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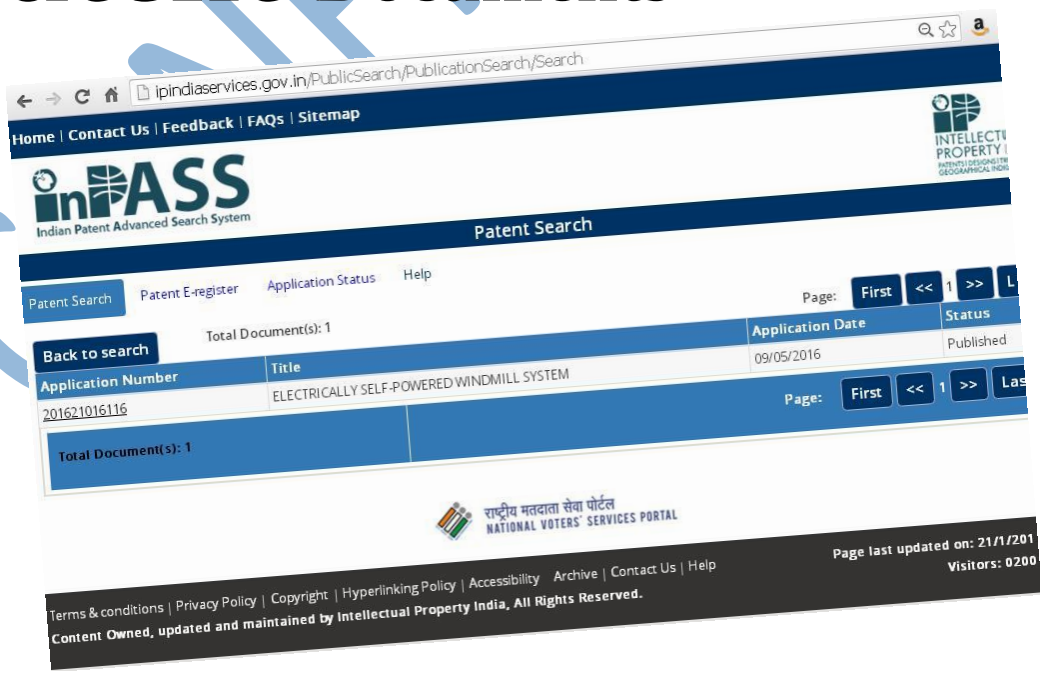
(71)**Name of Applicant :**
1)RAGHAVENDRA TRIPATHI
Address of Applicant :E203, ZENOBIA APARTMENT, BODAKDEV, AHMEDABAD 380054, GUJARAT, INDIA.
Gujarat India
(72)**Name of Inventor :**
1)RAGHAVENDRA TRIPATHI

(57) Abstract :
Abstract ELECTRICALLY SELF-POWERED i.e. external power independent WINDMILL SYSTEM primarily consist of (1) direct-drive low & variable-speed "Self-Excited inverted Synchronous Generator™ with zero starting torque & hence leads to early start; Digitally Controlled (2) Dynamic Load Management System delivering Maximum Power/ RPM while Rate of Change of RPM remains constant, at all winds, so blade™s low noise & less erosion and less mechanical stress and leads to higher Up-time & CUF (3) Auto Change-over Switch & dump load management system to maximizing the use of windmill power first then only AC mains used also protect from No/Over Voltage & over-speeding, (4) PWM ultra-fast Charge Controller with upto 50ADC charging for long battery life; and (5) True RMS Smart Energy Meter measuring & registering the net DC power consumed and data-logger storing performance vitals; (5) Manual Safety Switch to bypass the complete Digital System for repair maintenance or emergency.

No. of Pages : 29 No. of Claims : 6

Abstract from - our International Published Patent Documents



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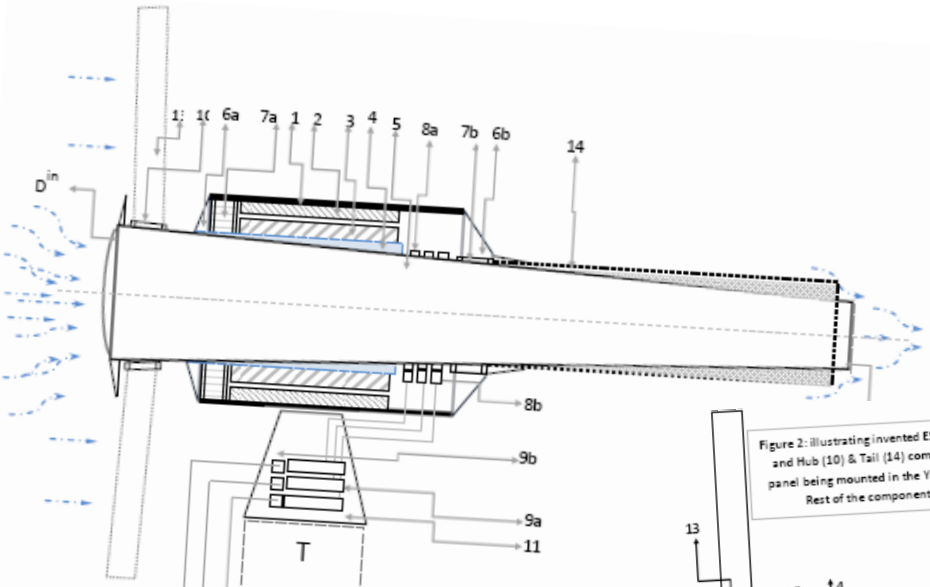
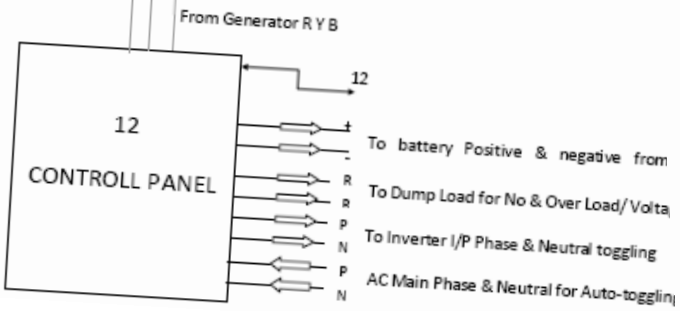
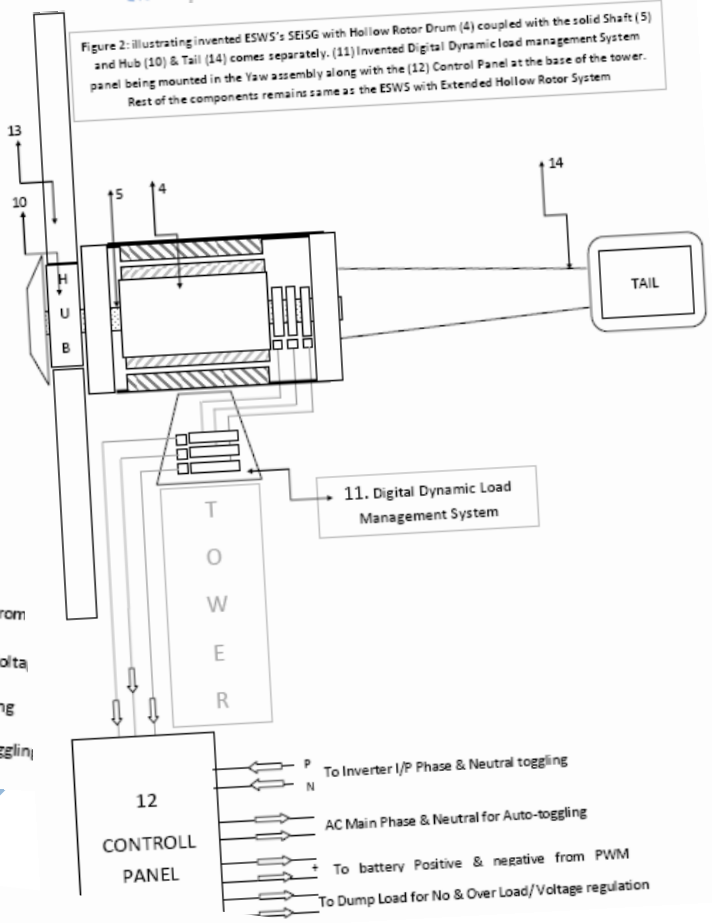
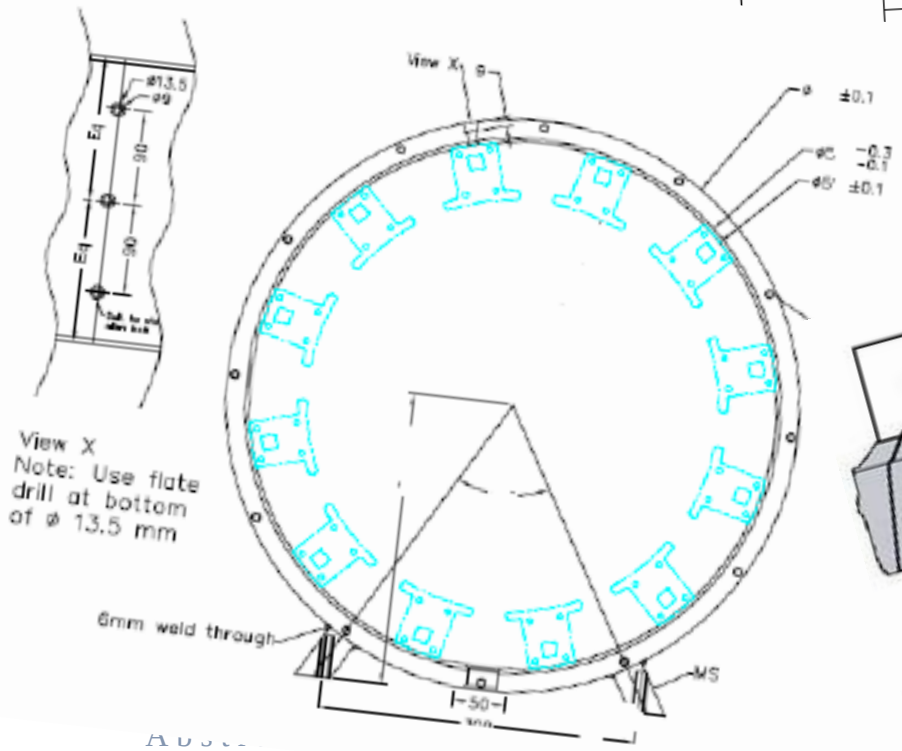
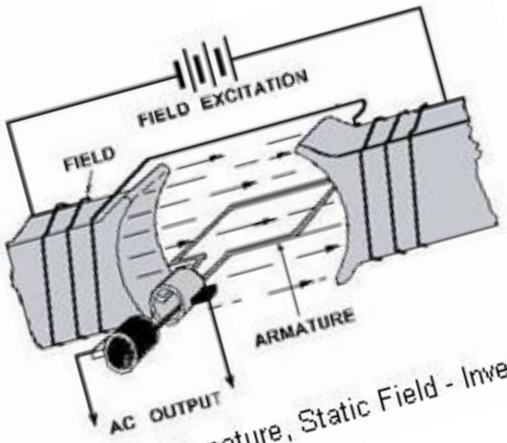


Figure 2: illustrating invented ESWS's SEiSG with Hollow Rotor Drum (4) coupled with the solid Shaft (5) and Hub (10) & Tail (14) comes separately. (11) Invented Digital Dynamic load management System panel being mounted in the Yaw assembly along with the (12) Control Panel at the base of the tower. Rest of the components remains same as the ESWS with Extended Hollow Rotor System

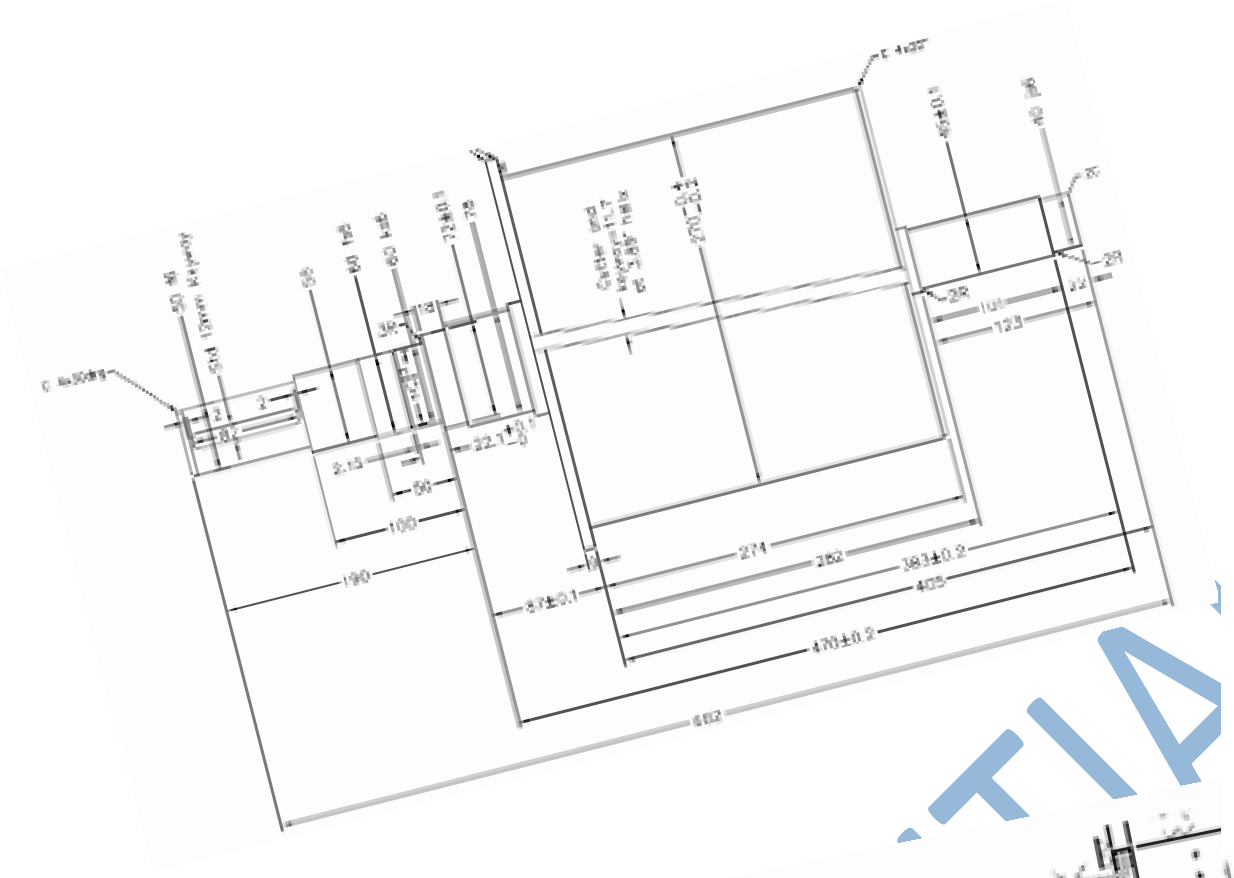
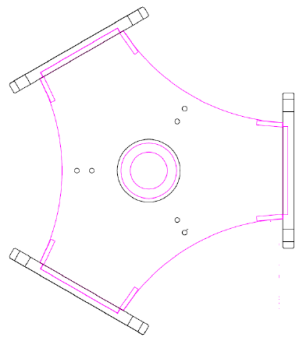
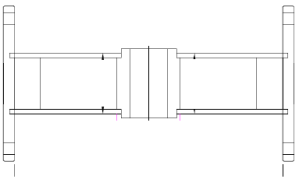
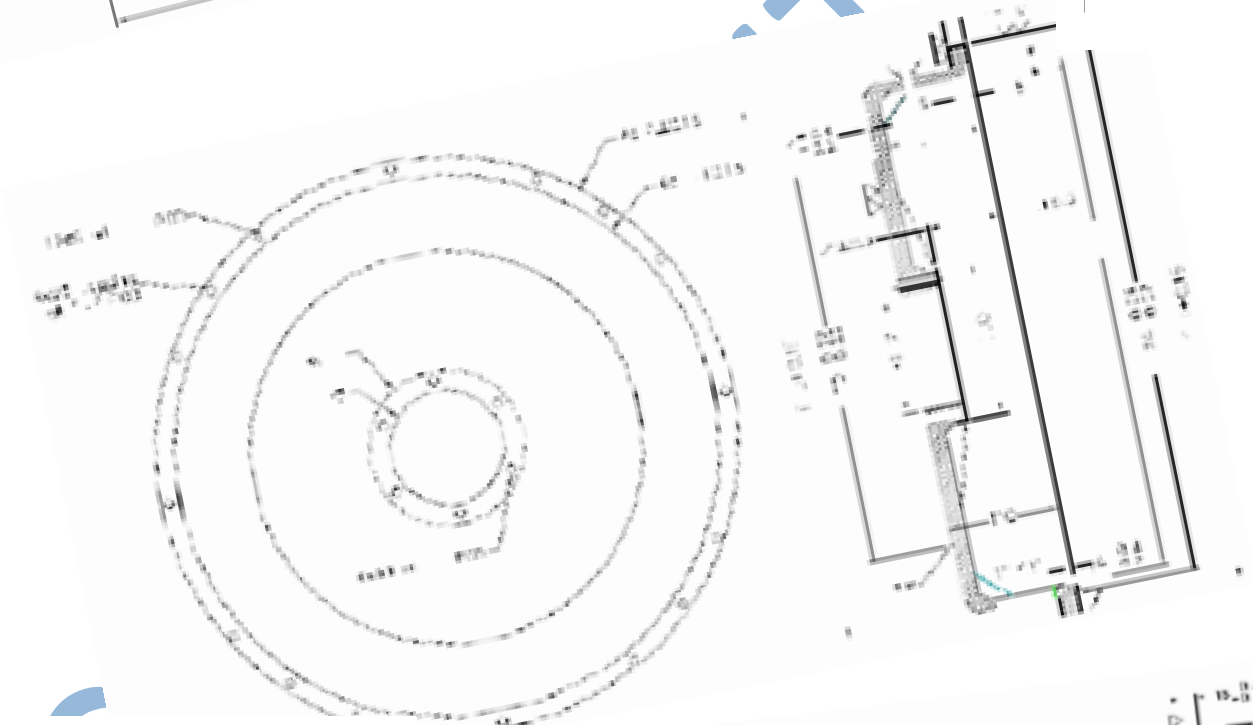
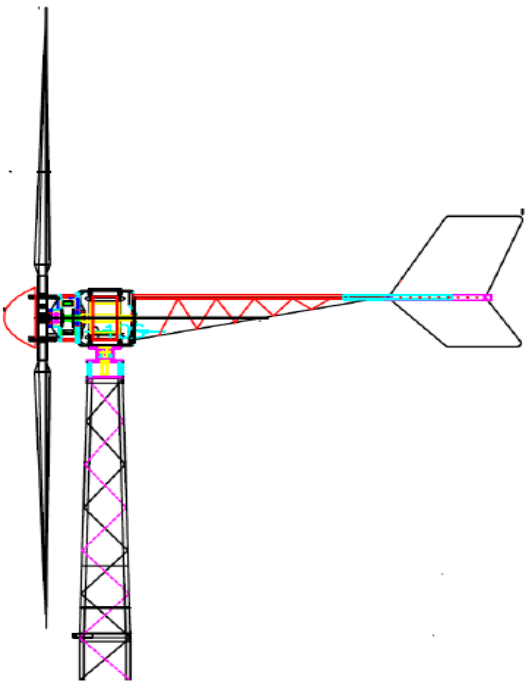
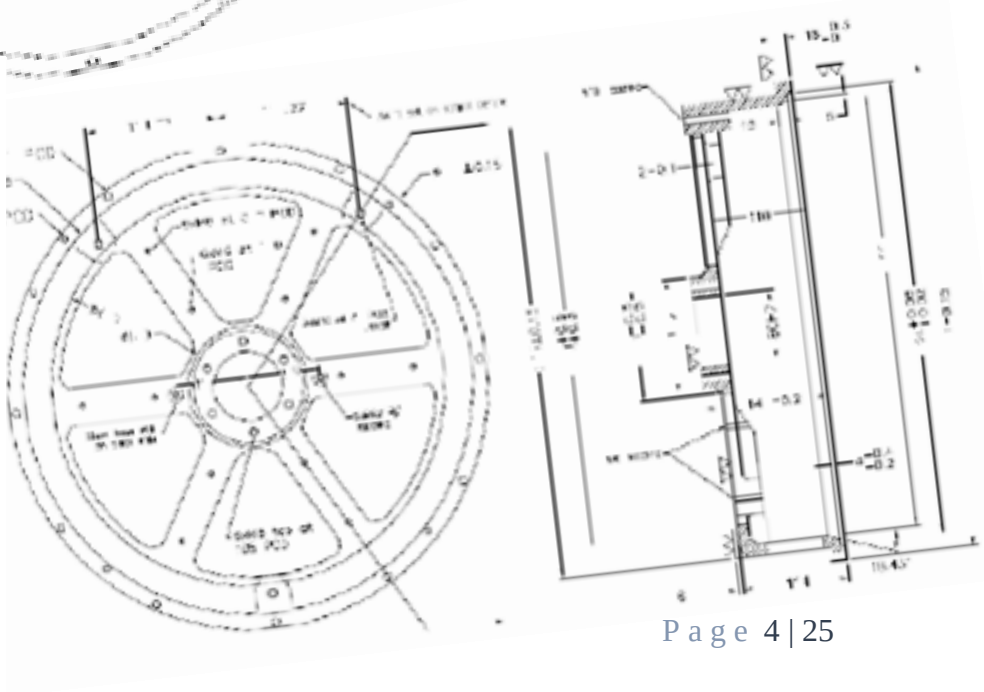




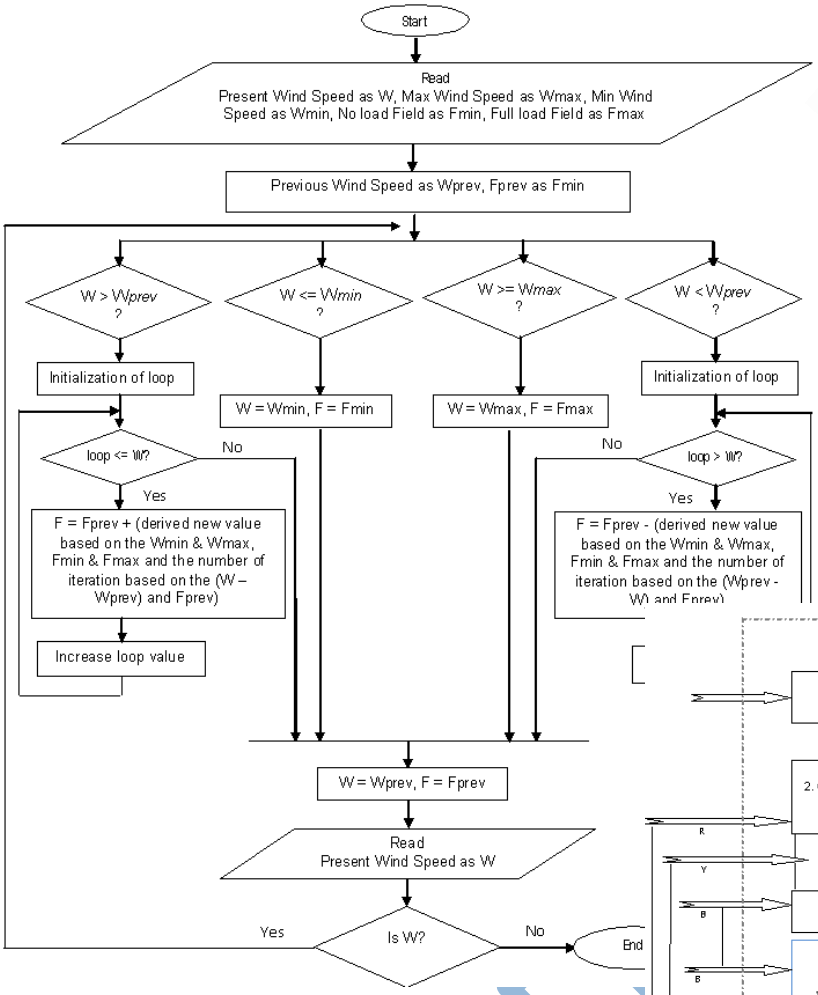


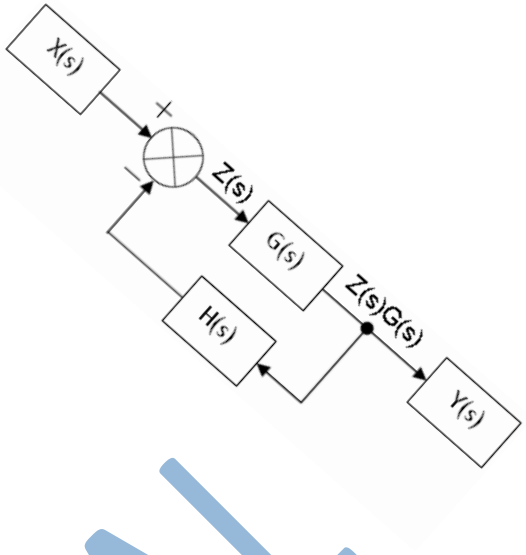


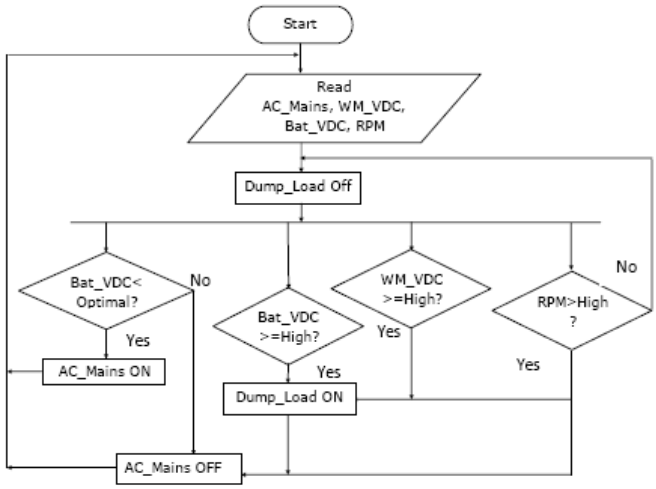
Rotaing Armature, Static Field - Inverted

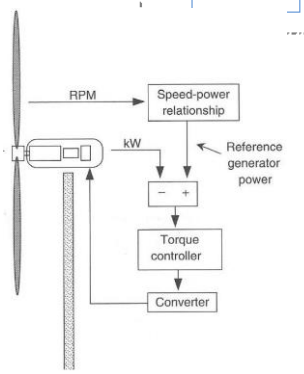
Flow Chart of Digitally Controlled - Dynamic Load Management System

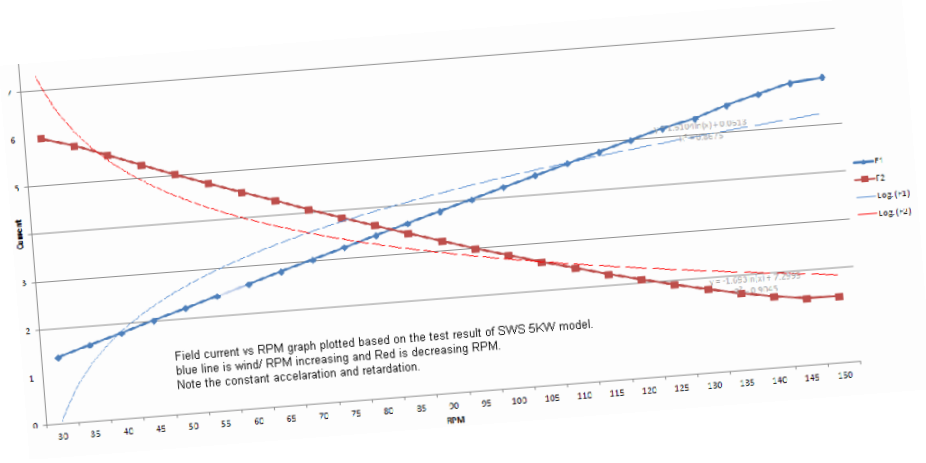


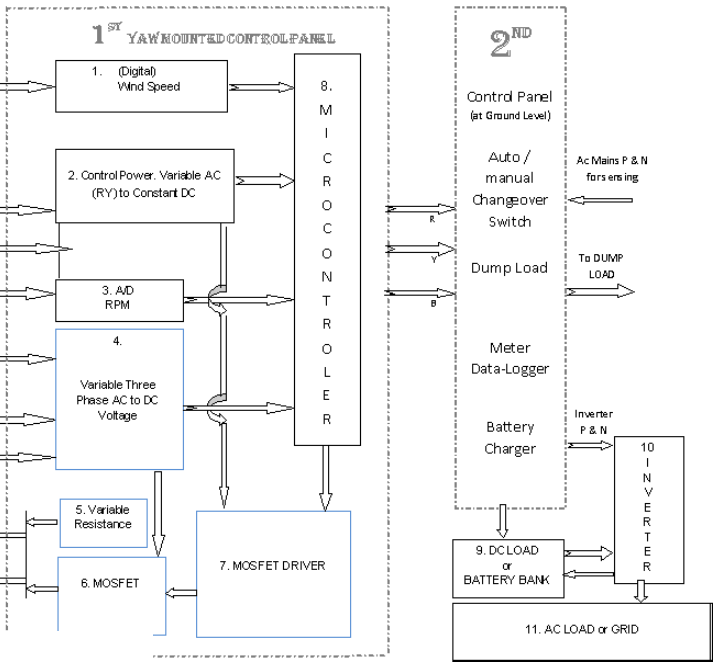


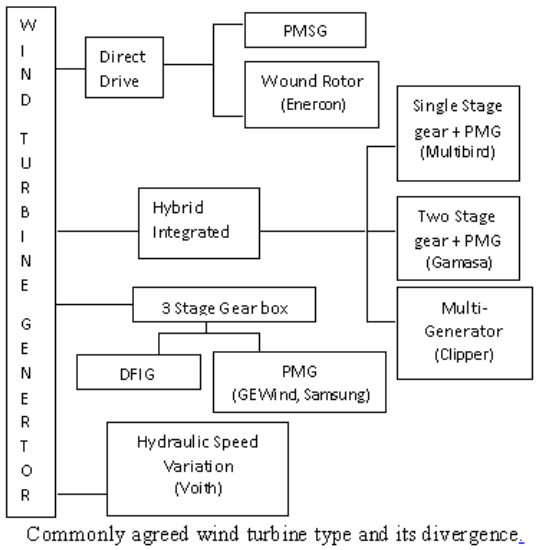


Algorithm of invented 'Auto Changer-over Switch' with 'Windmill Power First' and Over-speed, No & High Voltage Protection.









Commonly agreed wind turbine type and its divergence.

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The Invention:

"**e**lectrically **S**elf-powered **W**indmill **S**ystem", **eSWS**, mainly consist-of SEiSG– Self-Excited inverted Synchronous Generator, Digital– Dynamic 'Mechanical-Speed' to 'Electrical-Torque' convertor and Auto-Changeover-Switch.

1. SEiSG– Self-Excited inverted Synchronous Generator
   a. By controlling its little reactive power SEiSG can control the very large output.
   b. As there are just the residual magnetism (no permanent-or-electro), so-when the system is 'standstill' or 'even-at low-speed', there are no-withholding-forces and hence there are 'No-Wakeup-Losses'.
   c. Unlike PMG's where 'every failed-attempt to set itself into rotation, exerts negative-counter-forces, SEiSG can come-into-motion in winds as-low-as 1.5M/S.
   d. This 'early-start' and subsequent 'Dynamic-Load-Management' ensures SEiSG is "always-already-rotating".
2. Digital – Dynamic 'Mechanical-Speed' to 'Electrical-Torque' convertor
   a. Gradual "Load (air-gap flux) Management" ensures a never-before constant acceleration as-well-as retardation.
   b. Forced loading/unloading further lets the prime-mover/fly-wheel always rotate by dynamically matching O/P-KVA to available the I/P-KW wind-power.
   c. This enable eSWS to retain the 'moment of inertia' and it's 'state of motion' there by conserving the energy and at the same time be-best-prepared to harness any add-on winds-to-come.
   d. Continuous mechanical-speed to electrical-torque conversion also protects the system from over-speeding in any winds.
   e. Regulation of O/P terminal voltage at source (generation level itself), i.e. System only produces the voltage that is required at any given point of time. So no-addition charge-or-voltage regulator is required.
   f. Since eSWS is designed for constant-&-low voltage so in-order to increase the power it increase the current/torque. This makes it pre-designed to absorb large spikes of inductive-load without sacrificing the performance.
   g. Generation at low-and-constant speed drastically reduces the otherwise constant operational-noise, blade-surface chipping/erosion, centrifugal forces at the hub/blades and, yawing (in-line-of-wind) etc.
3. Auto Changeover Switch
   a. eSWS pushes 'it's-own-generated-power' first for consumption (off or micro-grid) before intelligently switching to battery-stored-power (beyond-backup) and finally jumping to the utility-mains (whenever required) and vice-versa.
   b. Maximum utilization (consumption) of 'its-own-generated-power', offsets the electricity otherwise would have costed at the maximum rate (billing), which is almost twice of any PPA or revers-metering rates.

Put-together, aforesaid makes eSWS a never-before self-sufficient and utter-safe to be used very-much amongst the crowd/ roof-top and can also act as the-only-power for the Disaster-Management-System. More-over 'low initial-&-subsequent maintenance-

cost' and higher-generation that-too by offsetting the electricity at highest-rate thean PPA & reverse-metering, being an off-grid, stand-alone self-powered system, speeds-up the Return-on-Investment.

Competitive Advantages:

1. eSWS being 'self-exciting' can take-care of itself even-without any external-or-backup electricity. So it can be relied upon even-when the other renewable or DG-&-Battery runs-out during prolonged-power failures!! Being electrical self-reliant also ensure no negative-metering.
2. eSWS has 'no-starting-torque' (non-PMG) and is a 'no-load' (self-excited) direct drive start so there are no-wake-losses, high uptime-&-CUF.
3. eSWS can generate the rated power lower RPM(90) and hence little-or-no Blade Erosion-&-Noise and exponentially-less centrifugal-forces at hub/ blade root.
4. eSWS has little-or-no mechanical-stress as there are no sudden acceleration-&-retardation inspite-of constantly 'varying-wind' and 'electrical loading/unloading' because of its invented 'Digital Dynamic Load Management System'.
5. eSWS's power is not dependent upon RPM like PMGs or Fixed-Speed-WTG, as it regulates it's output-voltage at source itself without sacrificing the power. All this leads to simplified, lesser electrical-&-electronic.
6. eSWS can perform with same ease-&-efficiency in low-or-high winds alike, through its continuous 'Digital– Mechanical-Speed to Electrical-Torque Convertor' that yields "Maximum Power/Revolution" and can deliver its rated power at desired low RPM while keeping the voltage low-&-constant but by increasing the current/ torque. These leads to lesser number of series costly battery (optional).
7. eSWS is not sensitive to aging/faults/temperature or synchronicity being electromagnet, forced-air-cooled and off-grid. Unlike PMGs, start-up voltage-regulation or external-short-circuit or unsteady-wind DO-NOT leads to stiff-performance.
8. eSWS is an indigenous product tested-proven and patented contributing both to "Made-&-Make in India" while Permanent rare-earth Magnets is expensive (imported as only available in China).

With above advantages over the other renewable and conventional power backup systems, the invented eSWS rightly placed for technical-commercial revolution.

Background of the Invention:

Power from renewable windmills has become much more important considering the ever growing power dependent population & the rise in pollution because of fossil fuels. Though windmills were there long before solar & modern windmills, yet its true-potential for domestic & mass usages could not yet be realized because of few techno-commercial reasons. The very need to overcome the following major short comings of the already present other renewable has given birth to eSWS.

- Others are dependent upon 'External Electricity' for one thing or other. So these systems become Impotent without the external & backup power, even if there is ample Sun & Wind.

- Constant consumption of 'external electricity' even when not producing may leads to NEGATIVE METERING.
- Solar requires regular surface cleaning, similarly PMG/ Geared Windmill has high wake losses because of high starting torques and if direct-drive than the high RPM leads to blade erosion & loud operational noise, all this ads to higher O&M cost.
- Permanent-Magnet is expensive, sensitive to - aging, temperature & faults, synchronicity & voltage regulation may cause problems during startup and also causes very stiff performance in case of external short circuit or unsteady wind. etc.

But the invented eSWS is designed to overcome all of the above limitations, as:

- Being 'self-exciting' can produce regulate & take-care of itself even without any external or backup electricity. So it can be relied upon and is always available when the others (including DG or Battery) runs-out during prolonged power failures!! Being electrical self-reliant leads to Reverse Metering (not negative metering).
- The invented ESWS has No Wake-Losses, High-Uptime and CUF as there are:
  - No 'starting torque' requirement being a non-PMG,
  - No Electrical Load / Start being a self-excited,
  - No friction being direct drive.
- ESWS can generate the rated power at lower RPM and hence lesser Blade Erosion & Noise and exponentially less centrifugal forces at blade root.
- No mechanical stress for because of sudden acceleration & retardation arising due to constantly varying wind & electrical loading unloading because of its invented 'Digital Dynamic Load Management System'.
- ESWS's power is not proportionate to RPM like PMGs or Fixed Speed WTG for achieving rated power, as it regulates the Output Voltage at source itself. All this leads to simplified, lesser electrical & electronic.
- ESWS's continuous 'Digital Dynamic - Speed to Torque Conversion' yields "Maximum Power per Revolution" and can deliver its rated power at desired moderate RPM while keeping the Voltage low & constant but increasing the charging current. These leads to lesser number of series battery cells.
- ESWS's efficiency & life span is not adversely affected because of temperature, aging, faults etc. being an electromagnet & forced air-cooled.
- ESWS's invented BLADELESS Hollow 'Rotor Extended Drum -RED' ensures higher power generation even at the locations with lesser wind potential.

With above advantages over the other renewable and conventional power backup systems, the invented ESWS rightly placed for technical-commercial revolution.

Object of the Invention:

The main objectives of the present invention – ESWS is to create a (i) self-reliant & self-sufficient windmill system that can harness (ii) maximum power out of any/ all unpredictable winds, with (iii) minimum cost and (iv) uttermost safety. These objectives are achieved through:

(1) Electrical Self-sufficiency - being a Self-excited SG with a 'Constant Regulated Power Supply' derived from its own initial variable AC power.

(2) Maximum Utilization of any or all the given Wind being non-PMG, Direct-Drive and Hollow 'RED' with higher inertia, ensures higher UPTIME.
(3) 'Maximum Generation per Revolution' for highest CUF through Dynamic Load Management System.
(4) Maximum Utilization of Generated & Stored Power First – Regulation of Voltage at Source and Intelligent Auto Changeover Switching.
(5) Safety of itself & the very surrounding – Dynamic Speed to Torque Conversion.
(6) Quantifying & registering cumulative net O/P –Smart Metering & Data-Logging.
(7) Minimum Initial, and other Operating & Maintenance Cost – being indigenous, low & constant RPM O/P without much of Electrical & Electronics and always protected being independent of external power for the same.

These 'object of the invention' are explained in details as follows:

(1) Electrically Self-sufficient – the invented Electrically Self-Powered Windmill System (ESWS), uses a never-before non-PMG Self-Excited Synchronous Generator. The bleak power initially produced is stepped-up in a closed loop in such a way that it can built-up & empower itself through its own Regulated Power Supply that stabilizes the variable AC into usable constant control DC power for all its electro-mechanical & electronic needs, making SWS a truly self-reliant & self-sufficient windmill system apt for remote unmanned operations.

(2) 'Maximum Utilization of any given Wind' is achieved through (i) Early Start - being a direct drive so no friction, non-PMG so No withholding & hence No Starting Torque requirement and No Load Start being a Self-excited Synchronous Generator, (ii) it's invented Hollow Rotor Extended Shaft amplify the wind for initial torque / start and ads to rotational torque (iii) Subsequent gradual & dynamic loading & unloading so that ESWS always remains in state of rotation', and (iv) Fly Wheel - higher moment of inertia because of its unique hollow rotor design. These merits put together ensures ESWS is "always already in the State of Rotation" and this high UPTIME translates into higher CUF.

(3) 'Maximum Generation per Revolution, irrespective of magnitude of wind & RPM, is achieved through (i) SEiSG's unique design and (ii) Digital – Dynamic Speed to Torque conversion. The O/P KVA is always matched to the changing (wind speed) I/P KW such that SWS is never too loaded or under-loaded with respect to the given wind and considering the Load (reactive & Real). Further (iii) 'High generator efficiency' and (iv) Low self-consumption & negligible losses of Electronic & Microcontroller being PWM further ads to maximum (net) generation/ rotation.

(4) Maximum utilization of produced & stored power is achieved through: (i) regulation of charging or the terminal voltage at the generation level itself that leads to high Charging Current while keeping the Voltage within the desired range (upto 120% of battery VDC to avoid sulphonation & corrosion), and (ii) the proprietary Auto Changeover/ Switch that pushes the Windmill than the Stored Power first even when the AC Grid is available and hence (a) offsets the costly Electrical Units, (b) utilizes the batteries scientifically on day-to-day basis which otherwise unused at times of rare power failures only. Note: toggling between Windmill Power & AC mains is done without using any external power!!

(5) The Invented ESWS ensures utter safety for itself & the surrounding by protecting itself from (i) over-speeding through its unique self-reliant Digital Dynamic Speed to Torque convertor which not only keeps the RPM under check but also ensure (ii) gradual & linear acceleration/ retardation. Similarly (iii) Open or No load voltage which indirectly leads to high RPM and mechanical instability is restricted governed through Dynamic Load Management System. In case of (iv) short current, the Dynamic Load Management System protects the itself & load by regulating O/P. True to its name, ESWS (v) never fails to protect itself & surrounding for because of unavailability external electrical power.

(6) ESWS comes with True RMS Smart Digital Energy Meter and in-built Data-logger. The proprietary energy KW/H meter digitally measures & cumulative stores the NET True DC RMS Power. The Data Logging, stores other vitals like Maximum RPM attained Maximum Power delivered, Windmill Up-time and other performance related statistics for end-user's information. It does not require any external power; power measured is net of the power used by the meter too!!

(7) The invented ESWS's 'Low Maintenance' & 'Long Life' is achieved through (i) minimum mechanical wear-&-tear & no wake Losses (ii) Simplified high-end electrical & electronic and durable mechanical structure and (iii) self-reliance. Being a Direct Drive (no gears so no friction), non-PMG (so No Withholding & hence No Starting Torque), Self-excited (so a 'No Load Start') and, Rotor being Hollow minimizes the surface area for least thrust; ensures a early start (high up-time) without any wake losses and stress to structure, subsequent Dynamic Loading & Speed to Torque Conversion leads to early Rated Power while the speed remains low & acceleration is linear/ gradual hence No Operational Noise & very little blade Erosion and also the Centrifugal forces at the hub root are exponentially less being at slower RPM; Similarly Yawing is swift as little force required to align in the line of wind due to low momentum as compared to blades at high RPM. Dynamic apt & gradual loading/ unloading with respect to changing wind & load also ensures smooth transition from 'no load' to 'full load'. Invented Generator type has no de-magnetization risk with time & temperature or faults, as in the case of PMGs. All this leads to low O&M cost and long-life too.

Aforesaid briefly summarizes the present invention's main objectives.

Summary of the Invention:

Windmills are subject to variable Input (wind) and fluctuating output (electrical load). So any actions taken are always the reaction of uncertain (already occurred) actions and hence are delayed. This lags are amplified as the input power changes with cube of wind. The (i) Signal transmission losses, (ii) harmonics & noises and (iii) processing speed, further enhances the delay. So the Invention here-in, instead of directly managing or controlling of windmill's input (wind – aerodynamic torque) or the output (real load – generator torque), it regulates its own O/P Voltage, Torque (current) & Speed at source (generation-level) itself.

This regulation at generation level itself without any external electricity and complex Electrical & Power Electronics was not possible with prevalent PMSG or

EESG, so the invented ESWS uses custom designed and never-before used SEiSG- **S**elf-**E**xcited **i**nverted **S**ynchronous **G**enerator.

By-controlling its little reactive power, the invented ESWS can alter & control the large output and tame the powerful variable input. Based on the negative feedback, in closed loop, the invented Digital - Dynamic Load Management System continuously calculate and increases or even decreases the field voltage using Pulse Width Modulation with respect available input power of wind so much so that the o/p Voltage & RPM remains within a narrow desired range, i.e. (i) the rate of change of voltage and (ii) acceleration or retardation of speed, always remains linear & constant, even with the changing winds and real load; through a complex algorithm and without using any complex Power Electronics & large Electrical Transformers etc.

This makes ESWS's Control System efficient, cost effective & durable while power at low & linear Speed leads to lesser blade erosion, noise & mechanical stress.

The invention mainly consists of:

1. Generator: SEiSG with Bladeless (optional) Hollow Rotor Extended Drum - RED, and
2. Controller: "Digital Dynamic Load Management System", with algorithm that acts continuously non-discreetly on real-time dynamic data, instead of working on general practice of using discreet samples or conditions based logic.

These main constitutes are explained in detail as follows:

1. The invented **S**elf-**E**xcited **i**nverted **S**ynchronous **G**enerator – SEiSG is an electrical machine, converts kinetic- rotational or linear to-&-fro energy into Alternating Current.

   The brief about the following other generators is to highlight the uniqueness of the SEiSG with respect to:

   1. Induction Generator - IGs are not commonly used in small windmill and hence are not discussed here-in;
   2. Synchronous Generator- SGs which are most commonly used for small windmills and are further classified based upon: (i) Field type– i.e. Rotating Magnetic Field or the Stationary Field (Inverted), (ii) Pole type - Cylinder (common) or the Salient Poles, (iii) Excitation type– PMSG (common) & EESG or SESG, (iv) Speed type – Fixed or the Variable Rotor Speed.

      These conventional Generators with any of above permutation & combination of Field, Pole, Excitation & Speed when used as Windmill Turbine then are termed as **W**indmill **T**urbine **G**enerator – WTGs and are further classified based on (a) Generator and (b) Speed, as follows:

      - WTGs, based on the Generator types:

        Induction Generator - Squirrel Cage & Wound Rotor (Optislip & Doubly-fed), etc.

        Synchronous Generator - Wound Rotor or PMSG, etc.
      - WTG, based on the Speed - Constant or Fixed; Variable or Limited Variable;

Variable Speed with - partial PE conversion or full PE conversion; Mechanical Torque Converter between rotor's low-speed shaft & generator's high-speed shaft controls the generator speed to the electrical synchronous speed; etc. The variable speed operation is possible only with: PMSG or SESG; SCIG or WRIG; and Switched Reluctance Generators.

The most common out of above for continues variable speed are PMSG or EESG but the invented SEiSG has never been used. Unprecedented as WTGs & unlike any other, the invention is an "Inverted/ Linear Synchronous Salient multi-pole Generator with Self-exciting Field".

So, by not using the already available WTGs or any it's variation, the invention has created altogether a new class / category in WTGs and henceforth shall be known as the "Self-Excited inverted Synchronous Generator" – SEiSG.

Advantage of the invented SEiSG:

1. It's large diameter & short axial length being 'inverted' actually helps the ESWS's center of gravity being closer to the CG of the tower as most of the weight is directly on the tower rather than being cantilever,
2. It uses its own armature power for excitation through AC-DC convertor which is digitally controlled in closed loop, so SEiSG is independent of any external power,
3. Rated power at low RPM can be attained being an Inverted Field which allows higher number of Poles being at inner periphery of large outer diameter
4. Reduction in fluctuation, mechanical stresses on machine shaft and the likelihood of fatigue & damage along with reduction in aerodynamically generated acoustic noise being a hollow rotor which provides more moment of inertia than the conventional solid rotor shafts with same weight,
5. Regenerative Storage – SEiSG unique 'hollow rotor' act as a large flywheel and smooth-outs the torque & power fluctuation prior to entering the power generation and,
6. Invented **R**otor with **E**xtended **D**rum –RED the long Hollow MS Cylindrical tapered/ cone Body with the larger diameter D^{in} [Fig1] always aligned in the line of wind & the much smaller diameter D^{out} at the wind exit creating huge pressure difference and hence speeds-up the wind in the tunnel which in turn creates the vacuum like effect (drop of pressure) at the entry & as well in the surrounding which again drags-in/ sucks the air closer to this air there-by speeding-up & pin-pointing the winds into the RED and even towards the blades (if used along with the rotor drum -optional). This is explained with the following consideration:
   6.1 P=F/A, where P- Pressure, F- Force & A- Area;

6.2 AV=constant conservation of mass, where A – Area and V-Velocity;

6.3 Bernoulli Theorem "pressure is inversely proportional to velocity";

6.4 Force F changes with area.

So when the wind enters into the invented Hollow Tapered Rotor Drum:

a) There's a change in cross-sectional area, $A^{out} < A^{in}$

b) As per the conservation of mass, $V^{out} > V^{in}$ (iii) As per Bernoulli, $P^{out} < P^{in}$

Now, when Wind flows into from D^{in} with the velocity $V^{in,}$ area A^{in} & pressure P^{in}, then compressive force will be $F^{in} = A^{in} * P^{in}$. As the wind flows further towards the smaller section, velocity will be higher, cross-sectional area will be smaller and pressure will also be drop. As a result, compressive force will also drop and become $F^{out} = A^{out} * P^{out}$. The net effect of $P^{out} < P^{in}$ (Bernoulli) and $V^{out} > V^{in}$.

This holds good within the Rotor Drum. But as this air comes out with high Velocity compared to the surrounding Wind Velocity, pressure just out of the D^{out} drops. This low pressure area attracts more air from the high pressure area i.e. Hollow Rotor Extended Drum nozzle. Similarly, just before entering the RED's D^{in} pressure drops and velocity increases in comparison to the surrounding pressure, this low pressure area attracts more wind from all the high pressure surroundings directions. As there is almost infinite air around the RED so this pressure continues.

Further the RED has the threads (intersecting the horizontal axis) or the spiral groves at the inner periphery with the descending thickness & distance between each threads, hence provides this speeding air (1) the rotational (starting) torque initially at the entry beginning with the larger teethes and subsequent twisting because of air whirlpool, (2) a rotational spinning momentum that leads to early start hence higher Up-time along with higher CUF since attracts more wind than the sounding.

Power from wind is proportion to cube of the wind speed. If (optional) Blades are also used than the blades are placed at the large outer diameter of RED which ads to (3) swept area and hence increases the production proportion to square of the diameter, and since the invented hollow rotor speeds-up & channelizes the with air within the tunnel & the surrounding too so increases the generation by cube of the wind speed. Note: there is (4) NO need of separate HUB!! Since the RED is hollow so the air passes through it instead of pushing it. So, (5) lesser the surface area exposed to wind lesser the thrust & damage to the mechanical structure and lesser the initial and subsequent O&M cost. Being hollow with large surface are exposed in-line of wind so (6) faster heat dissipation & cooling, apt for Regulation of Power at

source i.e. low voltage & high current. If used without blades, then (7) threat to birds recedes and there is (8) No constant operational blade noise and surface erosion. (9) More number of windmills can packed in a given area than the conventional windmills with blade as the prime-mover. RED provides (10) higher moment of inertia and act as a large flywheel. Note: a hollow rotor has higher inertia than a solid rotor of same weight. Since the RED has a very long axial length and as being covered with the square pipe at the tail end so there is (11) NO need of separate tail/ vain & its assembly for bringing the system in line of the wind mechanically automatically.

The other advantages being SEiSG continues as follows:

7. Direct control of 'air-gap torque' also aids in minimizing the RPM fluctuation, (viii) Variable speed operations helps produce 8-15% more power generation than fixed speed WTGs and further enables separate control for active/ reactive power.
8. The reactive power characteristics of SEiSG as WTG can easily be controlled via the field circuit for electrical excitation of electromagnets; Power, Voltage & RPM is controlled by managing the air-gap flux using invented 'Digitally controlled Dynamic Load Management System', as explained in the following 'Controller' section.

2. **Controller**- the second main constituent of the eSWS**:**

No windmill, be it a fixed or variable speed, can produce power successfully & safely without a Supervisory & Dynamic Control system in place. So, the invented 'Dynamic' Control manages the (i) Automatic Operations Safely, (ii) reduces the Operating Cost, (iii) provides consistent dynamic response, (iv) improvisation of quality & safety. The Invented ESWS's "Dynamic Control" dynamics affect the outcome of the controlled aspects itself and manages the Variable Speed operations.

The 'aerodynamic torque' affects all operations of a turbine and provides power that is delivered to load and it is the net torque from the wind consisting of contributions related to TSR, blade geometry, wind speed, yaw error and any added rotor drags etc. Each but for wind speed can be altered using a 'Control System'.

A variable-speed WTG can operate at different TSR, below the rated wind speed the controller tries to maximize the aerodynamic torque and above rated wind the controller attempt to limit the aerodynamic torque. In a pitch regulated turbine, the generator torque can be varied independently of the aerodynamic torque & other system variables.

variable-speed WTG's, Torque = f (generator torque control system) and
constant-speed WTG, Torque = f (aerodynamic torque, system dynamics)

In ESWS, the aerodynamic & generator torques can be controlled independently. Speed can be altered by changing either aerodynamic or generator torque, resulting in either an acceleration or retardation of the rotor. The DDLMS directly controls & manage the Generator Torque.

For invented ESWS, the relationship between Mechanical Speed and Electrical Load (reactive + real) can be explained as under, with following standard theoretical considerations:

1. WTG converts I/P Mechanical Torque into O/P Electrical Current.
2. O/P Power is the product of Voltage and Current i.e. P=V*I.
3. As per the 18th century's - *John Smeaton's* following basic rules:
   - Speed of blade tip is proportional to the wind speed,
   - Maximum torque is proportional to square of wind speed,
   - Maximum power is proportional to cube of wind speed.
4. Windmill Systems, where there is an energy or power balance, RPM will remain constant or within a range, irrespective of quantum of input & output powers, if
   (O/P Electrical Power) = (I/P Mechanical power)
5. In mechanical terms,
   Power = Torque * Angular Speed -------- (1)
   i.e. the O/P Torque will be proportionate to I/P power, if RPM is kept constant.
6. Similarly, in electrical terms,
   Power = voltage (E) * current -------- (2),
   (Induced Voltage- E is rate of change of flux "dφ/dt" developed by interaction of rotor magnetic field with moving conductors).

So, it can be deduced that the:
Electrical O/P Power would be proportionate to current/ torque, if RPM or the O/P Voltage is made constant within the range.

Based on the above assumptions, for the invented ESWS with energy or power balance (ignoring losses):

I/P mechanical power is proportional to (RPM * Torque) ---- (1)
O/P (electrical) power is proportional to (RPM * current) ---- (2)

So when I/P made equal to O/P then,
(RPM * torque) proportional (RPM * current)

<u>So, it can be deduced that O/P Current is proportional to I/P Torque as the Voltage is proportional to RPM.</u> So, O/P current drawn will be proportionate to I/P mechanical torque when terminal Voltage / RPM is kept constant.

So when, the O/P current drawn by the load (summation of reactive & real) is matched to the changing input wind then the rate of change

'Speed' & 'O/P voltage' becomes linearly proportionate & almost constant within the desired range, while the O/P Power increases exponentially with increase of torque because the excess mechanical rotational energy (Speed) beyond the desired Voltage is continuously converted into Electrical Torque or the Current.

Unlike, other Windmills where inorder to maximize the O/P Power the O/P Voltage is allowed to increase (much beyond the Charging or Grid Voltage) only by increasing the rotor Speed/ RPM as the field flux is constant (PMSG or EESG), but the invented ESWS (consist of SEiSG & DDLMS) increases the O/P (charging) current while keeping the O/P Charging terminal Voltage, by converting the excess RPM into electrical torque.

Practically, for a battery charging systems, any voltage in excess of the max series battery charging voltage is to be either Electrically (transformer) step-downed or electronically (charge controller) bucked, which is the case with all the prevalent system. But in-contrast the DDLMS regulates the charging voltage at source i.e. at generation level by restricting the RPM in the range just good enough for the desired voltage by loading the generator by increasing the (small reactive power) field current and thereby increasing the output current at constant voltage and hence increasing the total power (P=V*I).

So there is NO need of either heavy transformers or the complex PE to restrict & match the output voltage to that of the battery bank or grid voltage.

This 'regulation of power at source' has many advantages, like - Low initial and subsequent O&M cost, No Loud Blade Noise & Erosion being at low & linearly constant speed which is apt for humanly dense sites, no wake losses & sudden acceleration/ retardation leading to longer life. The dynamic load management also leads to higher power generation due to longer up-time and hence higher CUF, etc.

DETAILED DESCRIPTION OF THE INVENTION:

ESWS primarily consist of:

1. Generator with Hollow Rotor Extended Drum,
2. Digital Controller- for managing the aerodynamic/ generator torque and other aspects like:
    a. Regulation of Voltage/ Speed at generation level, while deriving the 'maximum power per revolution' through digital speed to torque conversion,
    b. Auto-changeover switch, Charger, DC energy meter & Data Logging, and dump load management.

Apart from the above invention(s), eSWS also consist of common or the standard components like:

1. Blades, hub, nose cone - (optional),

2. Mechanical Wind guiding mechanism – Yaw, Tail and Transmission Assembly consists of Brushes & Slip-ring,
3. Tower,
4. Battery & Inverter or the DC-Drive,
5. Dump Load, etc.

The aforesaid prime constituents are described in detail as follows:

1. Generator: The invented SEiSG further consists of following:

i. Rotor(3) – being an INVERTED SG, rotor consists of armature stamping with 72 slots, conductor/ windings for AC 3 Phase at the periphery of large outer diameter & its unique Hollow Rotor acts as (a) large Fly Wheel providing higher Moment of Inertia than the other prevalent solid rotor designs inspite of being lighter, also provides (b) faster heat deception and (c) acts as a tapered tunnel because of larger diameter for entry of wind and smaller diameter/ area for exiting wind creating the pressure difference, which (d) this pressured wind when made to rotate through the spiral groves in descending order provides the much needed torque for starting and subsequent loading. Rotor Shaft also holds Slip-ring. Just the stack-length of .5MM CRGNO customized Stamping and the winding data are changed for the different models. E.G. SL for a 5KW is around 200MM & consumes approx 50KG of copper and for 10KW SL is 270MM & consumes around 95Kg Copper in the rotor winding alone.

ii. Stator- the stationary Field Poles are mounted at the inner diameter of the large circumference, this allows more number of poles (12) apt for low speed as the RPM is inversely proportionate to number of Poles and also provide enough room to accommodate large Poles so that more & more copper can be filled for strong electromagnetic Field with minimum I^2R losses.

iii. Body- Mild Steel body has (approx) OD 575MM & ID 545MM and length to accommodate Stator & Rotor. This thick MS plate provides calculated magnetic path for the field and strength needed for low RPM high torque large Magnetic field operations in any weather as large surface area also provide faster heat deception.

iv. Front & Back body end Covers are casted fro from the Aluminum for light weight and appropriate strength to withhold the rotor bearings torque and rotor weight. This also holds brushes for transmission as the ESWS being a SEiSG.

v. Vents for Natural but Forced Air Cooling. This specially designed SS nozzle at front and back prevents water and other objects to pass through while the wind is guided inside as being aligned in the line of wind for continuous forced cooling.

vi. Transmission Assembly- specially designed Slip-ring & Brushes with customized materials are confined into the 360 degree vertical rotating (X-axis) Yawing Mechanism inorder to provide continues transmission to the 'Control Panel' at the tower bottom. The 3-phase variable AC Power is captured from the direct-drive rotor shaft mounted horizontally placed 3 slip-ring and respective brushes placed at the stationary end-cover. This

RYB and Field Positive & Negative (F+ & F-) is then captured from the vertical brushes mounted on stationary tower base end. From the transmission assembly these O/P RYB and I/O F+ & F- is terminated into Control System. Now, when the stationary field residual magnetic flux interacts with rotating conductors (armature) AC Voltage is induced proportionate to the field voltage. This generated AC Power is then captured and converted to DC and fed again to the Field which strengthens the magnetic field further which in turn generates more AC power, in a closed loop through the ESWS Control System. Since the ESWS is self-excited and external power independent so the constant DC power supply for itself is built from its generated variable AC using single phase transformer and 3 phase AC to DC bridge-rectifier etc. Ready with its own control power the on board computer further takes-up the charge and control the air gap flux in such a way that the O/P terminal voltage always remains within the desired range while keeping the rate of change of RPM linearly constant. So while the wind is positive, the O/P voltage & RPM are monitored & controlled within the pre-defined range and the O/P power is permitted to multiply with the rise in the O/P current (P=V*I if V is constant that P increase with increase in I). The generator design i.e. winding are such that desired No Load & O/P terminal Voltage is reached at relatively low RPM (around 50) and can deliver high power (current 100ADC) at such low RPM. Further, taming of wild input Winds, RPM and varying load is achieved through ESWS invited following Control System.

2. The details of the invented 'Control System' is as follows:
    a. Process: consist of point(s) that allows the process itself to be changed or influenced such as: (i) Development Generator torque (not influencing aerodynamics directly), excluding, since there is no conversion of electrical current (motor) into motion as ESWS has automatic mechanical Yaw & pitch control, (ii) AC-DC-AC convertor and Charge controllers, and (iv) overall conversion of wind's kinetic energy into electrical power through "Speed to Torque converter".
    b. Sensors & A-D Convertors: for measuring Wind Speed, RPM and other electrical parameters like generated & battery voltage AC/DC, current & power.
    c. H/W & S/W Logic or Algorithm: to determine what controls actions should be taken and when by basically providing connection between measured aspects & actions to affect that operation using Electrical Circuits providing a direct link from the o/p of the sensors to desired control action e.g. PLC signal to energize the relay coil etc., and computers or microcontroller handling digital & analog I/P programmed for complex logics and to provide dynamic response, (ease of changing the code at any given time gives it an added advantage).
    d. Power Amplifiers: providing power for the control action by amplifying the week signals from the controllers for Actuator.
    e. Actuators: for intervening in process to operation like electromechanical devices, resistance heaters, cooling fans, Relays, SCR, MOSFET etc.

Invented DDLMS controls the 'Turbine Torque' by 'Converting - Mechanical Speed/ Motion into Electrical Current/ Torque' through varying the Field Excitation (air-gap flux) or the Reactive Power, dynamically. The air-gap flux is constantly manipulated as per the Voltage and RPM, for always milking the **'Maximum possible Power per Revolution'**, without waiting further for the good wind or RPM which may or may not come.

Out of many design approaches for controller programming like - Adaptive Control or Optimal Control etc. the DDLMS primarily uses the:

- Search Algorithm' which constantly change the rotor speed in-order to maximize the power, and
- 'Quantitative Feedback Robust Control' which has a 'frequency domain' approaches for uncertain dynamics, working in a closed loop.

DDLMS is closed loop with Negative Feedback, Linear / Frequency domain control system. Being a 'Closed Loop' controller, it is very accurate, unaffected even with non-linearity and external noise is significantly reduced because of feedback mechanism which clears out the errors between input & output signals. (A Closed-Loop transfer function in control theory is a mathematical expression algorithm describing the net result of the effects of a closed/ feedback loop on the input signal to the circuits enclosed by the loop. Standard methods like proportional, derivative & integral controls). Here, the 'Linear Control' theory being applicable to systems made of devices obeying the 'superposition principal', which here means roughly that the output is proportional to input. These are governed by linear differential equations. These systems are amenable to powerful 'frequency domain' mathematical techniques of great generality (bandwidth, frequency response, Eigen values, gain, resonant frequencies, poles and zeros).

In other conventional "Dynamic Generator Torque Control methods" the speed at which a wind turbine shall rotate is controlled for – (i) efficient power generation and (ii) to keep the turbine components within designed speed and torque limits. This is important as the centrifugal force on the rotating blades increases as square of rotation speed and power of the wind increases as cube of wind speed, this makes hub roots & tower structure sensitive to over-speed.

In-contrast, the invented DDLMS controls the 'generator torque' without directly manipulating the aerodynamic torque. Unlike the other variable-speed WTGs, where, when the wind is below the rated speed, the aerodynamic torque is used to control rotor speed in-order to capture as much power as possible. The most power is captured when the Tip-Speed-Ratio is held constant at its optimum value typically 6 or 7. This means that as wind speed increases, rotor speed should increase proportionally (exponentially). Conventionally, the difference between the aerodynamic torque captured by the blades and the applied 'generator torque' controls the rotor speed. If the generator torque is lower the rotor accelerates and if the generator torque is higher the rotor slows down. But again in conventional systems it is difficult to find exact TSR, as it changes with time, location &

wind type. Tip Speed Ratio is the ratio of rotor to wind speed, but the wind at hub is different than the wind at blade tips so the conventional controllers using wind speed at hub for TSR will have errors. Moreover the efficiency of the systems designed to track and be closer to TSR depends upon the controller ability to change the rotor speed with wind which leads to mechanical stress, so any approach chasing TSR for rotor speed will not be error free and will not solve the basic problem.

Considering the above limitations of the above conventional standard methodology, the Invented DDLMS opted out of TSR chasing or rushing to catch up with the varying winds for dynamically matching the rotor speed closer to dynamically calculated TSR. Rather, DDLMS works on divergence of the standard theory of Search Algorithm (which tries to calculate rotor speed for maximum power at each moment.) Search Algorithm maximizes rotor energy capture inspite of poorly understood rotor performance, icing, mis-pitched blades etc.

Further in-contrast to the conventional methodologies the DDLMS actually ensures that the generator be always appropriately (summation of real & reactively) loaded (neither less nor more) at ALL Wind or RPM irrespective of the quantum, such that the (i) rate of change of terminal Voltage & (ii) acceleration as well as the retardation, both always remains linearly constant within the respective desired ranges.

The output KVA of the invented SEiSG is always matched (irrespective of the name-plate rating / KVA) to that-of the Input KW of the direct-drive prime-mover (wind) such that the terminal Voltage is always kept constant within the range, at all the wind speeds. This unconventional approach achieves the following:

1. Maximum possible Power per rotation or revolution, irrespective of magnitude of the available wind and RPM.
2. Linearly Constant Acceleration - rate of change rotor speed with respect to wind.
3. No wake loss and minimum mechanical stress on – hub/ blades & tower / foundation. This adds to longer life, low O&M and electrical unit cost.

The complex algorithm of DDLMS, continuously respond to continues (fig-13) real-time data (i.e. not on a discrete or sample based data) so its performance is not restricted by system clock or any external errors; unlike other Digital Systems which are not continuous but rather are sampled based dynamic A/D converters where the sampling rate is controlled by controller clock, affects the - (i) frequency content of processed information, (ii) design of control system, and hence the (iii) system stability itself; as the sampling rate affect subsequent control design & operation, including the determination of the values of constants and final system damping ratio, system natural frequency etc. Because of these effects, changes in sampling rate system turn unstable.

Further, The Invented 'Digital – Dynamic Load Management System' uses PWM technology for regulation of Field Voltage based on the proprietary

algorithm. PWM or PDM – Pulse Width or Duration Modulation provides control of the reactive power to the field. The average value of voltage fed to the field is controlled by turning ON & OFF the switch at very fast rate around 20KHz between (i) supply - armature AC-DC converted power being self-excited and the (ii) field coils. The longer the switch is ON compared to the OFF periods, the higher the total power supplied to the magnetic field for air-gap flux, i.e. if the Duty Cycle (proportion of 'on' time to the regular interval or 'period' off time) is low will corresponds to low power as the power is off for most of the time here as duty cycle is expressed in percent, 100% being fully on. The DDLMS being a PWM has following advantages:

a) Power loss in the switching MOSFET is very low/ negligible i.e. when switch is OFF there is practically no current and when ON & the power is being transferred to load there is almost no voltage drop across the switch. Power loss, being the product of voltage & current, is thus close to zero either ON or OFF.
b) Works well with Digital Control as ON/ OFF can easily set the needed duty cycle.
c) No D/A conversion is necessary so by controlling analog circuits digitally the system costs, power consumption, noise and size (space requirement) has drastically been reduced. The microcontroller used here-in includes the PWM controller and includes two, each of which has a selectable on-time and period.

Actual Working:

The invented generator's electromagnets fields are self-excited using 'Transformation & Rectification', amplified till the build-up voltage reaches the threshold voltage. Then the Invented "Digital Dynamic Load Management System' maintains the O/P terminal Voltage & the RPM through dynamically controlling the field voltage in way that the generator is always appropriately loaded and even quickly unloaded if the I/P KW from the prime-mover drops. The remaining armature power is made available for Battery Charging or end load. When wind is positive (more) from the previously sensed wind then the DDLMS also simultaneously instantly increases the field excitation by such a magnitude and in such a gradual away that again the O/P current and hence the KVA increases while the terminal voltage and the RPM is kept constant within the range. But increasing the torque (O/P Power) reduces the RPM and hence the O/P Voltage, so the dynamic equilibrium has to be maintained every moment between the available I/P KW, O/P Voltage & RPM such that "Maximum Power can be fetched per Revolution" irrespective of quantum of (i) Wind, (ii) RPM & (iii) End Load. The above discussed Panel is placed at the Yaw mounted Transmission Assembly and has following Input terminals (i) Wind speed, (ii) RPM, (iii) Field Current through IC based analog circuit (A/D), (iv) AC RYB, and Output is feed back to (i) Field DC positive & negative through switching circuit & D/A circuit. Aforesaid technology and the processes are far more complex than it has been made to look-like here, for shear understanding purposes. But irrespective of

complexity, what DDLMD has attained for its user is a uniquely new & revolutionary.

Second Control Panel at the ground level - consist of single phase regulation transformer and inductor, 3 phase AC-DC full wave bridge-rectifier, regulated power supply unit for the panel itself, micro-controller, Contactor & Relays etc. This Control Panel has "Auto-Changeover Switch", "Smart Metering and Data Logger" along with the other display and manual control mechanism. Terminals: From DDLMS regulated R Y B, To Battery B+ & B-, From AC Mains Phase & Neutral. To – Inverter's Phase & Neutral. Based on the Battery Potential, Windmill VDC & AC mains availability and with reference to pre-defined conditions; on-board Computer decides how and when to charge the battery bank. If power from windmill is there than batteries will be charged from the Windmill Power at the pre-regulated voltage and variable maximum possible current and since Windmill +/- are in parallel with Batter +/- through revere diode so access power from the wind is directly pushed to end load through the inverter; and when there is no Windmill Power and if the battery is still healthy & charged (beyond the backup needs) then AC Mains charging through Inverter's convertor (charger) is restricted and access stored power (beyond the back-up needs) is pushed (forced consumption) even if AC Grid Mains is available. Convertor's charging is only used when there is No Windmill Power and the battery potential has fallen beyond the pre-defined voltage level. This automatic intelligent toggling between the regulated Windmill DC Power and the converted from AC – DC Power for battery charging considering the battery present potential and power requirement for contingencies lets ESWS invented Auto Changeover Switch to optimally utilize the batteries and pushes for maximum utilization of windmill's generated power, from the day-one. This leads to faster Return on Investment not only for the invented ESWS but also for the Battery & Inverter which otherwise would have been used once in a while at the time of power failures. Further this on-board microcontroller measures the net (after all the losses and self consumption) true RMS DC power by measuring the Charging DC Voltage from the Windmill via the yaw mounted DDLMS Control Panel and the Windmill charging current (calibrated shunt). Apart from providing the present KW (V*I) generated the smart meter also stores the cumulative (energy generated till date) DC KW/H consumed by the end load. Similarly the Data-logger stores the vitals like: (i) Total Uptime (number of hours Windmill took to generate the cumulative registered power) this helps in knowing the average generation in various situations and whether, (ii) Maximum Charging Current drawn from the Windmill, (iii) Peak Power & RPM etc. This panel also has manual switch to by pass the AC mains or the Windmill Charging and proves to be very handy at times of faults & maintenance. Similarly host of analog meters, LED & LCD display helps manually understanding and verifying the various functions of the systems on site.

Apart from above propriety constituent of the invented ESWS, SEiSG comes with pre-assembled proprietary:

1. Tail and Yaw & Transmission Assemble specially designed for SEiSG's Large Diameter, Short Axial Length & Weight and to accommodate the invented Control Panel/ System – regulating the Voltage, Power and Speed at generation

level itself through The Dynamic Load Management System and Speed to Torque Convertor etc .

2. Rotor shaft mounted hub for blades, nose cone etc.
3. Tower are (i) structurally designed out of trusses made of light weight yet strong round MS pipes to balance on top - dead & dynamic weight and air thrust, (ii) it's modular design provides for ease of erection and transportation, and (iii) double hot zinc dipping provides longer life.

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