Neuro-Fuzzy Controllers for Power Quality Improvement of Grid Connected PV-Battery-Diesel based Hybrid Supply System

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Abstract: Diesel generators are commonly operated to supply electric power for many apartments, hospitals, institutes and industries during off grid mode. However, consumption of heavy diesel can causes harmful effect to atmosphere and surroundings. Under these circumstances, integrated photovoltaic system (PVS) to the diesel generators can able to give some viable solutions for many problems. In order to store the energy from PVS during off grid mode as well as to provide uninterrupted power supply into load bus, a battery bank is also incorporated into the system in this paper.These kinds of system are mainly connected in distribution system. Hence, a proper inverter controller needs to be implemented for maintaining power quality. Neuro-Fuzzy based controllers are implemented to use in the control block of the inverter to achieve the fast and precious responses during quick variations happens in the system. In addition with this, a sliding mode controller is also incorporated with inverter controller to regulate invert input current.A hardware- in the -loop by OPAL-RT devices is established to collect the results under various operating conditions.

Keywords: PVS, Power Quality, Hardware-in-Loop, Diesel Generator, Grid, Battery, Inverter, TS-Fuzzy**.**

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1. INTRODUCTION

Generally, diesel generators are often power sources in many places including grid mode as well as standalone mode especially where there is no access of electric power grid. Usually power cuts are commonly occurred in utility grid, hence many diesel generators needs to be established to operate an important loads including apartments, hospitals, universities, army posts etc. However, consumption of diesel can release harmful gasses into atmosphere as well as price of diesel is increase day by day. Hence, diesel generators (DGs) are not a good option when sensitive loads are connected. Therefore, combination of PVS-DG can be a feasible solution for solving many problems such as carbon emission, consumption of diesel, providing uninterrupted power supply, reducing power bill, etc. along with this, a battery backup must be integrated to the system [2-4]. Therefore PVS-DG-Battery system is considered in this paper. Further, the speed of the diesel generator will increase or decrease momentarily when increasing or decreasing the load respectively and also can exhibits maximum efficiency at operating load above 60% [2].The consumption of diesel will increase when there are sudden changes in load as well as connected reactive power loads. Hence, considered the DG is operating at constant load with generation of only active power to reduce consumption of diesel. The control of an inverter shouldbe compensatedthe reactive power consumed at load bus. In addition to this, DGs will exhibits poor performance during unbalanced generation current. Unfortunately loads operated at load bus in three phase distribution system are always unbalanced. To avoid this, control of an inverter is designed to maintain balanced currents of DG. This proposed control method can also be helped to maintain balanced grid currents when grid is in ON mode.Neuro-Fuzzy based controllers can perform very well compared with Proportional+Integral (PI) controller during random changes in system [5].

Usually the grid can be supplying the power demanded by the loads at local bus. However, during off grid mode, a battery must be required to maintain power balance. In the similar manner, a DG should be operated if more power demanded at load bus. A proper coordination can be adjusted the best operation among all these components without required by any man power. A grid connected PVS-DG-Battery model is considered to fulfill the following objectives in this work.

- To maintain power quality at PCC duringchanges in irradiance and load conditions.
- To reduce the consumption of diesel, the control of an inverter needs to be compensating reactive power then diesel generator needs not to supply any reactive power when it is in ON mode.
- There will besecond frequency oscillations existed in torque of generator and it will be directly reflected on shaft of diesel engine due to direct couple, hence the controller should be help to remove these oscillations from torque of diesel generator by maintaining balanced currents of DG under unbalanced/nonlinear load scenario. Hence, it can helpful to increase the fatigue life of DG shaft as well as can reduce heat generated by generator which can further help to reduce in diesel conception.
- Development of Neuro-Fuzzy based controllers on inverter for achieving fast response under random changes.
- To design controllers in such a fashion that battery will be allowed to charge from only PV and excess power from PV should be feed to the grid.

TheRLC filter is connected between AC load bus and inverter, therefore the control of aninverter should be operatedat various modulation indexes for three phases. However, rules generated by Neuro-Fuzzy based controllers have more powerful and suitable for

findings in easiest process [5]. The overview of the system is arranged in Section-2. Details about ANN-Fuzzy are given in Section-3. Proposed control of an inverter is presented in Section-4. Hardware-in the-Loop (HIL)for collecting the results through OPAL-RT devices is presented in Section-5. Conclusions are given in Section-6.

2. OVERVIEW OF THE PVS-DG-BATTERY SYSTEM

Generally, diesel generators are used for often power sources during no supply from grid [1]. Operating the diesel generator for light-load, unbalanced and frequently changing loads is increased the consumption of diesel [2]. However, consumption of heavy diesel causes many environmental impacts. Fortunately, there will be an enough space available on rooftop of apartments, hospitals or buildings in institutions. In addition to this, sufficient open space also will be available in some institutions and industries. This space will be sufficient to generate require amount of electrical power through PV modules.Hence, using PV panels for power generation in such a locations can decreases consumption of diesel as well as can also decrease electricity bill along with can also able to supply uninterrupted power to the loads. The real power transfer into grid from the PVS is done by regulating the voltage at dc-link through control of inverter. The combination of single and three phase, nonlinear loads are operated at the local bus. Modeling of battery, PVS, diesel generator, and filters are implemented by using [1-2, 8-9]. The diesel generator should be operated during high load demand when no supply from grid. Moreover, different kind of loads are operated at load bus including nonlinear loads, hence the effect of nonlinear load should be minimized on grid to improve the quality of power at other loads [10-11]. Similar research work has been done by many scholars recently, few of those are presented in this section. Authors in [1] proposed a system with PV/battery/diesel by using fuzzy controllers.

Authors [2] were implemented TS-Fuzzy controllerson PV-diesel-battery based standalone system. The role of a battery storage device for PV-diesel generator operated Microgrid is discussed by authors in [3]. Novel energy management system is developed by authors in [4] for PV-diesel-battery hybrid system. Authors in [12] have developed a PV-diesel generator based power supply system for hospital. Authors in [13] proposed a comprehensive controller is developed for hybrid wind-PV-diesel based standalone system. However, the authors in [2-4] are not considered grid.Similar concentrate on nonlinear regulator in PV based independent framework is introduced by creators in [14]. Be that as it may, Neuro-Fluffy based regulators are not introduced by creators in above explores. Furthera novel control of an inverter is proposed on inverter in this paper.

By and large nonlinear burdens are working at PCC which can infuse sounds into different burdens, thus, a functioning power channel ought to be incorporated [15] and a DSTATCOM will be also likely expected to repay responsive power requested by loads [16]. Further, there is existing of second recurrence motions in dc-connect voltage because of unequal and nonlinear burden at PCC. These motions increment the temperature at PV modules which decline the power age, consequently an original regulator is proposed to DC to DC converter to dispense with those motions. The inverter can function as dynamic power channel and DSTACOM by proposed control strategy.

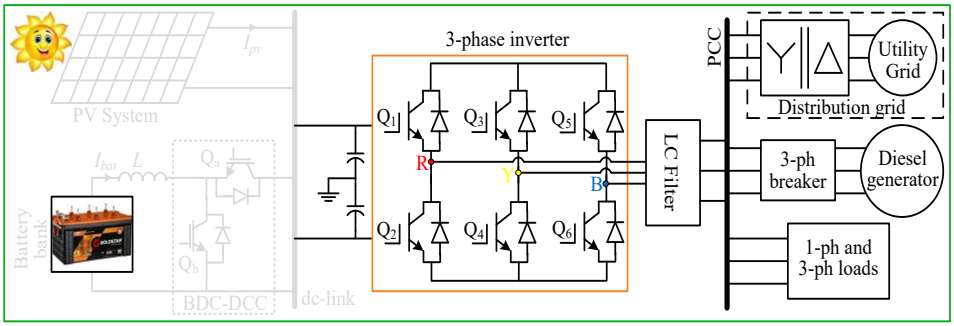

Fig. 1: Power Quality at PCC of a grid connected PVS-DG-Battery operated system.

3. NEURO-FUZZY SYSTEM

Comparing to fuzzy controllers, Neuro-Fuzzy controller can be able to adjust gains automatically with fast manner. The input of the system is considered from error. In order to achieve precious response of dc-link voltage, Neuro-Fuzzy system as shown in Fig. 2 is developed for all controllers.The generalized rules of Neuro-Fuzzy system are represented by 4 rules mentioned below fr the output (Y). Moreover, the same dc-link voltage signal is also given to inverter controller to regulate dc-link voltage, this can help to regulate dc-link voltage in case of battery gets full charged. In addition to this, oscillation in torque of diesel generator will increase the consumption of diesel as well as create shaking on shaft of the diesel engine which results decreases fatigue life of generator. Hence, the oscillations on diesel generator should be mitigate through bidirectional DC to DC converter which can be possible by comparing oscillations in voltage to zero. Along with battery, the diesel generator will be switched ON automatically once load power exceeds 40% of rated load of diesel generator. Following rules are implemented on Neuro-Fuzzy systems.

1st rule: if 'e' is M_1 and d(e)/dt is M_3 then $Y_1=p_1x+q_1y+r_1$
2nd rule: if 'e' is M_1 and d(e)/dt is M_4 then $Y_2=p_2x+q_2y+r_2$
3rdrule: if 'e' is M_2 and d(e)/dt is M_3 then $Y_3=p_3x+q_3y+r_3$
4thrule: if 'e' is M_2 and d(e)/dt is M_4 then $Y_4=p_4x+q_4y+r_4$

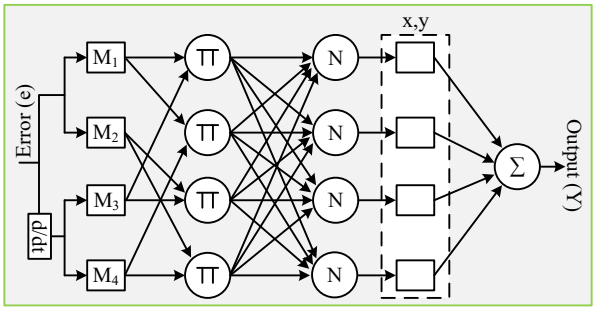

Fig. 2: Sketch of a Neuro-Fuzzy system.

4. VOLTAGE CONTROL AT PCC

An inverter must be placed between dc-link and PCC. Control method of an inverter needs to be maintained balanced voltages at PCC, compensating reactive power consumed by load at PCC and should supply active power from dc-link to PCC. Along with this, the inverter will be working as MPPT by regulating dc-link voltage in case of battery gets full charge. However, the frequency regulation is very important when there is no grid. Moreover, the active power transfer from dc-link to grid also depends on regulation of frequency. Hence, both dc-link voltage and frequency component is considered for regulating active power through inverter. The reactive power compensation is depends on rms voltage at PCC. Further, there will be a filter between inverter and PCC, hence the drop across filter needs to be included for regulating voltage at PCC. The oscillating parameters in direct and quadrature components are included to produce different modulation indexes for three phases of inverter legs to compensate the effect of unbalanced load.

The inverter with legitimate regulator should be produced for changing DC over completely to AC [16-18]. The inverter can ready to create required AC voltages with the assistance of tweak file once balanced out dc-connect voltage. The itemized proposed inverter regulator is introduced in Fig. 3. As it is an independent framework, the recurrence will be key variable. Changes in dynamic power will reflect in changing in recurrence. Thus, the reference part of direct hub current is produced through Neuro-Fluffy regulator by contrasting recurrence and its reference esteem. Also, the receptive worth of three stage flows is gotten by contrasting voltages and their reference values. This can assists with conquering voltage drop across channel obstruction regardless of burden current at PCC. The necessary heartbeats are delivered through space vector beat width tweak (SVPWM) strategy as displayed in Fig. 4.

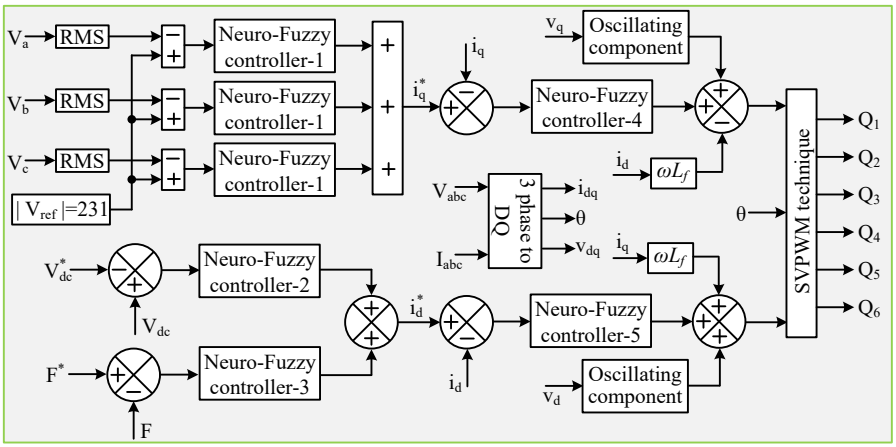

Fig. 3: Proposed control of Inverter.

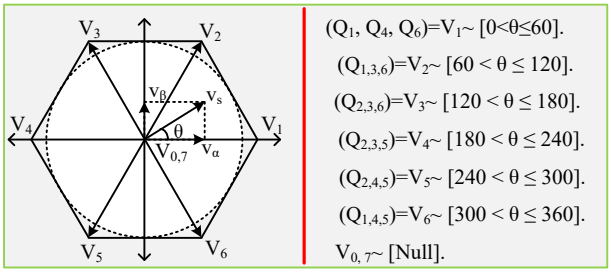

Fig. 4: SVPWM Technique.

5. RESULT AND DISCUSSION

Real Time Operating Systems (RTOSs) are a computerized test system to perform many errands like reasonable tasks [1, 4]. Broad outcomes are removing through one more PC for inspect results. A model arrangement of HIL by assistance of two OPAL-RTdevices is introduced in Fig. 5. The proposed model displayed in Fig. 1 is partitioned in to plant and regulator. A displayed portrayal of the HIL cycle of proposed framework with legitimate variety coding is portrayed in Fig. 6. Further the outcomes are introduced in following contextual analyses.

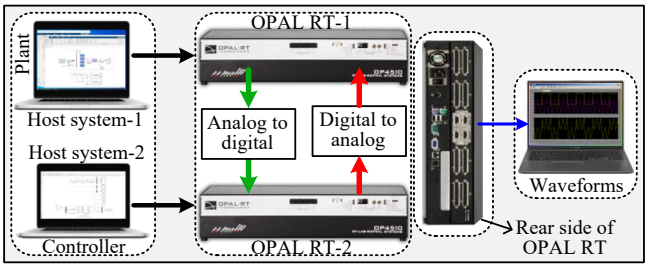

Fig. 5: Configuration of an OPAL-RT setup.

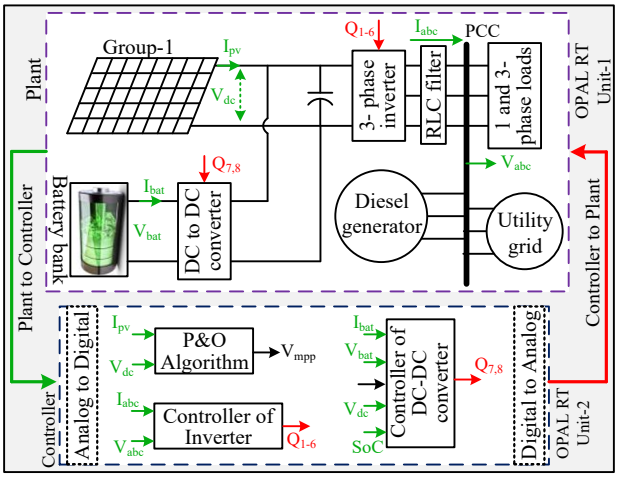

Fig. 6: Proposed model - HIL block.

Case-1: *Control of inverter under the operation of unbalanced load at load bus:*

The PCC is connected by unbalanced loads due to home loads, street lights, etc. These currents lead the system into unbalanced voltages due to unbalanced drops at lines. The unbalanced currents at PCC will be forced to make grid currents as unbalanced. The three phase and sensitive loads connected to grid will be suffer from these unbalanced voltages. The proposed control method f the inverter can make the balanced supply from the grid during the operation of unbalanced load at PCC. A profile shown in Fig. 7 is applied at PCC which draws more unbalanced currents. During this operation, the proposed control of the inverter should be produced different modulation indexes which can make balanced grid current as depicted in Fig. 8. Hence, the voltage at PCC becomes balanced which evidenced in Fig. 9. Fig. 10 shows respective RMS voltages and Fig. 10 respectively.

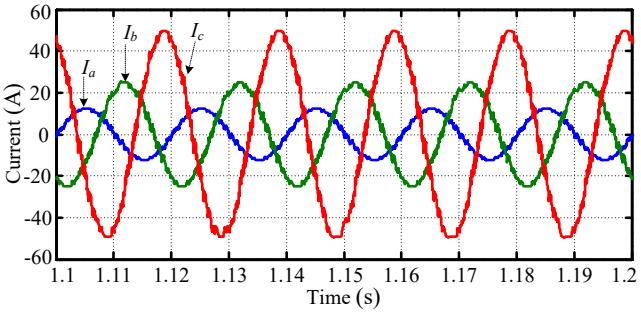

Fig. 7: Unbalanced load at PCC.

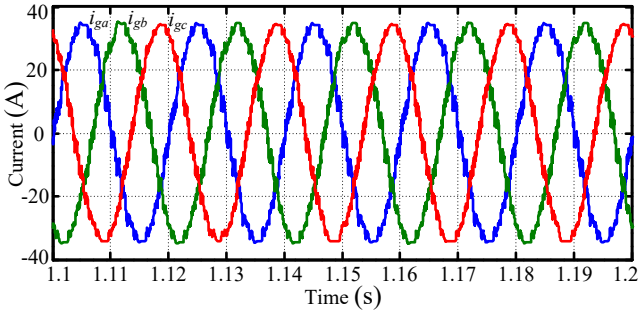

Fig. 8: balanced Grid's currents.

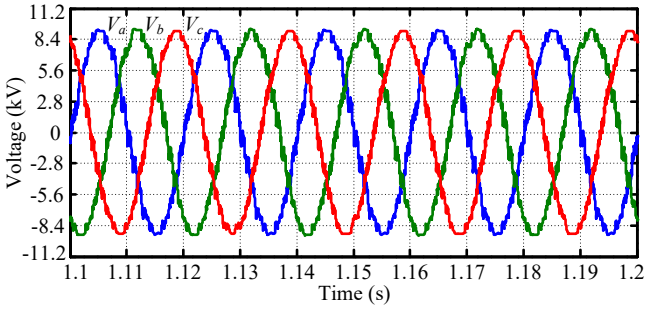

Fig. 9: Voltages at PCC.

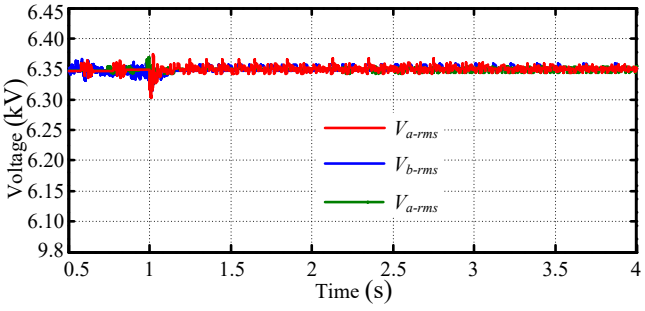

Fig. 10: RMS voltages.

Case-2: *Responses during the operation of nonlinear loads:*

For this situation study, a nonlinear burden is operated at load bus with profile as displayed in Fig. 11 (a). to lessen nonlinear impact on framework, the repaid nonlinear flows will infuse through inverter by proposed regulator. Thus, network flows can be sinusoidal and

can be a sound free. Relating inverter and framework flows are displayed in Fig. 11(b) and (c) separately. This can be accomplished by inverter regulator to work as dynamic power channel.

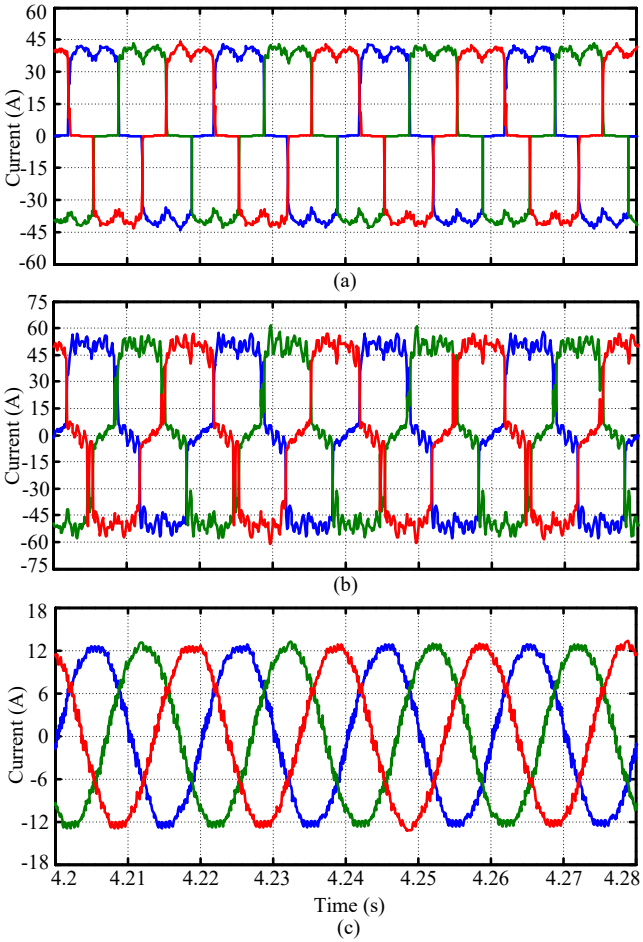

Fig. 11: Current of (a) Non-linear load (b) inverter, (b) Grid.

Case-3: Inverter working under the operation of reactive power:
Mainly reactive powers will be operated in a distribution system due to fans, ACs, inductive load etc. Therefore, a device like a DSTATCOM must be required to compensate reactive power which can reduce the supply of reactive power from the utility grid. This is achieved through proposed control method of the inverter. In order to compensate the reactive power at load bus, it should be circulated among inverter, filter and load. A 80KVAR of reactive power is applied at PCC at t=2sec as shown in Fig. 12 for testing the performance of the proposed method. It is observed that the grid supplied reactive power becomes zero which stated that the compensation of reactive power is done through the inverter by proposed control method.

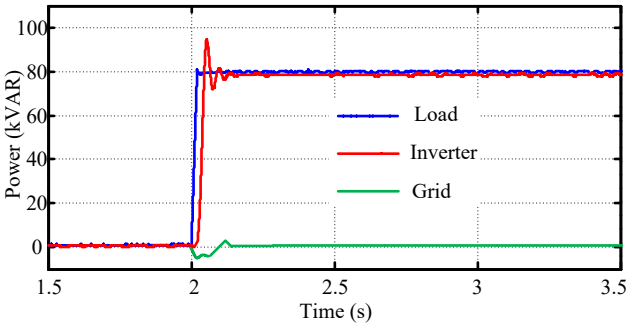

Fig. 12: Reactive powers in the system.

6. CONCLUSION

Hybrid PV-Diesel-Battery based power supply system is presented in this paper with the help of novel integrated control method to perform the best response. This kind of configuration is suitable for many apartments, hospitals, institutes and industries are having diesel generators for backup power supply during no supply from grid. The integration of PVS-DG-Battery can provide often solution to reduce electricity bill as well as pollution by reduction in consumption of diesel. The excess power generated from PV system will be stored in battery and also can feed to grid when battery gets full charged. These kinds of system are mainly connected in distribution system. Hence, proper inverter controller is implemented in this paper to fulfill the objectives. Neuro-Fuzzy based controller is implemented on inverter to enhance precious response. In addition with this, a sliding mode controller is also incorporated with inverter controller to regulate invert input current. Various results are presented with the help of HIL designed by using two OPAL-RT units.

Appendix:
Parameters of diesel generator.
Apart from 15kW of home load, there will be some extra loads needs to be operated in apartment like lift, lightings, water pump(s) etc. These loads will mainly operate on diesel generator when there is no supply from grid. To prevent from frequent switching ON and OFF of generator, there will be a time delay between grid OFF mode to switching ON generator. The generator will be switched ON automatically within 2 to 3 min in the situation of no supply from grid if load demand is more than 40 percent of generator capacity. 50kVA diesel generator with below specifications[17] is considered in this paper.

S.No	**Parameter**	**Value**
1	Manufacture	Greaves Power
2	Capacity	50kVA
3	Genset model	GPWII-PII-50
4	Number of phases	3
5	Voltage range (line to line)	380-440
6	Fuel consumption at (25, 50, 75, 100)% load	(4.7, 7.2, 9.97, 12.35)/H

Various parameters including inverter, dc-capacitor etc are considered from [18-20].

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