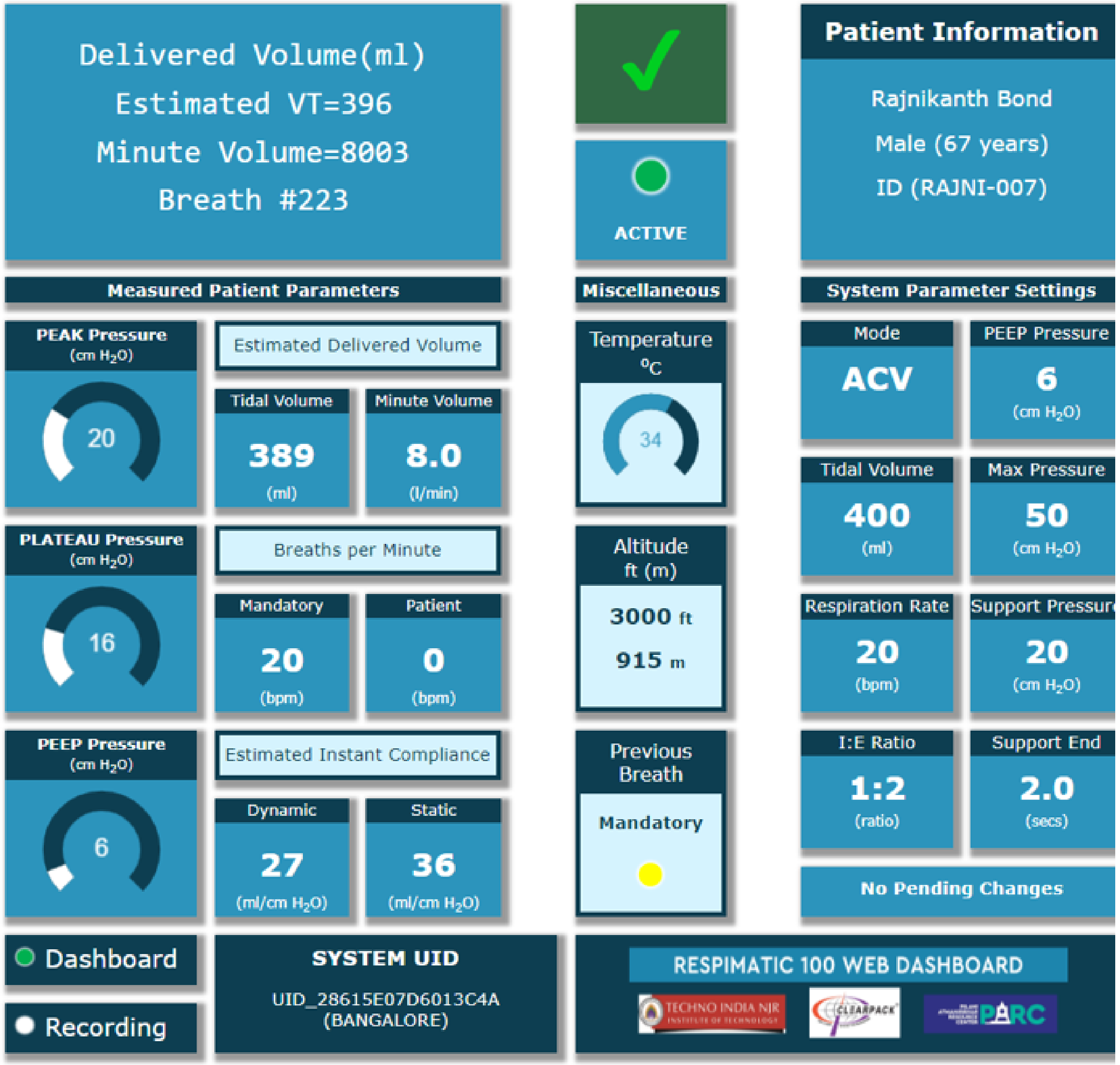
Anyone, anywhere in the world can monitor any patient via the WEB

Multiple specialists can monitor same patient

One specialist can monitor multiple patients

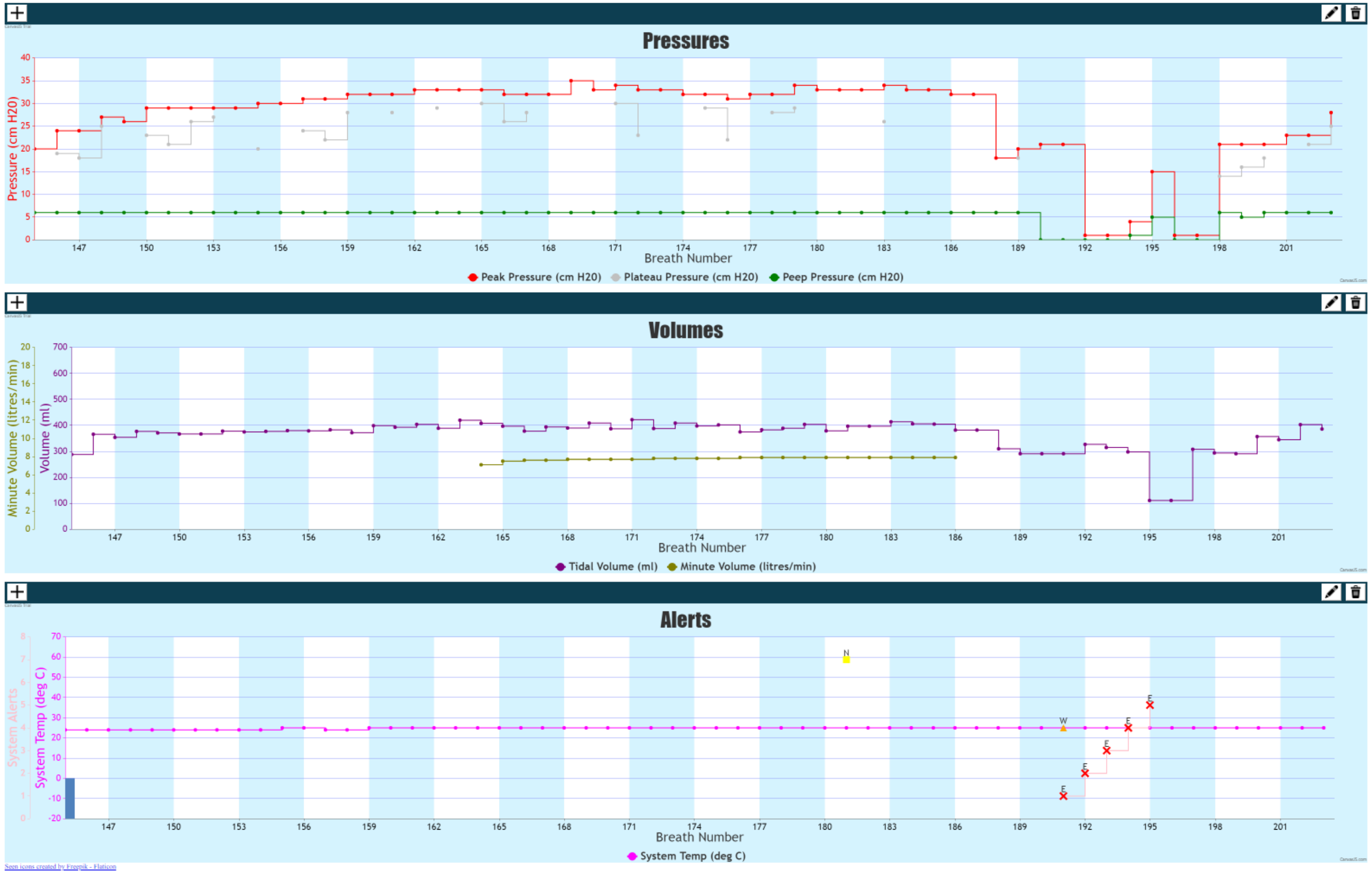
5 Dashboard views

- Snapshots
- Charts
- Statistics
- Breath Shapes
- Alerts




https://www.respimatic.com

# Dashboard
# Charts View



# Dashboard Statistics View

## Parameters Measured

| Parameter | Units | Min | Max | Avg |
|---|---|---|---|---|
| Peak Pressure | cmH20 | 1 | 35 | 28.1 |
| Plateau Pressure | cmH20 | 17 | 33 | 27.1 |
| PEEP Pressure | cmH20 | 5 | 7 | 6.0 |
| Tidal Volume Delivered | ml | 150 | 412 | 359.4 |
| Minute Volume Delivered | litres/min | 5.6 | 5.9 | 5.7 |
| Mandatory BPM | bpm | 15 | 16 | 15.2 |
| Spontaneous BPM | bpm | 0 | 1 | 0.7 |
| FIO2 | % | 50 | 50 | 50.0 |
| Instantaneous Static Compliance | ml/cmH20 | 14 | 30 | 18.4 |
| Instantaneous Dynamic Compliance | ml/cmH20 | 14 | 22 | 16.5 |
| System Temperature | degC | 29 | 30 | 29.2 |

## Miscellaneous Information

| Information | Value |
|---|---|
| Number of Breaths | 73 |
| Number of Mandatory Breaths | 56 |
| Number of Spontaneous Breaths | 17 |
| Number of Maintenance Breaths | 0 |
| Number of Missing Breaths (Comms Failure) | 0 |
| Number of Notifications | 0 |
| Number of Warnings | 2 |
| Number of Errors | 17 |

## Static Information

Patient Name: --

Patient Info: --

System Deployment Altitude: 3000 (915) ft(m)

## Parameter Settings Used

| Parameter | Units | Values |
|---|---|---|
| Ventilation Mode | mode | ACV,CMV |
| Tidal Volume | ml | 400,300 |
| Respiration Rate | bpm | 15,20 |
| I:E Ratio | ratio | 1:3,1:2 |
| PEEP Pressure | cmH20 | 6 |
| Maximum Pressure | cmH20 | 50 |
| Support Pressure | cmH20 | 25 |
| Support Pressure Termination | %flow,secs | F20% |
| FIO2 | % | 50 |

## Sequence of Parameter Combinations

| MODE | VT | RR | I:E | PEEP | PMAX | PS | TPS | FIO2 | # of BREATHS | Before BREATH# |
|---|---|---|---|---|---|---|---|---|---|---|
| ACV | 400 | 15 | 1:3 | 6 | 50 | 25 | F20% | 50 | 17 | 0 |
| CMV | 300 | 15 | 1:2 | 6 | 50 | 25 | F20% | 50 | 16 | 17 |
| ACV | 400 | 15 | 1:3 | 6 | 50 | 25 | F20% | 50 | 21 | 33 |
| ACV | 400 | 20 | 1:3 | 6 | 50 | 25 | F20% | 50 | 19 | 54 |

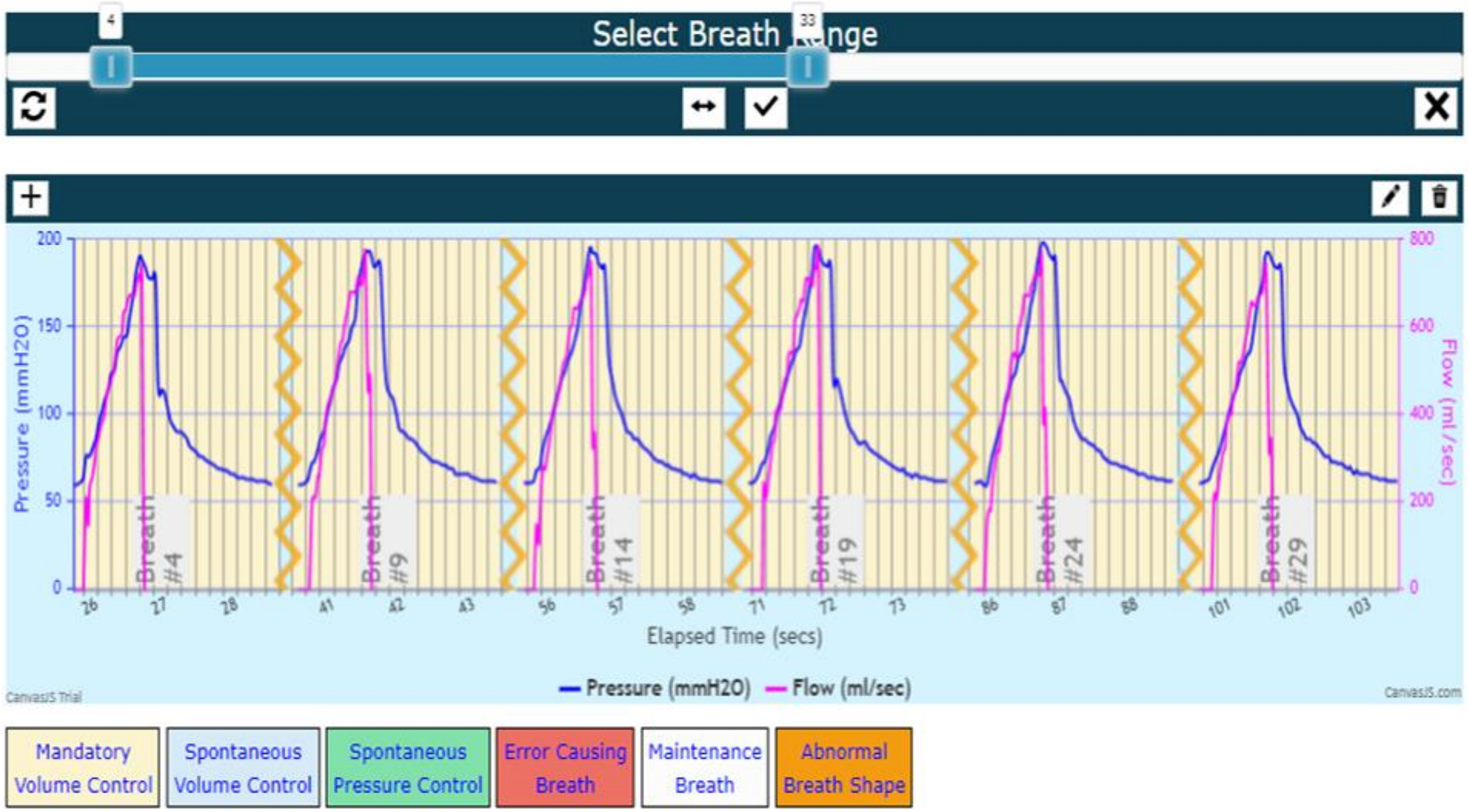
# *Dashboard Waveforms View*

Pressure and Flow Graphs

For Selected Breaths

Periodic Display

Display on demand



# *Dashboard Alerts View*

## Session Errors

ERROR #1 DateTime: [09-12-2022]06:55:16
Leakage in
Breathing Circuit
Switching to
Maintenance Breaths

ERROR #2 DateTime: [09-12-2022]06:55:21
[ERROR] state
Press PAUSE to show
the System state
leading to ERROR

ERROR #3 DateTime: [09-12-2022]06:55:25
Leakage in
Breathing Circuit
Maintenance mode
Deliver safe breaths

ERROR #4 DateTime: [09-12-2022]06:55:29
[ERROR] state

## Session Warnings

WARNING #1 DateTime: [09-12-2022]06:43:16
PEEP delta measured
up to -0.8 cm H20
Adjust valve/setting
YES -> Commit

WARNING #2 DateTime: [09-12-2022]06:43:19
PEEP delta measured
up to -1.0 cm H20
Adjust valve/setting
YES -> Commit

WARNING #3 DateTime: [09-12-2022]06:43:21
PEEP delta measured
up to -0.9 cm H20
Adjust valve/setting
YES -> Commit

WARNING #4 DateTime: [09-12-2022]06:55:14
PEEP delta measured

## Session Information

INFO #1 DateTime: [09-12-2022]06:45:23
1 Breath(s) missed
Info not received by
Dashboard due to
Internet packet loss

INFO #2 DateTime: [09-12-2022]06:46:26
1 Breath(s) missed
Info not received by
Dashboard due to
Internet packet loss

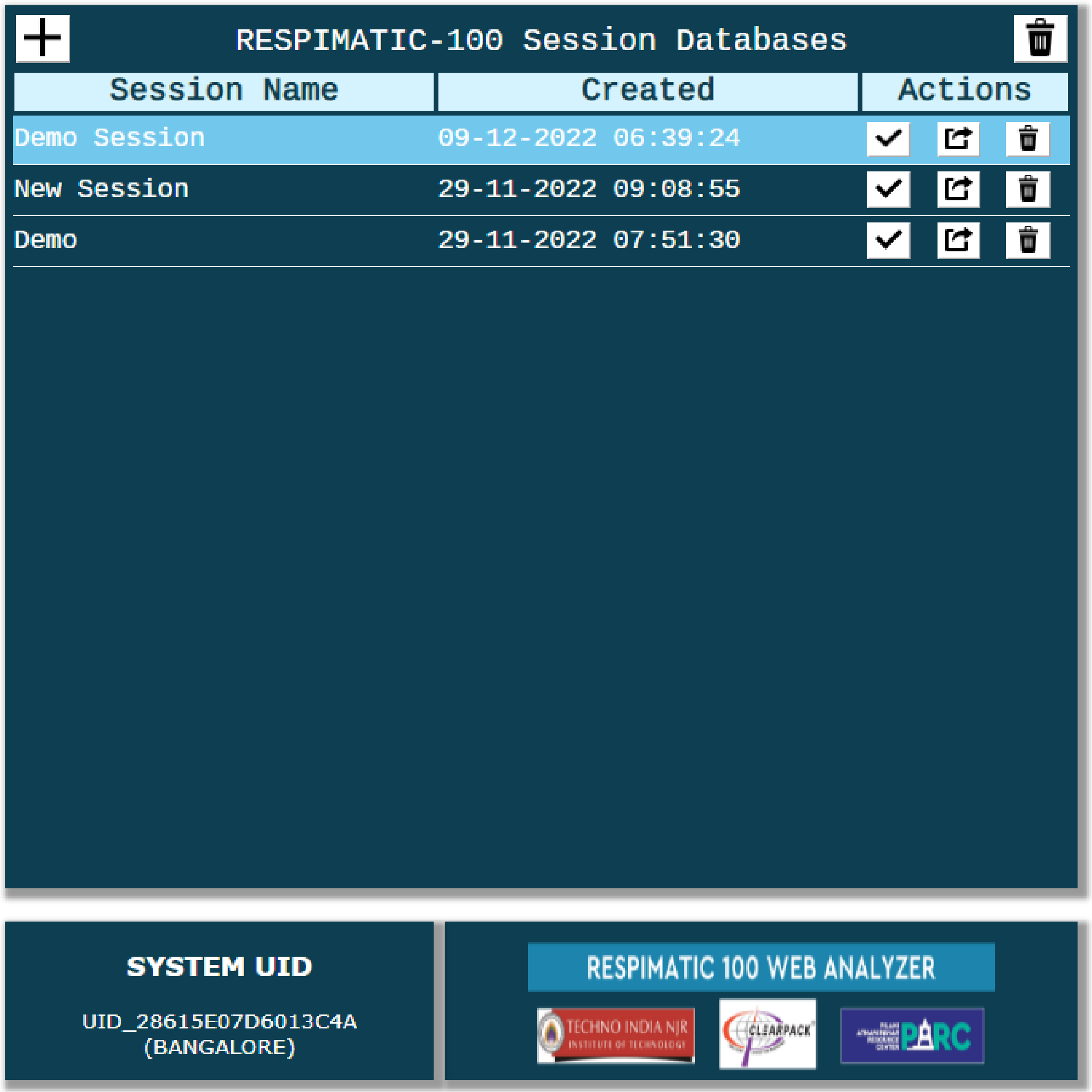
INFO #3 DateTime: [09-12-2022]06:47:17
1 Breath(s) missed
Info not received by
Dashboard due to
Internet packet loss

INFO #4 DateTime: [09-12-2022]06:47:28
1 Breath(s) missed

# *Analyzer*

Any patient Session can be recorded locally or remotely.

The recorded Session can then be analyzed off-line using the Analyzer.



# Front Panel
# The Human-Machine Interface

Simple Tactile buttons No delicate touch screen etc.

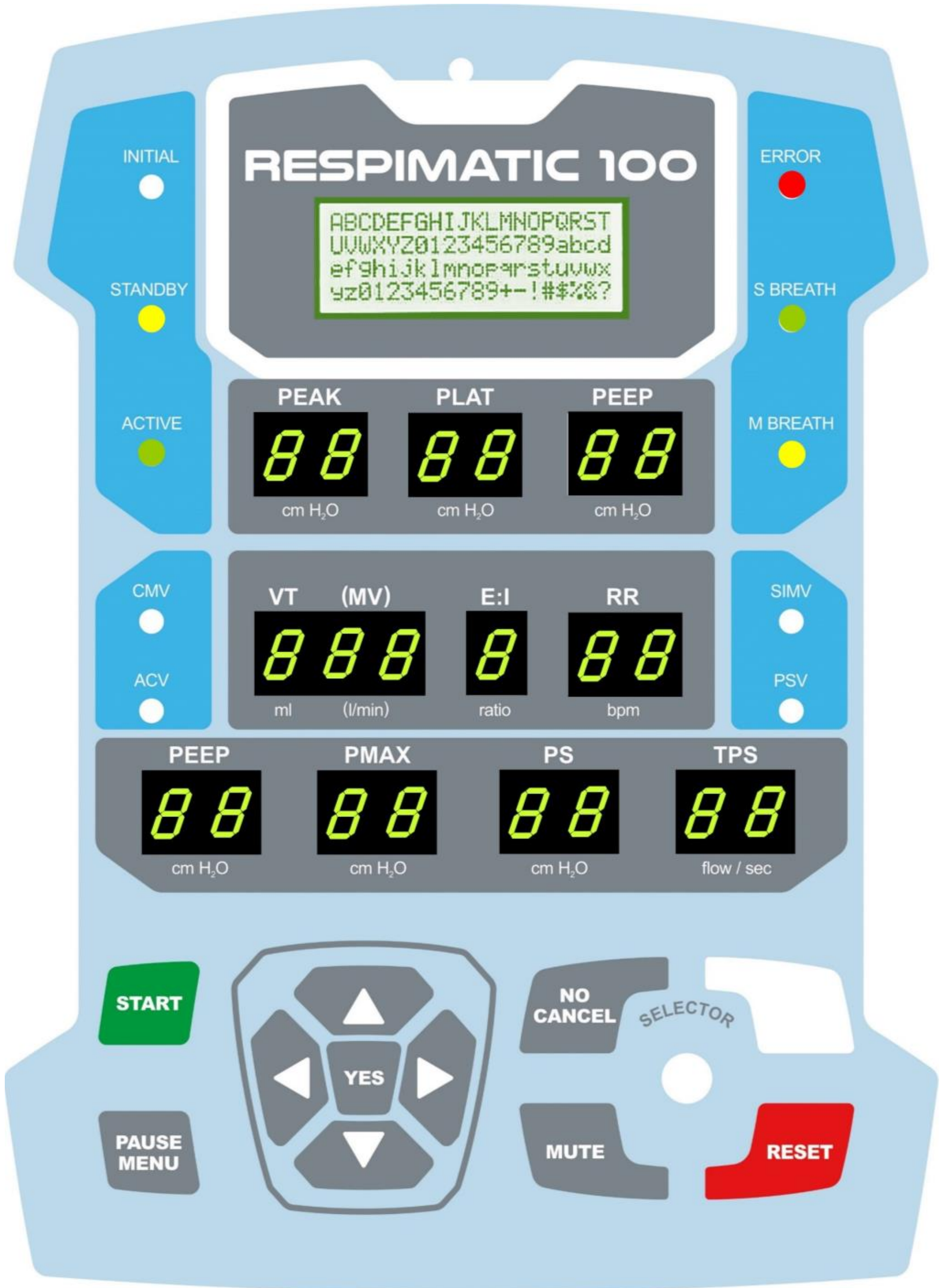
Easy to read 7-seg LED Parameters Display

Parameter selection using simple arrow buttons

4-line LCD Display for displaying Messages and Menus

Peak, Plateau, PEEP pressures displayed after each breath

Also shows Delivered Volumes, Lung Compliance, Breath types etc.

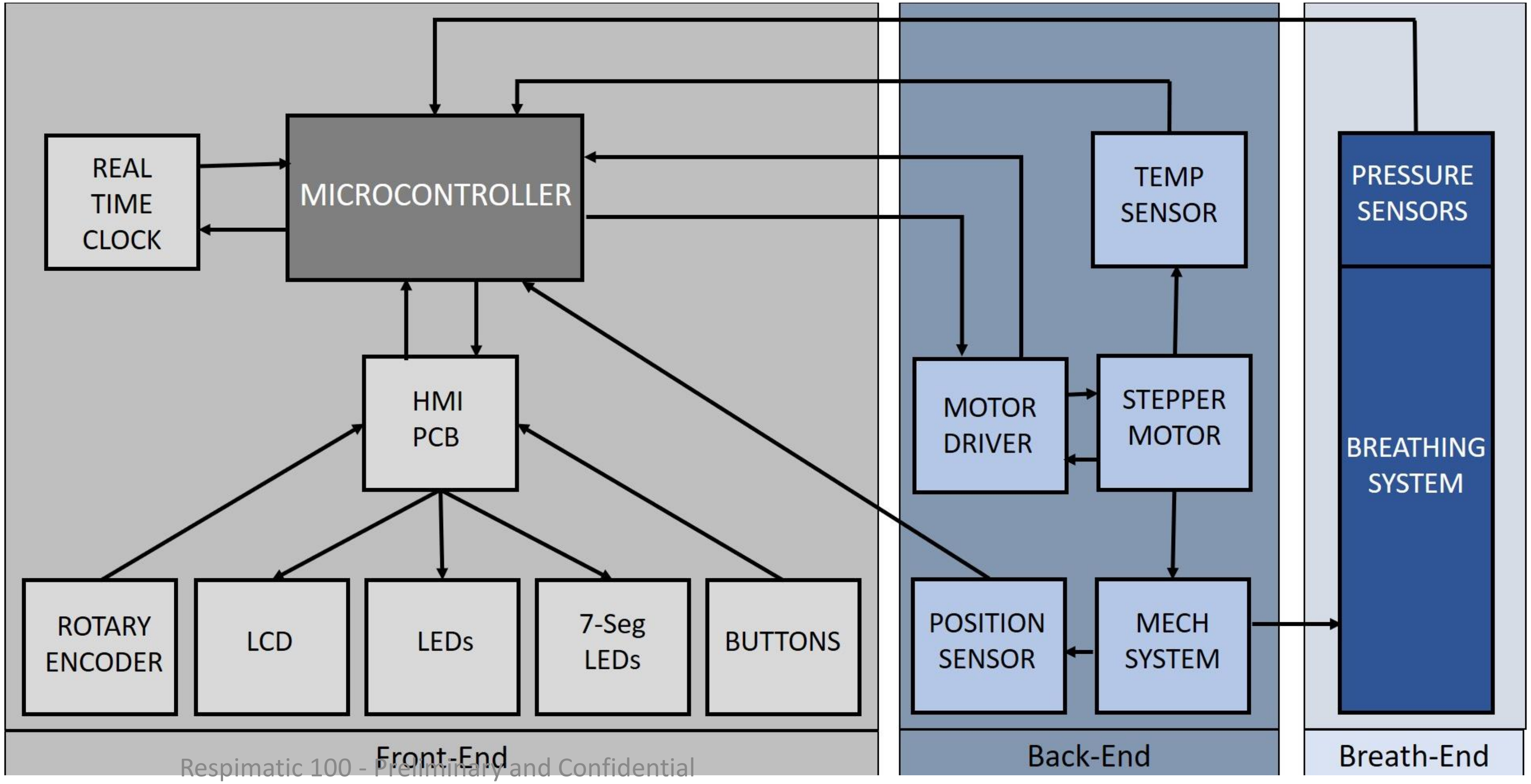


# System Architecture

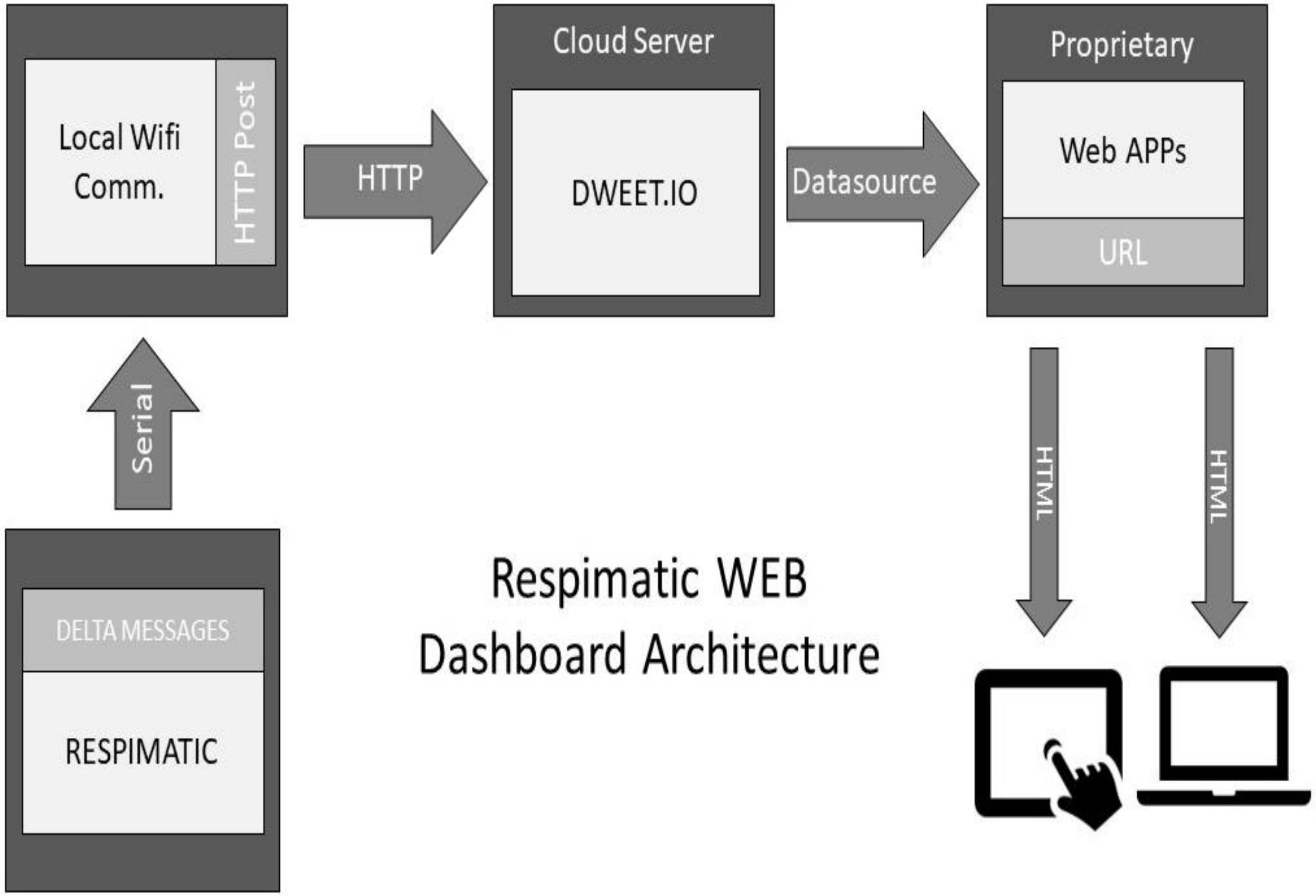
Clearly separated Frontend, Backend and Breathing system

IP is the Frontend design and Algorithms

Backend and Breathing System can have multiple avatars



# Remote WEB Architecture



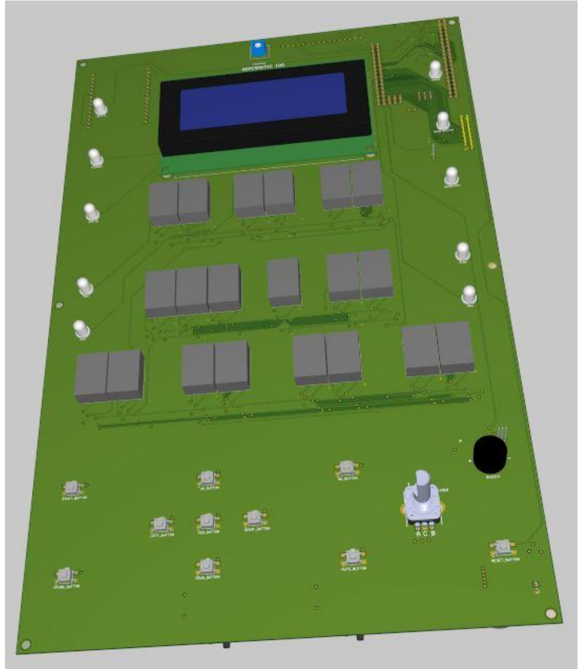
# *Respimatic 100 Under the hood*

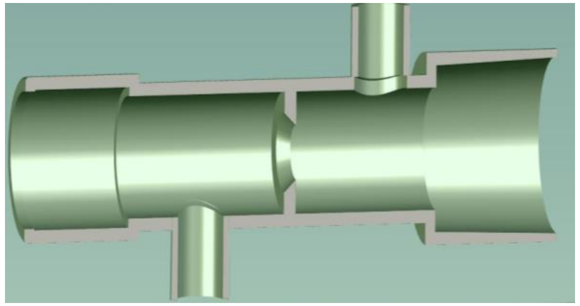
Low Production Cost

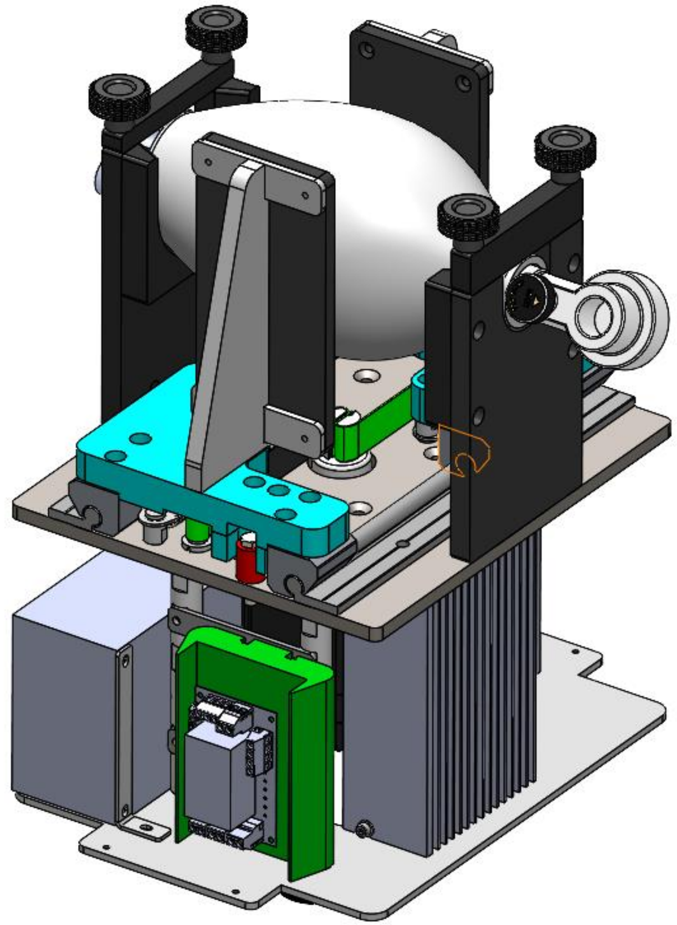
Compact and Robust

Intuitive HMI

Simple to operate







Simple Electronics COTS components

Rugged mechanical system

Essential Parameter monitoring

Full set of alarm conditions

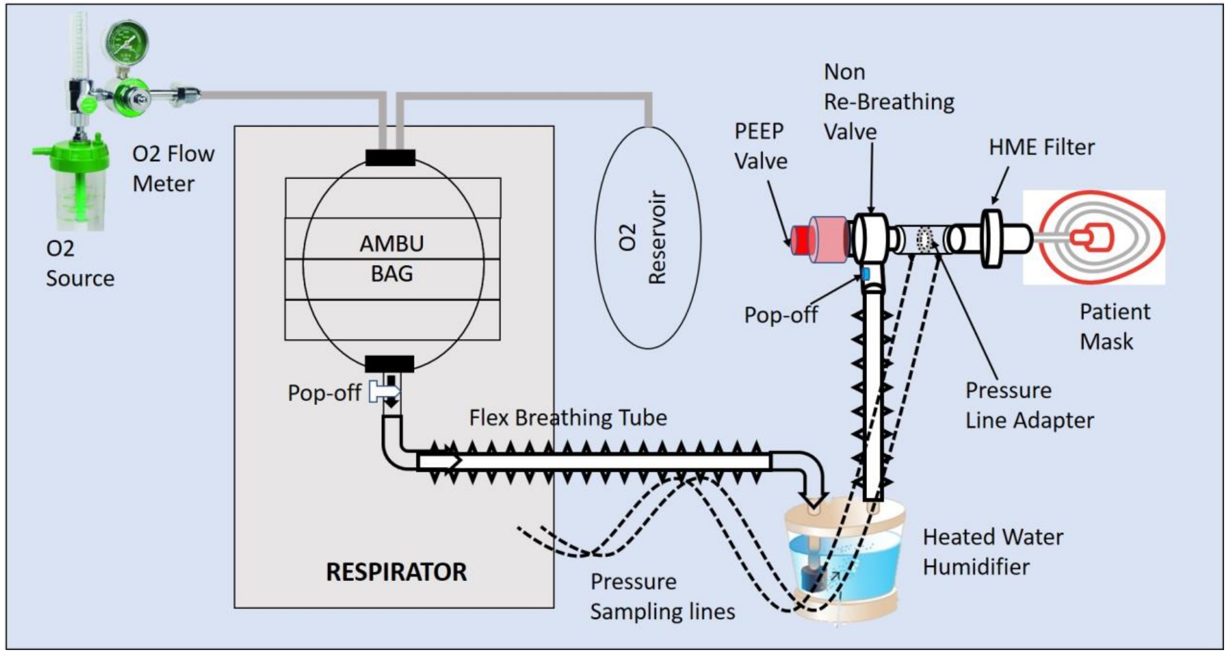
Robust, Suitable for mass production

# *Breathing Circuit*

- Proprietary, *patent-pending* Pressure line connector with Orifice plate
- COTS single-limb Breathing Circuit with NRBM
- BVM or Ambu Bag with Reservoir
- Pressure sensors, PEEP valve
- HME Filter
- Humidifier
- Oxygen Source

Off-the-Shelf Single limbed Circuit with NRBM

Proprietary Dual Pressure line Connector



# *Ventilation Modes*

## *The 4 most frequently used*

| ***Continuous Mandatory Ventilation (CMV)*** | ***Synchronized Assist Control Ventilation (Sync ACV)*** | ***Synchronized Intermittent Mandatory Ventilation (SIMV)*** | ***Pressure Support Ventilation (PSV)*** |
|---|---|---|---|
| Volume Controlled Mandatory Breaths<br><br>Ignore spontaneous breaths | Volume Controlled Mandatory Breaths<br><br>Volume controlled breaths in response to spontaneous breaths<br><br>Breath Synchronization | Volume Controlled Mandatory Breaths<br><br>Pressure supported breaths in response to spontaneous breaths<br><br>Breath Synchronization | Pressure supported breaths in response to spontaneous breaths<br><br>Monitoring of Minute Volume<br><br>Fallback to SIMV if insufficient Minute volume |

# *Volume Controlled Breaths (All modes)*

### *Tidal Volume (ml)*

200 to 600 ml
increments of 50 ml

### *Respiratory Rate (bpm)*

10 to 30 bpm
increments of 1 bpm

### *Inspiration/Expiration Ratio (I:E)*

1:1 1:2 1:3

### *PEEP ($cmH_2O$)*

4 to 15 $cmH_2O$
increments of 1 $cmH_2O$

### *Max Pressure ($cmH_2O$)*

20 to 50 $cmH_2O$
increments of 5 $cmH_2O$

### *$FiO_2$ Support*

System Managed
Externally Controlled
21% to 100%

# *Pressure Supported Breaths*

*(SIMV & PSV modes)*

## *Support Pressure (PS)*

5 $cmH_2O$ to 30 $cmH_2O$ in increments of 5 $cmH_2O$

## *Support Pressure Termination (TPS)*

Flow-dependent

- Terminate when flow falls to 10%, 20%, 30% of peak flow

Time dependent

- Terminate after 1.0 to 2.5 secs in increments of 0.5 secs

# Breath Synchronization

***Both ACV and SIMV modes***

- A must for patient comfort
- Synchronize Mandatory breaths with Spontaneous breaths
- Prevent breath stacking

# $FiO_2$ Settings

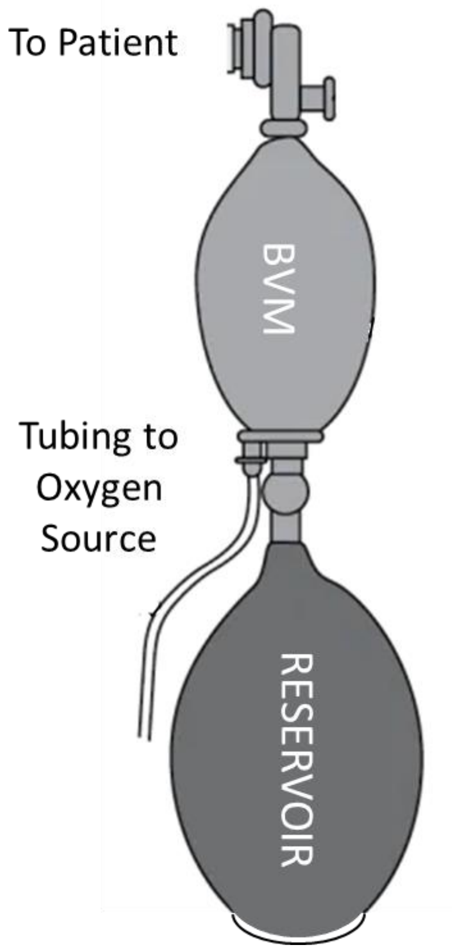
Without the Reservoir bag, $FiO_2$ delivered is the Atmospheric $O_2$ content at site

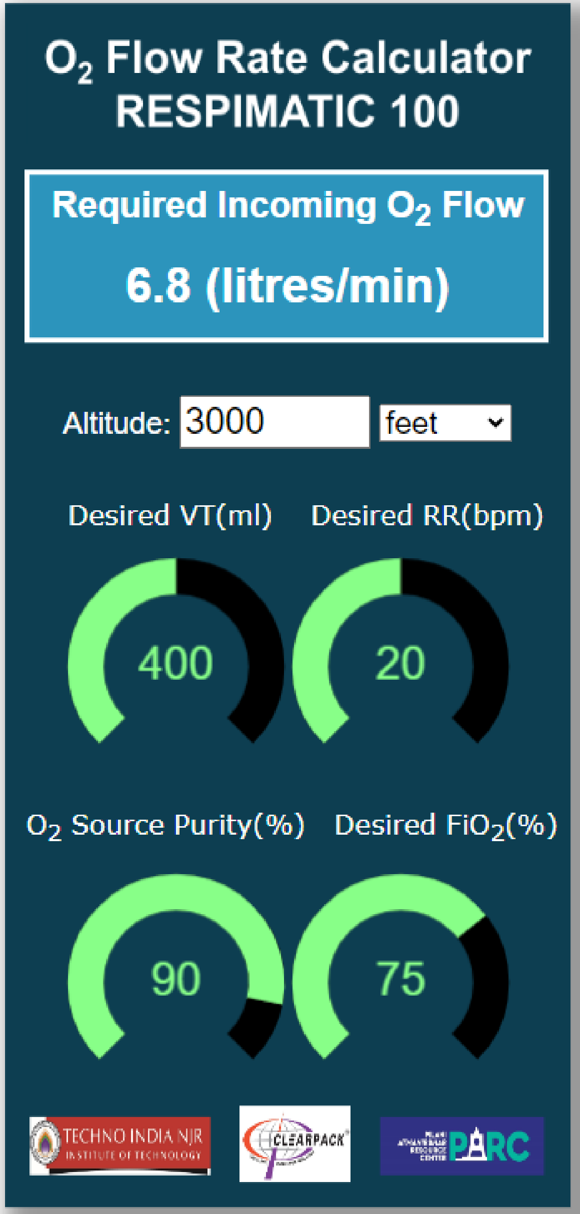
$FiO_2$ delivery with the Reservoir bag is mathematically modelled, calibrated and verified in the Lab to provide +/- 5% accuracy

Front-panel guides the user in setting the appropriate input $O_2$ flow rate from the $O_2$ source for a given $FiO_2$

The mathematical model provides for a possible $O_2$ concentrator as an $O_2$ source (purity < 100%)

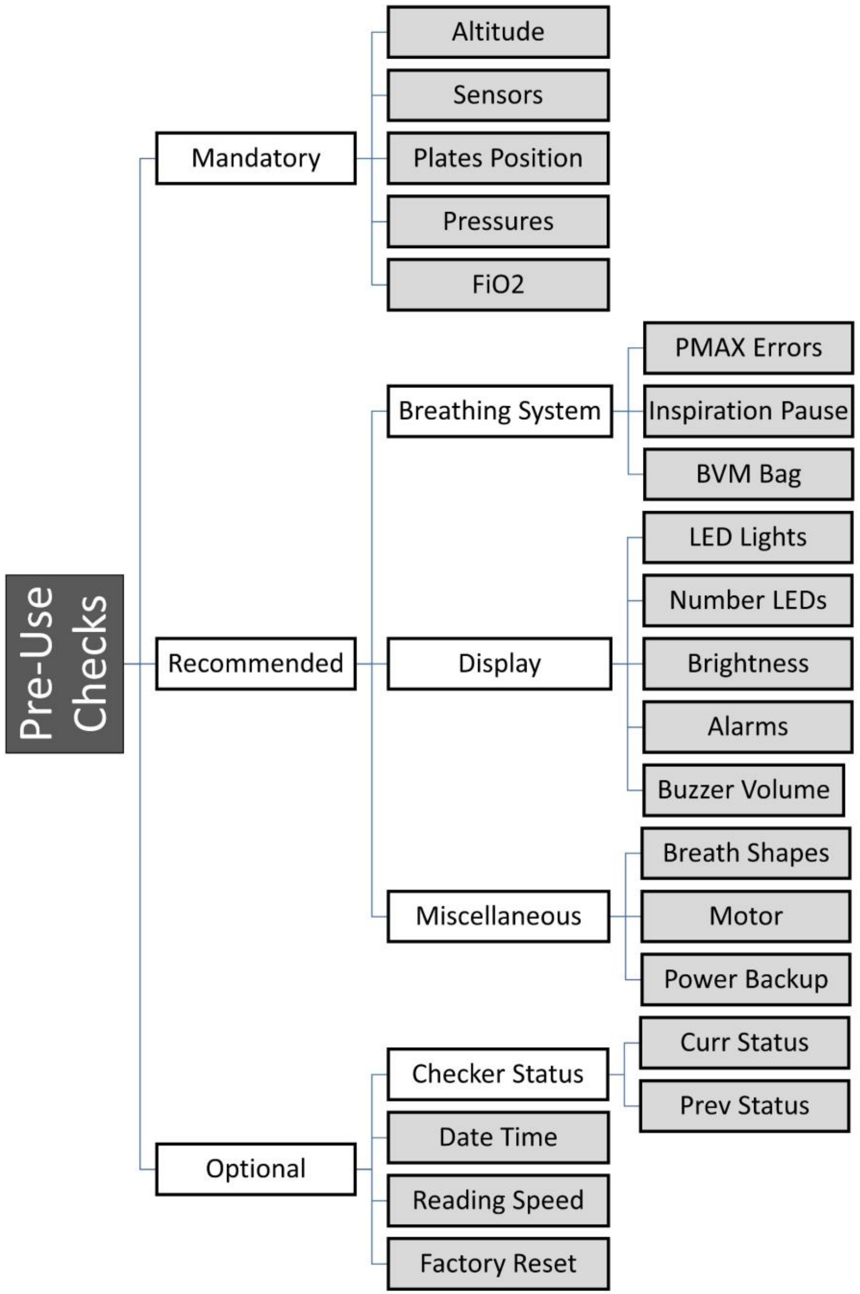
Online Web-accessible $FiO_2$ calculator is also provided for exploration purposes



# *Alarms and Safety Features*

- **Enforcement of Pre-use checks**
- **Alarms, Warnings and Notifications**
- **Maintenance Breaths till Alarm situation rectified**
  - Max Pressure Alarm
  - Pressure Loss Alarm
  - System Temperature Alarm
  - Sensor failure Alarm
  - Breathing Circuit Failure Alarm
  - Detect coughing/hiccuping fits
  - Inconsistent input parameters
  - And many more …



# *Power Consumption*

An online, sine-wave, external battery UPS recommended to continue operation during power outages

50 AH Car battery is sufficient to run the system for 5+ hours

100 AH Tubular battery is sufficient to run the system for 10+ hours


| Input Voltage | 180-250 V |
|---|---|
| Power Consumption | < 100 Watts |

# *Respimatic Testing Process*

Timing, Flow and Pressure Checks for all combinations of various settings

Automated Testing for all combinations of VT, RR, IE, PEEP, PS with randomized spontaneous breath triggers

Automated testing of full day runs checked for timing within 1% of theoretical expectations

All testing so far with a simple test lung
Next step needs a more sophisticated test lung

| CPAP | BiPAP | Respimatic-100 | ICU Ventilator |
|---|---|---|---|
| Continuous Positive Airway Pressure | Continuous Bi-Level Airway Positive Pressure | Mechanical Ventilation with 4 frequently used ventilation modes and controls | Mechanical Ventilation with sophisticated ventilation modes and controls |
| Non-invasive | Non-invasive | Non-invasive | Non-invasive / Invasive |
| High Flow + PEEP | Inspiratory Pressure + PEEP | VT + PS + PEEP | VT + PS + PEEP |
| Useful for Type 1 respiratory Failure (Hypoxemic) | Useful for Type 2 respiratory Failure (Hypercopnic) | Useful for Type 1 and Type 2 respiratory Failure | Useful for Type 1 and Type 2 respiratory Failure |
| Continuous flow at a constant pressure. Increases mean airway pressure to recruit collapsed alveoli. | Continuous flow at a constant pressure during inspiration and a different constant pressure during expiration | Independent control over the volume, the respiration rate and the pressure as required. | Independent control over the volume, the respiration rate and the pressure as required. |
| Useful only when patient can breathe on their own | Useful only when patient can breathe on their own | Useful when patient can or cannot breathe on their own | Useful when patient can or cannot breathe on their own |
| Only Spontaneous breaths that are patient triggered. | Only Spontaneous breaths that are patient triggered. | Spontaneous breaths PLUS Mandatory breaths controlled by RR and I:E | Spontaneous breaths PLUS Mandatory breaths controlled by RR and I:E |
| External FiO2 control | External FiO2 control | External FiO2 control | Direct Internal FiO2 control |
| Breath Syncing N/A | Breath Syncing N/A | Full Breath Syncing | Full Breath Syncing |
| No VT control | Indirect VT control (IPAP-EPAP) | Direct VT control | Direct VT control |
| No RR control | No RR control | Direct RR control | Direct RR control |
| No I:E control | No I:E control | Direct I:E control | Direct I:E control |
| External Humidity control | External Humidity control | External Humidity control | Direct Humidity control |
| No monitoring of Peak, Plateau or PEEP pressures | No monitoring of Peak, Plateau or PEEP pressures | Direct monitoring of Peak, Plateau and PEEP pressures | Direct monitoring of Peak, Plateau and PEEP pressures |
| Minimal alarm signals | Minimal alarm signals | Full set of Alarm signals | Full set of Alarm signals |

# *Compare & Contrast Various Systems*

# Thank you

# Backup

Market Analysis

Sample Waveforms

# *The Problem*
## *Scarcity & Affordability*

- India  has amongst the lowest per capita ICU beds in the World*
- 1.46 beds / 1000 people*
- 3.65 ICU beds / Lakh people*
- Only half of ICU beds are equipped with Ventilators
- A meagre 1.8 Ventilators for one lakh people*

- ICU ventilators are expensive equipment
- Unaffordable in remote clinics

- Ventilator Ambulances are
- Either non-existent except in few major urban centres,
- Or beyond the reach of majority of population

** As per April 2020 Study by Center for Disease Dynamics, Economics & Policy at Princeton University, USA*

# *The Problem*

## *Skilled Practitioners*

ICU Ventilators require highly skilled manpower to operate and monitor

# Ventilators lie unutilised due to shortage of doctors

Times News Network

**Jaisalmer:** The state government has given 17 ventilators, including 12 to Jaisalmer and five to Pokhran government hospitals. However, they were lying unutilised due to lack of doctors. The serious patients are being referred to Jodhpur and a large number of corona patients have died while undergoing treatment in Jodhpur.

On Tuesday, there were 42 fresh cases of Covid-19 in Jaisalmer district. On Sunday, 54 cases were reported. The condition of some patients is serious as they are being referred to Jodhpur which is a five hours journey from Jaisalmer.

MUCH TO IMPROVE

sion. The main reason behind referring serious patients to Jodhpur is non-availability of ventilator facility and posts of main doctors are lying vacant.

There are only two physicians in the Jaisalmer hospital of which duty of one of the doctors is to take tional doctor to run the ventilator whereas there is need of minimum two to three physicians, cardiologists etc.

Jaisalmer collector Ashish Modi said that all the 17 ventilators in the district are in operational condition and oxygen and other resources are available. He said that posts of cardiologist, physician are lying vacant due to which ventilators cannot be used for corona patients. Serious patients are referred to Jodhpur on time and Jodhpur divisional commissioner Dr Samit Sharma is monitoring the situation, he said. Jaisalmer government hospital PMO Dr VK Verma said that ventilator.

**व्यवस्थाओं को कोरोना:** सरकार ने दिए वेंटीलेटर, आधे से अधिक इंस्टाल नहीं किए

# प्रदेश में मरीजों की सांसें उखड़ रहीं, यहां स्टोर में 'शो-पीस' बने वेंटीलेटर

## कहीं पर्याप्त प्रशिक्षित स्टाफ ही नहीं

पत्रिका न्यूज़ नेटवर्क

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चूरू/चित्तौड़गढ़. प्रदेश में लगातार बढ़ रहे कोरोना वायरस के संक्रमण के बीच वेंटीलेटर की कमी होने पर सरकार ने वेंटीलेटर उपलब्ध करा दिए, लेकिन अस्पताल प्रशासन की लापरवाही के चलते जहां चूरू में आधे वेंटीलेटर अभी तक स्टोर में ही हैं। वहीं, चित्तौड़गढ़ के जिला अस्पताल में पर्याप्त प्रशिक्षित स्टाफ नहीं होने से परेशानी आ रही है तथा यहां भी 25 वेंटीलेटर इंस्टाल ही नहीं किए गए।

चूरू स्थित डेडराज भरतिया अस्पताल में कोरोनाकाल से पहले 12 वेंटीलेटर ही थे। बाद में प्रधानमंत्री राहत कोष के तहत तीन चरणों में 30 नए वेंटीलेटर भेजे गए थे। वर्तमान में यहां 27 वेंटीलेटर उपयोग लिए जा रहे हैं। शेष 15 इंस्टॉल तक नहीं कराए गए।

चूरू स्थित भरतिया अस्पताल के स्टोर में रखे वेंटीलेटर।

सात वेंटीलेटर मेल वार्ड में लगा दिए हैं। तीन को भी एक-दो दिन में इंस्टॉल करवा दिया जाएगा। भरतिया अस्पताल के पास जो वेंटीलेटर हैं, उन्हें जरूरत के हिसाब से इंस्टॉल कर दिया जाएगा। मेडिकल टीम को डेमो देकर प्रशिक्षित किया जाता है।

**डॉ. हनुमान जयपाल,** एसोसिएट प्रोफेसर, मेडिकल कॉलेज, चूरू

दरअसल, वेंटीलेटर का संचालन प्रशिक्षित स्टाफ ही कर सकता है। वह भी उस स्थिति में जब निश्चेतना विशेषज्ञ मॉनिटरिंग कर रहा हो। कोविड-19 के चलते सरकार ने जिला अस्पतालों को वेंटीलेटर उपलब्ध करा दिए, लेकिन चलाने के लिए यहां पर पर्याप्त प्रशिक्षित स्टाफ नहीं होने से परेशानी आ रही है।

## 23 वेंटीलेटर को इंस्टाल होने का इंतजार

**कोटा.** कोटा मेडिकल कॉलेज के कोविड अस्पताल में 52 वेंटीलेटर हैं और सभी चालू हैं। वहीं, कोरोना के बढ़ने के बाद 23 नए वेंटीलेटर और आए हैं। इंस्टॉल होना बाकी है। संचालन के लिए पर्याप्त कार्मिक हैं।

## 25 वेंटीलेटर इंस्टाल ही नहीं किए गए

चित्तौड़गढ़ के जिला अस्पताल में कोरोना से पूर्व पांच वेंटीलेटर थे, जो बढ़कर 42 हो गए हैं। इनमें से कुछ फोल्डिंग वेंटीलेटर है। वेंटीलेटर पर मरीज को रखने के लिए आईसीयू का प्रशिक्षित स्टाफ चाहिए और निश्चेतन के चिकित्सक की निगरानी की व्यवस्था होनी चाहिए। यहां आईसीयू का प्रक्षिक्षित स्टाफ करीब आधा दर्जन का ही है जो आईसीयू में है। यहां कुल 42 वेंटीलेटर में से अभी भी पांच पुराने एवं सात नए वेंटीलेटर ही काम में आ रहे है। 25 तो इंस्टाल नहीं किए गए।

## स्टोर की बढ़ा रहे शोभा

**कुचेरा (नागौर).** स्थानीय सांसद हनुमान बेनीवाल की अनुशंसा पर शहर के राजकीय सामुदायिक स्वास्थ्य केन्द्र को मिले पोर्टेबल वेंटीलेटर को सीएचसी के स्टोर में रख दिया गया है। चिकित्साकर्मियों ने बताया कि पोर्टेबल वेंटीलेटर वर्किंग मोड में है तथा जैसे ही जरूरत पड़ेगी। वार्ड में लेकर काम में ले लिया जाएगा।

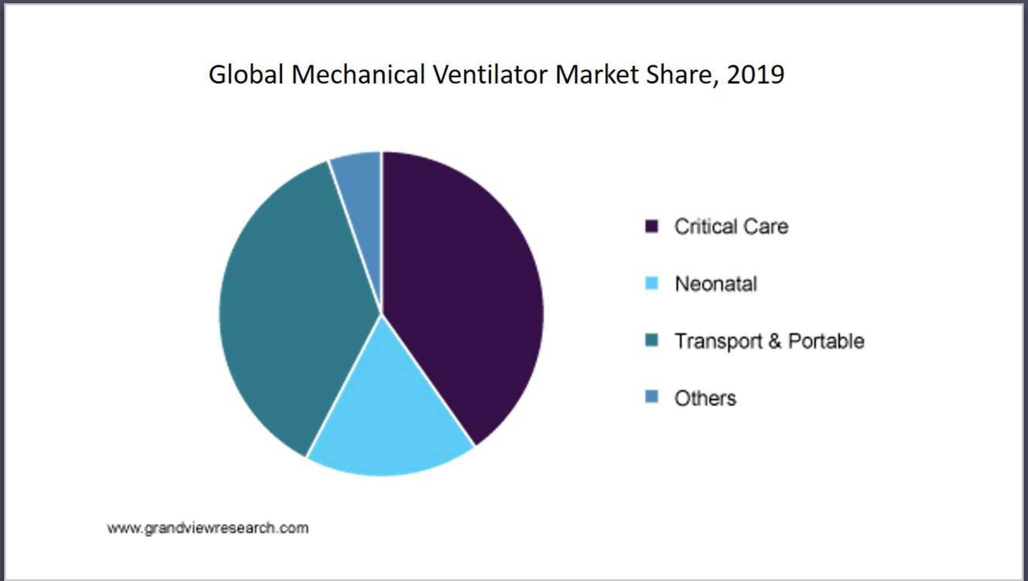
# *Market Need*

**25 to 50 ventilators per lakh people in developed countries**

**1.8 ventilators per lakh people* (India)**

**Even less for lower income developing and underdeveloped countries***

** As per April 2020 Study by Center for Disease Dynamics, Economics & Policy at Princeton University, USA*

# Breath Synchronization in ACV Mode

Tidal volume is delivered at regular intervals $T_i$.

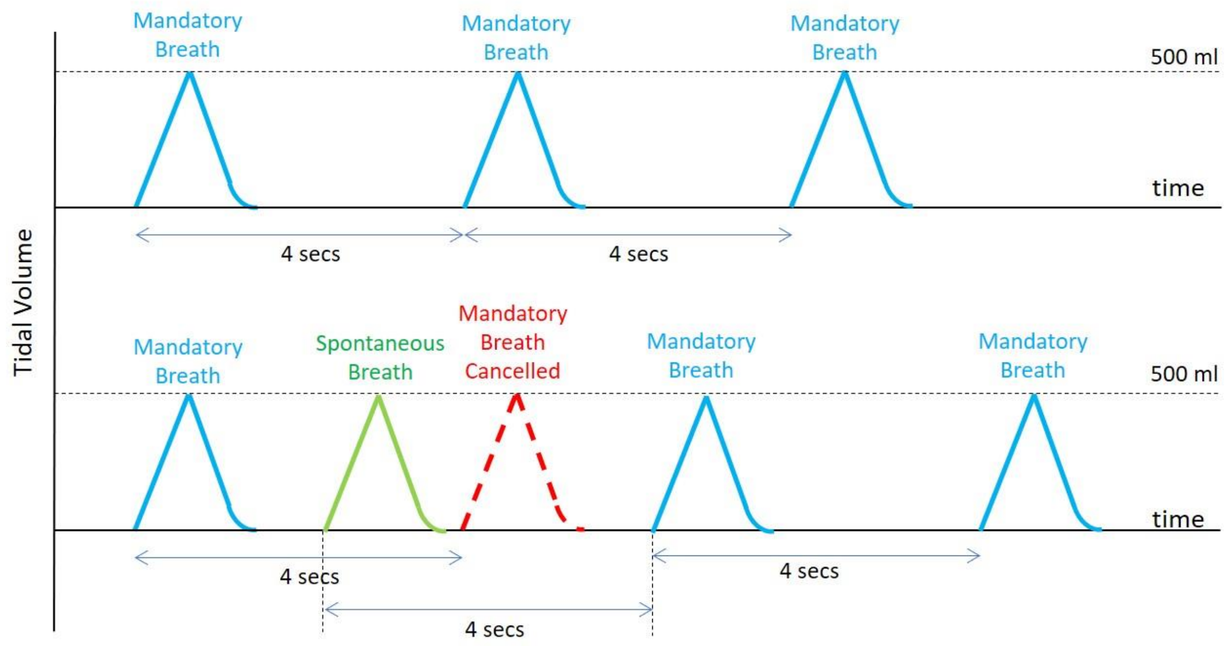
If spontaneous breath occurs during this interval at time $T_s$, the set tidal volume is delivered in response, and the next mandatory breath is set for ($T_s$+ $T_i$).

Again, if another spontaneous breath is detected before $T_s$ + $T_i$, a mandatory breath scheduled $T_i$ time in future.

## Breath Syncing in Synchronized AC Mode

There is no sync-window – the next mandatory breath is always rescheduled after a spontaneous breath

Example below: Tidal Volume = 500ml     Respiration Rate = 15 bpm

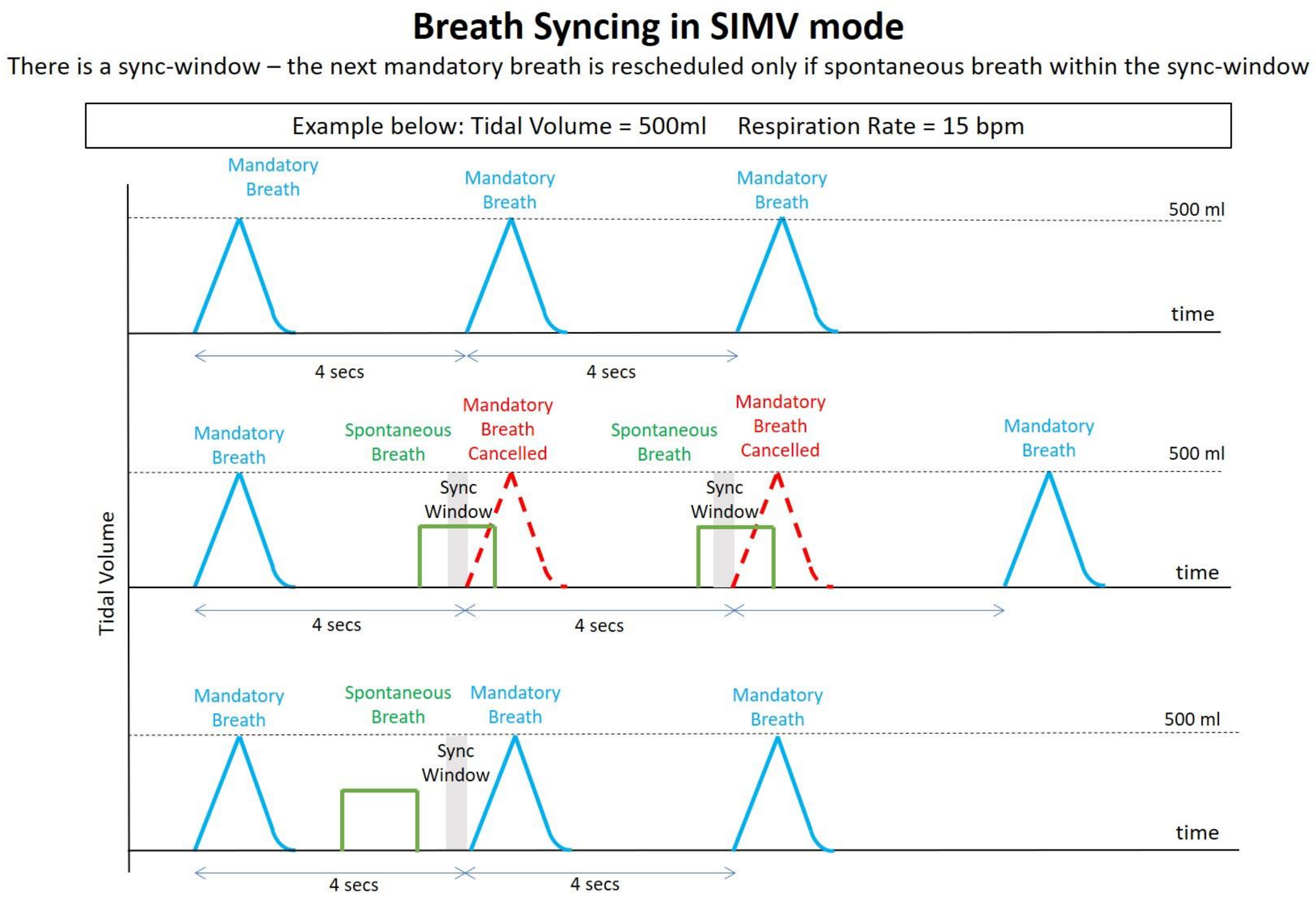


# Breath Synchronization in SIMV Mode

Tidal volume is delivered at regular intervals $T_i$.

If spontaneous breath occurs during this interval at time $T_s$, a pressure supported breath is delivered in response, and the next mandatory breath is set for ($T_s$ + 0.9 $T_i$).

This is to allow more spontaneous breaths but to trigger a mandatory VC breath if spontaneous breath is not detected within 90% of the mandatory breath interval.



# Exceptional Mandatory Breath in PSV Mode

Tidal volume is delivered at regular intervals $T_i$.

If spontaneous breath occurs during this interval at time $T_s$, a pressure supported breath is delivered in response.

The next mandatory VC breath is not delayed at all unless it is too close to the spontaneous breath (within 20% of $T_i$).

This avoids breath stacking issues.